AMAZING-6G
Amazing Large-Scale Trials and Pilots for Verticals in 6G

Deliverable 2.1

Initial Requirements and System Architecture

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Executive Summary

The Initial Requirements and System Architecture document main objective is to propose a 6G logical architecture built around the 4 main technology pillars of the project which are to provide 1/ compute and network support (through respectively the Compute and Network continuum paradigms), in addition to 2/ Artificial Intelligence and Machine Learning support and finally 3/ IoT support to Verticals. The general vision of AMAZING-6G is to complement the classical networking-oriented offer provided by Mobile Network Operator with smart and powerful additional features that Verticals can use to build their products. This way, they can entirely focus on the heart of their business without having to invest time and money into developing their own complex and technical enablers or toolboxes. Through initial requirement engineering, which is supported by establishing, for each of the 15 project Use Cases, a precise UC description and a preliminary high-level design (Context views), we finally end up with a unified set of functional and non-functional requirements which are meant to boot-strap the architecting process.

The methodology is based on Views (which focus on different aspects of the targeted system) and Perspectives which serve as a tool used for processing non-functional requirements. The functional view, derived from the functional requirements, proposes a first version of a logical 6G system architecture. It features a wide set of components aligned with both the AMAZING-6G technical objectives, and the 5GPPP vision for a 6G architecture as stated in [1]. In this initial version of the document, we only complement the functional view with a deployment view that gives insights on how the AMAZING-6G components can be deployed. That later view also elucidates how our system relates from the networking point of view to the supporting standalone 5G system augmented with AMAZING-6G new features, typically when providing Verticals with network slices tailored to their specific needs and requirements. The perspective section, in its initial version, addresses only a few non-functional properties. It defines for each of them, activities and tactics that can be used (e.g. either through added functionalities or deployment strategies) to achieve a property, such as performance or privacy, security and trust. This document is the first of three planned incremental iterations.

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List of Acronyms and Abbreviations

TERM	DESCRIPTION
µS	micro-Service
5GC	5G Core
5QI	5G QoS Identifier
A.K.A.	Also Known As
A6G	AMAZING-6G
AAA	Authentication Authorization Accounting
ACB	Access Class Baring
ACL	Access Control List
AF	Application Function
AGV	Automated Guided Vehicle
AI (AAS)	Artificial Intelligence (as a Service)
AI/ML OR AIML	Artificial Intelligence / Machine Learning
AIMLE	AIML Enablement
AIMLEF	AI/ML Exposure Function
AMC	Adaptive Modulation Coding
AMF	Access and Mobility Function
AMQP	Advanced Message Queuing Protocol
AP	Access Point
API	Application Programming Interface
AR	Augmented Reality
ARP	Allocation and Retention Priority
AUSF	Authentication Server Function
AUTHN	Authentication

AUTHZ	Authorization
AV	Autonomous Vehicle or Atrioventricular (as in H1&H2)
B5G	Beyond 5G
BLE	Bluetooth Low Energy
BLEMAT	Bluetooth Low Energy Micro-location Asset Tracking
BP	Blood Pressure
BS	Base Station
C&C	Command & Control
C&CC	Control & Command Center
C&CS	Control & Command Supervisor
CAAS	Compute as a Service
CCC	Central Control Centre
CCR-REG	Core Compute Resource Registry
CCS	Central Control Supervisor / Control Command Supervisor
CDM	Compute Decision Making
CDT	Compute Digital Twin
CE	Coverage Extension
CEAAS	Coverage Extension as a Service
CEDM	Coverage Extension Decision Making
CEF	Compute Exposure Function
C-ITS	Cooperative – Intelligent Transport System
CLE	Cooperative Localization Engine
CMUT	Capacitive Micromachined Ultrasonic Transducer
CNF	Cloud-native Network Function
CP	Control Plane
CPE	Customer Premise Equipment
CRA	Compute Resource Allocation

CRO	Compute Resource Orchestration
CR-REG	Compute Resource Registry
CSMF	Communication Service Management Function
CSO	Centralized Service Orchestrator (or SO)
CU	Control Unit
CV	Context View
DATAOPS	Data Operations
DBM	Decibel milliwatt
DC	Design Constraint
DCH	Design Choice
DDOS	Distributed Denial of Service
DIKW	Data-Information-Knowledge-Wisdom
DL	Downlink
DM-F/E	Decision Making frontend
DN	Data Network
DNS	Domain Name Service
DOA	Description of Action
DONOR-DU	Donor – Distributed Unit
DOS	Denial of Service
DP-REP	Deployment Policy Repository
DSO	Distributed System Operator
DT	Digital Twin
DT-DC	Digital Twin - Data Collection
DT-DMO	Digital Twin – Decision Modeling and Optimization
DT-F/W	Digital Twin - Framework
DT-REG	Digital Twin Registry

DT-REP	Digital Twin Repository
DT-SM	Digital Twin – Simulation and Modeling
DTVE-TSDB	Digital Twin – Virtual Entity Time Serie Database
DT-VI	Digital Twin – Visualization and Interaction
DU	Distributed Unit
E.G.	"exempli gratia" (Latin locution)
E2E	End-to-End
EC	Edge Computing
ECG	Electro-cardiogram
EE	Execution Environment
EGM	Electrogram
EMBB	Enhanced Mobile Broadband
EN	Edge Node
ESO	Edge Service Orchestrator
EV	Electric Vehicle
F/E	Front end
F/W	Framework
FC	Functional Component
FCAPS	Fault/Configuration/Audit/Performance/Security
FG	Functional Group
FL	Federated Learning
FLME	Federated Learning Management Engine
FLOPS	Floating Operation per Second
FM	Functional Model
FR	First Responder
FREQ	Functional Requirement

FRMCS	Future railway Mobile communication System
FV	Functional View
G/W	Gateway
GNB	Next generation NodeB *(replaces 4G eNB)*
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GSM	Global System for Mobile communication
GSM-R	Global System for Mobile communication - Railway
GUI	Graphical User Interface
H/M/L	HIGH/MEDIUM/LOW
H/W	Hardware
HMI	Human Machine Interface
HTTP	Hyper-Text Transfer Protocol
HVAC	Heating, Ventilation, and Air Conditioning
I.E.	"id est" (Latin locution)
I/F	interface
I/O	Input/Output
IAB	Integrated Access and Backhaul
IAB-DU	Integrated Access and Backhaul / Distributed Unit
IAB-MT	Integrated Access and Backhaul / Mobile Terminal
ID	Identifier (mostly in datatypes) or Intelligence Distribution - depending on the context
IDM	Identity management
IEEE	Institute of Electrical and Electronics Engineers
IIOT	Industrial IoT
INV	Instantiation View
IO&M	Inspection Operation and Maintenance (wind turbine)

IOT	Internet of Things
IOT-EF	IOT – Exposure Function
IOT-RO	IoT – Resource Orchestration
IOT-RREG	IoT – Resource Registry
IOT-SREG	IoT – Service Registry
IP	Internet Protocol
IR	Inventory Registry
ISAC	Integrated Sensing And Communication
IV	Information View
K8S	Kubernetes
KPI	Key Performance Indicator
LCC	Local Control Centre
LCM	Life-cycle Management
LCX	Leaky Coaxial (cable)
LEO	Low Earth Orbit
LIDAR	Light Detection and Ranging
MAC	Medium Access Control
MANO	Management Network Orchestration
MAP	Mobile Access Point
MBS	Multicast & Broadcast Service
MC-DATA	Mission Critical Data
MCP	Mobility Context Provider
MC-PTT	Mission Critical Push-to-talk
MCS	Mission Critical Service
MC-VIDEO	Mission Critical Video
MCX	Mission Critical {PTT, Video, Data Services}
MEC	Multi-access Edge Computing

ML	Machine Learning
MLMC	ML Model Catalog
MLMDE	ML Model Deployment Engine
MLMEE	ML Model Evaluation Engine
MLMTE	ML Model Training Engine
MLOME	ML Operation Management Engine
MLOPS	Machine Learning Operations
MNO	Mobile Network Operator
MQF	Message Queue Factory
MQTT	Message Queue Telemetry Transport
MSC	Message Sequence Chart
NAS	Non-Access Stratum
NDT	Network Digital Twin
NDV	Network Deployment View
NEF	Network Exposure Function (5G NF)
NF	Network Function
NFREQ	Non-Functional Requirement
NFV	Network Function Virtualization
NFV-I	NFV Infrastructure
NFV-O	NFV Orchestrator
NFVO-C	NFV-O Connector
NN	Neural Network
NPN	Non-Public Network
NR	(5G) New Radio
NRF	Network Function Inventory
NS	Network Slice
NSAAS	Network Slicing as a Service

NSI	Network Slice Instance
NSMF	Network Slice Management Function
NSP-REG	Network Slice Policy Registry
NSSAI	Network Slice Selection Assistance Information
NSSF	Network Slice Selection Function
NSSMF	Network Slice Subnet Management Function
NSST	Network Slice Subnet Template
NST	Network Slice Template
NTN	Non-Terrestrial Network
NWDAF	Network Data Analytics Function
NWEF	Network Exposure Function (AMAZING-6G)
OAM	Operation, Administration and Maintenance or Operation and Management
OBU	On-Board Unit
OPS	Operation per Second
O-RAN	Open RAN
OS	Operating System
OSS	Operations Support System
OV	Operation View
P	Priority Level (i.e. H/M/L) used in requirement tables only
P/F	platform
PAE	Position Acquisition Engine
PCF	Policy Control Function
PDU	Protocol Data Unit
PFDA	Platform Data Analytics
PFDV	Platform Data Visualization
PHY	Physical layer

PLMN	Public Land Mobile Network
POV	Point of View
PPDR	Public Protection and Disaster Relief
PSA-UPF	PDU Session Anchor UPF
PST	Privacy, Security & Trust
PTT	Push-To-Talk
PV	Photo Voltaic
QCI	QoS Class Identifier
QOE	Quality of Experience
QOS	Quality of Service
R/T OR RT	Realtime
RAM	Random Access Memory
RAN	Radio Access Network
RAT	Radio Access Technology
RC	Radio Controller
RC-C	Radio controller - Connector
RCS	Remote Control Supervisor
RDF	Resource Description Format
RDT	Resource Digital Twin
REC	Renewable Energy Community
REDCAP	(5G NR) Reduced Capability
REF	Resource Exposure Function
RESP.	Respectively
REST	Representation State Transfer
RF	Radio Frequency
RFID	Radio-Frequency IDentifier
RI	Resource Inventory

RLC	Radio Link Control
R-NSSAI	Request Network Slice Subnet Assistance Information
RPC	Remote Procedure Call
RRC	Radio Resource Control
RRM	Radio Resource Management
RSU	Roadside Unit
RTK	Realtime Kinematics
RTT	Round-Trip Time
RTU	Remote Terminal Unit
RU	Radio Unit
S/W	Software
SA	Standalone
SAT	Satellite
SBI	Service Based Interface
SD	Slice Differentiation
SDN-C	Software Defined Network-Controller
SEC-F/E	Security frontend
SIEM	Security Information and Event Management
SIM	Subscriber Identify Module
SLA	Service Level Agreement
SLA-R	SLA - Repository
SMF	Session Management Function
S-NSSAI	Single (or Subscribed) Network Slice Selection Assistance Information
SO	Service Orchestrator
SOTA	State of The Art
S-REG	Service Registry
S-REP	Service Repository

ST-REG	Slice Template Registry
STS	Ship-to-Shore
STT	Shore-to-Truck
SUC	System use-case[1]
SUPI	Subscription Permanent Identifier
TAI	Tracking Area Identity
TCP	Transmission Control Protocol
TEU	Twenty-foot Equivalent Unit
TLS	Transport Layer Security
TMF	TeleManagement Forum
TOC	Table of Content
TOS	Terminal Operating System
UAV	Unmanned Aerial Vehicle
UC	Use Case[1]
UDM	Unified Data Management
UDR	Unified Data Repository
UE	User Equipment (e.g., mobile phone)
UGV	Unmanned Ground Vehicle
UL	Uplink
UML	Unified Modelling Language
UMV	Unmanned Mobile Vehicle
UNIS	Unified requirements
UP	User Plane
UPF	User Plane Function

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1 Use Case (uppercase without hyphenation (-)) related to a AMAZING-6G Use Case seen as scenario (cf the 15 UCs of this project; use-cases (like in System use-case or SUC) relates to the UML notion of a use-case, and is not to be mixed-up with Use Case, despite both conceptually refer to a "case of use".

UPF-BP	User Plane Function - Branching Point
UPF-UC	User Plane Function - Uplink Classifier
URLLC	Ultra-Reliable Low Latency Communication
V2X	Vehicle to X
VE	Virtual Entity
VE-SO	Virtual Entity Orchestration
VE-SREG	VE Service Registry
VE-SREP	VE Service Repository
VIM	Virtualized Infrastructure Manager
VM	Virtual Machine
VNF	Virtual(ized) Network Function
VNF-NS-REG	VNF/NS Registry
VP	Viewpoint
VPN	Virtual Private Network
VR	Virtual Reality
VRU	Vulnerable Road User
VS.	versus (Latin locution)
W.R.T.	with respect to
W/	with
WMS	Warehouse Management System
XAAS	X as a Service (CaaS, NSaaS, CEaaS, AIaaS, IoTaaS)
XR	Augmented/Virtual Reality
ZSM	Zero-touch Network and Service Management

1 Introduction

The 5GPPP White Paper on 6G architecture [1] identifies many trends and directions that should be taken into account when designing the next generation 6G terrestrial mobile networks architecture. Those directions include: intelligent networks, AI as a Service, IoT support & massive twining, dynamic function placement, compute and network continuum, etc.

Following those trends, AMAZING-6G main goal is to enpower Verticals (businesses involved in vertical domains such as HealthCare, Transport, etc.) with enablers implementing such technologies. Due to the very nature of AMAZING-6G (Stream-D), another equally important goal is to demonstrate through a multi-domain large number of Use Cases, how Verticals can benefit from those novel functionalities to enhance and boost their products and businesses.

The four main technical pillars of AMAZING-6G consist of network and compute continuums in addition to IoT and AI/ML support. Having AMAZING-6G working hand-in-hand with a supporting 5G system allows not only to provide high speed/low latency ubiquitous communication to Verticals but more importantly, a whole set of novel functionalities they can use at will to create new amazing applications.

The AMAZING-6G logical architecture introduced in this document shows how combining 5G features to the novel AMAZING-6G components (AI/ML, IoT, networking and compute enablers) allows *Mobile Network Operators (MNO)* to perform a radical paradigm shift by supporting Verticals not only with ubiquitous cellular networking, but also with sophisticated features which eventually help them to focus on the heart of businesses. Doing so, they can propose more powerful and novel software solutions to their customers, while decreasing time to market.

The requirement engineering process, which is classically preceding the subsequent work on the system architecture, is here seconded with a set of precise Use Cases descriptions and associated preliminary high-level designs (Context views). Analyzing UCs and working on their initial designs, altogether allow us to come up with a unified set of functional and non-functional requirements. Those requirements are then used to bootstrap the architecting process.

The architecting methodology is based on architecture Views (which focus on different aspects of the targeted system) and architecture Perspectives which are a tool used to process non-functional requirements before mapping them to architecture views.

As far as views are concerned, we have the Context view (already introduced) which comes early in the architecting process. It is followed but the Functional view that proposes a Functional Model (layered model that groups functionalities per domain and type) and a functional decomposition which goes in the detail of each functionality part of the architecture.

In this initial version of the document, we only complement the Functional view with a Deployment view. This second view gives insights on how the AMAZING-6G components can be deployed and how our system relates -from the networking point of view- to the supporting standalone 5G system augmented with AMAZING-6G new features. Some other views (listed in Section 2.2.3) will be added in the next version, including the Information view that defines the functional component logical interfaces and supporting data structures.

The Perspective section, in its initial version, addresses a few non-functional properties only. It defines for each of them activities and tactics that can be used (e.g. either through added functionalities or deployment strategies) to reach a property, say performance or security. This process produces a set of design choices which are then used to complement the architecture views.

1.1 Structure of the document

Section 2 (Architecture Methodology) provides the essential information to understand the process used to conduct the architecture work. It introduces concepts such as views, perspectives and viewpoints. It also elucidates the requirement engineering process, and all steps involved which eventually lead to the set of unified requirements (embedded into the Volere template).

Section 3 (Use Case descriptions) is dedicated to updated Use Case descriptions, compared to their original description in the project "Description of Action" document.

Section 4 (Context views) defines a Context view for each of the UCs. Each Context view complements its corresponding UC description with a high-level preliminary design. In particular, each figure in a Context view elucidates what sort of support the UC expects from the AMAZING-6G system (e.g. AI support, compute support, dedicated customised network slice,...). As such Context views help identifying UCs functional requirements.

Section 5 (Functional view) provides a *Functional Model (FM)* that features a set of *Functional Groups (FG)* arranged in layers and columns. Each FG group is made of a collection of functionalities (*Functional Components (FC)*) that collectively cover one of the technology pillars already introduced before (networking, compute, AI/ML and IoT), Additional FGs dealing with transversal aspects such as security, management and service level agreement are also added to the FM.

All components are precisely described, however in D2.1 only an informal textual form is used. Those descriptions (for both FGs and FCs) are complemented with *System use-cases (SUC)* which aim to elucidate how different components from different groups can cooperate with each other in order to achieve a particular complex behaviour (e.g., creating a network slice, implementing a federated learning solution, creating a *Digital Twin (DT)* or requesting compute support).

Section 6 (Deployment view) discusses different AMAZING-6G deployment strategies with regard to the 5G supporting network, addressing in particular some of the business implications impacting the different parties involved.

Section 7 (Perspectives) addresses and processes a few system properties, which results in some design choices which are used to complement/challenge the different system views.

Finally, Section 8 (Conclusion) gives a summary of the work achieved so far in this initial version of the system architecture and gives highlights on which updates and additions are planned for the second iteration of the document (D2.2).

The Table 1 below gives a quick access to the most important outcomes of this document.

Table 1: Summary of project outcomes and quick access links

Category	Outcome	Link
Use Case description & Context Views (resp.)	**H1:** Wearable ultrasound patch for cardiac function monitoring	Sections 3.1 & 4.1
	H2: Event-aware real-time reprogramming of pacemaker through wearable patch	Sections 3.2 & 4.2
	P1: Ubiquitous B5G/6G communication and slice deployment across operators for PPDR AR/VR assisted control centres	Sections 3.3 & 4.3
	P2: Mission critical services interoperability with other system	Sections 3.4 & 4.4
	P3: Emergency private B5G/6G communication on-the-move	Sections 3.5 & 4.5
	P4: Arctic area search and rescue operation	Sections 3.6 & 4.6
	P5: Emergency private B5G/6G communication on-the-move	Sections 3.7 & 4.7
	E1: Renewable energy communities	Sections 3.8 & 4.8
	E2: Robotized offshore wind turbines blade inspection & maintenance	Sections 3.9 & 4.9
	E3: Solar energy monitoring control and predictions using B5G/5G communications and edge-cloud	Sections 3.10 & 4.10
	T1: Protection of vulnerable road users	Sections 3.11 & 4.11
	T2: Enhancing urban security with UGV monitoring	Sections 3.12 & 4.12
	T3: Wireless signalling on rail tracks	Sections 3.13 & 4.13
	T4: Tele-operation as a back-up to autonomous driving	Sections 3.14 & 4.14
	T5: Port logistics and transport optimization and safety	Sections 3.15 & 4.15
Views	**Functional view**	Section 5
	Functional model and FG descriptions	Figure 38, Section 5.1
	Functional decomposition (list of FCs per FG)	Section 5.2
	Overall AMAZING-6G architecture figure (cut-away)	Figure 39
	System use-cases	Section 5.3
	Network Deployment view	Section 6
Perspectives	Performance	Section 7.1
	Energy Efficiency	Section 7.2

2 Architecture methodology

In D2.1 we shall apply the Rozanski & Woods [2][3] principles and we shall structure the document accordingly. Following those principles the AMAZING-6G architecture will consist of a set of *Views* and *Perspectives*, as defined in the next sections.

However, prior to working on views and perspectives (i.e., the actual architecture) we shall focus on performing 1/ a thorough requirement engineering process (see Section 2.2.1) and as introduced earlier, 2/ some prelimary UC design (see Section 4). Those two activities help to elucidate 1/ the Functional view (using functional requirements) and 2/ a set of perspectives (using non-functional requirements) focussing on system properties.

Both the set of requirements and context views constitute the essential pieces of information that capture the 15 Use Cases needs and therefore drive the architecting work.

Those requirements, either functional or non-functional are synthetized within a Volere spread sheet (see Section 2.2.2).

WP2 will release three iterative versions of the same document with increasing level of detail and completeness.

Before getting further into the architecture process, we introduce in the next sub-section some elements of terminology from Rozanski & Woods [3] .

2.1 Views, Viewpoints & Perspectives

Views are used to described non-overlapping aspects of a concrete system and defined as:

> *"A view is a representation of one or more structural aspects of an architecture that illustrates how the architecture addresses one or more concerns held by one or more of its stakeholders." [3]*

In AMAZING-6G we shall define the following views. Some of them are generic while others are application dependent and therefore bound to our 15 project Use Cases. Those later ones are marked with an asterisk

- Context view*
- Operation view* (starting in D2.2)
- Functional view
- Information view (starting in D2.2)
- (Network) Deployment view (partly * in D2.2)
- Instantiation view (starting in D2.2)

In order to describe a view, architects use **Viewpoints** which aggregate different architectural concepts like for instance data flows, sequence diagrams, data modelling... in order to describe that particular aspect of the system. The definition by the IEEE 1471 standard [6] is:

> *"A viewpoint is a collection of patterns, templates, and conventions for constructing one type of view. It defines the stakeholders whose concerns are reflected in the viewpoint and the guidelines, principles, and template models for constructing its views. " [6]*

In AMAZING-6G we shall be using various *Unified Modeling Language (UML)*-based viewpoints to describe various aspects of a view, e.g.:

- *Data modelling (Information view):* specification of data models using UML object-oriented modelling;
- *Interface modelling (Information view):* definition of the various methods that the functional components need implementing for other components to use (staying at a logical level);

- *UML use-cases (Context view):* to specify the interactions taking place between the scenario actors (including UC-own sub-systems sitting outside the perimeter of the AMAZING-6G system) and the AMAZING-6G system itself;
- *UML sequence diagrams (Functional view):* sequence diagrams (a.k.a. message sequence charts or interaction diagrams) provide a temporal sequence of interactions occurring between actors and/or functional components (each materialized by a lifeline) during a specific behavior pattern;
- *Data flows (Information view):* identifying the flows of data between the different functional components during a specific task;
- *Textual descriptions (all views).*

This list is not exhaustive and additional viewpoints could be used if needed.

Finally **Perspectives** are defined as:

An **architectural perspective** *is a collection of activities, tactics, and guidelines that are used to ensure that a system exhibits a particular set of related quality properties that require consideration across a number of the system's architectural view.[6]*

where a quality property is defined as:

A **quality property** *is an externally visible, non-functional property of a system such as performance, security, or scalability [6]*

Perspectives provide a more abstract description of a system, focusing on how the system behaves in opposition to what the system must do. Focusing on the qualities of the system, versus its functionalities, we can derive a number of categorized high-level objectives that need then to be analyzed (resulting into the so-called strategies and tactics) before being translated into concrete *Design Choices (DCH)*. Those categories are the architecture perspectives. The following preliminary set of perspectives is relatively common among IT systems and is by no mean to be considered as exhaustive; additional perspectives could be needed depending on the nature of the targeted IT system:

1. Trust, Security and Privacy (usually split into three separate perspectives);
2. Availability and Resilience;
3. Evolution and Interoperability;
4. Performance and Scalability.

2.2 Architecture process

Having introduced views, viewpoints and perspectives, we describe now the architecture process in greater detail, starting with "requirement engineering".

The overall objective of AMAZING-6G is to provide support to verticals in various areas such as networking, compute, AI and IoT, relying on 5G communication, paving the way to a vertical-centric B5G/6G system. In our case the B5G/6G system is to be considered as a composite and cooperative system that consists of 1/ a standalone 5G system and 2/ the AMAZING-6G system it-self which aims at augmenting the 5G system capabilities.

In that context, Verticals' requirements are meant to capture via textual descriptions the Verticals' needs (customers of the AMAZING-6G + 5G standalone system) when addressing that supporting system. Clearly identified needed functionalities will be described via functional requirements while desired system properties will be captured within non-functional requirements.

2.2.1 Requirement engineering

Before going through the requirement engineering process, it is worth reminding that requirements in a Use Case can be:

- *Use Case specific:* they are relating to how the Use Case must be implemented and operated;
- *Relating to the targeted system:* they are requirements concerning 1/ the combined features/capabilities brought by AMAZING-6G and the 5G provider (functional requirements), and 2/ all non-functional aspects that the UC must meet (and the targeted system must of course implement mechanisms which guaranty those non-functional aspects). For example, the performance of any Use Case sub-system highly depends on performance-related features provided by the targeted system, same goes for security and many others.

The requirements collected during the first phase of the requirement engineering process target both cases above, however in the context of this document, which is about designing the AMAZING-6G logical architecture, we will mainly focus on the second category. Indeed, the purpose of the requirement engineering is to collect, analyze and unify all requirements (*Functional Requirements (FREQ)* and *Non-Functional Requirements (NFREQ)*). Most of requirements address specifically the AMAZING-6G system, but sometimes also the supporting 5G system (e.g., NR RedCap-related requirements).

We now go through the different steps of the requirement engineering process.

- *Requirement collection:* requirement collection goes mainly through brainstorming among Use Case participants, involving technical people responsible for the design but also business partners and customers. The two last categories of people would clearly focus more on NFREQs such as *Quality of Experience* (QoE)-related, privacy & trust, usability, availability while technical people would in addition also consider functional requirements and non-functional requirement such as scalability, performance, reliability, security etc.

  Beside technical brainstorming, performing a tentative preliminary high-level design allows Vertical to:

  - o Identify the required actors and roles;
  - o Elucidate potential interactions with the targeted system and their nature (in terms of Actions for instance);
  - o Identify features/functionalities that the targeted system should offer to the Verticals to support their products (applications) and ease their business (embodied here into Use Cases).

  Those different aspects are captured by the Context view (see Section 4 for more detail). As explained in this section, elucidating the UC Context view should be addressed very early, combined with additional brainstorming.

- *Requirement analysis and unification -* this activity can be split into the two following steps:
  - o *Requirement consistency check:* to check and deal with potential requirement inconsistencies, especially when multiple sources are involved;
  - o *Requirement rewriting, factorization and alignment:* to discard duplicates and factorize as much as possible, to align with common vocabulary.
- *Requirement mapping:* the unified FREQs need to be mapped to the Functional view (see Section 5) where one or more *Functional Groups (FG)* and *Functional Components (FC)* can be identified as participating to implementing the FREQs. The unified NFREQs are not mapped the same way as FREQs. Instead, they are mapped to one or several perspectives which need to be analyzed and resolved. In a nutshell, perspective resolution consists of elaborating tactics and identifying *Design Choices (DCH)* that may involve functional components, but also deployment strategies, or information-related strategies (more on perspectives and their resolution in Section 2.2.4).

The result of this process is a list of so-called Unified requirements (both FREQs and NFREQs) which are compiled into a Volere template (see next Sub-Section).

Only *Unified requirements (UNIs)* will be available in that Volere template, however, for each of them, the template provides traceability information (column L in Figure 1) which points to their origin UC(s).

2.2.2 Requirement supporting tool

This section introduces a supporting tool used to synthesize the outcomes of the various steps described above, in the form of an Excel sheet. This is the main outcome of Task 2.1, after various requirements have been unified. It is then updated during the mapping phase.

> **Important note**: this Volere template can be downloaded from the project WEB-site here [5]. It gives all AMAZING-6G unified requirements. It includes also traceability information regarding the individual UC requirement contributions.

The AMAZING-6G Volere template (see Figure 1 below) used to collect Unified requirements [5] is an extension[2] of the original Volere template [4], augmented in order to comply with the Rozanski & Woods methodology using Views, Viewpoints and Perspectives [2][3] (rightmost columns with green headers).

In particular, this extension allows us to capture the essence of the view / perspective mappings as explained in Section 2.2.4.

Figure 1: Excerpt of the AMAZING-6G Volere template.

2.2.3 Views overview

2.2.3.1 Context view

The purpose of the *Context View (CV)* is to make an initial attempt at formalizing the definition of the UC by:

- Identifying the actors involved and their role(s) as actions (UML bubble);
- Identifying all UC sub-systems involved in the UC and interacting with either, actors, other sub-systems and mostly with the so-called "Targeted System" which consists of a standalone 5G *Terrestrial Network (TN)* alongside our AMAZING-6G system (eventually complemented with an *Non-Terrestrial Networks (NTN)*);
- Elucidating sub-systems roles w.r.t. other entities;

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2 This extension originally comes from the Internet of Thing Architecture flag-ship project aiming to define an architectural reference model for IoT (FP6, 1011-2013)

- Elucidating the roles and duties expected by the UC from the Targeted System, or said in other words, what functionalities/features the combined AMAZING-6G and 5G system, must provide the vertical with, in order to design its business application (in our case the UC demonstration). Elucidating the Context view can be seen as a first UC high-level design attempt. Together with necessary technical brainstorming, they help to identify both FREQs and NFREQs. This explains why elaborating Context views comes early in the architecting process.

In Section 4, each UC Context view will be structured as follows:

1. A list of actors and roles;
2. A list of sub-systems;
3. the features and services the targetted system shall supply to the Vertical (they are shown in "bubbles" in the "targeted system section";
4. A list of µServices that are handles by CaaS (those which are not, don't have the µS suffix);
5. AUML diagram, where we find from left to right 1/ Vertical-owned (far) Edge servers, 2/ the Targeted System which consists of the 5G RAN, 5G Core and AMAZING-6G, and 3/ the Vertical side which can be a cloud or additional Vertical-owned servers (usually backend servers).

2.2.3.2 Operation view

While a Context view addresses the targeted system as black box, meaning only "duties/responsibilities" are explicitly shown (no FCs), an *Operation View (OV)* goes one step forward, elucidating 1/ requests addressed by the Vertical to the targeted system, and 2/ the components that are addressed formally. Operation views will be addressed in D2.2.

2.2.3.3 Functional view

The *Functional view (FV)* is probably, with the Information view, the view requesting most of work as it covers many different, but related aspects. The activities for building that view up are:

- To elaborate and describe a *Functional Model (FM)* that consists of a set of functional groups organized in horizontal layers, usually from the less (bottom – networking) to the most abstract top – Vertical-related and decision-making), keeping as vertical pillars the FGs that serve more than one horizontal layer. FGs identified in the FM are the same FGs found in the Volere template and used for requirement mapping;
- Based on the FM, to identify per FG the functional components that are needed to cover the FG technical objectives. At this stage the collected FREQs are a main source of information for completing this activity. This results in a functional decomposition that eventually provides the main viewpoint of the FV. The functional decomposition shows all FGs filled up with their respective FCs. Figure 44 shows the first version of the AMAZING-6G functional decomposition;
- To provide high-level descriptions of all FCs in textual terms, focusing on their purposes and goals;
- To elucidate a set of *System Use-Cases (SUC)* that aim to identify typical essential patterns resulting from 1/ either person-to-system or physical object-to-system interactions or 2/ from internal platform processes. Examples of such SUCs include: invoking Coverage Extension as a Service, invoking Network Slice as a Service, invoking Compute as a Service, authenticating to AMAZING-6G platform, building digital twins up, etc. Those SUCs will be essential to establish a common understanding of what the system does, and how it does it, using for that purpose both textual descriptions/explanation (D2.1) and UML sequence diagrams (D2.2 & D2.3). They are an essential tool that helps 1/ challenging the architecture design robustness and 2/ testing its soundness. They also are a very valuable input to the WP3 and UCs WPs, helping them to follow the architecture principles for the sake of architecture compliance.

As far as viewpoints are concerned, we will use the UML notation for static and dynamic inter-FG interactions, e.g., UML sequence diagrams and UML use-cases for interactions taking place across the system boundary box.

2.2.3.4 Information view

The *Information View (IV)* is all about data/information and interface. This view will therefore elucidate the following information-related aspects:

- To provide component interfaces and associated data models;
- To elucidate the flow of data exchanged between AMAZING-6G system FCs and those occurring across the boundaries of the system;
- To elucidate the structure of the database (registries and repositories)

The viewpoints used for the IV are 1/ UML data flow diagrams, 2/ UML data class/object modelling and 3/ interface modelling.

The Information view plays an important role in elaborating precise sequence diagrams in the System Use case section where informal transitions between the different lifelines (as planned in D2.2) would be replaced by the actual `class.method(…)` calls (planned for D2.3)

2.2.3.5 (Network) Deployment view

In AMAZING-6G, we shall consider both UC-specific deployment views (to be described in the UC-related deliverables D4.x, D5.x and D6.x and a generic one described in this documents, a.k.a. the *Network Deployment View (NDV)*.

The Deployment views will address the coupling between AMAZING-6G and the supporting standalone 5G system and will show in one single figure the 5G system, the subset of AMAZING-6G architecture interacting with it, and also some typical Vertical deployments inspired form the project UCs. In D2.2 and D2.3 we will update the NDP with some typical deployment strategies for selected UC domains and address *Non-Terrestrial Networks (NTN)*.

2.2.3.6 Instantiation view

In the context of AMAZING-6G, the *Instantiation View (INV)* elucidates how the enablers developed in WP3 map to the logical functoinal components identified in WP2.

Different viewpoints can be used, such as an overlay to the architecture figure or a series of tables where WP3 enablers (column) are mapped to the WP2 FCs (row).

Assuming the large number of enablers and FCs and in order to keep the table readable we will implement one table per technology pillar of WP3. This view will be addressed in D2.2. and updated in D2.3.

2.2.4 Perspective overview

According to Rozanski & Woods [3], an architectural perspective "is a collection of activities, tactics and guidelines that are used to ensure that a system exhibits a particular set of related quality properties that require consideration across a number of the system's architectural views" [3].

In this definition, a quality property is meant to be "an externally visible, non-functional property of a system such as performance, security or scalability" [3].

As we can see, architectural perspectives are orthogonal to architectural views; therefore, any architecture or design decision pertaining to non-functional or quality requirements often spans more than one architectural views, if not all.

We identify hereafter a comprehensive list of perspectives which are relevant to AMAZING-6G. Each perspective focuses on specific NFREQs or desired quality properties of the architecture. The following

list is a set of perspectives that can be of interest for AMAZING-6G, though probably not all will be eventually covered:

- *Evolution (or evolvability)*: is a quality of a system that has been designed in such a way it can easily be adapted to new technologies;
- *Interoperability:* ability of a system to easily interoperate with other systems at various levels like technical, syntactical, semantic and organizational;
- *Availability:* ability of a system to be fully (or partly) available when required;
- *resilience:* ability of a system to effectively handle failure or attacks that could affect the system availability;
- *Privacy, security and trust*:
  - *Privacy*: ability of a system to deal with all kinds of personal data and in particular to implement reliably privacy policies about accessing, sharing that data or hiding people's identity;
  - *Security*: ability of the system to reliably control, monitor and audit who can perform what actions on what resources, to detect and recover from failures insecurity mechanisms and resist to cyber-attacks;
  - *Trust*: ability of a system to establish and enforce trusted relation between the different parties involved in a system (end-users, component, data) in such a way system operation and behaviors comply to expected ones.
- *Performance:* ability of a system to predictably perform its operations within its mandated performance requirements and profiles;
- *Scalability:* ability of the system to cope with increasing demand in computing, networking, storage resulting from increasing volume of system usage;
- *Usability:* quality that illustrates how easy a system can be used, how easy data can be apprehended by the end-users, how easy the *Graphical User Interface (GUI)* is understandable and ergonomic while maintaining efficient work.

The non-exhaustive list of qualities may be updated or adapted according to the architects' needs.

Each desired quality will then be associated with a set of activities (for instance activities associated with Trust, Security and Privacy are the collection of trust requirements, the conduction of risk and threat analysis, the definition of a trust model, etc.) Then defining a certain number of tactics allows showing how the desired system quality can eventually be reached. Because a tactic can span more than one view, the implementation of a tactic through DCHs can lead to more than one of those DCHs (e.g., a tactic for realizing anonymity can lead to a collection of DCHs relating to data structure for the Information view and DCHs relating to interfaces, storage and security-related functionality in the Functional view).

As shown in Figure 2 below, architecture perspectives (the grey horizontal boxes) focus on system properties/qualities and are orthogonal to the architecture views. As a consequence, when deciding to consider a tactic that would allow the system to reach a desired quality, it results in the definition and implementation of concrete DCHs that impact more than one view(s), if not all.

Figure 2: Architecture Views and Perspectives.

In the Perspective section of this deliverable (Section 7), we will describe perspectives using a table structure as shown in Table 2 below:

Table 2: Perspective description.

Targeted System Quality	Describes the overall objectives of the considered perspective (say Privacy), considered as a category. From the requirement analysis phase, we will come up with several objectives falling under one of the lists of perspectives (see above), each one of these objectives (say privacy related objective) will be declined into one or several tactics (say anonymization, pseudonymization, etc.), which can be considered as high-level DCH.
Requirement(s)	Gives the list of NFREQs concerned with that perspective.
Activities	Gives a list of activities needed when dealing with the perspective. It includes activities like: • Performing a threat analysis; • Performing system / network stress assessment; • Simulations; • Updating list of requirements; • Validating against requirement (especially for any NFREQ associated with performance thresholds), etc.
Tactics	Consists of a set of high-level abstract design choices that can be used to reach a desired property. Then each one of these tactics binds to a set of DCHs which relate to a particular view as explained earlier. Such DCHs can be: 1. Adopting certain algorithms; 2. Adopting specific deployment strategies; 3. Adopting a certain architecting choice; 4. Adopting a certain structure and/or deployment of data/information 5. Introducing specific FCs,t etc.

As far as DCH description is concerned we will be using the following Table 3 structure (note however that in practice we would not mix up different NFREQs -here, privacy and performance- in a single table):

Table 3: Example of Design Choice descriptions.

Design Choice ID	View	FG/FC	Technical description
PRIV-01	FV	Security/ *xyz* FC	This component is responsible for...
PERF-01	NDV	n/a	In order to fulfill this desired quality, the deployment of....

3   Use Case descriptions

In this section we shall address all UCs one by one, providing updated descriptions, compared to those provided initially in the project Description of Action. They are complemented with Context views in Section 4.

3.1   Wearable ultrasound patch for cardiac function monitoring [H1]

Echocardiography (i.e., cardiac ultrasound imaging) is an indispensable tool for diagnosis, intervention and follow-up of heart (and other) patients. In medical emergencies, and especially during hospitalization and intensive care treatment for life-threatening heart (and other) diseases, heart function is always a question and hard to assess without echocardiography. In traumatology, (close to) real-time monitoring of heart function is needed in the field, during a short time frame, for patients with hypovolemic shock, in order to assess volume replacement and other critical parameters. Furthermore, after undergoing repair surgery or implantation of structural heart devices (e.g., prosthetic heart valves) patients need frequent follow ups after discharge to assess their cardiac function.

However, echocardiography is a highly specialized task which needs to be performed by a cardiologist. This means that heart function assessment can only be performed intermittently and only while the patient is present in the hospital. Furthermore, the frequency of such assessments will be limited by the availability of cardiologists (i.e., staff shortage), as well as by financial constraints (i.e., cost of care). In other words, echocardiography can never be performed for extended periods of time (i.e., continuous monitoring) and often not exactly when indicated. In an attempt to address those limitations, surrogate markers for cardiac output (e.g. blood pressure curves, central venous oxygen saturation or near infrared spectroscopy measurements of organ perfusion) are frequently used in intensive care settings, as they are easily available and do not demand specialized personnel. However, such surrogate markers do not assess the heart directly, are subject to variations not only related to cardiac function and therefore flawed and cannot replace echocardiography.

3.1.1   Use Case objectives and relation to the project technical objectives

New adhesive-patch-based, ultrasound devices, leveraging *Capacitive Micromachined Ultrasonic Transducer (CMUT)* and similar transducer technologies, are appearing on the market, enabling totally new ways of exploiting cardiac functional imaging [7]. These patches, which are semi-permanently attached to the patient's body, promise to enable more frequent assessments and monitoring for longer periods of time. This way critical time points before, during, and after hospital interventions (e.g., surgery) can be covered. Furthermore, patients can be monitored during advanced treatments for heart failure, such as intensive care therapy or while being moved in the ambulance. Finally, patients can be monitored at home, at work, on-the-move, or even during exercise.

Patch-based, cardiac ultrasound assessment can be automated by deploying AI-based, ultrasound image analysis algorithms on the edge. These algorithms will extract cardiac function parameters, such as ejection fraction. Also, hemodynamic (e.g., blood pressure) and *Electro-Cardiogram (ECG)* data can be integrated into analyses for addressing different clinical situations.

Figure 3 depicts the cardiac assessment solution comprising a 6G-enabled, ultrasound patch (ECG and blood pressure sensing are optional) on the left-hand side and the 6G RAN and Core hosting AI-based image analysis on the edge on the right-hand side. The AI-based assessments are communicated to the cardiologist via the Clinical backend which is connected to the 6G-System via a Data Network such as the Internet.
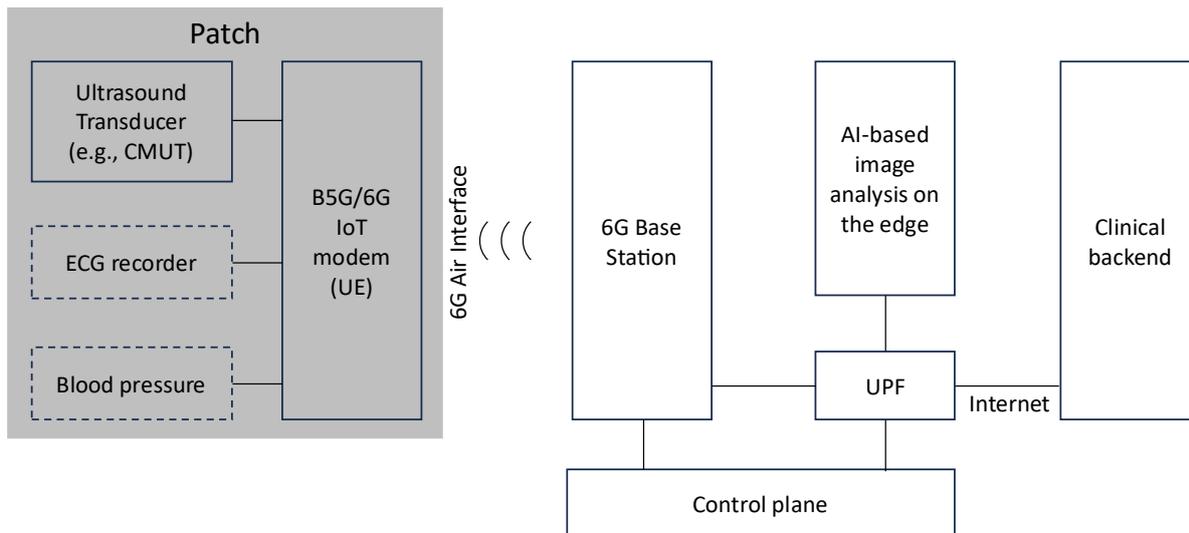
Figure 3: H1 Use Case overview.

This solution may prove to be a powerful new tool for early detection of critical changes in cardiac function and complications to treatment, such as cardiac effusions, cardiac tamponades, and pulmonary hypertensive crises. Similarly, the effects of drug treatment can be monitored more closely by continuous registration of cardiac ultrasound data in the hospital and by providing daily short registration updates when discharged to home or lower-level care settings. The latter also enables early discharge from the hospital. In short, cardiac ultrasound patches combined with edge-based AI analysis will improve patient outcomes and lower the cost of care, while improving patient and caregiver experience (i.e., quadruple aim in healthcare, see e.g.,[8]).

3.1.1.1 Clinical Scenarios

As described above, an ultrasound patch with cardiac function analysis on the edge could benefit patient treatment during several stages of the patient's journey (e.g., during treatment and after returning home). However, each of these stages sets different requirements for the patch, the AI-based analysis, and their deployment on the 6G System. Specifically, the following three variables can be helpful when defining different clinical scenarios:

- *Location:* at home `(H)`, during transportation – i.e., in the ambulance – `(T)`, or at the hospital – i.e., during intervention or in the intensive care unit – `(I)`;
  Power source: battery `(B)` or cabled `(C)`;
- *Data analysis:* offline – i.e., batch – processing `(O)` or real-time analysis `(RT)`.

It should be noted that these variables are inter-dependent and may lead to conflicting requirements. For example, in ambulatory settings `(H)`, the patch will need to be battery-powered `(B)`. This severely limits its energy budget and therefore real-time analysis – i.e., continuously sending data to the edge in real-time – `(RT)` will not be feasible. However, for this situation offline analysis the `(O)` option is sufficient. On the other hand, during surgery `(I)` the patient can be tethered to an external power supply `(C)` and real-time monitoring is needed and possible.

Therefore, even though twelve different combinations of these variables can be imagined, some are not possible, while others may not lead to realistic clinical scenarios. As a matter of fact, the two example scenarios described in the previous paragraph – i.e., `H-B-O` and `I-C-RT` – are the most useful ones. These will be addressed in the project and be identified as "H1A" and "H1B" respectively:

- *H1A (`H-B-O`):* home-based, battery-operated use with offline analysis, for testing of heart function during ambulatory exercise, such as walking stairs, running, or bicycling (e.g.,

assessment of contractile reserve (how much extra above baseline work level the heart can work during exercise, i.e. how much the heart can increase its blood volume output per minute when needed) during exercise to further fine-tune medication therapy). Nowadays, exercise echocardiography is an advanced assessment only performed in select specialized centers.

- *H1B (I-C-RT):* intensive care monitoring of cardiac output in patients with circulation failure and continuous titration and adjustment of medical treatment that supports heart function and circulation, such as direct infusions into the veins of drugs that 1/ increase heart frequency and contraction like *Epinephrine*, *Levosimendan* or *Milrinone* or 2/ dilate the arterial vessels such as *Nitroprusside* or again *Milrinone*. Temporary pacemakers may be adjusted based on input from the patch to optimize heart function and output.

It is foreseen that a single patch product (i.e., multi-use ultrasound patch) and associated AI service on the edge could address both clinical cases. For example, the patch could have a power connection which could be used to charge the battery (H1A), but alternatively also to power the patch continuously while still attached to the patient's body (H1B). In the latter case, the patch could switch to continuous mode, streaming real-time image data to the edge, while the AI service deployment on the edge would switch to a real-time deployment by allocating additional resources (i.e., computational resources on the edge and a low-latency, high-bandwidth slice deployment). Therefore, it should be noted that, even though potentially a single device is involved, the requirements (and in particular the *Key Performance Indicators (KPI)* for the 6G System are profoundly different.

3.1.2 Main innovations and challenges

3.1.2.1 Innovations

- *H1A:* intermittent heart function monitoring with a battery-powered, 6G-enabled, ultrasound patch and offline, AI-based, ultrasound analysis on the edge. Additionally, blood pressure and ECG can be integrated into analyses. This innovation enables regular check-ups, incidental assessments (in case of symptoms), and follow-ups (after discharge from the hospital) at home. It also enables daily follow-ups at the general ward. Typically, assessments are needed daily or much less frequently;
- *H1B:* continuous heart function monitoring with a tethered, 6G-enabled, ultrasound patch and real-time, AI-based, ultrasound analysis on the edge. Additionally, blood pressure and ECG can be integrated into analysis. This innovation enables direct intervention at the onset of deterioration during treatment and at the intensive care unit.

3.1.2.2 Challenges

- *H1A:* achieving sufficient device battery life for the wearable ultrasound patch. The challenge lies in the fact that a significant amount of B-mode ultrasound data will have to be uploaded to the edge to perform a single cardiac function assessment, whereas the patch will have a small form factor, as it needs to be comfortably wearable by the patient during exercise;
- *H1B:* achieving sub-second, end-to-end delay for ultrasound capturing, transmission to the edge, AI-based edge computing, and notification of the clinician;
- *H1A + H1B:* developing an AI-algorithm for cardiac function assessment based on ultrasound and possibly other modalities (e.g., ECG, blood pressure). Note that the algorithm will need to have short response times for the H1B case, as outlined above.

3.1.3 General context and set-up

3.1.3.1 Actors

- *Torstein:* patient;
- *Per:* e-cardiologist;

- *Anna:* paramedic;
- *Henrik:* surgeon;
- *Echo patch:* attached to the patient;
- *6G System:* for communication between patch and edge, and algorithm deployment on the edge;
- *AI-based, cardiac function assessment algorithm:* deployed on the edge.

3.1.3.2 Set-up

The focus of this Use Case within AMAZING-6G will be a feasibility assessment of the overall concept. The actual demonstration will be of relatively low *Technology Readiness Level (TRL)*, focused on showing that the requested clinical function (i.e., cardiac function assessment based on wearable ultrasound) can be achieved with B5G NR RedCap communication technology and B5G edge computing capabilities. In particular, a small-form-factor, battery-powered, wireless ultrasound patch will not be realized, also because integrated, low-power electronics to produce B-mode, ultrasound data may not become available within the project's timeframe.

The anticipated test set-up is shown in Figure 4. A wearable, patch-based, ultrasound transducer (Xu labs, San Diego, USA) is applied to the patient's chest, for continuous ultrasound imaging. It is connected to a Verasonics research ultrasound machine, which produces B-mode, ultrasound data (i.e., grey-scale moving video). A connection is made between Verasonics and the Quectel RC255C (NR RedCap) evaluation board, which functions as the UE towards the B5G System. It communicates with TNO's Hi5, B5G research facility which comprises a base station (Amarisoft), Core, and Edge. The OUS AI-algorithm will be deployed on this Edge and send its resulting data (i.e., cardiac function parameters such as ejection fraction) to some PC on the Intranet or Internet.
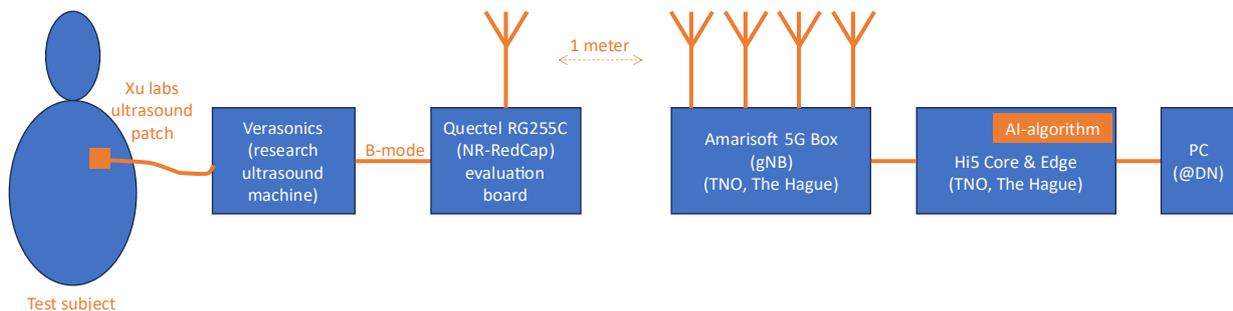
Figure 4: Anticipated H1 test set-up.

The demonstration will take place at the TNO office in The Hague. However, it is conceivable that a patient's ultrasound (B-mode) data will be captured and recorded at OUS and that this recording will be used for the demonstration instead.

3.1.4 Technology providers and other partners

- *OUS:*
  - AI-based, cardiac function assessment algorithm (technology).
- *TNO:*
  - NR RedCap communication technology, comprising UE (i.e., NR RedCap modem), RAN, and Core and including measurement framework for detailed assessment of UE energy usage (enabler);
  - Edge computing capability (enabler).

3.1.5 Pre-requisites and assumptions

- Availability of a human test subject and passing associated ethical procedures;
- Availability of Verasonics ultrasound machine (on loan from other department at OUS or TNO);
- Development work to connect Verasonics to Quectel and/or an ultrasound data recording system.

3.1.6 Stories

3.1.6.1 Story 1

3.1.6.1.1 Short description

Torstein, a 65-year-old male carpenter, lives on a remote island. Torstein has a known heart valve insufficiency and a stable, compensated heart failure, for which he is on medications. He gets three-monthly check-ups using the echo patch and a home blood test. The check-up results are commented upon by Per, his e-cardiologist, who sees Torstein's images after AI-analysis in his office in the city. Per also adjusts Torstein's medications accordingly. From one day to the other, Torstein faces an increase in symptoms with dyspnea at rest, dizziness and fatigue. He applies the echo patch to his chest that demonstrates an increased dilatation of his left pumping chamber and reduced contractions, as the results are automatically compared to those of his previous check-up. Per gets an emergency message, reads the results indicating acute deterioration, rules out myocardial infarction, and calls an ambulance boat to bring Torstein to the hospital on the mainland.

The echo patch remains applied to Torstein's chest during transportation, but is connected to a wired supply by Anna, the paramedic. The connection of the wire automatically triggers real-time analysis of Torstein's heart function. Torstein's heart function deteriorates which is immediately detected by real-time analysis on the edge. Anna prepares for cardiac arrest which occurs during transportation. Adequate chest compressions during resuscitation are documented by the echo patch and resuscitation is successful. In the emergency room, a full standard echo is performed documenting a valve problem that needs acute surgery. The echo patch remains on for real time function monitoring on the way to the operating room. Henrik, the surgeon, fixes his valve problem.

In post-op intensive care, the echo patch documents a deterioration in heart function 12 hours after surgery and IV drugs for inotropic support are started. The patch shows improved heart function a few hours later. Torstein is transferred to ward care on day 2, with the patch echo intermittently used every day for medication adjustment (reverted to battery operation to enable Torstein to walk around).

On day 5, Torstein is discharged from the hospital with daily echo patch follow-up.

On day 8, he is feeling sick, and the patch echo shows pericardial effusion in need of drainage at hospital. He is discharged home on the same day with daily echo patch checks for the first week, then weekly checks for four weeks and finally he reverts back to the regular three-monthly intervals, including battery powered patch echo during standardized exercise to detect cardiac reserves for further optimization of therapy.

A new follow up parameter is included in his regime from now to pick up any deterioration even earlier: exercise echocardiography with the patch on when cycling on his ergometer bike at home. Per can adjust medications to prevent new attacks of heart failure.

3.1.6.1.2 Steps

- *Step 1:* patient deterioration at home. Patch batch echo upload to compare with previous images;
- *Step 2:* continuous real-time analysis patch echo in ambulance. Cardiac arrest and resuscitation. Patch indicates effective chest compressions;
- *Step 3:* on hospital standard echo: confirms heart failure and diagnoses worsened valve regurgitation (flail valve in need of stat surgery);
- *Step 4:* continuous patch monitoring with real-time AI analysis in intensive care when preparing for surgery – medications administered for stabilization;
- *Step 5:* transportation to the operating room;
- *Step 6:* surgery;

- *Step 7:* intensive care after surgery. Patch echo detects function deterioration day 1 – medical treatment dose titration supported by real time echo patch data input;
- *Step 8:* ward care after stepping down from ICU. Daily intermittent patch echo detects improved heart function and medications can be downregulated;
- *Step 9:* discharge home with medications for heart failure. Patch echo follow-up at home;
- *Step 10:* day 8, feels sick. Patch echo: pericardial effusion. Return to hospital for drainage;
- *Step 11:* home again, daily and later weekly and finally three-monthly follow-up intervals;
- *Step 12:* new follow-up parameter at home. echo patch exercise test, ergometer cycling with battery powered patch for contractile reserve analysis indicates to change in drug regimen at an earlier stage.

3.2 Event-aware real-time reprogramming of pacemaker through wearable patch [H2]

Permanent pacemakers are critical medical devices used to manage abnormal heart rhythms, particularly brady-arrhythmias i.e., conditions where the heart beats too slowly. They help maintain adequate heart rate and cardiac output, preventing symptoms like fatigue, dizziness, syncope, or even sudden cardiac arrest. The primary patient population includes:

- Older adults with age-related conduction system disease;
- Patients with atrioventricular (AV) block or sick sinus syndrome;
- Individuals with congenital heart block and those recovering from cardiac surgeries or myocardial infarction that affect electrical conduction.

Reprogramming of permanent pacemakers is essential to ensure the device continues to meet the evolving clinical needs of the patient over time. Although pacemakers are implanted with initial settings tailored to the patient's condition, physiological changes, disease progression, or lifestyle factors often require adjustment. Furthermore, there is also a high demand for event-aware reprogramming of pacemakers to adjust sensing and pacing modes depending on the patient daily activities within a closed-loop system.

Current pacemaker reprogramming technologies rely on inductive or *Radio Frequency (RF)* telemetry wands. These handheld devices communicate wirelessly with the implanted pacemaker – typically via radiofrequency – to adjust parameters such as pacing mode and sensing/pacing thresholds. In current clinical practice, reprogramming is performed shortly after implantation (within the first two weeks) and during routine follow-ups every 3 to 12 months. Reprogramming typically requires patients to visit specialized centers with telemetry programmers. Also, there's limited integration of contextual data (e.g., activity level, symptoms) for dynamic adjustment of therapy. In conclusion, the current practice for optimizing pacemaker settings is labor-intensive, infrequent, and does not adapt to the patient's daily activities. This leads to less-than-optimal patient outcomes, reduced patient comfort and increased cost-of-care.

3.2.1 Use Case objectives and relation to the project technical objectives

Event-aware, real-time wireless reprogramming of the pacemaker is proposed to adapt device performance to a patient's daily activities in a closed-loop, remote, and automated set-up. This requires continuous communication between the implanted device and the edge, currently a power-hungry limitation.

For the event-aware reprogramming, an AI-based algorithm is deployed at the edge, enabling semantic activation of the pacemaker, triggered only when truly needed, while filtering out environmental noise or irrelevant events. Edge computing leverages greater computational resources compared to the more

limited capabilities of a wearable device. The edge infrastructure also supports sensor fusion from devices like accelerometers to recognize patient activity context. The AI model processes *Electrogram (EGM)* data from the pacemaker to issue real-time commands for adjusting pacing and sensing thresholds. Beyond therapy automation, this data supports short-term performance evaluation and clinical decision-making.

To mitigate communication constraints, a wearable patch is proposed as a gateway between the pacemaker and mobile networks (RFID ←→ NR RedCap). Using RFID backscattering, the patch allows low-power reprogramming communication, while linking the pacemaker to the edge for EGM transmission and control. Critically, the Edge-AI model is personalized for each patient and fine-tuned during hospitalization using data from a temporary pacemaker—an external, short-term support device with leads inserted into the heart via a vein.

Figure 5 depicts the cardiac assessment solution comprising a 6G-enabled patch (ECG) on the left-hand side and the 6G RAN and Core hosting AI-based signal analysis on the edge on the right-hand side. The AI-based assessments are communicated to the cardiologist via the Clinical backend which is connected to the 6G-System via a Data Network such as the Internet.
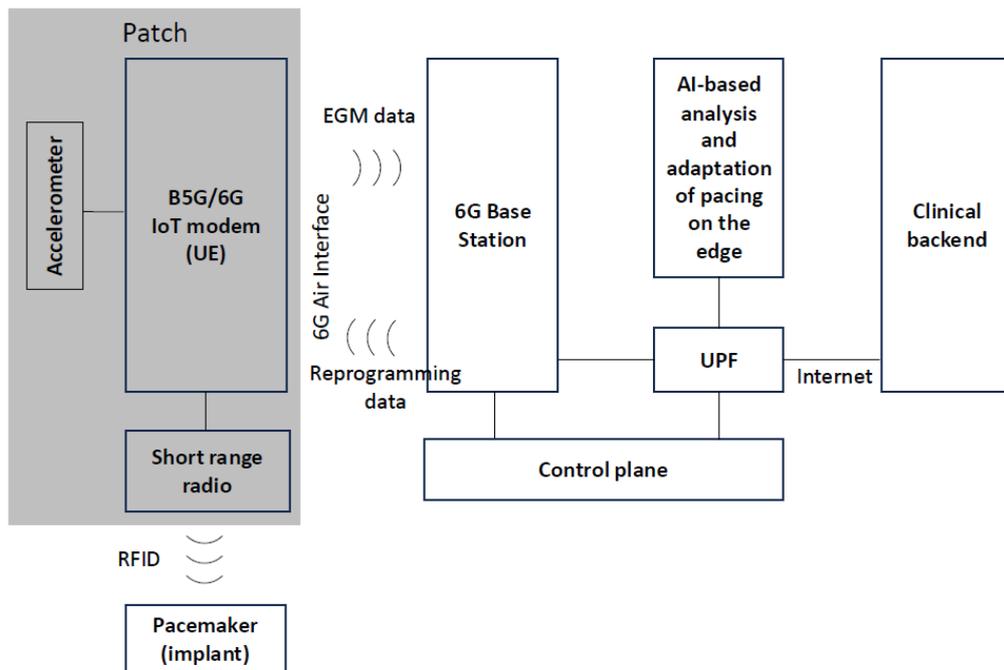
Figure 5: H2 Use Case overview.

Technological and societal impacts: fixed sensing and pacing thresholds may lead to oversensing or under sensing, particularly during recovery, as the patient's condition evolves. Additionally, real-time reprogramming of permanent pacemakers is currently not feasible, as it requires the patient to be physically present for the programmer to be attached, data to be sensed, and parameters to be adjusted. Existing systems depend on an active transmitter embedded in the pacemaker. These limitations highlight the need for an externally controlled, intelligent system capable of dynamic and personalized pacemaker management — forming the basis for the proposed AI-based, low-latency, backscatter-enabled communication framework.

Scientific impact: the Edge-AI model compensates for the limited data rate and the harsh communication conditions of intrabody backscattering channels. By implementing AI at the edge, we significantly reduce the computational burden and on-device processing latency for body-worn hardware, despite the additional latency introduced by edge communication. This approach results in

an energy-efficient, low-latency wireless pacemaker communication system with minimal hardware and computational requirements both inside and outside the body.

This solution will enable:

1. Real-time reprogramming of permanent pacemaker parameters, including dynamic adjustment of threshold settings;
2. Event-aware triggering of the pacemaker to reduce unnecessary activations, thereby delaying the need for battery replacement and enhancing patient outcomes and experience;
3. Minimizing of the additional energy consumption of the implanted pacemaker required for maintaining wireless communication with the wearable patch reader through the use of backscatter communication, in order to extend the pacemaker's battery life;
4. Personalized pacemaker reprogramming and control, adapting to the individual's physiological and clinical conditions;

Cloud/edge-based control allows the clinician to access the patient, while in ambulatory status and reduces the need for physical access.

3.2.2 Main innovations and challenges

3.2.2.1 Innovations

- A pacemaker communicating via an RFID backscatter link with a wearable patch;
- A wearable patch serving as a bridge between the pacemaker and the 6G system;
- An adaptive AI algorithm enabling event-aware reprogramming of the pacemaker;
- A personalized AI model for permanent pacemakers, trained on data from a temporary pacemaker;
- An AI model designed to compensate for deficiencies in the intrabody backscatter communication link

3.2.2.2 Challenges

- *Ultra-Low Latency Requirement:* the entire feedback loop – including uplink data transmission, cloud-based analysis, and downlink command delivery – must be completed within 80ms. Notably, the short-range backscattered link alone can contribute up to 50ms of (2-way) latency. Consequently, transmission to/from the 6G System Edge and the latency of the algorithm itself must be within 30ms;
- *AI Model Training and Feature Extraction from pacemaker telemetry data:* the AI model must be specifically trained to extract the most useful features from the sensed data enabling timely and accurate decision-making despite the inherent communication constraints;
- *Co-registration of ECG and EGM data:* the temporary pacemaker ECG data should be co-registered efficiently with permanent pacemaker EGM data for fine tuning the AI model to the individuals;
- *Battery life:* the patch must have sufficient battery life, in spite of the battery being small and continuous data being sent/received with short latency to/from both pacemaker (via backscatter) and 6G System.

3.2.3 General context and set-up

3.2.3.1 Actors

- *Patient (Mr. Smith):* wears the implanted device and patch, shares his medical history during treatment;
- *Cardiologist (Dr. Myhre): monitors patient data remotely, makes clinical decisions, assesses the pacemaker settings adjustments made by the AI algorithms from a clinical perspective during the*

initial period of several days and then over several weeks after automatic reprogramming is well-established;

- *Pacemaker: implanted into the patient, communicates with patch via backscatter;*
- *Patch: attached to the patient, bridges between pacemaker backscatter and 6G System;*
- 6G-System: for communication between patch and edge, and algorithm deployment on the edge;
- AI-based pacemaker assessment and reprogramming algorithm assesses cardiac function while being context-aware and provides updated settings for the pacemaker.

This is illustrated by Figure 5 and Figure 6.

3.2.3.2 Set-up

Figure 6 below shows the system set-up. It employs intrabody communication using a backscattering (RFID) link to connect a wearable patch reader to the implanted pacemaker. The patch reader collects physiological data sensed by the pacemaker and transmits it to the edge. In the edge, an AI algorithm extracts relevant features from the data and compares them with baseline (ground truth) features. Based on the resulting error signal, the AI generates commands to adjust the pacemaker settings.

- *Step 1:* we use the collected ECG dataset from the temporary pacemaker to train and fine-tune a patient-specific AI model and optimize the model to extract meaningful features for semantic interpretation and control;
- *Step 2:* we simulate the complete system (including backscatter link, transceiver, and pacemaker response) and fine-tune the AI model under simulated intrabody conditions to ensure robustness and low latency;
- *Step 3:* we evaluate the model using test datasets under varying environmental conditions and hardware parameters.
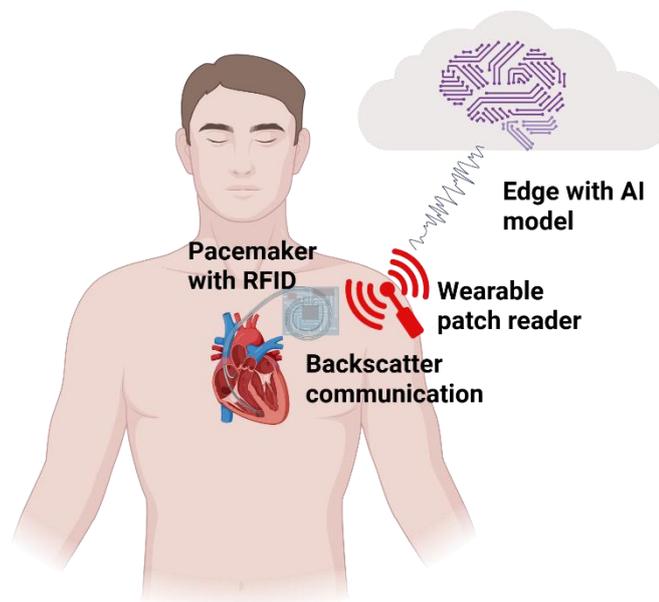
Figure 6: System set-up with interconnections (The figure is generated by biorender.com).

3.2.4 Technology providers and other partners

- *OUS:*
  - Defines system requirements and specifications from a clinical perspective;
  - Provides datasets collected from temporary pacemaker patients;
  - Provides AI model training and patient-specific fine-tuning;
  - Simulates and evaluates intrabody backscatter communication performance.

- *TNO:*
  - Assesses and implements the edge communication link (specifically, a feasibility study into battery life will be done, given the required communication patterns of the application);
  - Deploys the AI model on the mobile network edge;
  - Specifies the functional requirements and high-level design of the wearable patch reader.

3.2.5 Pre-requisites and assumptions

1. Availability of a human test subject and approval through the required ethical procedures;
2. Access to a temporary pacemaker for collecting a diverse dataset covering sensing and pacing parameters for model training;
3. Availability of an exercise testing machine (stress test), combined with ECG, for monitoring physical activity.

3.2.6 Stories

Mr. Smith, a 67-year-old retired schoolteacher, was rushed to the emergency department after experiencing sudden dizziness and multiple episodes of fainting at home. Upon arrival at the hospital, an electrocardiogram (ECG) revealed a third-degree atrioventricular (AV) block. Given the urgency of his condition, the cardiology team led by Dr. Myhre immediately decided to implant a **temporary pacemaker**. A central venous catheter was inserted, and a pacing lead was positioned inside the right ventricle. The external pulse generator, placed at the bedside, was programmed to deliver basic ventricular pacing to stabilize Mr. Smith's heart rate. Over the next several days, he was monitored continuously using surface ECG, and the pacemaker settings were adjusted manually to ensure proper pacing. Mr. Smith began to recover, but his heart's intrinsic rhythm did not show signs of improvement. Daily assessments confirmed that the AV block persisted and was unlikely to resolve spontaneously. After careful evaluation, Dr. Myhre concluded that Mr. Smith would require a **permanent pacemaker** to ensure long-term rhythm management and prevent future episodes of syncope or sudden cardiac arrest. Mr. Smith, who now has a permanent pacemaker implanted was discharged from the hospital. A wearable patch was applied to his chest which continuously communicates with the pacemaker, transmitting EGM data from the pacemaker to the Edge-AI for real-time, event-aware reprogramming based on his daily activities, or to the clinical center for ongoing monitoring. As an example, when Mr. Smith begins biking, the AI-enabled device adjusts in real time by increasing the pacing rate from a resting level of around 60 bpm to 90–110bpm, based on sensor inputs such as body motion and respiration. If increased physical effort or signal fluctuations are detected, the pacing output, specifically the amplitude or pulse width, may also be adjusted to ensure consistent cardiac capture. As the activity subsides, both the pacing rate and output return to baseline, maintaining physiological responsiveness and energy efficiency.

Mr. Smith's patient journey is illustrated in

Figure 7 below.
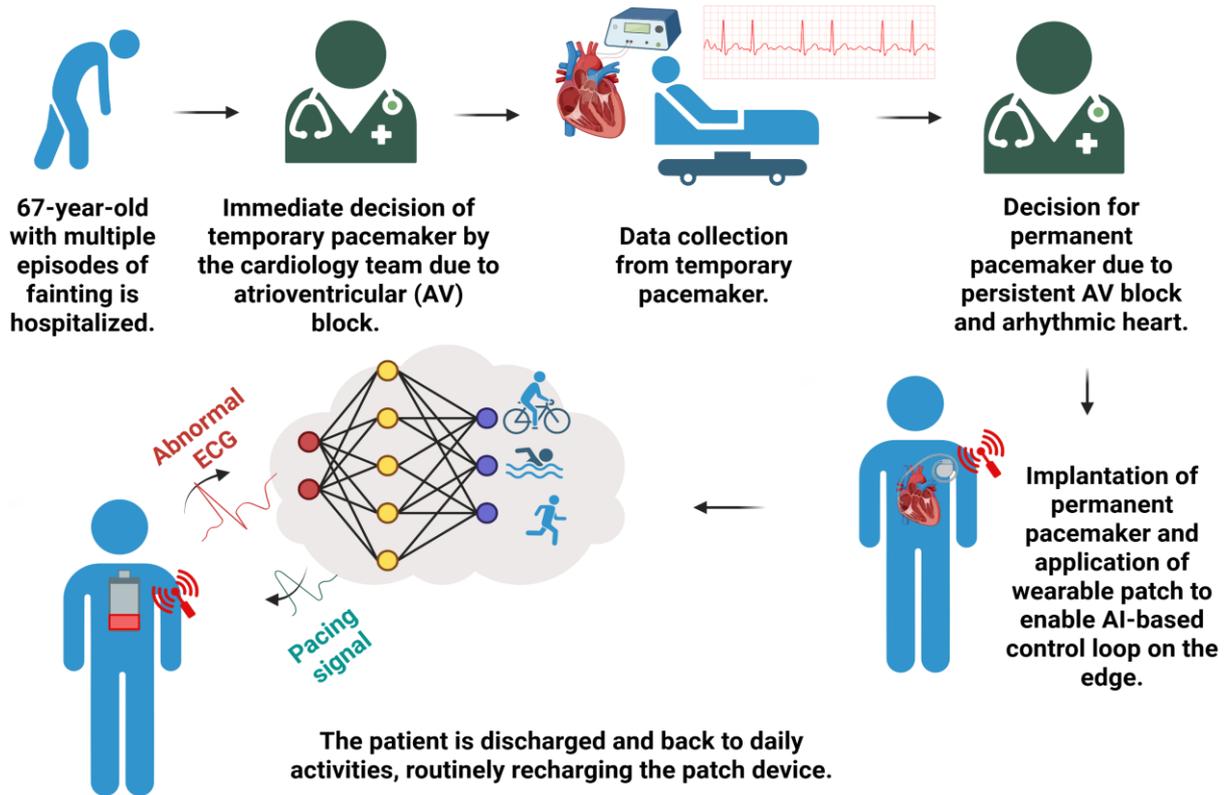
Figure 7: Patient journey (the figure is generated by biorender.com).

3.3 Ubiquitous B5G/6G communication and slice deployment across operators for PPDR AR/VR assisted control centres [P1]

For emergency service teams, reliable and secure data processing and communication are crucial. With mission critical broadband services and infrastructure at their disposal, first responders can communicate with the *Local Control Center (LCC)* and *Central Control Centers (CCC)* more efficiently. Also, they can be accurately assisted by high performance models and predictions and enhance their situational awareness. It is essential that robust and reliable communication is maintained in the area affected by an incident, even if the digital infrastructure is destroyed or underperforming. Therefore, this Use Case aims to deliver ubiquitous B5G/6G connectivity to a *Public Protection and Disaster Relief (PPDR)* campaign through interworking and convergence of multiple networks.

Assuming a wide-area emergency (wildfire/earthquake), with disruptions on the digital infrastructure, this use case will be designed for a high priority and increased quality PPDR service deployment, with a network slice over a private B5G/6G network, that can be interconnected to a public B5G/6G network. The PPDR service will maximize coverage and network performance within the affected area. This Use Case will demonstrate an end-to-end PPDR network slice over a private and a public *Radio Access Network (RAN)*, the orchestration of network resources on-demand, the provision of *Multi-Access Edge Computing (MEC)* capabilities, and the interconnection of B5G/6G Core networks through their Application Functions, for fast provisioning and seamless operation.

3.3.1 Use Case objectives and relation to the project technical objectives

The objective of the Use Case is two-fold with innovations at the network and the application integration layer. At the network layer, we need to ensure ubiquitous connectivity for the PPDR emergency teams, over multiple private B5G/6G networks and public ones. The end-to-end quality of service requirements

for the PPDR slice will be defined, and the required reliable mechanisms will be investigated. This Use Case will also demonstrate fast private B5G/6G network set-up, addressing areas where B5G/6G coverage is poor or nonexistent.

At the application layer, PPDR campaigns rely on various applications as shown in Figure 8. In order to demonstrate an autonomous operation at the edge of the network, this use case will showcase situation monitoring, including the ground assets, through *Unmanned Vehicles (UMV)*, closed loop control and collaboration among robots, it will execute prediction models for the situation propagation, while AR/VR will enhance PPDR awareness.

3.3.2 Main innovations and challenges

3.3.2.1 Innovations

- Ubiquitous Connectivity: As in the International Mobile Communication (IMT)-2030 Framework [9], ubiquitous connectivity aims to bridge the digital divide by enhancing connectivity through interworking and convergence between networks and systems, ensuring broader access to communication services;
- Fast private network provisioning and end-to-end network slicing with stringent requirements for PPDR Use Cases, including various backhaul enabling communication technologies;
- End-to-end slice orchestration with-mission critical network services and PPDR applications (e.g., push-to-talk, video streaming, Virtual Reality (VR) or Augmented Reality (AR) enabling services, collaborative robots, and emergency alert broadcast).

3.3.2.2 Challenges

- To investigate the orchestration of PPDR slices over various private and/or public networks for interconnecting people, equipment and PPDR applications;
- To ensure fast set-up of a high-speed, bi-directional connectivity between the emergency field and the CCC, including the necessary backhaul deployments;
- To provide set-up of a B5G/6G-enabled, multi-user, location-based, AR/VR experience e.g., for the CCC operators to fully immerse themselves in the emergency;
- To investigate the effect that a fully disaggregated B5G/6G architecture and the relative placement of B5G/6G functions, interfaces, MEC, and backhaul/fronthaul solutions may have on the overall delay;
- To include AI-enabled closed loop control of drones/robots and data acquisition, in PPDR situation analysis/prediction.

3.3.3 General context and set-up

3.3.3.1 Actors

- *PPDR Remote Command Supervisor (PPDR RCS);*
- *PPDR Central Command Supervisor (PPDR CCS);*
- *PPDR First Responders (PPDR-FRs);*
- *UMVs/Robots;*
- *Citizens (affected);*
- *Satellite Mobile Network Operator (MNO).*

3.3.3.2 Set-up

The specific PPDR Use Case is gradually deployed with the following four steps, as shown in Figure 8: Ubiquitous B5G/6G communication and slice deployment across operators for PPDR overview.
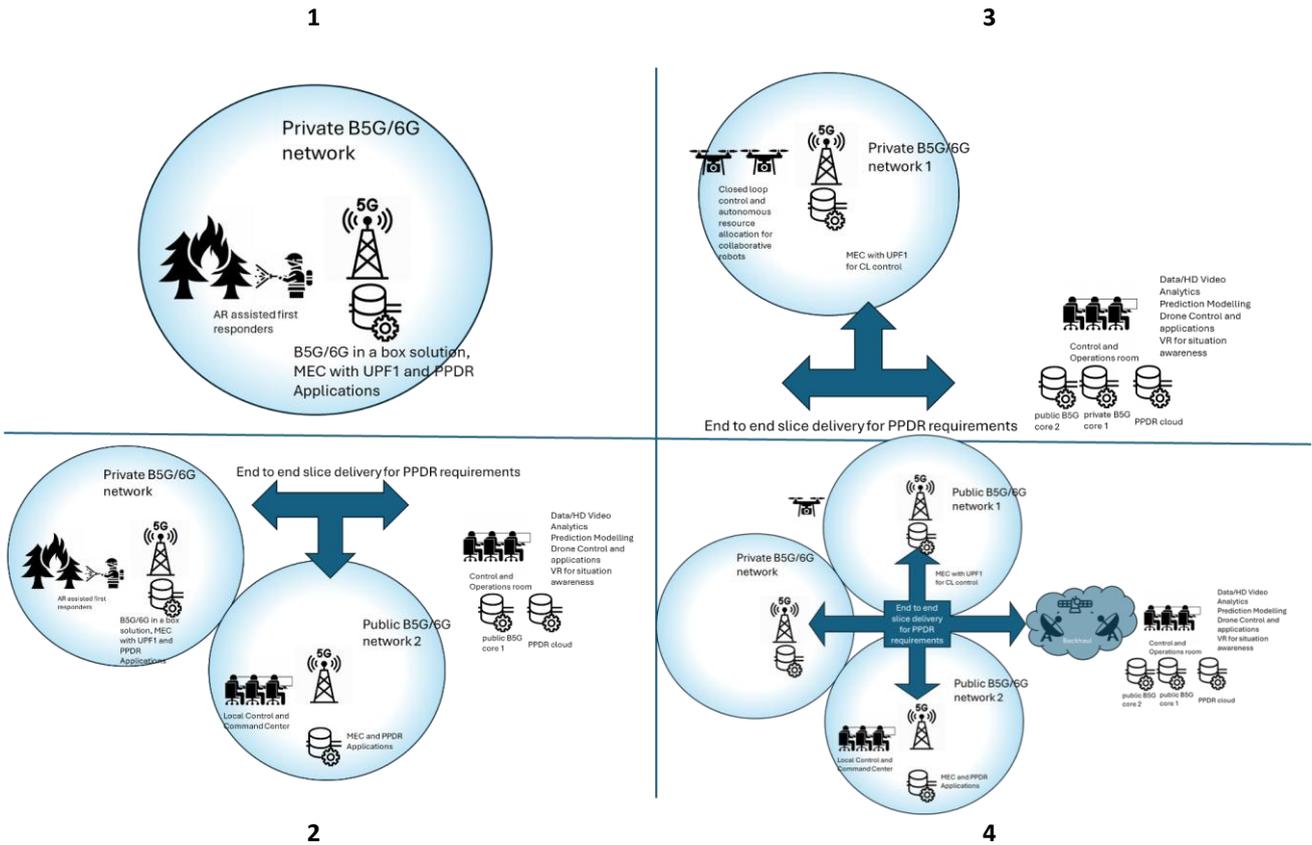
Figure 8: Ubiquitous B5G/6G communication and slice deployment across operators for PPDR overview.

1. **Private 5G/6G network with PPDR services/applications**

In order to demonstrate autonomous operation at the edge of the network, this PPDR Use Case will showcase the following indicative services:

- *Push-to-Talk (PTT)* and *Mission-Critical (MCx) PTT (MC-PPT)*: instant voice communication with group calls, priority handling, and low latency; essential for PPDR field coordination (including but not limited to point to point, multicast, etc.);
- *Video Streaming:* live video streaming from body cameras, drones or vehicles to Control Centers; critical for situational awareness, with optional stream selection;
- *Group messaging and data exchange:* secure, group-based messaging with voice, text, image, and video capabilities for team collaboration;
- Geolocation and asset tracking;
- AR/VR optimized service;
- Emergency Alert Broadcast System (public warning system);
- Orchestration: on demand 5G/6G network set up to provide guaranteed resources depending on requirements and reconfiguration needs for network slices.

2. **Private network connected with central Control Center**

PPDR slice set-up between the (remote) emergency site and the Central Control Centre. Mechanism for surveying backhaul availability is developed and deployed.

3. **End-to-end slice delivery for PPDR requirements**
4. **Slice deployment over multiple private and public B5G/6G networks**

PPDR network slice deployment with high priority and increased quality. Main challenges will be the orchestration of the network resources on-demand, and the interconnection of B5G/6G core networks, as well as the effect of a fully disaggregated B5G/6G architecture on the overall delay and on XR assisted PPDR campaigns.

3.3.4 Technology providers and other partners

- *UPAT:* Use Case owner, implementation of communication, Compute as a Service and application enablers, mission-critical-critical services, integration of xR-assisted applications, UMVs or robots in the PPDR scenarios. Infrastructure setup, trials execution and performance measurements;
- *WINGS:* development of application, AI and IoT technology enablers for environment monitoring and incident detection. Provision of monitoring devices (e.g., thermal cameras, environmental sensors, etc.) for the trial demonstration;
- *PNET:* development of communication and Compute as a Service technology enablers, integration and validation of mission-critical services. Provision of a B5G/6G private network for the PPDR trials execution, with resource management through the OpenSlice *Operations Support System (OSS)*;
- *OQTEC:* satellite technology provider, mainly through a replica utilized for validating and testing modifications within an emulated environment before the launch (FlatSat). Pilot demonstration of a NTN service for first responders' communication, and additional resiliency to the PPDR Use Case;
- *TID:* definition of the Use Case requirements, design of the system architecture, validation of interoperability between public and private networks for the PPDR service deployment.

3.3.5 Pre-requisites and assumptions

n/a

3.3.6 Stories

3.3.6.1 Story 1 for PPDR responders

3.3.6.1.1 Short description
The emergency incident is resulting in losses of connectivity in the region, with partially destroyed infrastructure and under-performing services.

3.3.6.1.2 Steps

- *Step 1:* first responders of the emergency service team, upon reception of an alert, are being equipped with wearable devices/cameras, UEs, and they bring collaborative UMVs or robots with them;
- *Step 2:* first responders undertake to also carry the infrastructure equipment (Patras5G Autonomous Edge);
- *Step 3:* upon reaching the affected area, a private network is launched (with the Autonomous Edge) to increase the available capacity, until the connectivity is fully repaired in the region. This is providing connectivity to the rescuers-first responders and the LCC;
- *Step 4:* an SMS alert is broadcasted to the emergency teams and the population (citizens), through the private network infrastructure;
- *Step 5:* the PPDR slice orchestration is initiated, over the private network, and MCx become available to rescuers and the LCC;
- *Step 6:* autonomous situation monitoring of the emergency, and the ground assets, through AR/VR, UMVs or robots, execution of prediction models for the event propagation; all these are ongoing;

- *Step 7:* when the recovery phase for the subject event is notified, connectivity services (configured slice, private network) are restored to normal conditions.

3.3.6.2 Story 2: connectivity of the PPDR field with the Remote Control Center;

3.3.6.2.1 Steps

- *Step 1:* PPDR slice (from Story 1 for PPDR responders) extension over a 2nd 'still available' private/public mobile network, to cover the immediate communication needs in the affected area;
- *Step 2:* search and location of the available backhaul connectivity options, connection establishment to the RCC;
- *Step 3:* end-to-end slice deployment (as in step 4 of set-up);
- *Step 4:* when the recovery phase for the subject event is notified, connectivity services (configured slice, private network) are restored to normal conditions.

3.4 Mission critical services interoperability with other systems [P2]

This Use Case aims at providing and enhancing the interoperability of mission critical services with other non-3GPP systems and functions closely together with P3 and P4 Use Cases. Interoperability will be tested in the 5GTN test facility in Finland[3], which can comprehend both indoor and outdoor testing and evaluations. The combination of multiple connectivity solutions will benefit mission-critical Use Cases by providing the maximum possible coverage for the on-site field units such as first responders. The technological challenges of providing interoperability for mission-critical services across networks and national borders at both network and application level are being addressed by public-private partnerships[4].

3.4.1 Use Case objectives and relation to the project technical objectives

The main objective of the Use Case is to make B5G/6G networks interoperable with non-3GPP networks such as Wi-Fi, IoT sensor networks and Satcom (NTN) systems and to create seamless connectivity solutions between them across national networks. For example, in the Search & Rescue area we aim at improving *Quality of Service (QoS)* by extending the network coverage, reliability or capacity via optimal placement of Mission Critical Services at the tactical bubble side. Combination of the networks i.e. via multi-path protocols or networking bonding can be used to maximize throughput or increase redundancy.

This is tested at 5GTN test facility in Finland, Oulu. The Use Case is deployed in real operating environment with more restricted and controlled laboratory-type facilities. Part of the used technology and developments for network interoperability can be used also in the context of P4 within the limits of network availability in northern Finland.

P2 works closely with WP3 enablers, and especially with WiFi & NTN integration, identification and selection of backhauling and network performance monitoring and control. The selection of backhauling aims at considering alternative wireless options when wireline (fiber) is not available and evaluates how the wireless backhaul might limit the available services. In this case, these services might be deployed at the edge. Naturally, network performance monitoring and control enabler will be utilized in the decision-making process of the network selection and alternatively even for selecting energy-aware network and application configuration.

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3 https://www.vttresearch.com/en/5g-and-6g-test-network-environment

4 https://cordis.europa.eu/project/id/284863/reporting/it

3.4.2 Main innovations and challenges

3.4.2.1 Innovations

- Seamless connectivity solution for MCx;
- Joint multi-flow coordination;
- Seamless handover between the networks.

3.4.2.2 Challenges

- Developing a seamless data exchange solution among different types of networks;
- Finding optimal points to switch to the most suitable connectivity, under the given connectivity environment;
- Maintaining quality of service.

3.4.3 General context and set-up

3.4.3.1 Actors

- *First responders (FR)*: search and rescue personnel, directing and operating eSleds;
- *eSled:* eco-friendly search and rescue area vehicle with B5G communication hotspot;
- *Mobile Access Point (MAP):* extending the wireless network in the rescue area, onboard with eSled;
- *Command & Control Center (C&CC)*: remote site with control team and supervisor;
- *5G TN operator:* in charge of setting wireless connectivity to the area;
- *Drone operator (optional):* directing and operating drones in the area (might require operating license).

3.4.3.2 Set-up

The high-level Use Case description is provided in Figure 9 below and specified in the Context view later in this document. In high level, we have two actors FR and C&CS located on- and remote site, respectively. C&CC will be located at the B5G lab in Oulu and holds the connectivity options of using B5G/5G, WiFi, and NTN. The search and rescue area will be located first indoor and later outdoor within the 5G TN coverage area for testing the connection interoperability.
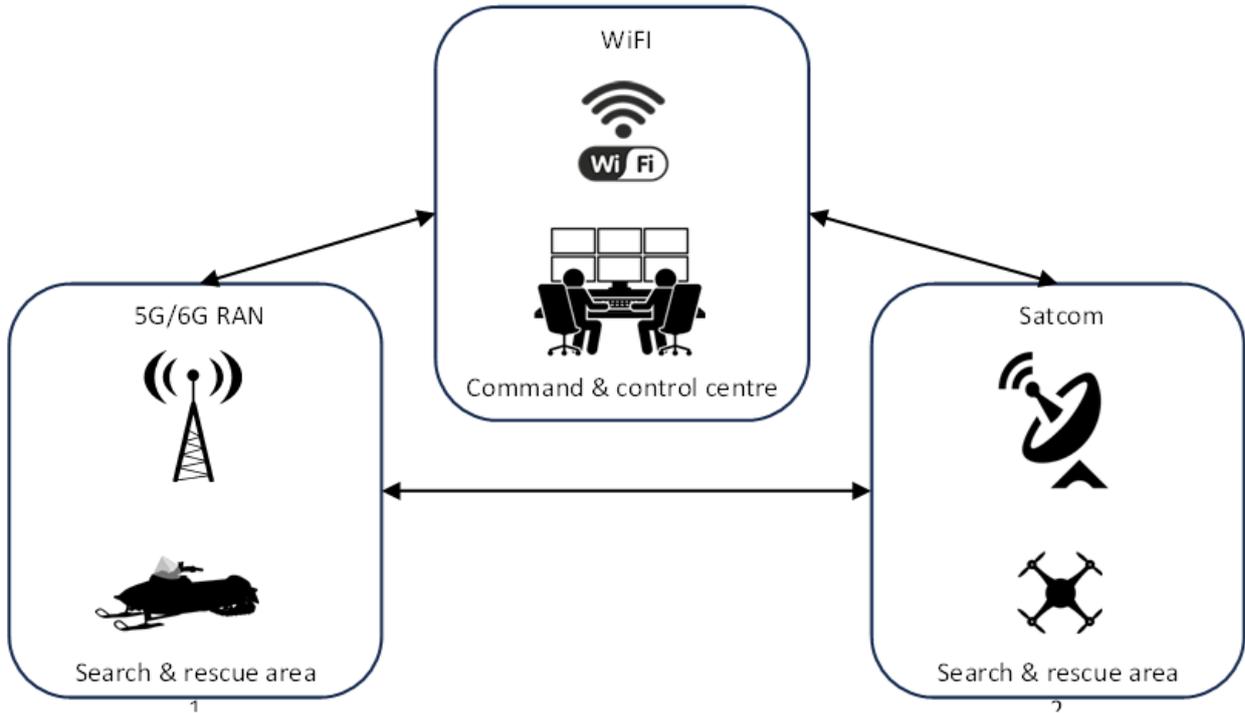
Figure 9: Use Case overview for Mission Critical services interoperability with other systems.

3.4.4 Technology providers and other partners

- *VTT:* UC leader, ICT R&D technology development, 5G TN private operator:
  - Coordinates the design, deployment and evaluation of communication systems (5G, B5G, alternative communication with optional WiFi 6/7 and satellite (NTN)) with existing and temporary networks in site. Performs testing of the essential components in Oulu facility;
  - Provides NTN-required equipment.
- *FMI:* system definition and requirement adviser. Considers the usage and integration of multi-connectivity in P4;
- *Aurora Powertrains Ltd:* system definition and requirement adviser. Considers the usage and integration of multi-connectivity in P4 from the perspective of devices onboarding to eSled.

3.4.5 Pre-requisites and assumptions

- No changes to existing 5G TN frequency licenses;
- No drastic changes to Starlink offering or connectivity options.

3.4.6 Stories

3.4.6.1 Story 1

3.4.6.1.1 Short description

In the fell area, a first responder's vehicle embarks on a mission critical journey. This vehicle, equipped with cutting-edge technology, is designed to ensure seamless communication and connectivity, no matter what the environment. As the vehicle navigates through the rugged terrain, it constantly assesses the available networks. The onboard system is programmed to prioritize the best network among, ensuring that the first responders always remain connected.

3.4.6.1.2   Steps

- *Step 1:* in the initial phase of the journey, the vehicle relies on a robust 5G network, providing high-speed data transmission and real-time communication;
- *Step 2:* when the vehicle enters an uninhabited area where there is no 5G network coverage or the coverage is weak. At this point, the vehicle's system automatically switches to a satellite network;
- *Step 3:* when 5G network is available, the vehicle's system automatically switches from the satellite network to 5G.

3.4.6.2   Story 2

3.4.6.2.1   Short description

User X (FR) is not able to send critical video stream from the field to C&CC and is suffering from poor 5G connection by coverage or capacity, which is also observed by the indicators (delay, throughput, packet loss) of network performance. Due to this, several options depending on the QoS requirements exist:

a) Coverage is increased by bringing MAP (car, robot, drone) nearby the user;
b) Capacity is increased by using multiple networks via network bonding or multi-path protocols;
c) Data is prioritized and sent via best available network (B5G, NTN, Wi-Fi).

As a consequence, user X is able to send critical videos to C&CC, which can playback the stream with good quality.

3.4.6.2.2   Steps

- *Step 1:* user X is heading to place Y which is located indoor or outdoor within the poor coverage of 5G in 5G TN;
- *Step 2:* user X starts the video streaming application towards the video server, which is located in the edge or C&CC;
- *Step 3:* C&CC launches the playback application. At this point the network is also monitored at C&CC;
- *Step 4:* the video stream is lossy, stalling or poor quality, observed also via network counters or UE statistics;
- *Step 5:* options a), b) or c) is applied according to QoS requirements with seamless handover between the networks;
- *Step 6:* video quality is improved;
- *Step 7:* user X stops the streaming.

3.5 Emergency private B5G/6G communication on-the-move [P3]

This Use Case is intended to facilitate the operation of private B5G/6G networks independently of the RAN/*Open RAN (ORAN)* and core network components of public networks, particularly in scenarios where the satellite link is obstructed or shadowed. The goal is to deploy only essential parts of the RAN and core network entities in the mission area at the edge of the network, which allows efficient network usage and deployment for public protection actors in case of emergency. As such, the PPDR infrastructure is needed to deploy in the mission area where local public networks may not be available or trusted in terms of security and privacy.

3.5.1 Use Case objectives and relation to the project technical objectives

Figure 10 below presents the Use Case overview. This Use Case allows us to have efficient usage of private B5G/6G networks because the user bandwidth and traffic will be handled within the private cells. We implement essential parts of the RAN and core networks and allow mobile users to have a good quality of service with enough system capacity in case of emergency. The aim is to design and evaluate the on-the-move concept for various architectures of mobile PPDR networks by the measurements taken

from true field trials. This Use Case has also strong interconnection between P2 and P4 Use Cases and will be developed within 5G TN premises at Oulu.

This Use Case has two options: 1/ independent private network and 2/ integrated private network. In 1/ the objective is to deploy essential RAN and core B5G parts using O-RAN without direct access requirement to the Internet, which can be utilized as a private network in the field (on-the-move) i.e. in the disaster area. The deployment is essential for the first responders to communicate with each other. In addition, local services at the edge (MEC) of this private network can be used for video processing, object detection and sensor data analysis. Traffic classification is needed for prioritizing critical data. In 2/ the main objective is to deploy slicing and dedicated slices for data prioritization.

3.5.2 Main innovations and challenges

3.5.2.1 Innovations

- Deployments of key RAN and CN components dedicated for the scenario;
- Customized services to the search rescue area and disaster area;
- Analytics framework for private B5G/6G networks with data collection and monitoring of network traffic flows.

3.5.2.2 Challenges

- Developing an integrated private network architecture and operation by combining network slicing and private networks;
- Optimizing the radio and network resources between public and private networks;
- Managing complexity of the network design and operation.

3.5.3 General context and set-up

3.5.3.1 Actors

- *FR:* search and rescue personnel, directing and operating eSleds;
- *eSled:* eco-friendly search and rescue area vehicle with B5G communication hotspot;
- *MAP:* extending the wireless network in the rescue area, onboard with eSled;
- *C&CC:* remote site with a control team and supervisor (C&CS);
- *5G TN operator:* in charge of setting wireless connectivity to the area;
- Directing and operating drones in the area (might require operating license).

3.5.3.2 Set-up

The high-level Use Case description is provided in Figure 10 and specified in the Context view later in this document. In high level, we have limited the actors to FRs and C&CC in the disaster area where local services are deployed either via integrated or independent private networks. C&CC will be located at the B5G lab in Oulu and in charge of preconfiguring the needed services and MEC for local deployment.
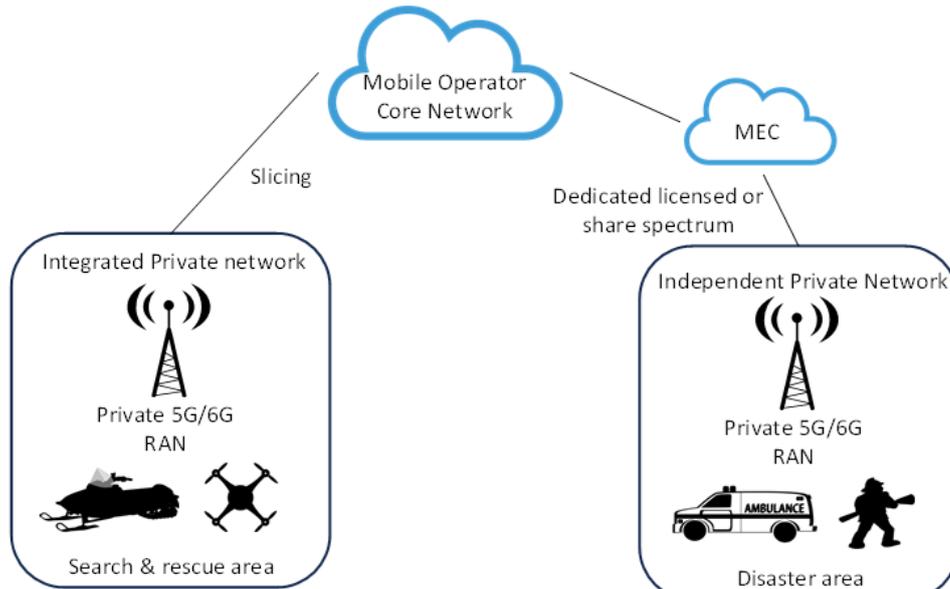
Figure 10: Use Case overview for Emergency private B5G/6G communication on-the-move.

3.5.4 Technology providers and other partners

- *VTT:* UC leader, ICT R&D technology development, 5G TN private operator. VTT also coordinates the design, deployment and evaluation of communication systems on-the-move (5G, B5G) with existing and temporary networks in site. Performs testing of the essential components in Oulu facility.
- *FMI:* system definition and requirement adviser;
- *Aurora Powertrains Ltd:* system definition and requirement adviser.

3.5.5 Pre-requisites and assumptions

n/a

3.5.6 Stories

3.5.6.1 Story 1

3.5.6.1.1 Short description

In the rugged fell area of northern Finland, the region rescue service had deployed a moving private communication network. This network, operating at the network edge, ensured that all services maintained a satisfactory quality of service for end users, even without access to the public Internet.

One winter morning, an emergency call came in about an avalanche on the fells. The rescue unit quickly mobilized and headed to the remote location. A vehicle equipped with the moving private network providing the connectivity their team. The network's edge services allowed the people in rescue units to communicate with each other, to access topographical maps, monitor scene through thermal imaging cameras, and normal cameras. The operation manager could coordinate with team members scattered across the area, ensuring that everyone was aware of the situation and could respond accordingly.

3.5.6.1.2 Steps

- *Step 1:* static independent private network with essential RAN and core network parts. Works independently without access to Internet;
- *Step 2:* services at the edge (E.g., Video service, Object detection, Lidar data processing);
- *Step 3:* moving private network.

3.6 Arctic area search and rescue operation [P4]

Arctic area Search & Rescue operation aims to provide effective ways of using B5G/6G connectivity to communicate between first responders in the field and the Command & Control Center to achieve fast situational awareness. In case of natural disasters, such as an avalanche in an arctic area, immediate and effective rescue response is critical for locating missing people with the help of enhanced connectivity by the rescue team. A pilot is planned to demonstrate the use case at the Sodankylä airport test track (Sod5G) and in the Luosto area in Lapland, Finland. Figure 11 illustrates the Use Case overview taken from the project plan.

3.6.1 Use Case objectives and relation to the project technical objectives

Due to climate change, extreme weather events and fast phenomena are becoming more common and can cause natural disasters such as avalanches also in smaller mountains. The terrain in such areas during winter is often difficult to reach and observe efficiently, requiring human intervention, and it usually lacks high B5G/6G coverage due to its sparsely populated nature. This Use Case sets three main vertical objectives:

a) Increase situation awareness and first responders' efficiency with the use of modern technology;
b) Decrease the number of human search units in the area with the help of a);
c) Use environmentally friendly solutions and devices within the use case, such as eSleds.

Furthermore, from the perspective of technical objectives, we aim to combine the output of sensor instrumentation into a deployable, on-board solution over eSled empowered and integrated with multi-connectivity both from *Terrestrial Network (TN)* and *Non-Terrestrial Networks (NTN)*. Thus, this package is considered as MAP with deployable and mobile connectivity equipment. The seamless integration, reconfiguration, and handovers of these networks are enabled by real-time network performance monitoring and control, which can also aid in the identification and selection of backhauling dynamically. Although the demonstration focuses on one rescue unit, a tactical bubble with multiple rescue teams, possibly with WiFi integration, is considered. A digital twin enabler can be used in conjunction with the context awareness functionality to generate real-time 3D model of the on-site surroundings for improving situation awareness. Finally, the integration of network exposure APIs can lower the threshold for programming the B5G/6G interface for various data types by sensor instrumentation.

The demonstrations and pilots taking place at the Sod5G test track in Sod5G and eventually in Luosto area verify the system behavior both on 1/ on-board sensor instrumentation and 2/ network perspective. We aim to maintain mobile connectivity between first responders and C&CC at any cost via intelligent handovers between available networks and data/service prioritization depending on the QoS requirements. Optimally, we aim to reduce energy consumption within the developed solutions and components i.e. by setting and optimizing the video parameters due to streaming or utilizing energy-savvy RAN configuration.

It is expected that the on-board solution with its network dynamicity, showcases new innovative ways of technology usage in critical communications for natural disasters. Optionally, we will investigate and consider the system feasibility for summer times where ATV's, robots or drones can substitute to eSleds.

3.6.2 Main innovations and challenges

3.6.2.1 Innovations

- *Command & Control Center (C&CC)* remotely surveying the disaster site and on-site operations with high situation awareness;
- Networked vehicles equipped with the necessary devices for search and rescue, enabling faster response time;

- Dynamic network orchestration and application prioritization & adaptivity against harsh transmission conditions mainly cause poor coverage 5G/B5G or environmental conditions (e.g. weather);
- Parallel video monitoring and network measurement systems operated and controlled remotely by C&CC assisting the on-site units remotely;
- Accurate monitoring and measurement of the network efficiency enabling fast reaction and adaptation in the network and ensuring KPIs are reached;
- Optionally, a digital twin model of the snow depth at the avalanche site can 1/ be viewed on the first responder's portable screen, and 2/ build up a geographical model of the site area using real-time LiDAR imaging.

3.6.2.2   Challenges

- Ensuring B5G/6G network connectivity, passing through critical mobile data with the lowest possible latency, even in areas with weak signals;
- Identifying and prioritizing critical/most critical mobile data originating from the search and rescue team;
- Deployment of end-to-end network orchestration for applications;
- Ensuring system functionality, also under arctic temperatures;
- Local movable communication hotspot powered by an eSled battery.

3.6.3 General context and set-up

3.6.3.1   Actors

- *First responders (FR)*: search and rescue personnel, directing and operating eSleds;
- eSled: eco-friendly search and rescue area vehicle with B5G communication hotspot;
- *Mobile access point (MAP)*: extending the wireless network in the rescue area, onboard with eSled;
- *Command & Control Center (C&CC)*: remote site with control team and *Command & Control Supervisor (C&CS)*;
- *5GTN operator:* in charge of setting wireless connectivity to the area;
- *Drone operator (optional):* directing and operating drones in the area (might require operating license).

3.6.3.2   Set-up

The high-level Use Case description is provided in Figure 11 and specified in the context views later in this document. At a high level, we have two actors, FR and C&CC, located on a remote site, respectively. eSled is equipped with the instrumentation depicted in the previous subsection, and C&CS is in charge of supervising and instructing the system from a remote distance. The connectivity between FR and C&CC is done using B5G/5G, WiFi, and NTN.
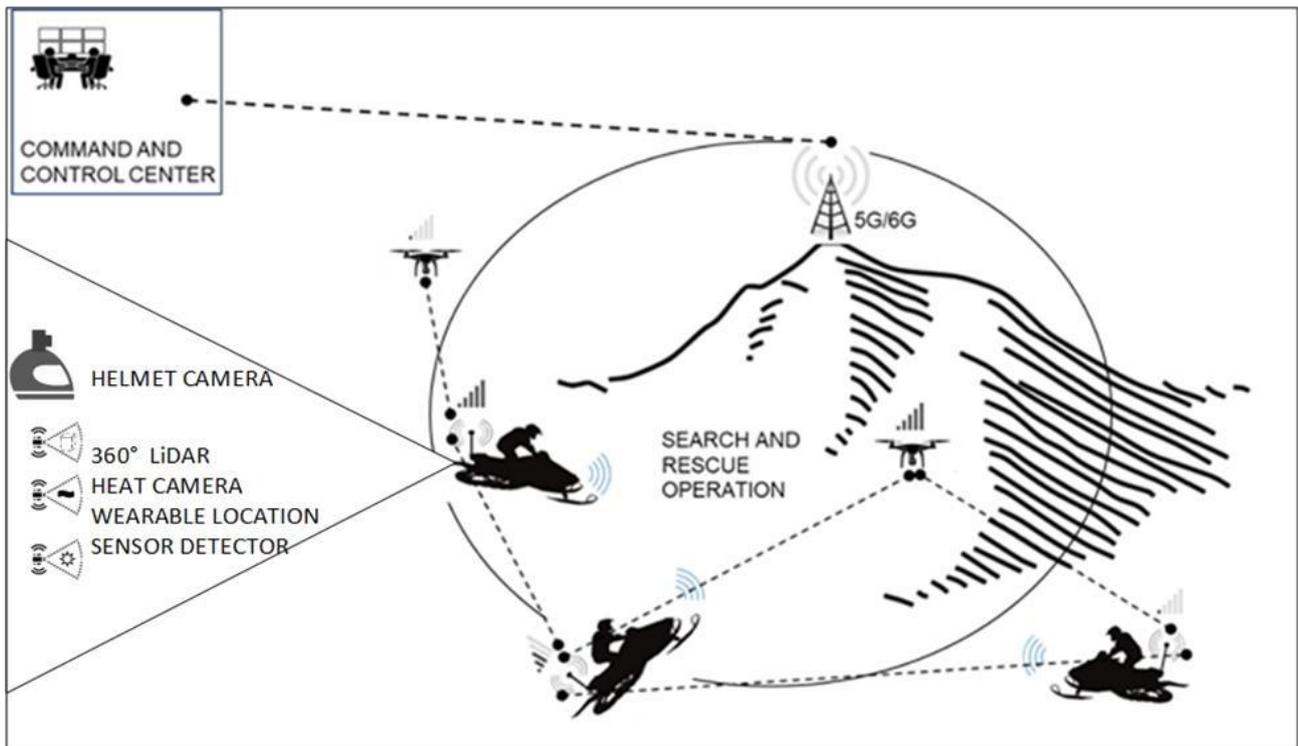
Figure 11: Use Case overview for Arctic Area Search & Rescue Operation.

3.6.4 Technology providers and other partners

- *FMI:* on-board monitoring systems, local communications systems, Sodankylä test track host, C&CC operator, drone operator:
  - o Will define the accident site rescue operation first encountered. FMI is not rescuing operator, but personnel have experience and induction in voluntary rescue operations;
  - o Will provide the measurement devices (e.g. video camera, LiDAR, thermal camera, wearable sensor monitoring) for the first encounter unit, along with monitoring data collection unit and C&CC monitoring equipment. The profile of detected (avalanche) site as a combination of measurement systems will be provided;
  - o The main development site of Use Case is FMI Sodankylä test track, with private 5G test network and a variety of meteorological monitoring instrumentation. Part of the work will be conducted in Luosto skiing center (with partial 5G coverage) and Aurora Powertrains depot are in Pyhätunturi (no 5G coverage);
  - o The primary first encounter team vehicle eSled. The reference and optional platform consist of a drone. FMI hosts the drone measurements when applicable.
- *VTT:* ICT R&D technology development, 5GTN operator for Sodankylä test track:
  - o Coordinates the design, deployment and evaluation of communication systems (5G, B5G, alternative communication with optional WiFi6/7 and satellite) with existing and temporary networks in site. VTT also performs pre-testing of the essential components together with P2 and P3 Use Cases.
- *Aurora Powertrains Ltd:* provider of eSled, eSled operator, eSled battery systems management;
- *APT:* APT hosts the eSled fleet and designs and develops the alternative power source of measurement and communication systems based on eSled battery systems.

3.6.5 Pre-requisites and assumptions

- Snowy winter for using eSleds;

- GPS availability needed for location and time synchronization;
- Instrumentation can be powered via eSled and/or using a battery bank for arctic temperatures;

3.6.6 Stories

3.6.6.1.1 Short description

An avalanche has occurred in the mountain area with uncertain information of possible victims. C&CC in charge of the rescue operation sends a rescue unit to the area using eSled electrical snowmobile with carry-on sensor instrumentations capable of monitoring the area and terrain changes after the avalanche. The rescue unit -consisting of first responder(s)- interconnects from on-site to C&CC using the best available connectivity powered by B5G, WiFi, or NTN depending on the network coverage and service requirements. Data and service prioritization plays an essential role in weak signal/coverage areas, where all the data from various sensor devices cannot be transmitted to C&CC in real-time or within QoS requirements. Visualization of data from various sensor devices, as well as network performance indicators, will help the viewer to understand the benefit and adaptiveness of the development system in the Use Case demonstration and pilots.

3.6.6.1.2 Steps

- *Step 1:* C&CC is informed of an avalanche and potential victims in the area and eSled is sent to area as first responder;
- *Step 2:* eSled hosting first responder pilot approaches the avalanche site;
- *Step 3:* eSled carries sensor instrumentation in the back-bag, embedded with fixed installation to eSled trunk box. Sensor instrumentation can consist of GPS tracker, 360º camera (if selected to on-board camera), LiDAR, heat camera, personal tracking device transceiver and spectrum analyzer for tracking phones, all powered by eSled;
- *Step 4:* eSled pilot helmet camera or 360º camera captures real-time view from the site. GPS data is used to pinpoint the location and moving direction of the first responder to C&CC premises;
- *Step 5:* the first responders track avalanche victims and/or their devices. For example, using heat camera, personal tracking device transceiver and Spectrum analyzer for tracking phones. The sensor systems are constantly monitoring the surrounding area;
- *Step 6:* the first responder LiDAR is building a 3D model of the avalanche site, estimating the amount of snow and the size of avalanche area;
- *Step 7:* sensor data from all the above-mentioned instruments are delivered in real-time to C&CC preferrable in B5G quality and speed, but in case of limitations due to harsh conditions, any means and quality possible, using B5G, WiFi and satellite communications;
- *Step 8:* C&CC communicates with the FRs through an audio link for detailed instructions;
- *Step 9:* when the first responder's area search and evaluation in the avalanche site is completed and C&CC is issuing rescue operation, the first responder will establish temporary B5G base station through available communication systems (B5G, WiFi, satellite). Power supply for the base station is arranged via eSled battery systems.

3.7 Emergency private B5G/6G communication on-the-move [P5]

Emergency private B5G/6G communication on-the-move is a rapidly deployable, mission-critical communication system that provides localized B5G/6G connectivity, supporting MCS such as *Mission Critical Push-to-Talk (MC-PTT)*, *Mission Critical Video (MC-Video)*, and *Mission Critical Data (MC-Data)*. Enabled by network slicing, this solution ensures reliable, low-latency, and resilient communications for public safety and defence operations.

3.7.1 Use Case objectives and relation to the project technical objectives

3.7.1.1 Objectives of the Use Case with Respect to the Public Safety Domain

The Use Case will enable the operation of a private B5G/6G tactical network independently of the backhaul network, considering the case of a shadowed satellite link. The end-goal is to deploy only essential parts of the RAN and Core Network entities in the mission area at the edge of the network.

B5G E2E slicing will be implemented over the tactical network, allowing for allocation of resources based on the capabilities required by the different stakeholders. In this approach, different slices, with specific needs, will be configured for the three main groups of users envisioned for PPDR scenarios: healthcare professionals, safety personnel and intervention troops. To ensure the best possible quality of experience for the targeted users of the PPDR use case, specific prioritization techniques will be investigated, including *Access Class Barring (ACB)* and *Allocation and Retention Priority (ARP)* mechanisms that could guarantee privileged users access and communication establishment even in case of network congestion. Additionally, traffic prioritization parameters will be implemented at the slice and RAN levels, leveraging on the 3GPP defined *QoS Class Identifiers (QCI)* for B5G PPDR MCx Use Cases.

Furthermore, *Multicast and Broadcast Services (MBS)* could be implemented in the tactical network scenario over a dedicated slice, consolidating the B5G/6G nature of the Use Case. Whereas broadcast services will provide the same content simultaneously to all users in a geographical area, multicast services will deliver the same data simultaneously to only a selected subset of users in the area and dynamically optimize the transmission based on users' feedback. In this approach, specialized B5G *User Equipment (UE)* that implement MBS could be tested and validated within the Romanian cluster.

3.7.1.2 Expected Value for the Public Safety Vertical and Its Customers

The deployment of mobile, private B5G/6G networks tailored for emergency scenarios delivers added value to the public safety sector and the communities it serves. For public safety agencies -including firefighters, law enforcement, and military responders- this solution introduces a new level of operational resilience. It ensures robust, high-bandwidth communication channels even in the most remote or infrastructure-compromised locations, enabling real-time coordination and mission-critical communications.

By leveraging network slicing, edge computing, and possibly multicast-broadcast capabilities, these mobile networks foster seamless interoperability between diverse emergency response units. This greatly enhances situational awareness, accelerates decision-making, and enables more agile and scalable deployments as crises unfold. Crucially, agencies are no longer dependent on congested or failing public networks, gaining full control over communications infrastructure during high-stakes operations.

For citizens and communities, the benefits are equally significant. The improved speed and effectiveness of emergency response teams can directly translate into saved lives, reduced injuries, and minimized damage to homes and infrastructure. Moreover, the visible presence of cutting-edge communication systems reinforces public confidence in the ability of emergency services to act swiftly and efficiently, even under the most challenging conditions.

Ultimately, this Use Case demonstrates how advanced B5G/6G technology can serve as a critical enabler of safer, more resilient societies.

3.7.2 Main innovations and challenges

3.7.2.1 Innovations

This Use Case introduces several innovations that push the boundaries of current B5G/6G capabilities, particularly in the context of mission-critical, on-the-move communications for public safety.

A key innovation is the use of NTN backhaul to interconnect local radio access nodes (gNBs) with a centralized Core Network. This enables reliable, high-speed connectivity even in remote or infrastructure-deficient areas -such as forests, mountains, or disaster zones- where terrestrial backhaul is unavailable or damaged.

Complementing this, the implementation of an interworking mechanism between macro and local 5G *Standalone (SA)* Core Networks allows seamless operation and coordination across distributed network layers. This final architecture should have dynamic transitions between centralized and localized network functions, providing continuity of service regardless of backhaul availability.

Additionally, the Use Case will investigate the possibility of showcasing a MBS that enables the efficient distribution of data to multiple users simultaneously. Whether disseminating real-time situational updates to field units or broadcasting critical alerts to command centers, MBS significantly enhances the scalability and responsiveness of emergency communications.

3.7.2.2 Challenges

Implementing this advanced emergency communication use case presents a set of technical challenges that underline the complexity of enabling next-generation B5G/6G capabilities in real-world, mission-critical scenarios.

One of the challenges lies in interconnecting a local gNB with a macro B5G Core Network via a satellite link. This requires overcoming issues related to high latency, variable link stability, and stringent signaling synchronization requirements, all while maintaining the low-latency and high-reliability standards necessary for mission-critical applications. Ensuring seamless integration and consistent performance over such a non-terrestrial backhaul is both technically demanding and crucial for success in remote deployments.

Another potential challenge is the implementation of a specialized network slice for MBS. MBS slicing must guarantee efficient, prioritized, and synchronized content delivery across a range of emergency users with diverse connectivity needs. This involves configuring precise resource allocation, ensuring *Quality of Service (QoS)*, and dynamically adapting to changing conditions on the ground -all within the constraints of a mobile, potentially infrastructure- limited environment.

Addressing these challenges is essential for achieving the Use Case goal of delivering robust, field-deployable, and scalable B5G/6G communications tailored for public safety operations.

3.7.3 General context and set-up

The set-up will be hosted inside a utilitarian truck and its architecture is depicted in Figure 12 below. For the creation of the outdoor "tactical bubble", which helps to improve coverage, a portable B5G cell site will be connected to the infrastructure available in the truck, including a B5G *Baseband Unit (BBU)*, a local B5G SA Core Network, Edge Compute servers, and a satellite backhaul link. The satellite backhaul link will assure connectivity to the Internet and to the Macro B5G SA Core Network from ORO's Bucharest 5G Lab via the N2 and N3 interfaces.

Based on the availability of the satellite backhaul interface, the Use Case will be piloted in two distinct scenarios:

- *Scenario 1:* the satellite backhaul link is available and the tactical site gNB is connected directly to ORO's 5G Lab SA Core Network via the N2 and N3 interfaces;
- *Scenario 2:* the satellite backhaul link is unavailable and the tactical site gNB is connected to the local B5G SA Core Network and edge compute servers.
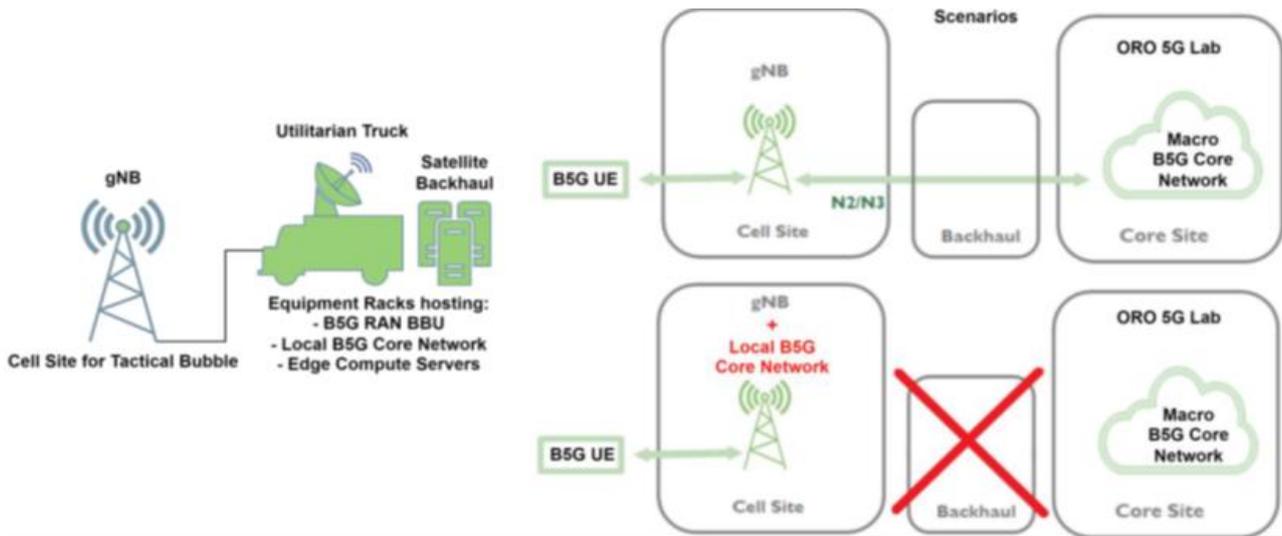
Figure 12: P5 set-up.

3.7.4 Technology providers and other partners

This Use Case relies on a collaboration of key technology providers, each delivering critical components for mission-critical communications:

- *ORO:* will be responsible for the design, development, and deployment of the technical infrastructure supporting the Use Case. This includes provisioning the portable B5G radio access network (gNB), the local 5G SA Core Network, the Edge Computing environment, and establishing the satellite backhaul link. ORO will also lead the integration and validation activities, ensuring end-to-end slicing and MCx services are fully operational. Additionally, ORO will participate in field testing and contribute technical expertise in configuring and optimizing the tactical communication setup;
- *STS:* will bring domain-specific operational knowledge and expertise derived from real-world emergency response missions and lead the implementation of the MCx platform, encompassing MC-PTT, MC-Video, and MC-Data. STS will provide input on functional requirements, tactical workflows, and communication protocols that align with national emergency procedures. Their participation in the testing scenarios will help validate the usability and effectiveness of the system in live-like conditions, ensuring that the technical implementation meets the practical needs of public safety and security forces in the field.

3.7.5 Pre-requisites and assumptions

The deployment of the emergency private B5G/6G network relies on key conditions. It assumes the satellite backhaul will be intermittently available to connect the tactical network to the macro core when terrestrial links fail. The system is designed for rapid set-up in remote or disaster-affected areas where infrastructure is limited. All equipment -portable gNB, local core, edge servers, and rugged user devices- must be pre-configured for quick deployment and harsh environments. Compliance with 3GPP standards ensures interoperability across vendors and smooth integration with public safety workflows. Trained personnel are essential for effective use of MCx services and coordinated operations. Finally, all necessary regulatory permissions for the use of satellite links must be secured beforehand to avoid delays.

3.7.6 Stories

This section outlines the practical demonstrations of the Use Case through detailed storyboards that illustrate how the B5G/6G tactical network solutions will enhance emergency response operations.

Each story presents a step-by-step progression of real-world scenarios, emphasizing how advanced technologies such as satellite backhaul, MCx services, network slicing, and edge computing come

together to support mission-critical communications. These narratives provide insight into the dynamic interaction between various public safety actors and the innovative infrastructure, showcasing improved coordination, situational awareness, and operational efficiency in diverse crisis environments.

3.7.6.1 Story 1

3.7.6.1.1 Short description

The scenario involves an intervention that will take place in a mountainous and forested area, in response to a wildfire. Emergency response teams including ambulance services, firefighters, and gendarmes will be involved. The satellite backhaul link is available and the tactical site gNB is connected directly to ORO's 5G Lab SA Core Network via the N2 and N3 interfaces.

First responders will rely on the tactical bubble to coordinate real-time operations via MCx services, including voice, video, and data. The system will support multicast/broadcast services and dedicated network slicing to maintain service continuity and low-latency communication throughout the intervention.

3.7.6.1.2 Steps

- *Step 1: satellite link and tactical bubble activation:*

  The satellite communication link is activated, and the B5G/6G tactical bubble is deployed on-site. This ensures mission-critical connectivity for all field units, enabling MCx services (voice, video, data);

- *Step2: formation of Operational Response Groups and Local Command Center. Intervention dedicted communication groups are defined inside the MCx system as follows:*
  - *Gendarmerie units:* assigned to secure and delineate the operational perimeter.
  - *Firefighting teams:* deployed for wildfire containment and suppression.
  - *Emergency medical crews (ambulance teams):* positioned to provide first aid and medical evacuation support.
  - *Joint coordination structure:* established to facilitate seamless cooperation between the leadership of all three response categories.

  Communication channels are also established with remote command and control centres to ensure strategic oversight and operational synchronization;

- *Step 3: B5G E2E slicing*

  B5G E2E slicing will be implemented over the tactical network, allowing for allocation of resources based on the communication capabilities required by the different stakeholders. In this approach, different slices, with particular needs, will be configured for emergency response teams: ambulance services, firefighters and gendarmes. To ensure the best possible quality of experience for the targeted users of the PPDR Use Case, specific prioritization techniques will be investigated, including *Access Class Baring (ACB)* and Allocation and *Allocation and Retention Priority (ARP)* mechanisms that can guarantee privileged users access and communication establishment even in case of network congestion. Supplementary, traffic prioritization parameters will be assessed at the slice and RAN levels, leveraging on the 3GPP defined QCIs for B5G PPDR MCx Use Cases;

- *Step 4: Multicast and Broadcast Services*

  MBS could be implemented in this tactical network scenario over a dedicated slice, consolidating the B5G/6G nature of the Use Case. Whereas broadcast services will provide the same content simultaneously to all users in a geographical area, multicast services will deliver the same data simultaneously to only a selected subset of users in the area and dynamically optimize the transmission based on users' feedback;

- *Step 5: Gradual Demobilization*

  Once the area is stabilized and no further critical intervention is required, the tactical bubble and associated communication infrastructure are deactivated in a controlled manner, ensuring no loss of operational data or disruption to any ongoing post-incident support.

3.7.6.2   Story 2

3.7.6.2.1   Short description

In this scenario, the intervention will take place under extreme weather conditions e.g., heavy snowfall. Emergency response teams, including ambulance services, military units equipped with heavy snow removal machinery and gendarmerie forces for area security and coordination, will be involved. The satellite backhaul link is unavailable, and the tactical site gNB is connected to the local B5G SA Core Network and edge compute servers.

First responders will rely on the tactical bubble to coordinate real-time operations via MCx services, including voice, video, and data. The system will support edge processing, multicast/broadcast services, and dedicated network slicing to maintain service continuity and low-latency communication throughout the intervention.

3.7.6.2.2   Steps

- *Step1: Tactical Bubble Activation*

  The 5G tactical bubble is deployed on-site. This ensures mission-critical connectivity for all field units, enabling MCx services (voice, video, data);

- *Step2: Formation of Operational Response Groups and Local Command Center*

  Intervention dedicated communication groups are defined inside the MCx system as follows:

  - *Gendarmerie units:* assigned to secure and delineate the operational perimeter;
  - *Military units equipped with heavy snow removal machinery:* deployed to remove snow and ice, ensuring that access routes are cleared and maintained;
  - *Emergency medical crews (ambulance teams)*: positioned to provide first aid and medical evacuation support;
  - *Joint coordination structure:* established to facilitate seamless cooperation between the leadership of all three response categories.

- *Step 3: B5G E2E slicing*

  B5G E2E slicing will be implemented over the tactical network, allowing for allocation of resources based on the capabilities required by the different stakeholders. In this approach, different slices, with particular needs, will be configured for emergency response teams: ambulance services, military units and gendarmes. For assuring the best possible quality of experience for the targeted users of the PPDR Use Case, specific prioritization techniques will be investigated, including ACB and ARP mechanisms that could guarantee privileged users access and communication establishment even in case of network congestion. Supplementary, traffic prioritization parameters will be investigated at the slice and RAN levels, leveraging on the 3GPP defined QCIs for B5G PPDR MCx Use Cases;

- *Step 4: Multicast and Broadcast Services*

  MBS could be implemented in the tactical network scenario over a dedicated slice, consolidating the B5G/6G nature of this Use Case. Whereas broadcast services will provide the same content simultaneously to all users in a geographical area, multicast services will deliver the same data simultaneously to only a selected subset of users in the area and dynamically optimize the transmission based on users' feedback;

- *Step 5: Enhanced Situational Awareness and Real-time Monitoring through edge computing*

    Leveraging edge computing servers significantly enhances situational awareness by processing data locally in real time, enabling faster decision-making and reducing latency in critical operations. Updates are relayed to local command posts;

- Step 6: Gradual Demobilization:

    Once the area is stabilized and no further critical intervention is required, the tactical bubble and associated communication infrastructure are deactivated in a controlled manner, ensuring no loss of operational data or disruption to any ongoing post-incident support.

3.8 Renewable energy communities [E1]

This section describes the first AMAZING-6G Use Case in the energy vertical sector (UC E1), specifically focused on *Renewable Energy Communities (REC)*. The UC addresses the enhancements enabled by 6G networks in the joint optimization of energy and comfort management in smart buildings equipped with IoT sensors and actuators, through the assistance of AI/ML applications deployed at the edge or cloud. Starting from the target experimental environment, which encompasses a smart building with heterogeneous areas dedicated to offices, labs and data centers, the UC E1 will also scale via emulations and analytical studies towards wider and heterogenous REC scenarios. The objective will be to evaluate the replicability of the experimentally validated scenario in other environments and to derive guidelines for the customization of the proposed solution in RECs with different characteristics, e.g., in terms of buildings' type (residential, offices, industry, campuses, hotels, etc.), geographical position, dimension and composition, as well as level and intelligence of renewable energy generation capabilities. This last aspect will also be analyzed in collaboration with UC E3, focusing on the monitoring, control, and prediction of solar energy consumption.

From a technical perspective, the system proposed in this UC will collect, aggregate and process data from different IoT data sources connected via 6G network, guaranteeing pervasive indoor/outdoor coverage, low latency and high reliability. Moreover, it will leverage edge and extreme-edge computing as well as AI/ML capabilities offered by the 6G infrastructure. The ultimate goal is to optimize the global process of energy consumption and production across one or more buildings through the use of AI solutions, while ensuring a high level of comfort for the end-users in a seamless and automated manner, always following a human-centered and personalized approach. To better understand this energy optimization, imagine buildings that not only consume energy, but also have the capabilities (e.g., solar panels) to produce more energy than they require. This surplus energy could be sold at a national distribution point, or shared between different buildings within a community. The optimization of the comfort of building inhabitants is crucial for achieving market acceptance of the proposed solution. This will be achieved through the use of algorithms that model end-users' profiles, behavior and preferences, fed by users' implicit or explicit feedback and environment sensors measurements. To summarize, the Use Case aims to find the optimal balance between energy optimization and end-user comfort, considering both individual buildings or broader communities of buildings.

3.8.1 Use Case objectives and relation to the project technical objectives

This UC combines aspects of smart cities and smart energy contexts, with smart buildings increasingly interconnected and controlled by AI-driven applications enabling more efficient management of urban environments and energy consumption, also improving the quality of the citizens' lives. The primary objective is to coordinate the control of various systems within single buildings and among multiple buildings and renewable energy sources, achieving a global optimization at the REC level, while ensuring the desired level of comfort for the users. This is expected to promote the efficient usage of renewable energy sources and the widespread creation of new RECs, with positive impact on the environment and

the reduction of carbon emissions, helping to reduce energy-related expenses and guarantee the satisfaction of the final users.

The UC involves the adoption of several technology enablers proposed in the AMAZING-6G project, going beyond the pervasive and QoS-guaranteed connectivity offered by 6G networks. The global coordination of various buildings, owned and/or administered by different stakeholders, requires the collaborative processing of data collected from several IoT platforms with guarantees in terms of data confidentiality, data protection, and trustworthiness. The IoT platforms provide a first degree of aggregation and unification of heterogeneous data from different sensors at the building level, in a scalable manner across various floors and rooms. Computing resources on devices and local edge nodes will securely process the data on premises, adopting *Artificial Intelligence/Machine Learning (AI/ML)* modelsScaling up to the REC level requires an efficient use of resources throughout the entire continuum, from devices to edge and cloud resources, where data from multiple buildings can be efficiently collected and analyzed to enable synergies in joint decisions and the training of more accurate models.However, implementing such a complex system introduces several challenges, which will be examined in detail in the following section.

While energy consumption and its cost are important considerations, it is also essential for this use case to evaluate the inhabitants' satisfaction and their overall comfort. To achieve this, it is essential that any recommendations or insights driven by the AI applications also take these aspects into account. For this purpose, the system involves not only IoT platforms for environmental data (e.g., CO_2, lux, temperature, humidity), but it also considers preferences and feedback directly expressed by users, as well as profiles automatically extracted from context. Additionally, to further extend the solution, the REC management system could consider interacting with national energy *Distribution System Operators (DSO)* for cost-effective energy sharing solutions and new business models.

The implementation of this UC will integrate several technologies and enablers that will be developed in WP3. The IoT platforms investigated in T3.4 will be used to collect, unify, and aggregate data from various sensors (energy, environment, and user feedback) and control actuators in smart buildings, adopting 6G technologies for wireless interconnections at the sensor or IoT gateway level. The resource orchestration techniques investigated in T3.2 will enable the efficient management of the workload of energy management applications across the continuum of devices and local edge nodes within buildings. Moreover, this will be further extended to near-edge and cloud resources when moving to distributed scenarios at the REC level. Finally, AI/ML and *Machine Learning Operations (MLOps)* enablers developed in T3.3 will be crucial to address the challenges of designing, training and deploying AI/ML applications in REC scenarios, characterized by multiple stakeholders and a variety of data that shall be considered as confidential, leading to the adoption of techniques to guarantee data privacy.

3.8.2 Main innovations and challenges

3.8.2.1 Innovations

- Global energy optimization considering renewable sources and energy storage;
- Joint management of energy and environment sensors with ML support;
- Coordinated management of energy in scalable REC scenarios (building and group of buildings);
- Development of AI models for energy consumption and user comfort optimization including *Explainable Artificial Intelligence (XAI)* and *Federated Learning (FL)* techniques for explainability and privacy;
- IoT platforms integrating different data sources from edge to cloud and exposing data to AI/ML applications.

3.8.2.2 Challenges

- Coordinated management of IoT platforms and computing resources in the device-edge continuum in smart buildings;

- Optimization of placement strategies for AI/ML functions in single buildings or among multiple buildings (at the REC level);
- Trade-off strategies for joint optimization of energy and user comfort management;
- Ensure scalable data management and data privacy especially when dealing with end-users from different buildings.

3.8.3 General context and set-up

This section describes the actors involved in the UC and the high-level set-up of the system. For a detailed version, please refer to Section 4.8.

3.8.3.1 Actors

The following actors constitutes the bulk of the UC and will be considered for implementation and experimental validation:

- *"Prosumer" members of the REC*: "abstract" actors (households, smart building, smart campus, smart office, etc.) that produce (e.g., via solar *Photo Voltaic (PV)* or wind turbines) and consume energy;
- *End-users, like citizens, smart buildings' inhabitants, etc.*: final consumers of the smart energy management services at building and at REC level, getting advantages on environmental sustainability, reduced energy costs, level of comfort perceived in the buildings, and quality of life in general;
- *REC managers or operators:* responsible for coordination of REC energy management and resources. In particular, they are responsible for the management of the renewable energy generation assets within the community (e.g., solar PV, wind turbines);
- *Network Operator:* manages the 6G infrastructure and provides 6G connectivity with QoS guarantees, e.g., through network slices dedicated to the energy management applications;
- *Technology providers and system integrators:* develop and provide core platform components (IoT and MLOps platforms, local private network and computing infrastructure;
- *Application developers (including AI/ML data analysts) and energy management solution providers*: implement the logic and the intelligence of the energy management system, usually with cloud-native applications and AI/ML models.

3.8.3.2 Set-up

At the architectural level (see Figure 13 below), for this UC the project will also investigate and analytically evaluate models for the interaction between the REC and the DSO. This interaction allows to integrate the distributed renewable energy sources from the REC into the grid in a secure, efficient and convenient manner. At the technical level, the REC needs to coordinate with the DSO for the connection of the renewable generation units to the local distribution grid, requiring the sharing of (near-)real-time data on energy production, consumption, voltage level, and grid constraints to guarantee the stability of the overall grid system and to avoid congestions. Operationally, the DSO may request the REC to adjust generation/consumption, e.g., during peak loads or voltage issues. Moreover, the REC can provide *Flexibility as a Service* to the DSO to further increase the efficiency of the grid management (e.g., through demand response or energy storage discharge strategies). From a business perspective, the model can involve dynamic tariffs for the payment of the distribution network usage. Moreover, the DSO may also act as a mediator for local energy markets, facilitating or overseeing peer-to-peer energy trading among REC members (DSO as neutral market facilitator).
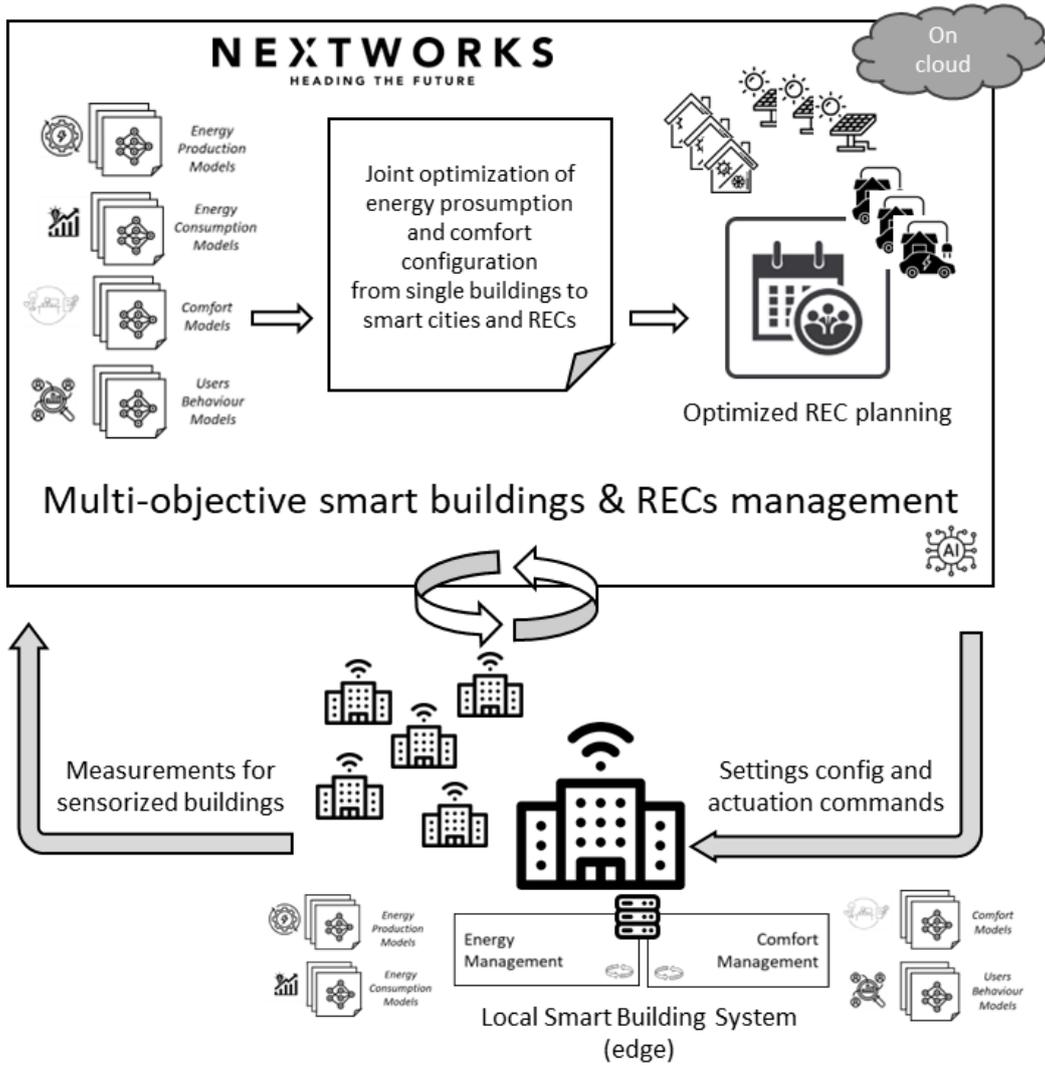
Figure 13: E1 set-up.

3.8.4 Technology providers and other partners

- *ORO:* mobile network operator provisioning the testbed and the connectivity as well as the IoT sensors (environmental, energy) and ideally also actuators. It also provides computational computing and storage resources;
- *NXW:* technology provider and system integrator for energy/comfort building management, with focus on data collection, MLOps, Service and Resource Orchestration, AI/ML models and applications for energy management;
- *SIMTEL:* renewable energy management solution provider, with focus on production side, jointly with E3;
- *CAPG:* technology provider, with focus on development of AI/ML models and MLOps platform for network configuration and automation.

3.8.5 Pre-requisites and assumptions

n/a

3.8.6 Stories

3.8.6.1   Story 1

3.8.6.1.1   Short description

This user story is related to joint management of energy and comfort optimization within a single building. The solution leverages smart building devices, including IoT sensors and actuators connected via 6G, to retrieve real-time data on indoor/outdoor environmental conditions, as well as information on the presence of people in rooms and the usage of appliances and devices, including their related power consumption. Moreover, AI/ML techniques are adopted for profiling user behaviors and preferences with regards to the interactions with the smart building system (e.g., use of rooms and devices on daily, weekly and monthly bases, preferences on rooms settings like temperature, humidity, curtains, lighting, etc.) and for predicting energy consumption and generation (for buildings equipped with PV) on the basis of weather conditions, geographical area, building position and layout. The first category of AI/ML models is trained locally on edge computing nodes at the building in order to preserve the confidentiality of the data, which is associated with the building's users (users' personal data will not be collected in any case). The second category will initially adopt public data or models, since they are generalized and valid for different types of buildings. However, the models will be continuously validated and re-trained in case of drift detection.

3.8.6.1.2   Steps

1. *Local Data Collection:* smart building data is collected from IoT sensors and smart meters, via IoT platforms in local edge nodes, using 6G connectivity. The following type of data is collected:
   - Indoor/outdoor environmental conditions (temperature, humidity, CO_2, air quality indexes, etc.);
   - Room occupancy (presence of people in a room, number of people);
   - Appliance and devices usage (on/off status, power consumption);
   - Whenever available, renewable energy generation (e.g., in the case of PV or local storages).

2. *Local Data Aggregation:* data is locally aggregated and unified at the building level, to overcome the heterogeneity of vendor-specific protocols and data models. Privacy preserving mechanisms are applied: personal data is never collected and, where needed, data anonymization techniques are applied;

3. *AI/ML Training:* AI/ML models are trained to model the profile of building usage and users' preferences:
   - Occupancy and energy consumption patterns (daily, weekly, monthly use of rooms, appliances and devices, with related energy consumption);
   - User comfort preferences per room and per activity (temperature, lighting, curtains, etc.);

4. *AI/ML-based Local Data Analysis:* at inference time, using the trained models, the system continuously predicts the following:
   - Occupancy and related comfort preferences;
   - Energy consumption patterns;
   - Renewable energy generation, e.g., based on solar PV forecasts.

   For the last two points, models can be initialized with public datasets / models and progressively retrained according to the local validation;

5. *Decision on Local Optimization:* the system analyzes the combination of the predictions to take optimization decisions, with an algorithm that finds the best compromise on the following objectives (different weights can be applied to each aspect based on users' preferences):
   - Maximization of comfort levels for the building's occupants;
   - Minimization of energy consumption / costs;

- Maximization of locally generated (or stored) renewable energy, if applicable;

6. *Actuation:* depending on the system configuration (user preferences), the system can 1/ autonomously apply the optimal settings by controlling the actuators (lighting and blinds, HVAC, appliances) or 2/ send suggestions about recommended actions and related motivation via mobile applications or 3/ any other type of user interface in the smart building;

7. *User Feedback Collection:* in the case of suggestions provided by the system, the user can either accept or override the proposed actions. This provides implicit feedback that is further used by the system to refine the models and the decision strategies. Similarly, in case of automated configuration, any further command manually provided by the user is considered as feedback to the decisions taken by the system;

8. *Continuous Learning and Self-Adaptation:* the system continuously validates the AI/ML models, according to 1/new data on occupancy and comfort preferences, also on the basis of the feedback collected from the user (step 7), and 2/ energy consumption/production data and environmental conditions. This will allow detecting potential drifts and trigger the re-training and update of the models used in step 4.

3.8.6.2 Story 2

3.8.6.2.1 Short description

This second user story extends the joint optimization of comfort, energy consumption and energy production via renewable sources at the entire REC level. The solution still leverages AI/ML techniques for modelling smart building profiles, energy consumption patterns and renewable energy production capabilities. Moreover, it leverages edge/cloud continuum and *Federated Learning (FL)* techniques to build more accurate models through the collaboration of multiple buildings participating in the REC. The use of computing resources for training and retraining is optimized according to the edge nodes capabilities and related energy sources of the buildings that participate in the FL groups. Training tasks are distributed among edge and cloud nodes considering constraints on data confidentiality and the requested level of trustworthiness; moreover, they are scheduled taking into account energy consumption constraints.

3.8.6.2.2 Steps

1. *Local Data Collection:* data is collected from IoT sensors and smart meters, via IoT platforms in local edge nodes, using 6G connectivity. This happens in each building participating in the REC. The same type of data considered for the user story 1 is collected. Moreover, data on renewable energy production is collected from the dedicated renewable sources present in the REC;

2. *Local Data Aggregation:* as in user story 1, for each smart building participating in the REC;

3. *AI/ML Training:* this step exploits MLOps mechanisms to enable the collaboration among the buildings of the REC for AI/ML training purposes, via federated learning and optimizing the distribution and scheduling of training tasks among buildings, depending on their edge capabilities and considering the impact on energy consumption. The objective is to obtain more accurate models on building usage and user preferences, for one or more categories of homogeneous buildings. This step includes the following sub-steps:

   i. Training of local AI/ML models at each building level, on 1/ occupancy and energy consumption patterns and 2/ users comfort preferences;

   ii. FL-based collaboration, with buildings sharing local model updates with a FL aggregator operating at the REC level. This ensures that local data is maintained at each building and not shared with the rest of the system;

   iii. At the REC level, the FL aggregator merges the models elaborated by different buildings. This step is performed on the cloud. Different aggregation strategies can be adopted, categorizing buildings to tune the models based on different criteria (e.g., residential vs

offices, geographical area, etc.). Global models are created to capture common patterns across the REC, for energy consumption, comfort preferences and renewable energy generation;

iv. The aggregated model is redistributed to the participating buildings.

The procedure is repeated until the model converges.

Training tasks are distributed and coordinated across the edge–cloud continuum by the MLOps platform logic, which assigns heavier training tasks to buildings with higher and possibly renewable-powered edge resources and schedules the task in time slots more suitable in terms of energy consumption or pricing.

4. *AI/ML-based Local and Global Data Analysis:* at inference time, using the trained models the system continuously predicts the following metrics in a distributed manner and with different levels of aggregation:

- Occupancy and related comfort preferences – locally, at each building level;
- Energy consumption patterns – locally at each building level and centrally at the REC level considering aggregated consumption data shared by the buildings;
- Renewable energy generation – locally at each building with PV capabilities and centrally at the REC level considering aggregated data shared by the buildings or other renewable energy generation sources;

5. *Decision on Global and Local Optimization:* the system analyzes the combination of the predictions to take optimization decisions globally at the REC level, in terms of energy consumption and production across all the buildings and the renewable energy sources, in combination with per-building optimization of the trade-off between comfort level and energy consumption considering user profiles and preferences. This decision stage can be performed by a set of collaborating close/open loops that work with REC or per-building scope, under hierarchical coordination mechanisms for detection and mitigation of conflicts between local and global decisions. As in user story 1, the objective is to maximize comfort level based on user's preferences, but here the minimization of energy consumption / costs and the maximization of renewable energy usage is handled at the entire REC level;

6. *Actuation:* depending on the system configuration (user preference), the systems in each building can autonomously apply the optimal settings by controlling the actuators (lighting and blinds, HVAC, appliances) or send suggestions about recommended actions and related motivation via mobile applications or other types of user interfaces in the smart building. Moreover, the centralized system can actuate decisions at the REC level, e.g., for scheduling of energy storage, peer-to-peer energy exchange or actuation of flexibility services to the DSO (this will be just emulated).

7. *User Feedback Collection:* as for user story 1, users' explicit or implicit feedback is collected as input for tuning models and decisions strategies;

8. *Continuous Learning and Self-Adaptation:* local and global AI/ML models are continuously monitored and, in case of accuracy degradation or change in the conditions, they are retrained based on the detection of local or global drifts, or when new entities enter the REC.

3.9 Robotized offshore wind turbines blade inspection & maintenance [E2]

Offshore wind is developing very rapidly and as a result, wind turbine *Inspections, Operation and Maintenance (IO&M)* are also a rapidly growing activity. However, IO&M as performed today still is

suboptimal and requires significant efforts of technicians under difficult and dangerous offshore conditions. It is expected that skilled personnel will become scarce and so future shortage of technicians may pose a challenge on the ambitions on offshore wind.

Consequently, the sector is moving towards automized and robotized IO&M, where for instance drones make images of wind turbine blades, which are afterwards being analyzed by technicians to assess the structural 'health' of the blade. This development has the potential to lower risks (less people offshore), increase sustainability (less boat transfers) and lower costs (less downtime).

Drone-based inspection and maintenance of blades in offshore wind farms aims to enable onshore control to be in the loop for the inspection activities. The information gathered during the inspection activities will be further enhanced by the use of numerical models or digital twins of the wind turbine blades. The goal is to reduce the time between inspection and decision-making, and to make inspection data available onshore faster than currently possible, if not in real time.

3.9.1 Use Case objectives and relation to the project technical objectives

The main objective of this Use Case is to demonstrate how B5G connectivity and edge computing greatly enhances robotized and automated inspection and maintenance by closing the control loop between sensing and the control room. In order to achieve this, accurate localization of the drone across the blade and informed decision-making through real-time feedback are required.

Beyond the drone technology itself, the technology development firstly is on sensing techniques as the drone enables carrying various instruments. For this, ultrasonic and even X-ray sensing techniques are being developed, next to 'traditional' visual camera sensing. Secondly, blade digital twins are being developed that are fed with inputs from sensors, allowing for automatic evaluation of structural health. This should result in a decision on what action to take: do nothing, repair the blade, or replace it. Lastly, there are developments regarding the connectivity between the drone and its sensors, the digital twin, and/or the control room. This connectivity is the focus of this Use Case. The primary objective of this Use Case is to demonstrate how B5G connectivity and edge computing significantly enhance robotized and automated inspection and maintenance by closing the control loop between sensing and the control room. To achieve this, localization of the drone across the blade and decision-making through real-time feedback are required

3.9.2 Main innovations and challenges

3.9.2.1 Innovations

- Real-time collection of sensor data from the wind farm to the onshore monitoring center;
- Analysis of sensor data combining digital twin and numerical models;
- Integration of multiple sensing capabilities (e.g., imaging, ultrasound) on the drone, including B5G connectivity;
- Accurate localization of the drone during inspection will be achieved using a combination of localization techniques, such as *Global Navigation Satellite Systems (GNSS)*, *Realtime Kinematics (RTK)*, Lidar.

3.9.2.2 Challenges

- Improving network reliability and data rates when supporting large amounts of sensor data, e.g. ultrasound;
- Achieving highly accurate localization of the drone along a turbine blade during inspection with the current technologies;
- Supporting low round trip time (<100ms) to allow real-time control loop.

3.9.3 General context and set-up

3.9.3.1 Actors

- *Drone operator:* the drone operator will fly the inspection drone to the wind turbine blade and proceed with moving the drone along the blade according to the inspection plan to take measurements, e.g. imaging or ultrasonic;
- *Off-shore inspection technician:* the technician supports the inspection close to where the drone is located, to guide the inspection, e.g. to change where the drone needs to move next;
- *On-shore support team:* the support team uses the data from the inspection, as well as historical data, to make decisions while inspecting the blade health e.g., using a digital twin.

3.9.3.2 Set-up

The high-level Use Case set-up is depicted in Figure 14 below. The B5G network will provide the 5G connectivity to the maintenance drone. The drone is equipped with multiple sensors (e.g. ultrasound, imaging, etc.) enabling the drone to perform various measurements. In addition, a positioning module (e.g. GNSS receiver) installed on the drone allows the drone to determine its position during the measurement. The measurement data are transferred via the B5G network to the digital twin system where the data will be processed and analyzed. The onshore control center may use the collected data for decision making during the inspection.
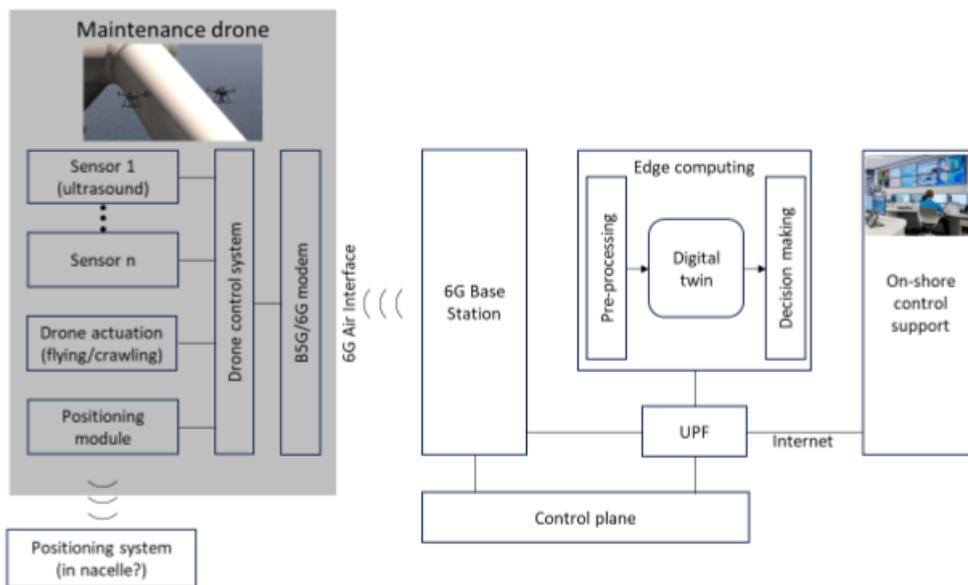
Figure 14: Robotized offshore wind turbine blade inspection and maintenance Use Case overview.

3.9.4 Technology providers and other partners

- *TNO:* will set up the B5G/6G network and will provide expertise on networking and application side;
- *Fieldlab Zephyros:* will provide the location for the testbed as well as a turbine blade (taken from an actual wind turbine).

3.9.5 Pre-requisites and assumptions

Due to regulatory and safety restrictions, the testbed set-up will have several constraints:

- The B5G/6G network will be placed onshore in an indoor location. Setting up a B5G/6G network in an offshore wind farm requires an outdoor spectrum license which is more difficult to obtain compared to an indoor license;

- The turbine blade used for the tests is a loose blade positioned on the ground and not actually attached to a wind turbine;
- The localization of the drone needs to be tested separately, as the indoor location cannot support the localization technique based on both GNSS and RTK.

3.9.6 Stories

3.9.6.1.1 Short description

In this first story, the sensor data will be sent to the onshore control support and the decision making will be made by visual inspection and without real-time feedback.

3.9.6.1.2 Steps

- *Step 1:* the drone is turned on and the connection to the B5G/6G network is established;
- *Step 2:* the drone pilot flies the drone towards the turbine blade;
- *Step 3:* the drone takes high resolution images of the blade surface, and these images are sent to the onshore control support through the B5G/6G connectivity;
- *Step 4:* the onshore control support analyses the images and makes decisions accordingly; These decisions are then communicated to the drone pilot. Depending on the taken decision, the drone pilot might have to redo the blade inspection, or the inspection is completed.

3.9.6.2 Story 2

3.9.6.2.1 Short description

In this second story, the sensor data will be sent to the digital twin system.

3.9.6.2.2 Steps

- *Step 1:* the drone is turned on and the connection to the B5G/6G network is established;
- *Step 2:* the drone pilot flies the drone towards the turbine blade;
- *Step 3:* the drone performs an ultrasound scan of the blade surface, and the measurement data are sent to the digital twin system through the B5G/6G connectivity;
- *Step 4:* the digital twin system processes the measurement data and uses it to assess the health of the blade. A decision will be made to determine the next activity the drone needs to perform. Ideally, this control loop will occur in real-time; however, due to the limitations of our current digital twin system, the processing may take a considerable amount of time. It is envisioned that this limitation will be overcome in the future, allowing for the realization of a real-time control loop.

3.10 Solar energy monitoring control and predictions using B5G/5G communications and edge-cloud [E3]

This Use Case focuses on the deployment of an end-to-end solar energy monitoring, control, and forecasting system using B5G/6G communications and edge-cloud computing. The solution integrates field-level photovoltaic data acquisition with remote control of energy assets and predictive analytics.

UC partners are developing an edge-to-cloud architecture, where industrial-grade edge devices with 5G RedCap (3GPP Release 17) capabilities are deployed at solar power plants. These devices interface with inverters via Modbus (TCP/RTU), perform local data processing, execute control commands, and ensure secure communication with the cloud through encrypted protocols (TLS, VPN). Data buffering and resilience mechanisms are built in to support field deployment under varying network conditions.

The edge devices are connected via B5G/6G infrastructure, as detailed in Figure 15, to a centralized management platform hosted in an edge-cloud. This enables *Ultra-Reliable Low-Latency*

Communication (URLLC) for real-time command execution, as required by national energy authorities. The system also incorporates a machine learning layer for short-term energy production forecasting using real-time telemetry and external data sources (e.g., weather APIs).

Key engineering goals include achieving sub-3ms network latency, 99.999% service reliability and availability, and supporting high connection densities. The architecture is designed to be modular, scalable, and compatible with future Use Cases such as predictive maintenance and grid-responsive control. The platform's performance is continuously monitored through technical KPIs and validated against societal, environmental, and economic impact indicators.

3.10.1 Use Case objectives and relation to the project technical objectives

The primary objective is to enhance the operational efficiency, responsiveness, and scalability of distributed photovoltaic infrastructures by using 5G/B5G communication capabilities.

The edge devices will perform local data acquisition and processing tasks, including telemetry collection (e.g., power, current, voltage metrics), threshold-based alerting, and remote command execution. These functions are complemented by robust security features such as encrypted communication (TLS, VPN), memory protection, and integration with *Security Information and Event Management (SIEM)* systems. In the event of intermittent connectivity, the devices will be capable of buffering data locally and automatically reconnecting to ensure data continuity and system reliability.

Connectivity between the solar plant and the cloud infrastructure is enabled through a B5G lab network, using macro gNBs located near the deployment site in Bucharest. This ensures reliable and low-latency data exchange with the edge-cloud platform, where a centralized energy management system processes incoming telemetry, enables remote manual control, and provides operator dashboards.

One of the key innovations of the platform is the integration of a cloud-based machine learning engine for real-time forecasting and decision support. Developed ML models will leverage edge-collected data and external sources—such as weather forecasts (irradiance, temperature, cloud cover)—to generate short-term predictions of solar energy production. These predictions will be exposed via secure APIs to energy distribution operators, enabling forecast-driven operational adjustments, optimized energy dispatch, and increased participation in energy markets.

The expected value for the renewable energy sector includes higher operational efficiency through automation and centralized coordination, improved grid responsiveness by enabling near-instantaneous control actions, and increased revenue due to better alignment between production and market demand. Furthermore, the platform will allow energy producers to reduce downtime by detecting faults earlier and to meet sustainability targets through measurable reductions in CO_2 emissions and cleaner energy output. For energy operators and prosumers, the system brings secure remote access, resilient performance in harsh environments, and enhanced maintainability through over-the-air updates and cloud-based diagnostics.

Technologically, this use case will demonstrate the viability of deploying scalable, modular IIoT architectures in the energy sector using B5G/6G technologies. additionally, the scope includes validating the use of 5G NR RedCap devices in field conditions, the effectiveness of edge-cloud coordination for low-latency and high-reliability scenarios, and integrating machine learning within operational workflows for renewable energy forecasting. These capabilities are essential enablers for the broader transition toward intelligent, flexible, and carbon-neutral energy systems.

3.10.2 Main innovations and challenges

3.10.2.1 Innovations

This Use Case brings together several advanced technologies to demonstrate a next-generation approach to managing solar energy infrastructure. A central innovation lies in the deployment of 5G RedCap edge devices, compliant with 3GPP Release 17, which are designed for industrial use. These

devices offer support for network slicing, secure remote access, and native communication with field equipment over Modbus protocols, making them ideally suited for energy applications.

Another key innovation is the use of a B5G/6G-enabled edge-cloud architecture that supports URLLC. This is particularly important for time-critical operations such as responding to fine-tuning commands from national grid authorities within strict regulatory deadlines. The system ensures that round-trip latency remains well below 1s, enabling near-instantaneous execution of remote-control commands.

Machine learning is also a core part of the platform's value proposition. Forecasting algorithms are deployed on edge-cloud infrastructure, where they process both real-time telemetry and external data sources such as weather forecasts. This integration enhances the accuracy and timeliness of solar energy production predictions, thereby improving operational planning and market participation.

The platform's architecture is designed to be modular and scalable, supporting future enhancements such as predictive maintenance, automated fault detection, and real-time optimization of energy flows. Additionally, strong emphasis is placed on security, with built-in support for encrypted communications, memory protection, secure protocol bridging, and integration with SIEM systems.

3.10.2.2 Challenges

Despite its technical potential, the implementation of this Use Case presents several significant challenges. One of the primary difficulties lies in deploying and operating a B5G/6G *Industrial Internet of Things (IIoT)* solution at scale within the critical and highly regulated energy sector. Ensuring that edge devices are robust, secure, and maintainable—while being distributed across remote and varied locations—requires a high degree of coordination and rigorous engineering.

Meeting the strict performance requirements of the underlying network is another critical challenge. The system must consistently achieve low latency (<3ms), high reliability (99.999%), and near-continuous availability to support safe and effective operation of URLLC-dependent functions.

Forecasting energy production in real time introduces further complexity. Accurate predictions rely on ingesting diverse data sources, including weather conditions and internal performance metrics, all of which must be processed efficiently while keeping infrastructure and computation costs under control.

Operational resilience is also a concern, particularly in environments where connectivity may be intermittent. Edge devices must be capable of local caching, automatic reconnection, and over-the-air software updates, all while ensuring data integrity and secure operation.

3.10.3 General context and set-up

The overall architecture of the Use Case (see Figure 15 below) follows a distributed edge-cloud design, enabled by B5G/6G network connectivity. As illustrated in that figure, the system is organized into three main layers: the field (edge) layer, the network infrastructure layer, and the cloud/management layer.

At the field level, solar inverters and energy storage units are instrumented with industrial edge gateways. These devices interface with the power electronics over Modbus TCP and Modbus RTU (RS485) protocols and are installed on-site at an operational solar plant in Bucharest, Romania. The gateways are equipped with 5G NR RedCap modems (compliant with 3GPP Release 17), enabling direct wireless connectivity to the mobile network and supporting slicing and URLLC capabilities. They also integrate edge processing capabilities, including real-time telemetry capture, threshold-based alerting, local caching, and command execution logic.

The network layer includes macro gNBs in proximity to the solar site, which route traffic through a dedicated B5G testbed. Specific network slices are configured for different data flows—such as a high-priority URLLC slice for control messages and a standard eMBB slice for bulk telemetry uploads—ensuring quality of service for each operational requirement.

The cloud/edge layer supports the orchestration and data management components of the platform. An energy management system is deployed here, alongside GPU-enabled servers that host the machine learning modules for forecasting energy production. Data from edge devices is collected via *Message Queue Telemetry Transport (MQTT)* over TLS, processed, and visualized through dashboards exposed to both operators and third-party energy stakeholders.

External data sources, such as weather forecast APIs, are integrated into the cloud layer, enhancing the accuracy of forecasting models and enabling predictive control strategies. Remote control commands can also be sent from the cloud layer to the field layer in under one second via the URLLC slice, ensuring compliance with national grid authority regulations that require production adjustments within a 5mn window.
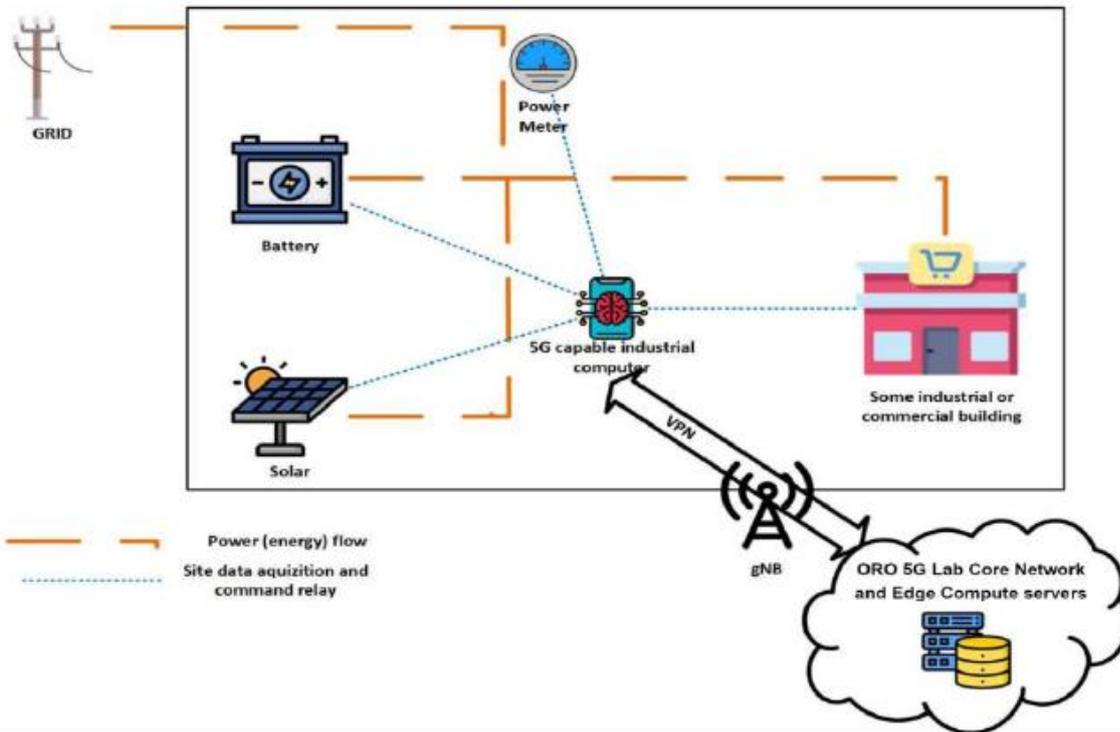
Figure 15: Solar energy monitoring, control and predictions using B5G/6G communications and edge-cloud Use Case overview.

3.10.4 Technology providers and other partners

- *ORO:* provides the B5G/6G network infrastructure, including macro gNBs and edge-cloud computing resources. Enables network slicing, URLLC, and edge-cloud orchestration to support low-latency control and real-time data processing;
- *SIMTEL:* develops and deploys industrial edge computing devices with 5G NR RedCap (3GPP Rel. 17) connectivity. Supplies the energy management platform, integrates Modbus communication stacks, and implements machine learning models for energy production forecasting. Also responsible for cloud/edge integration and telemetry pipelines;
- *AMAZING-6G project (framework):* offers testbed support, interoperability frameworks, and evaluation environments for B5G/6G Use Cases. It enables access to advanced infrastructure, validation tools, facilitating cross-domain integration and benchmarking of network KPIs and service reliability.

3.10.5 Pre-requisites and assumptions

The deployment of this Use Case is based on several key technical and operational pre-requisites as well as a number of underlying assumptions regarding infrastructure availability, regulatory context, and equipment readiness.

From a network infrastructure perspective, it is assumed that ORO's B5G/6G test network, including macro gNBs with slicing capabilities, is fully operational and available in the Bucharest area where the solar plant is located. The presence of a URLLC-enabled slice with verified performance (<3ms latency) is essential for remote control operations, in compliance with national grid regulations requiring energy adjustments within 5mn.

On the equipment side, it is assumed that SIMTEL's industrial edge gateways are available and certified for field deployment, with proper integration of 5G NR RedCap modems supporting 3GPP Release 17. These gateways must be capable of headless operation, local data caching, and secure communication (TLS, VPN) under intermittent connectivity conditions. It is also assumed that the edge devices can physically interface with the solar inverters via Modbus TCP/RTU, and that the inverters themselves are accessible and open to third-party monitoring/control.

For the cloud and edge computing layer, it is a prerequisite that the servers must support containerized deployment, telemetry ingestion, and model lifecycle management with minimal downtime. A stable and secure cloud-to-field communication bridge (e.g., MQTT over TLS) must be configured and monitored.

In terms of external data sources, it is assumed that reliable APIs for weather forecasting and geolocation mapping are available and that they can be integrated into the prediction logic. These APIs must meet minimum requirements in terms of availability, rate-limiting, and data granularity to ensure accurate forecasts.

Finally, on the regulatory and operational front, it is assumed that energy producers (such as the solar plant operator) are compliant with national requirements related to grid coordination and that they support external control interfaces for fine-tuning production in real time.

3.10.6 Stories

3.10.6.1 Story 1 Real-time grid adjustment triggered by national energy authority

3.10.6.1.1 Short description

This story demonstrates the ability of the solar energy system to respond in real time to a grid balancing request from the national energy authority. It showcases low-latency command propagation over a URLLC slice, edge-based actuation, and compliance with regulatory timelines.

3.10.6.1.2 Steps

- *Step 1 - Grid notification trigger:* the national energy authority issues a request to adjust energy production due to an observed imbalance in the grid. The request is sent to the energy producer's control system hosted on the cloud edge;
- *Step 2 - Command dispatch via URLLC slice:* the energy management platform immediately generates a control instruction (e.g., reduce output by 10%) and dispatches it to the relevant edge gateway via the dedicated URLLC slice provided by ORO's B5G infrastructure;
- *Step 3 - Low latency transmission & acknowledgement:* the edge gateway receives the command with sub-3ms latency, confirms receipt, and logs the timestamp to the cloud for audit purposes;
- *Step 4 - Inverter adjustment execution:* the edge device sends a Modbus command to the inverter controller at the solar plant, adjusting the inverter's power setpoint in accordance with the request;

- *Step 5 - Status feedback loop:* updated telemetry data confirming the adjustment (e.g., new power output, current values) is pushed back to the cloud platform and visualized on the operator dashboard;
- *Step 6 - Regulatory compliance check:* the entire event chain (from request to final actuation) is logged and reviewed to confirm completion within the 5-minute regulatory window.

3.10.6.2 Story 2: Predictive energy production optimization using machine learning

3.10.6.2.1 Short description

This second story illustrates how machine learning models running in the edge-cloud use weather forecasts and real-time telemetry to predict solar power output and proactively optimize energy production.

3.10.6.2.2 Steps

- *Step 1 - Data collection:* edge devices continuously collect telemetry data (currents, voltages, power metrics) from solar inverters and send it securely to the cloud platform via the 5G/6G network;
- *Step 2 - Weather forecast integration:* external weather forecast APIs provide updated data on solar irradiance, temperature, and cloud cover, which is ingested by the cloud system alongside telemetry;
- *Step 3 - Machine learning model execution:* the ML engine processes combined data streams to generate short- and medium-term power output forecasts, running on GPU-enabled edge-cloud servers;
- *Step 4 - Forecast validation:* predicted energy production values are compared with actual real-time data, and the model is continuously refined for accuracy improvement;
- *Step 5 - Proactive control recommendations:* based on the forecasts, the platform suggests optimized inverter setpoints and storage management strategies to maximize energy yield and grid compliance;
- *Step 6 - Operator decision & automation:* operators receive these recommendations through a dashboard or API and can approve automated adjustments, which are then executed by the edge devices via low-latency network slices;
- *Step 7 - Result monitoring:* the system monitors outcomes, logging energy production improvements and ensuring the changes align with regulatory and economic goals.

3.11 Protection of vulnerable road users [T1]

In the transport domain, the protection of *Vulnerable Road Users (VRU)* is one of the most important topics and it is aligned with the goal of the Vision zero initiative[5]. The Use Case will exploit B5G/6G technologies to enhance the safety of a visually impaired person crossing a complex junction. This will focus on energy efficiency increasing the awareness of the network on this topic.

A *Roadside Unit (RSU)* equipped with sensors such as cameras and LiDAR, connected via the B5G/6G network, will monitor critical road areas, tracking the movements of vehicles, pedestrians, bicycles, etc. Furthermore, some of these entities can transmit real-time position and other data using standard *Cooperative Intelligent Transport System (C-ITS)* messages, either through B5G/6G OBUs or smartphones (typically by VRUs). The data streams from these sources are collected by a digital twin which computes a junction risk level based on the aggregated data. The computation needed to assess the risk level (e.g., detection and tracking) can be done on the edge of the network depending, for example, on the RSU battery status and power consumption, and on the actual status of the solar panel

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5 https://visionzeronetwork.org/about/what-is-vision-zero/

(e.g., producing less energy than the currently consumed power). The orchestration function could consider these factors to automatically move the computation between the RSU and the edge, keeping track of the context to avoid gaps in the application processing.

The risk level is timely analyzed to send suggestions to the visually impaired users for increasing their safety while crossing a road and in any other potentially dangerous situations. The feedback is sent to their smartphone via B5G/6G and notified, for example, using vibration or sounds.

The RSU will be powered through a solar panel, and it will be equipped with monitoring tools to evaluate network and computational resource usage and the related energy consumption. Indeed, the application deployment will be done considering also energy consumption aspects and power generation factors. The orchestration procedure will select the most befitting deployment based on the need of computational resources by the application (i.e., CPU, RAM) and its energy consumption footprint together with the availability of renewable energy produced on the RSU. APIs will be developed and provided for this.

Additionally, a digital twin of network elements including *Radio Access Network (RAN)*, edge servers, RSUs, and UEs will be created to foster network awareness and ease the automated deployment of network and computational resources.

3.11.1 Use Case objectives and relation to the project technical objectives

This Use Case aims to achieve two primary objectives: firstly, it seeks to furnish essential information to individuals with disabilities, such as the visually impaired, in order to enhance the safety of their urban journeys in the smart city. Secondly, it endeavours to design technical tools for enabling developers to deploy applications utilizing B5G/6G networks, with a focus on minimizing energy consumption. This involves utilizing battery-powered devices recharged by locally sourced renewable energy, optimizing resource allocation based on application power requirements, and other energy-conscious strategies.

These objectives will be realized through the utilization of network slicing and orchestration technologies, taking into consideration both the environmental impact of computational processes and the societal benefits of enhanced safety measures.

3.11.2 Main innovations and challenges

3.11.2.1 Innovations

The main innovations of the T1 Use Case are listed below:

- The implementation of such a Use Case requires real-time collection and analysis of data. Network slicing can be used to optimize the collection, automatically configuring the network in the best way and allocating computational resources. Moreover, the difference between the use of private and public networks will be assessed to evaluate pros and cons and the possibility to have a synergic use of the two types of networks;
- Digital twins will be used for real-time, massive data collection. This will be done both at application level and for monitoring the network status, increasing the network awareness of the real world but also of its internal status for what regards the energy management;
- The power consumption of the RSU will be constantly monitored and the computational tasks can be automatically moved between the RSU and the edge, considering different metrics (power consumption network status, etc.) One of the main challenges is to maintain the context of the services when moved across different hardware platforms (e.g. from RSU to edge and *vice versa*): considering that safety services are addressed it is very important to keep the inactivity of the service as short as possible when moving it;
- New APIs will be built to allow the deployment of applications, considering the energy status of edge and far edge devices (e.g., RSUs). This will help developers hiding the complexity of the

network and leaving them concentrating on the high-level behavior and on the optimization of the consumption.

3.11.2.2 Challenges

In general, the main challenges are related to the scalable real-time collection and analysis of data to have a prompt response. Moreover, this is extended to the orchestration of services minimizing its impact on the final user.

A second aspect is related to the creation of effective APIs to be used to deploy applications that can consider power consumption as an important metrics.

3.11.3 General context and set-up

The high-level schema of the T1 Use Case is shown in Figure 16 below:

Figure 16: T1 high-level schema.

The right part of the picture represents the real junction with the RSU and its sensors, connected and non-connected cars and VRUs and the visually impaired person with its personal device.

On the left side of the picture the core elements are listed. The edge server is devoted to host the applications that will be orchestrated to and from the RSU. In the core you can find the two digital twins (network and application) and the energy-aware APIs. Finally, the core network with all the advanced functionalities and the interaction with all the other elements (APIs, orchestrator, edge, etc...) will be provided by HPE.

3.11.4 Technology providers and other partners

The Use Cases will be designed and implemented with the help of several partners:

- *LINKS Foundation:* LINKS is the leader of the Use Case and will provide the digital twins, the RSU with sensors, battery and solar panel and all the intelligence to analyze on field data an give feedback to the users, Moreover, it will work on the energy APIs and will provide the OBU and the end user device (smartphone with dedicated app) with all the SW needed to exchange standard C-ITS data;

- *Nextworks:* Nextworks will provide the technologies to orchestrate the Vertical Services involved in the Use Case across the continuum. The intelligent allocation of network and computing resources will be take into account several factors, like resoruce availability or the battery level of far edge devices (OBUs);
- *Bellantenna*: Bellantenna will provide RAN access with a full gNodeB. The antenna will have a compact design for easy integration in urban infrastructure. The baseband software will run on general purpose hardware and will be Compatible with standard interfaces either with 5G-NSA and/or 5G-SA scenarios and compliant with public network Core networks requirement if the project team decided to pursue this route. Bellantenna will explore both N77 and Millimiter wave option;
- *TIM:* TIM will support the implementation of the Use Case focusing on the radio network infrastructure and spectrum aspects, especially for what concern the problems related to the coexistence (i.e., mutual interference) between the private network deployed for the Use Case and the commercial one. Interworking aspects between the two networks will be also investigated in collaboration with the other partners. Support to the activities related to the spectrum use will be also provided;
- *HPE:* HPE will provide to the testbed an instance of its commercial HPE Aruba Networking Private 5G core network, to be integrated with the other elements of the mobile network deployed to support the Use Case. HPE's core network supports network slicing and exposes APIs for network performance monitoring, software and network function management, QoS control, and user provisioning. These will be leveraged to enable the orchestration and monitoring objectives of this Use Case;
- *UC3M:* UC3M will contribute to the design of the orchestration algorithm with analytical and ML tools to ensure that the tight timing constraints are met while optimizing the energy consumption.

3.11.5 Pre-requisites and assumptions

The Use Case is based on a private 5GA network that will be made available from the activities of the ENVELOPE project [15]. A public network will also be used and provided by TIM. Moreover, all the data exchange will be based on standard C-ITS messages.

The orchestration will be based on the SW provided by Nextworks.

3.11.6 Stories

3.11.6.1 Story 1: protection of Vulnerable Road Users

3.11.6.1.1 Short description

An impaired road user is crossing a complex junction navigating with its portable personal device. Several other connected and non-connected cars and other users are moving in the same area. All the data of connected and non-connected (through the sensors) devices are collected and analyzed in real time to enhance the safety of his movement in the intersection.

3.11.6.1.2 Steps

- *Step 1:* the visually impaired user and other vehicles and pedestrians are moving in the intersection area;
- *Step 2:* all data coming from connected users and from RSU sensors are collected in the Digital Twin and analyzed to compute possible risks for the users. Moreover, all the data related to the network are collected in the network digital twin and made available to the network elements (like orchestrator, core, etc...);
- *Step 3:* the network is configured to accommodate all the flows giving priority to those more related to safety (e.g. using network slicing);
- *Step 4:* if a risk arises, a notification is sent to the UE of the target person;

- *Step 5:* the battery of the RSU is low and the solar panel is not supplyng enogh energy to power the RSU and its sensors. The orchestrator moves energy-intensive tasks (e.g detection) from the RSU to the edge keeping the context.

3.12 Enhancing urban security with UGV monitoring [T2]

In this Use Case, citizens facing critical situations such as aggression, vandalism, or illegal acts can call for intervention through a dedicated app, prompting an *Unmanned Ground Vehicle (UGV)* to analyse the scene and alert the illegal activities to the authorities. Equipped with sensors and a B5G/6G-enabled OBU, the UGV orchestrates safety applications seamlessly between itself and edge network resources. A further aspect considered in the Use Case is the teleoperation of the UGV. Situations may occur in which human intervention is needed to guide the vehicle (e.g., in case of an emergency event, the UGV should perform some specific movements to better understand the situation). In these situations, further network resources must be allocated to guarantee the quality of service required for remote operation.

3.12.1 Use Case objectives and relation to the project technical objectives

The objectives of T2 are closely related to the enhancement of UGV operations, with a focus on reducing energy consumption (and consequently increasing the robot's operational time) and on the orchestration activities. More specifically, we aim:

- To leverage edge computing to offload safety applications from the UGV to the edge, reducing battery energy consumption and prolonging the UGV's operational lifespan without disrupting services. Different types of operation will be offloaded trying to understand the limits done by private and public network in terms of performances (e.g. delay);
- To ensure that the transition of applications maintains contextual continuity and is performed in an energy-aware manner, as described in the previous Use Case (T1);
- To support semantic scene recognition at the edge to enable the UGV to swiftly respond to emergencies in specific urban areas such as parks;
- To guarantee high-quality teleoperation capabilities by allocating sufficient network resources (e.g. using network slicing) when remote human control is required.

3.12.2 Main innovations and challenges

3.12.2.1 Innovations

The main innovations of the T2 Use Case are the following:

- Orchestration mechanisms for enabling seamless transition of applications between the UGV and the edge. Specifically, the target will be not to have disruption in the service provided by the application, meaning that the computational tasks will maintain their context when moved across different hardware platforms. Moreover, the specificity of public and private networks will be tested to see which services can be offloaded in terms of their requirements;
- Teleoperation of the UGV requiring dynamic allocation of network resources. Network slicing will be used to dynamically manage the network to ensure that the applications have the required amount of network resources.

3.12.2.2 Challenges

There are different technical challenges that will be faced in this Use Case:

- *Dynamic Mobility and Location Awareness:* UGVs operate in dynamic environments, constantly moving and changing their positions. The activities will focus on the understanding of the best places and moments to offload depending on the context but also on the network status (and on e.g., the past knowledge of this status);

- *QoS guarantees:* ensuring consistent QoS for UGV tasks is crucial. Offloading decisions must account for latency, reliability, and bandwidth constraints. A balance between QoS requirements and resource availability will be analyzed;
- *Security and Privacy*: offloading tasks to external servers raises security concerns. Data privacy, authentication, and encryption are critical. Ensuring secure communication channels and protecting sensitive information during offloading will be faced in T2;
- *Fault Tolerance and Redundancy:* ensuring task continuity and redundancy is vital. T2 will focus on strategies for fault detection, recovery, and seamless migration of services.

3.12.3 General context and set-up

The high-level schema of the T2 Use Case is shown in Figure 17 below:

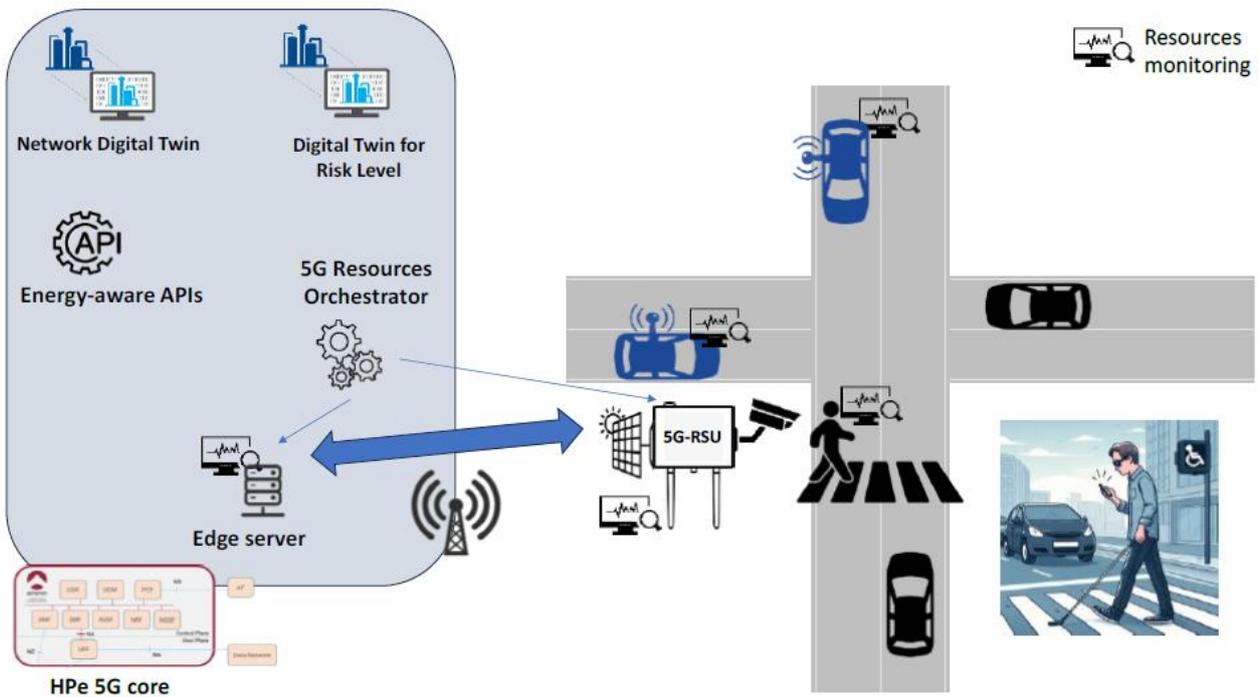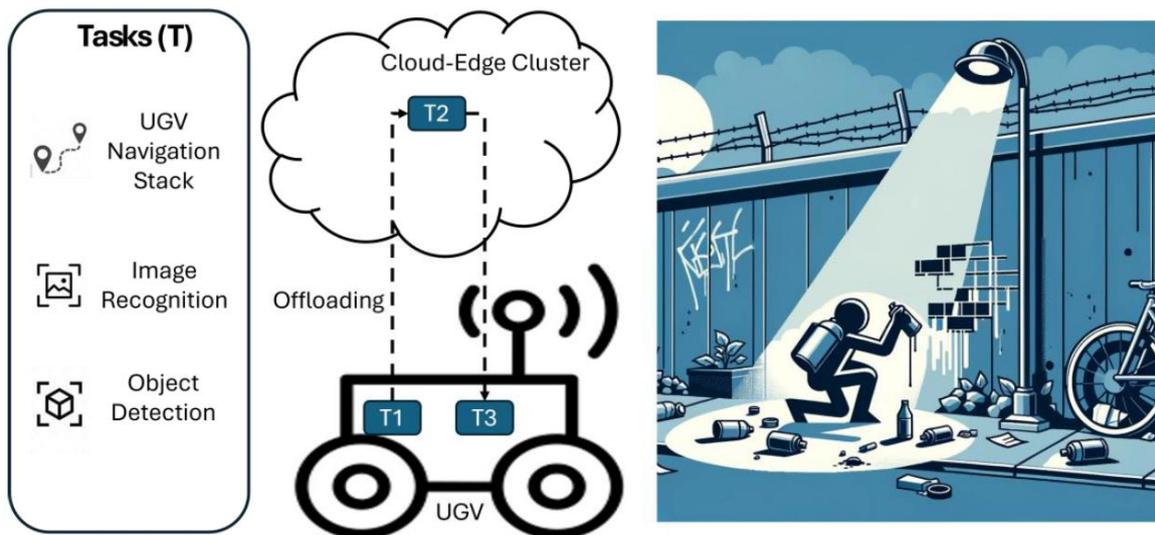**Figure 17: T2 high-level schema.**

The UGV moves to better analyze a potentially dangerous situation. The B5G/6G network continuously monitors the context, offloading some of the robot's tasks to extend its operational time. The orchestrator can dynamically migrate services between the UGV and the edge (and *vice versa*), while preserving contextual awareness and accounting for both current and predicted network conditions.

The tasks that will be considered for offloading are image recognition and object detection and, more challenging, the UGV navigation stack that controls in real time the robot movement.

3.12.4 Technology providers and other partners

The Use Cases will be designed and implemented with the help of several partners. More specifically:

- *LINKS Foundation:* LINKS is the leader of the Use Case and will provide 1/ the connected UGV for all the testing activities, 2/ all the SW that operates the UGV and will be orchestrated and 3/ the app for triggering the UGV operation. Moreover, LINKS will work on the collection of data through the network and applicative digital twin;
- *Nextworks:* Nextworks will implement the technologies required to orchestrate the Vertical Services supporting the UGV mission across the compute continuum. The intelligent allocation of network and computational resources will take into account dynamic factors such as current and predicted network conditions, resource availability, and the battery level of the UGV. To extend the robot's operational time and maintain situational awareness, the orchestrator will enable the offloading of computationally intensive tasks, such as image recognition, object detection, and the real-time navigation stack, between the UGV and edge nodes;

- *Bellantenna:* Bellantenna will provide RAN access with a full gNB. The antenna will have a compact design for easy integration in urban infrastructure. The baseband software will run on general purpose hardware and will be Compatible with standard interfaces either with 5G-NSA[6] and/or 5G-SA scenarios and compliant with public network Core networks requirement if the project team decided to pursue this route. Bellantenna will explore both N77 and mmWave option;
- *TIM:* TIM will support the implementation of the use case focusing on the radio network infrastructure and spectrum aspects, especially for what concern the problems related to the coexistence (i.e., mutual interference) between the private network deployed for the use case and the commercial one. Interworking aspects between the two networks will be also investigated in collaboration with the other partners. Support to the activities related to the spectrum use will be also provided;
- *HPE:* HPE will provide to the testbed an instance of its commercial HPE Aruba Networking Private 5G core network, to be integrated with the other elements of the mobile network deployed to support the Use Case. HPE's core network supports network slicing and exposes APIs for network performance monitoring, software and network function management, QoS control, and user provisioning. These will be leveraged to enable the orchestration and monitoring objectives of this Use Case;
- *UC3M:* UC3M will contribute to the design of the orchestration algorithm with analytical and ML tools to ensure that the time and resource constraints are met while optimizing the energy consumption.

3.12.5 Pre-requisites and assumptions

The Use Case is based on a private 5G network that will be made available from the activities of the ENVELOPE project [15]. A public network will also be used and provided by TIM. The UGV with a proper OBU for advanced connectvity will be provided by LINKS.

The orchestration will be based on the software enablers provided by Nextworks.

3.12.6 Stories

3.12.6.1 Story 1

3.12.6.1.1 Short description

A pedestrian is walking in a park at sunset when they suddenly notice a person exhibiting suspicious behavior. Using the AMAZING-6G App on their smartphone, the pedestrian reports the potential threat. A UGV patrolling the area moves to the indicated location and analyzes the scene using its onboard sensors (e.g., camera).

3.12.6.1.2 Steps

- *Step 1:* the user reports a dangerous situation with the App;
- *Step 2:* the network send the UGV in the indicated location to analize the scene;
- *Step 3:* the network, analyzing the context and based on previous behavior decide if offloading some of the UGV operations;
- *Step 4:* the offloading is managed by an orchestrator keeping the context (when possible);
- *Step 5:* the UGV collects useful information on what is happening.

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6 Non-Standalone

3.13 Wireless signalling on rail tracks [T3]

This Use Case explores the deployment of B5G and 6G wireless communication systems for railway signalling, aiming to offer an alternative/redundant method of transmitting railway trafic, that is traditionally carried by traditional hardwired infrastructure, with the use of advanced wireless and sensing technologies. The goal is to improve safety, reliability, and resilience of train operations, particularly under challenging conditions such as natural disasters or infrastructure failure.

3.13.1 Use Case objectives and relation to the project technical objectives

The objective of this Use Case is to demonstrate the capabilities of B5G/6G technologies in supporting resilient, secure, and efficient railway signalling systems. The key values for the Vertical (railway operations) and its customers includes:

- Enhanced safety and reliability of signalling through real-time wireless communication and trackside sensing;
- Rapid recovery and redeployability in the aftermath of natural disasters or vandalism;
- Continuous train integrity and positioning monitoring, enabled by integration of *Integrated Sensing and Communication (ISAC)*;
- Reduced dependency on vulnerable hardwired infrastructure, e.g., copper cables;
- Use and validation of 5G/6G enablers like network slicing, ISAC, and *Leaky CoaXial (LCX) cable*-based sensing.

3.13.2 Main innovations and challenges

3.13.2.1 Innovations

- Multipath handling for reliable transmission of railway signaling over redundant routes;
- ISAC capabilities for simultaneous data communication and sensing to enable:
  - Enhanced train positioning;
  - Collision avoidance;
  - Obstacle detection;
  - Infrastructure health monitoring.
- LCX cable-based trackside sensing for train presence and movement detection;
- O-RAN-based trackside links as backup for communication reliability;
- Network slicing for critical signaling traffic isolation.

3.13.2.2 Challenges

- Ensuring reliability and redundancy in high-speed and harsh environments;
- Guaranteeing full coverage in remote or disaster-affected areas;
- Compliance with railway safety regulations for signaling;
- Latency requirements for real-time signaling must be consistently met.

3.13.3 General context and set-up

3.13.3.1 Actors

- *Train operators:* equip trains with localization and communication modules;
- *Infrastructure managers:* deploy LCX cables, O-RAN equipment, and trackside sensors;
- *Technology providers:* offer 5G/6G equipment, campus RAN, and sensing platforms.

3.13.3.2 Set-up

The set-up involves two trains travelling one behind the other along a test track. The train in front is equipped with communication and localization equipment as well as an ISAC unit, enabling enhanced

positioning, obstacle detection, infrastructure health monitoring, and collision avoidance. The rear train communicates through a terrestrial 5G/6G network and maintains a sidelink connection to the front train to ensure coordinated movement and safety.

Along the rail line, LCX cables are deployed to perform both communication and sensing functions. These cables transmit 5G signals and receive reflected waves, enabling real-time train detection and positioning, which supports continuous train integrity monitoring and redundancy for the signalling process. Additionally, O-RAN units are installed along the track to act as a redundant communication link between the train and the network infrastructure, enhancing the overall reliability of the system.

To simulate future deployments, the Use Case employs *Future Railway Mobile Communication System (FRMCS)* over a 5G private campus RAN. This configuration mirrors the expected replacement of GSM-R and provides a baseline for evaluating the performance of wireless signalling technologies under realistic operational conditions.

3.13.4 Technology providers

- *TUC:* provides the B5G/6G network infrastructure, including core and RAN, and oversees the implementation;
- *SRCC:* Use Case owner, interface with railway authorities;
- *UoS:* ISAC for obstacle detection ;
- *ISRD:* deployment of O-RAN on the trackside, integration with the TUC campus network

3.13.5 Pre-requisites and assumptions

- All trains involved are equipped with 5G/6G-compatible communication modules;
- A private campus 5G RAN is available for testing purposes;
- GSM-R KPIs serve as the baseline for performance comparison;
- Trackside LCX cables and O-RAN units must be correctly installed and calibrated;
- Environmental conditions allow for meaningful sensor data collection (e.g., no radio interference).

3.13.6 Stories

3.13.6.1 Story 1: Enhanced Safety and Train Integrity Monitoring

3.13.6.1.1 Short description

This story demonstrates how continuous communication and integrated sensing enable safe coordination and spacing between two trains operating on the same track. The front train, equipped with localization and ISAC capabilities, constantly transmits its position, speed, and integrity status over a 5G/6G link. The rear train receives this information through both the terrestrial network and a direct side-link connection, allowing it to adapt its speed and braking in real time to maintain a safe distance. Simultaneously, LCX cables along the track monitor train movement by transmitting and analyzing reflected 5G signals, providing an additional layer of redundancy for positioning accuracy. This setup ensures reliable, low-latency communication and situational awareness, significantly enhancing operational safety.

3.13.6.1.2 Steps

- *Step 1:* the front train initiates movement and begins transmitting localization and integrity data via the 5G/6G link;
- *Step 2:* the rear train receives data via terrestrial network and sidelink, adjusting speed to maintain safe separation;
- *Step 3:* LCX-based sensors detect both trains' positions, confirming data accuracy and redundancy;

- *Step 4:* the control center receives real-time updates via the 5G core, enabling dynamic signalling decisions.

3.14 Tele-operation as a back-up to autonomous driving [T4]

Autonomous vehicles are being actively tested and piloted across Europe. While not yet widely deployed, they represent a promising solution for enhancing road safety and transport efficiency as technology and regulatory frameworks continue to evolve. However, in complex or unpredictable scenarios—such as construction zones, adverse weather, or poorly mapped areas—autonomous systems may not be able to guarantee safe navigation. This Use Case explores a robust tele-operation fallback mechanism, whereby a human operator remotely takes control of the vehicle when the AI determines that autonomous driving is no longer viable. The transition is enabled via a B5G/6G link and supported by intelligent ML-based decision-making and advanced network service and slice orchestration across the UE-edge-cloud continuum.

3.14.1 Use Case objectives and relation to the project technical objectives

This Use Case focuses on enabling seamless and safe transition from autonomous driving to remote human control in scenarios where autonomous systems face limitations. It highlights the role of ML-driven decision-making, low-latency communication, and intelligent orchestration in ensuring reliable vehicular operation. In particular, it aims to:

- Demonstrate seamless switching between autonomous and tele-operated driving using a resilient B5G/6G communication framework;
- Ensure operational continuity and enhance safety in complex or unpredictable driving scenarios;
- Leverage ML-based anomaly detection to trigger mode-switching when autonomous navigation becomes unreliable or unsafe;
- Utilize high-bandwidth, low-latency communication to support real-time tele-operation, including video, sensor streaming, and vehicle control;
- Implement intelligent orchestration and dynamic service placement across the UE-edge-cloud continuum;
- Implement dynamic end-to-end network slice control to ensure performance guarantees for tele-operation.

3.14.2 Main innovations and challenges

3.14.2.1 Innovations

- ML-based anomaly detection algorithm to dynamically assess the driving context and determine when to switch from autonomous to tele-operated mode;
- Distributed context recognition through fusion of onboard sensing, *Vehicle-to-X (V2X)* communication, and external situational awareness data for enhanced decision-making;
- Flexible placement of intelligence across the vehicle OBU, network edge, and cloud to evaluate trade-offs in latency, accuracy, and availability of context information;
- B5G/6G-based high-bandwidth, low-latency communication enabling reliable tele-operation even in remote or complex environments;
- EdgeApps framework with network exposure allowing real-time adjustments to QoS based on events such as obstacle detection or traffic management signals;
- *Zero-touch Network and Service Management (ZSM)* of vehicular services using AI/ML to predict mobility patterns, network and compute resource demand, and energy utilization, ensuring continuity and QoS for mission-critical services like tele-operation. ZSM will perform two tasks: 1/ intelligent service placement in UE-edge-cloud continuum, and 2/ dynamic end-to-end network slice control, which is in charge of the dynamic network resource configuration through integration with telco

operator interfaces (e.g., CAMARA, CAPIF) to proactively optimize slice configurations and traffic handling. This ZSM solution refers to the following three technological enablers: network and compute resource management, network exposure (exposing network to vertical services), and dynamic end-to-end network slice control (proactive and optimized slice configuration).

3.14.2.2 Challenges

- Network limitations, including poor coverage, high latency, and congestion, can impair real-time tele-operation by degrading video and controlling signal quality;
- Human operator constraints, such as delayed response times or limited availability, can affect the safety and reliability of remote driving;
- Vehicle-side limitations, such as sensor malfunctions, hardware failures, or degraded visibility due to environmental conditions, reduce operational effectiveness;
- Video and communication quality issues, such as low resolution, frame drops, or lag, impact the operator's ability to perceive the environment and make safe decisions;
- Legal and regulatory uncertainties, particularly around cross-border operations, complicate implementation and require harmonization across jurisdictions;
- Remote interaction with human drivers, including interpretation of non-verbal cues or cooperative maneuvers, remains a challenge when the operator is not physically present.

3.14.3 General context and set-up

The test set-up includes a vehicle navigating real-world road conditions, monitored via AI. When conditions are deemed unsuitable for autonomous operation, the ML model triggers tele-operation. The switch is performed via a private 6G RAN link, which supports high-throughput, low-latency video and control traffic. ML-based decision support, encapsulated within EdgeApps, can be flexibly deployed across the continuum — from the vehicle's OBU to edge nodes or centralized cloud — depending on latency, resource availability, and context-awareness requirements.

Actors involved in the UC are:

- *Autonomous vehicle:* it is equipped with onboard computing units, sensors, and V2X communication modules for perception, decision-making, and connectivity;
- *Remote tele-operator:* (s)he is located at a centralized control centre, responsible for manual vehicle control during tele-operation mode using real-time data and video feeds.

3.14.4 Technology providers and other partners

- TUC provides and delivers:
  - The autonomous vehicle platform, including sensors, onboard processing unit, and integration with tele-operation interfaces;
  - The 6G infrastructure, including the private RAN and core network functions;
  - The ML-based anomaly detection algorithm and assists with evaluation of algorithm placement and performance impacts.
- IMEC delivers:
  - Intelligent service placement across UE-edge-cloud continuum (ZSM service orchestration);
  - Dynamic network slice control to configure network resources in runtime based on the Quality on Demand requests stemming from the trigger to switch from autonomous to teleoperation mode;
  - Network exposure mechanisms on the 5G Core, allowing EdgeApps (wrapping the logic of ML-based service) to request QoS profile changes when switching between modes.

3.14.5 Pre-requisites and assumptions

- All vehicles are equipped with fully functional sensor suites and onboard compute resources;
- A stable and high-performing end-to-end network is deployed to support safe and efficient tele-operation.

3.14.6 Stories

3.14.6.1 Story 1

3.14.6.1.1 Short description

This story illustrates the core Use Case i.e., the vehicle transitions from autonomous to tele-operated mode upon encountering a scenario beyond its autonomous capabilities.

3.14.6.1.2 Steps

- *Step 1:* the vehicle operates autonomously along a predefined route until it encounters a complex construction zone with unclear lane markings;
- *Step 2:* the ML-based algorithm detects degraded performance in situational awareness and triggers the switch to tele-operation;
- *Step 3:* a remote operator receives an alert, takes control via the virtual dashboard, and safely navigates the vehicle through the complex area;
- *Step 4:* once normal driving conditions resume, the vehicle regains autonomous control, and the tele-operation session ends.

3.14.6.2 Story 2

3.14.6.2.1 Short description

This story illustrates the role of the technological enablers such as ZSM, dynamic end-to-end network slice control, and network exposure, in the case of mission-critical services such as tele-operation.
The role of ZSM is to perform intelligent orchestration, and in particular, placement of vertical services (such as the AI-based service used for switching from autonomous to teleoperation mode) along the UE-edge-cloud continuum depending on the contextual information and real-time monitoring data. On the other hand, network exposure principles will be used for dynamic triggering of network slice configuration to ensure performance guarantees for teleoperation.

3.14.6.2.2 Steps

- *Step 1 (precondition):* ZSM monitoring module collects real-time monitoring data from the compute and network infrastructure where tele-operation services, including the ML-based algorithm, are running (ZSM monitoring);
- *Step 2 (precondition):* ZSM service orchestrator module makes service placement decision based on the real-time monitoring data, and the service requirements placed in the intent (ZSM decision-making). This step ensures that sufficient resources are allocated for the ML-based algorithm wrapped in a vertical service package and deployed in the UE-edge-cloud continuum;
- *Step 3 (service runtime):* when the ML-based algorithm detects degraded performance (as described in Section 3.14.6.1), the switch to tele-operation happens, and the network performance need to comply with the service requirements to ensure safe and efficient tele-operation. Using network exposure, in particular Quality on Demand API (Camara APIs) on the 5G Core, will allow the ML-based service to request higher network quality when making decision to switch to teleoperation;
- *Step 4 (service runtime):* once the request is placed, the network conveys it to the ZSM intelligent network slice controller, which configures the network slice in an end-to-end manner to ensure the required levels of QoS for tele-operation;
- *Step 5 (service runtime):* the ZSM monitoring module continues real-time network and compute monitoring, and the service orchestrator as well as network slice controller subscribe to that data to assess the impact of their decisions or to perform service or slice reconfigurations.

3.15 Port logistics and transport optimization and safety [T5]

The Use Case of the Port of Thessaloniki in AMAZING-6G is focused on the operations occurring in its Container Terminal (*Ship-to-Shore (STS)* and *Shore-to-Truck (STT)* operations). Containers in ThPA S.A. are being handled 24 hours a day, 365 days a year at the designated area of the Container Terminal in the western part of Pier 6 (quay 26). It is part of the Free Zone and it extends in a 550m long and 340m wide area (352.000 m2) with a storage capacity of 5,200 *Twenty-foot Equivalent Units (TEU)* in ground locations while it can serve vessels with a draught of up to 12 meters. The Container Terminal is fully equipped with modern container handling equipment while it features technical facilities and an experienced technical support team. Loading and unloading of containers from and to ships is conducted by 4 STS cranes, 2 of which are specially designed New Panamax STS cranes that were recently delivered. The handling, storage and stowage of containers is conducted by straddle carriers and a series of modern container handling equipment such as reach stackers, tractors, front lifts, trailers and forklifts.

This Use Case aims to foster operational efficiency, safety, and human-machine interaction, by reducing potential disruption of operations and the environmental footprint of port logistics and transport operations. This is achieved by enabling real-time, massive twinning, by extending a digital twin platform developed for process monitoring and tele-operation. The platform will be tested in a pilot that covers an end-to-end port process, i.e., from vessel unloading to loading trucks.

3.15.1 Use Case objectives and relation to the project technical objectives

The objectives of the Use Case in relation to the projects technical objectives are:

- The optimization of operational efficiency through process optimization (including cargo handling, optimized routes, and equipment operation). This optimization leads to increased overall logistics efficiency, reduced operational downtime, and better resource utilization;
- Real-time visibility through instant and continuous data transmission (high-speed connectivity, low latency), allowing operators to have visibility into cargo movements, levels, and conditions, ensuring effective supply chain management;
- Enhanced safety and security through real-time surveillance, monitoring, and response mechanisms based on high-definition video streaming, sensor data analysis, and quicker response times to potential security threats or emergencies;
- Improved supply chain resilience by providing robust connectivity even in remote or challenging environments to ensure uninterrupted communication and data flow, reducing the risk of disruptions.

3.15.2 Main innovations and challenges

3.15.2.1 Innovations

- Real-time collection, monitoring and analysis of data combining digital twin, B5G/6G, AI/ML, simulation and IoT technologies;
- Orchestration of seamless tele-operations;
- Integration and exposure of sensing capabilities, from the network to the end user. Use of sensors, cameras, etc., integrated through B5G/6G;
- Network slicing: B5G/6G network slicing capabilities will allow for dedicated network slices for critical data transmission.

3.15.2.2 Challenges

- Enhanced connectivity, reliability and data rates, enabling real-time massive twinning, data processing and analytics. This is crucial for the synchronization of operations in a port, where milliseconds can affect logistics and supply chain efficiency;
- Massive twinning and seamless IoT Integration: B5G/6G's ability to connect a vast number of devices per square kilometer enables comprehensive IoT deployment. In a port setting, this means everything from cranes, vehicles, containers, to sensors can be interconnected, providing a seamless flow of information and automation in near real-time;
- Sustainability (environmental, societal, and economic): port operations pose a wide range of challenges related to severe environmental impacts, security, congestion, and conflicts over land use. The digital transformation offers an opportunity to confront those challenges, however most ports are struggling to keep up with the implementation of digital services and technology; while at the same time they face difficulties in following the demanding sustainability agendas leading towards climate neutrality;
- Limitations: 1/ from the cranes side, 2/ from the communications side (ultra-low E2E latency, high bitrate, reliability), 3/ of the human factor.

3.15.3 General context and set-up

In the Port of Thessaloniki, containers are being handled 24 hours a day, 361 days a year at the designated area of the Container Terminal in the western part of Pier 6 (quay 26). It is part of the Free Zone and it extends in a 550m long and 340m wide area, with a storage capacity of 5,200 TEU in ground slots.

The loading & unloading of containers (see Figure 18 below) is handled by STS port cranes, and Straddle Carries that stow full containers in the Port's yard in designated areas or on the vessel. Depending on the type of and the amount of goods being shipped, weather conditions, and many more, a vessel may be docked for several days in a row, resulting in increased port dues. Any disruptions in operations may result in respective claims from either side.

ThPA S.A. through the AMAZING-6G project and UC T5 implementation, wants to verify the solution via piloting activities, in order to reassure having an alternative plan of operations in case of need, reduce risks of disruptions while improving its operational efficiency.
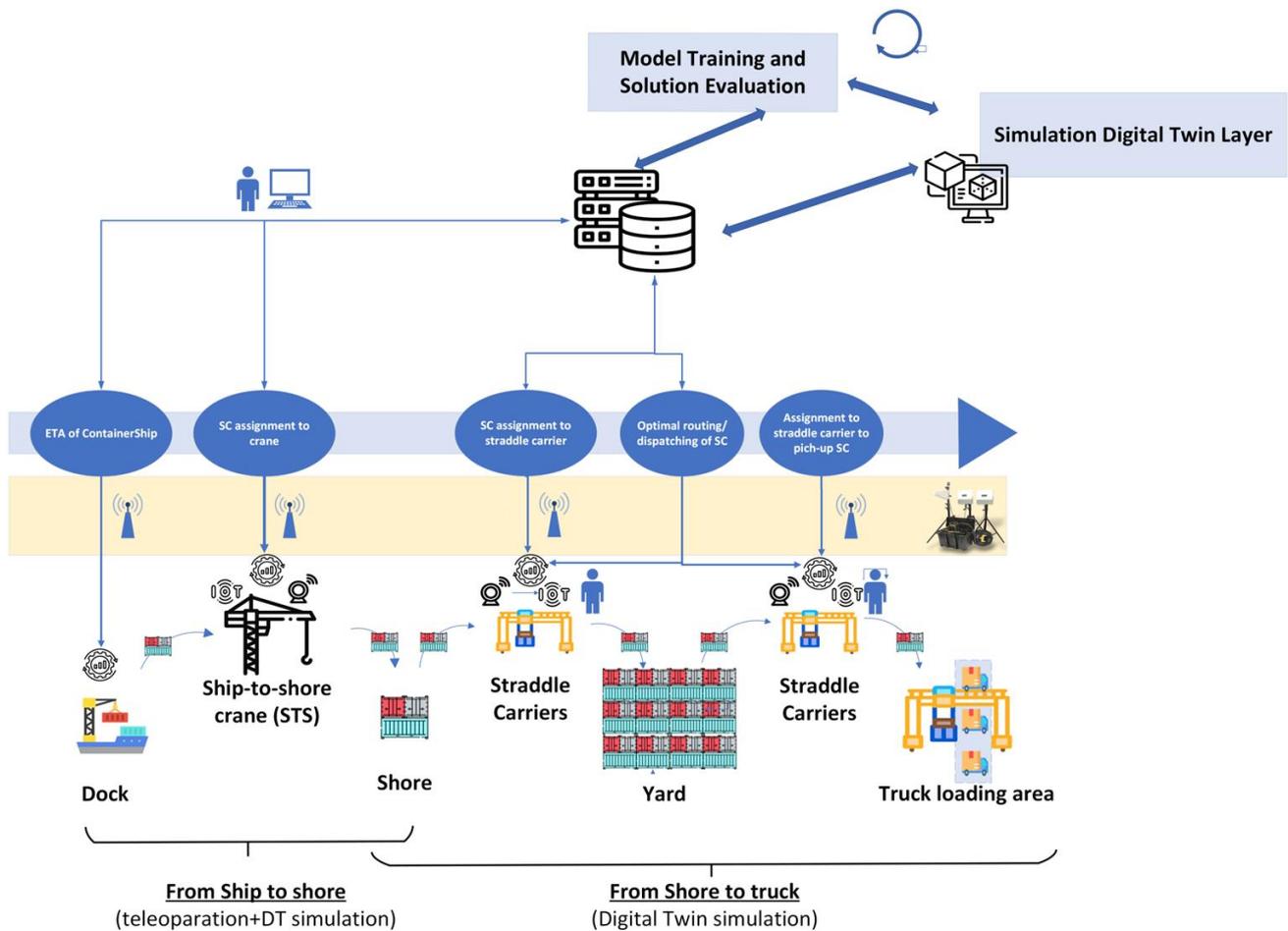
Figure 18: T5 set-up.

3.15.4 Technology providers and other partners

Below, is an overview of the main actors and their respective roles in T5 Use Case:

AMAZING-6G – T5 team:

- *ThPA (port operator):* provide UC testbed and port equipment/infrastructure; will oversee the smooth orchestration of the pilot;
- *CERTH/HIT:* research and technology provider;
- *WINGS:* technology developer;
- *ACRO:* B5G/6G technology provider.

Compliance Authorities/supervising Bodies:

- *Authorizing authorities:* monitor and ensure compliance/provide permits (if needed);
- *Vendors/contractors:* oversee procedure while piloting stage, to ensure smooth transition from as-is to pilot stage.

Other internal consulting teams:

- For the *Port of Thessaloniki,* that pilot is to be implemented, a number of departments need to approve or oversee the pilot procedure, to ensure smooth implementation so that the involved equipment will be able to function in as-is state or/and not be impaired:
  - *Container Terminal:* STS and Straddle Carriers' operators; Gate, Documentation, Finance and Operations Dpt;
  - *Equipment & Maintenance Division:* Electro-/mechanical engineers;

      o *ICT Division*;
      o *Safety & Security Department*.

3.15.5 Pre-requisites and assumptions

n/a

3.15.6 Stories

The pilot implementation is broken down into two sub-cases. The digital twin is developed in a virtual environment with a series of avatars of vehicles, containers, and machines (cranes, etc.) that utilize real-time data. To achieve this result, the AnyLogic simulation software will be instrumented as it contains an explicit UI for 3D representations that replicate the real world, as well as capabilities for discrete event and agent-based modeling, along with the integration of custom optimization routines.

3.15.6.1 Story 1

3.15.6.1.1 Short description

[1] From ship to shore: STS cranes are used to move containers between ships and the quay, handled by operators on board. In this subcase, remotely controlled and monitored operations of STS cranes are introduced (equipped with sensors and cameras), utilizing the B5G/6G network; with automated cranes being able to perform additional functions autonomously (e.g., video streams may not be continuously transmitted), so that one crane operator can supervise multiple cranes simultaneously.

3.15.6.1.2 Steps

- *Step 1:* STS receives bay or stow plan;
- *Step 2:* positioning of STS;
- *Step 3:* coordination with Straddle Carriers;
- *Step 4:* operator starts procedure;
- *Step 5:* Straddle Carrier picks-up/drops down.

3.15.6.2 Story 2

3.15.6.2.1 Short description

[2] From shore to truck: STT Straddle Carriers are used to move containers from the quay to the areas for loading the trucks. Similar to STS, Straddle Carriers are also equipped with sensors and cameras, to optimize the routing between the areas of (un)loading. Moreover, cameras are used for monitoring and human intervention, especially for navigating areas where people are present. This requires reliable exchange of position (and other) data collected from 3D sensors using B5G/6G connectivity. The digital twin platform will simulate the complex process of moving containers within the port, in order to support the transition of these processes towards full automation. This solution is intended to replace the current equipment with AGVs. AGVs could be used in real life implementations according to the port's current expansion/investment plan. In that case, the addition of AR will allow the representation of asset information on the ground with geolocation in real-time. This will enable improved response and efficiency in event resolution.

3.15.6.2.2 Steps

- *Step 1:* Straddle Carrier places in yard/picks up a container;
- *Step 2:* container is loaded on truck;
- *Step 3:* driver is approved for take-off;
- *Step 4:* gate exit of truck.

4 Context views

As already explained in the Section 2.2.3.1, elucidating Context views is an intial step towards UC design (high-level design) where actors, main components and their roles are identified. But most importantly a Context view also highlights which sort of support is expected from a 5G network augmented with AMAZING-6G Vertical-supporting features. This resulting B5G/6G system is called "targetted system" throughout this section as it is the target of the requirement engineering process, and of course also the target of the architecting activity.

Not only the Context view throws the basis of UC design and deployment strategy, it also plays an important role in the requirement (both fonctional and non-functional) engineering process as explained in Section 2.2.1.

4.1 H1 Context view

The H1 Use Case comprises two distinct clinical cases: H1A and H1B. The H1A clinical case addresses intermittent monitoring of a patient's heart function at home, in particular while exercising. The patch will be battery-powered. The H1B clinical case addresses continuous real-time monitoring of a patient's heart function will on the intensive care unittime. The patch will rely on a external power supply.

4.1.1 Actors and roles

- Patients:
  - They are equipped with an ultrasound transducer patch;
  - Depending on clinical case, their blood pressure (BP) and heart operation (ECG) may be monitored too.
- Cardiologist:
  - They can access patient's record any time;
  - They receive AI-flagged record notifications;
  - They must review AI-flagged record for re-interpretation and decision making.

4.1.2 Digital subsystems

- `Ultrasound transducer:`
  - Provides ultrasound imagery from the heart at a configurable sampling rate;
- Portable `ECG` transmitter (number of leads to be determined, e.g., 1 or 3 leads):
  - Provides ECG at a configurable (e.g. 512Hz, 12 bits) sampling rate. Typically, 10s ECG data per minute.
- `BP` monitor:
  - Provides BP information at a configurable sampling rate.
- `Clinical backend:`
  - Sets up all specific AMAZING-6G services (`Operation Management`);
  - Creates and manages a patient dedicated time-stamped database [both H1A and H1B];
  - Stores in this database a set of vitals including ECG, BP and AI-annotated ultrasound heart imaging communicated by the AMAZING-6G-managed `AI-based imagery analysis µS`;
  - Notifies the cardiologist in charge about flagged records for immediate verification and needed subsequent actions.
- `Device discovery`: responsible for discovering sensors relating to the patient (might not be used in real implementation depending on the level of integration of sensors into a single device);
- `Sensor management`: responsible for configuring the various used sensors i.e patch and possibly ECG and/or BP. It relies on device discovery typically and sets sampling rate and data transfer duration & period up according to the 2 scenarios specific requirements. It is also

responsible for collecting data from patch and possibly BP and/or ECG, and for pushing it towards the `AI-based imagery analysis µS` via the `NR RedCap modem`;

- `NR RedCap modem:` provides low energy tranmission between the patch and the gNB.

4.1.3 AMAZING-6G+5G standalone

The `Targeted system`:

- Provides AI support for learning and inference phase of the `AI-based imagery analysis µS`;
- Provides optimal computation to the `AI-based imagery analysis µS` (especially GPU power);
- Provides optimal placement according to QoS constraints (edge vs. cloud);
- Provides highly reliable and very low latency 5G communication between Patch{/ECG/BP} and Clinical backend.

4.1.4 µServices

- `AI-based imagery analysis µS`: it performs AI-based interpretation of heart ultrasound imagery, correlates it with additional vitals data and annotates them with a diagnosis. Flags any image coming with an anomaly in heart function.

4.1.5 UML diagrams
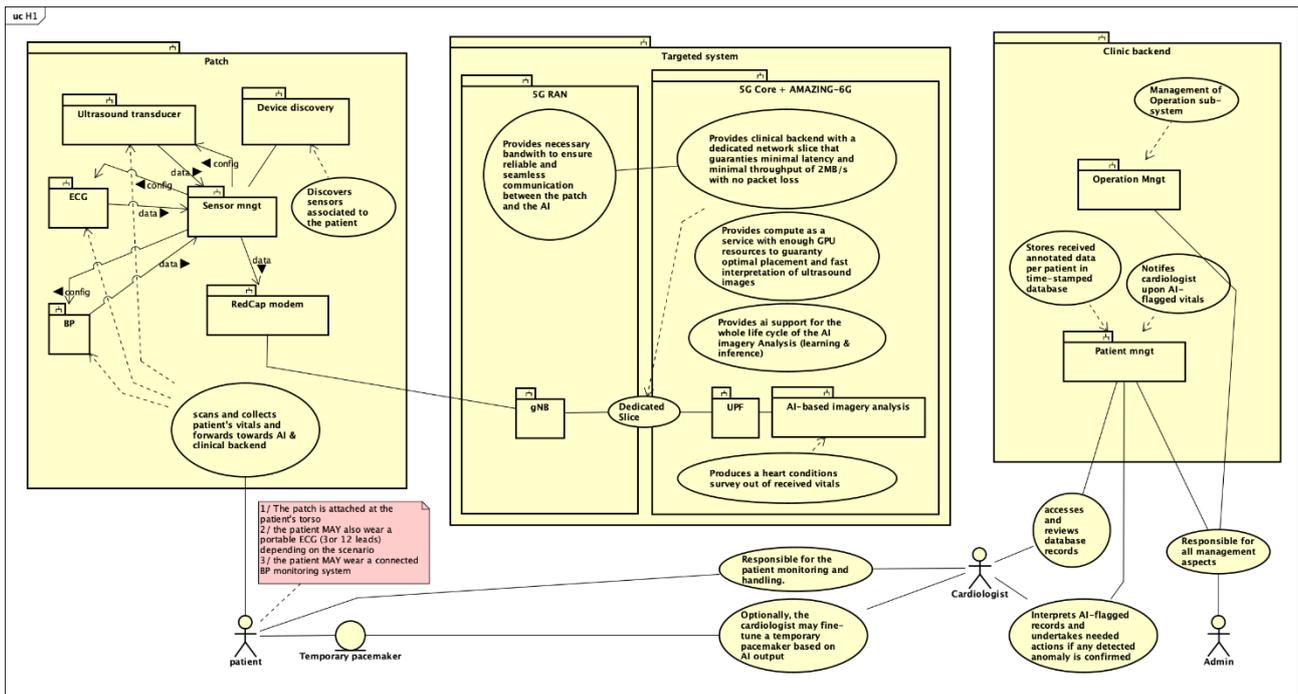
Figure 19: **H1 Context view.**

4.2 H2 Context view

The H2 Use Case concerns a heart patient who got a pacemaker implanted. The operation of the pacemaker is continuously monitored and, if needed, adjusted in real-time by AI on-the-edge.

4.2.1 Actors and roles

- Patients:

- o Equipped with a permanent backscatter-enabled pacemaker and a wearable patch bridge between the patch and the 6G System.
- Cardiologist:
    - o Can access patient's record any time;
    - o Receives notifications whenever the pacemaker either encounters a malfunction or when heart malfunction is detected.

4.2.2 Digital subsystems

- `Patch`: the patch sub-system comprises the following sub-systems:
    - o `Accelerometer Feed`: collects sensor data from an patch embedded accelerometer and pushes this data towards the `Patch` and `Pacemaker Manager`;
    - o `RFID Reader`: provides 2-ways communication with the pacemaker using backscattering. Information from/to the pacemaker is pushed to the `Patch` and `Pacemaker Manager` sub-system;
    - o `Patch and Pacemaker Manager`: it is responsible to send acceleraometer- and pacemaker-related data to the `AI-based Pacemaker Controller µS` and to push received pacemaker fine-tuning instructions to the pacemaker.
- `Clinical backend`:
    - o Sets up all specific AMAZING-6G services (`Operation Management`);
    - o Creates and manages a patient dedicated time-stamped database;
    - o Stores in this database records with pacemaker telemetric, detected activity and pacemaker fine-tuning recommendation, e.g. if the model decides to modify the settings for a specific activity due to a change in the patient's health status;
    - o Notifies the cardiologist about pacemaker fine-tuning recommendations if any.

4.2.3 AMAZING-6G+5G standalone

The `Targeted system`:

- Provides AI support for inference phase of the `AI-based Pacemaker Controller µS`;
- Provides optimal computation to the `AI-based Pacemaker Controller µS` (especially GPU power);
- Provides optimal placement according to QoS constraints (edge vs. cloud);
- Provides highly reliable and very low latency 5G communication between `Patch`, AI and `Clinical backend`.

4.2.4 µServices

- `AI-based Pacemaker Controller µS`: this service receives ECG data from the temporary pacemaker or EGM data from the permanent pacemaker and data from the accelerometer, then after analysis and assessment of patient likely activity, perform the event-aware reprogramming of the pacemaker. The model is pre-trained with patients' data.

4.2.5 UML diagrams
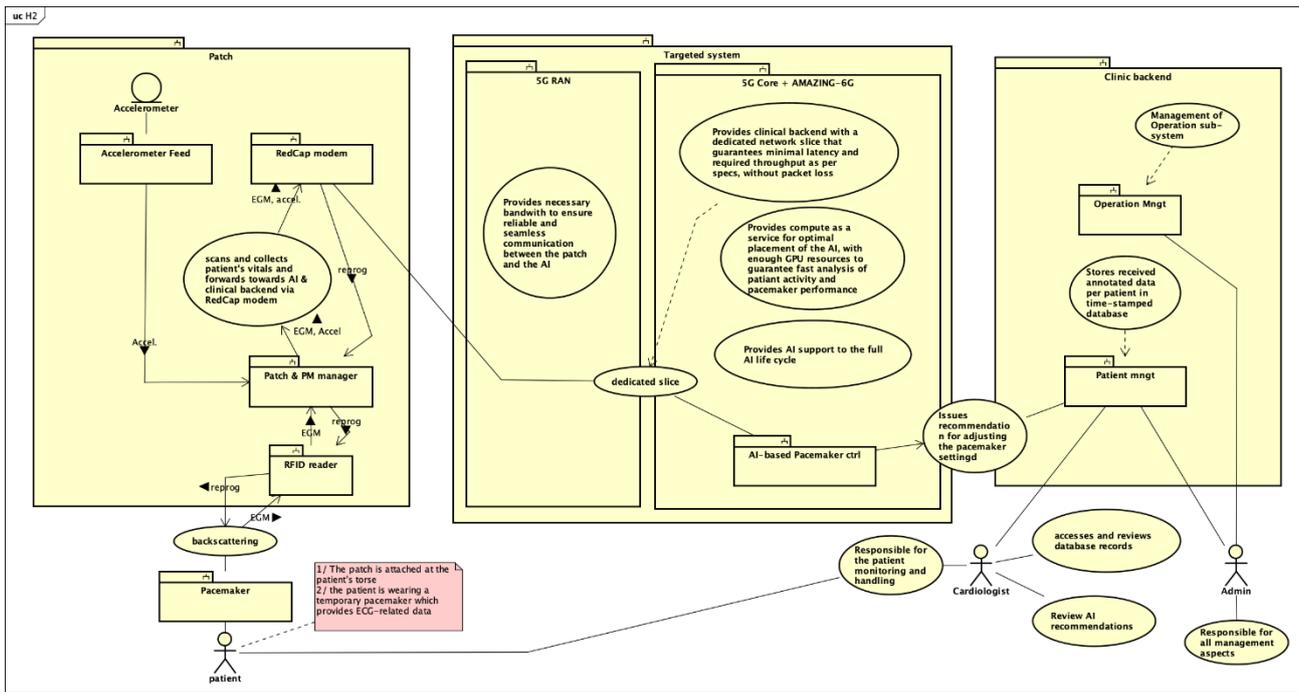
Figure 20: H2 Context view.

4.3 P1 Context view

4.3.1 Actors and roles

- *PPDR Remote Command Supervisor (PPDR-RCS)*:
  - o Receives situation monitoring from UMVs/Robots cameras, and PPDR-FRs cameras;
  - o Decides about the rescue operation;
  - o Instructs PPDR-FRs, UMV/Robots for moving to/capturing an area of interest.
- *PPDR Central Command Supervisor (PPDR-CCS)*:
  - o Receives initial incident detection alert from environment monitoring sources;
  - o Receives situation monitoring from UMVs/Robots cameras, and PPDR-FRs wearable ones;
  - o Guides the rescue operation, based on situation monitoring and relevant analytical data.
- *PPDR First Responders (PPDR-FRs)*:
  - o perform instructions received from PPDR-CCS or PPDR-RCS. These include alerts for emergency actions and incident recovery;
  - o Carry UMVs/Robots, and infrastructure equipment (Autonomous Edge), to the field of incident;
  - o Provide video streams from wearable cameras, while operating on the field.
- UMVs/Robots:
  - o Provide video streams from attached cameras, while operating on the field.
- Citizens (affected):
  - o Receive alert messages broadcasted from the mobile network.
- Satellite MNO (emulated-see below)):
  - o Provide emergency 5G NTN links for PPDR rescuers.

4.3.2 Digital subsystems

- Patras5G Autonomous Edge: a mobile box for private 5G/6G network deployments, including 5G New Radio (NR), network and service orchestration, while extensible with MEC capabilities. An updated list of features is available under Patras 5G Wiki. PPDR services/applications will be operational on this sub-system (by UPAT/PNET);
- *Customer PremisesEquipment (CPE);*
- Environment monitoring IoT platform, with thermal cameras, environmental and other sensors, for incident detection (by WINGS);
- Satellite Emulator environment (FlatSat), with a *Non-Terrestrial Network (NTN)* service for first responders' communication (by OQTEC);
- UPAT/P-NET Edge server;
- UPAT/P-NET Cloud server.

4.3.3 AMAZING-6G+5G standalone

- Provides reliable data processing and communication to the PPDR-FRs, UMVs/Robots, Local & Remote Control Centers, including the support of mission critical services and applications;
- Provides extended mobile coverage & network performance in the area of the incident;
- Enables the PPDR slice configuration over multiple mobile 5G/6G networks, including a mechanism for surveying the available backhaul networks;
- Supports a smooth roaming service by mobile networks, where a specific radio infrastructure is disrupted.

4.3.4 µServices

- *Push-to-Talk (PTT)* and *Mission-Critical (MC) PTT (MC-PPT): Push-to-Talk (PTT)* and *Mission-Critical (MC) PTT*: A server/client-based service implementing PTT and MCPTT functionality, supporting 3GPP-compliant SIP/IMS signaling, low-latency RTP media streaming, and QoS-optimized group and private voice communications. PTT allows faster and more efficient communication between actors;
- Video Streaming: microservice allowing for transmission of video from a client to the *Command & Control Center (C&CC)*, allowing better situational awareness and coordination of on-the-field personnel. The received streams can be further forwarded to interesting parties for information sharing. Different slices will allow personnel in command priority access to the deployed 5G network;
- Geolocation and Asset Tracking: A microservice for real-time geolocation and asset tracking, utilizing GNSS, cellular, and Wi-Fi positioning, with support for geofencing, telemetry ingestion, and low-latency event publishing via REST and MQTT APIs;
- AR/VR optimized service: A microservice optimized for AR/VR applications, providing low-latency 3D content streaming, real-time spatial mapping, and edge-compute acceleration for rendering, with support for high-bandwidth data transport in both downlink- and uplink-oriented traffic, depending on the scenario;
- UMV/Robot assistance services: enable real-time telemetry exchange, remote command and control, collaborative autonomous navigation orchestration, and sensor fusion processing. The analysis of the gathered data from multiple sources will allow for better understanding of the situation and enable the standalone operation of these devices without human intervention if needed;
- Orchestrator: An end-to-end network service lifecycle management, supporting ETSI MANO-compliant service modeling, instantiation, and automation of *Virtual Network Functions (VNF)/Cloud-native Virtual Function (CNF)* across multi-domain environments and *TeleManagement Forum (TMF)* compliant APIs. This includes, but is not limited to creation, deployment and management of Kubernetes, automated deployment of network applications, creation and management of 5G networks on demand.

4.3.5 UML diagrams

Figure 21 shows a private 5G/6G network which is deployed on the field of the affected area, including RAN, core and edge node capabilities. Various PPDR services (PTT, video, voice, etc.) become available, facilitating situation awareness and communication means to First Responders, and the Local Command/Control Center. First Responders downstream content from the Local Center, while upstream content is sent from wearable devices/cameras, UEs, collaborative UMVs or robots. Automated network slice set-up is provides guaranteed resources for the PPDR QoS requirements. For non-5G native devices, potentially used, operation will be established through a *Customer Premises Equipment (CPE)* that will operate as a 5G router.
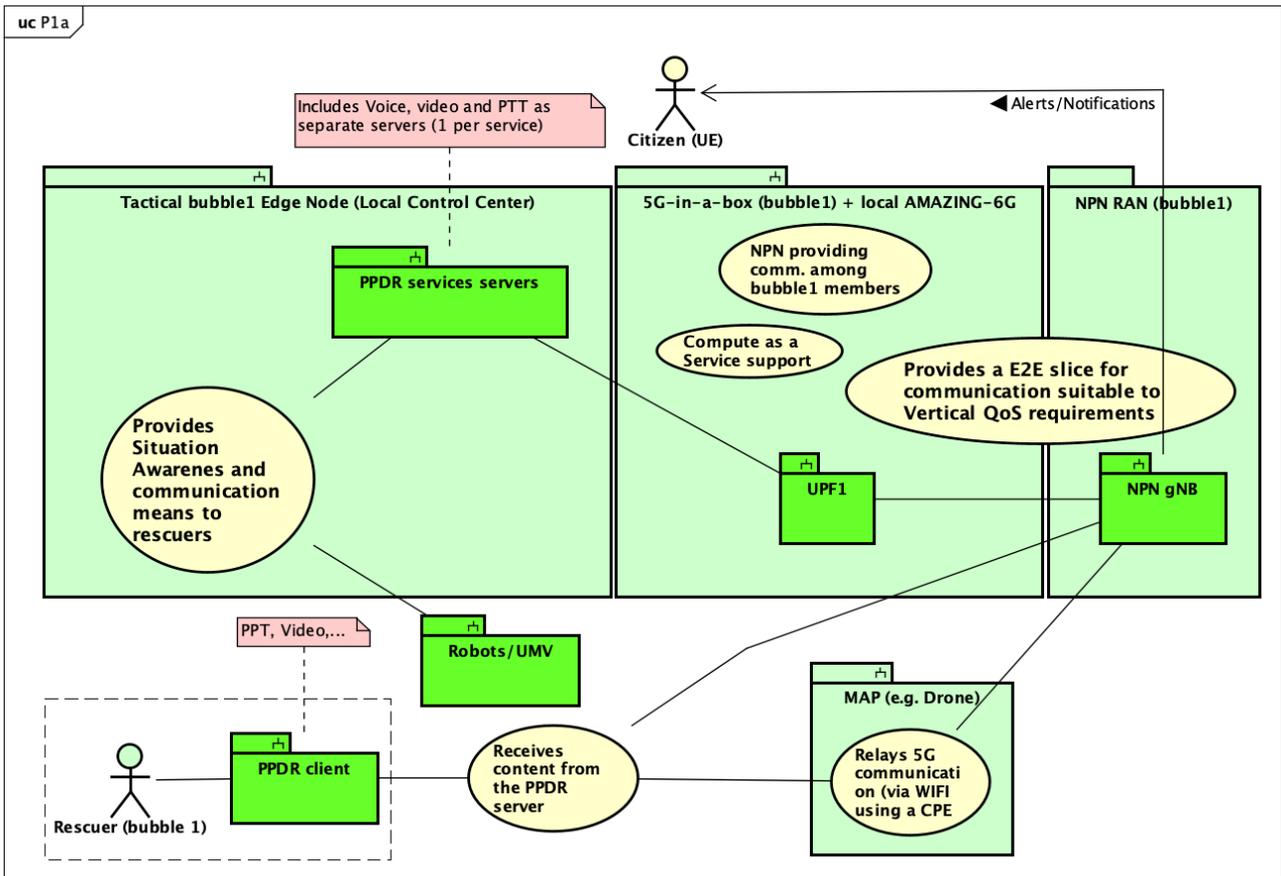
Figure 21: P1a Context view.

For more effective incident handling and better situational awareness, additional First Responders already operating in the area, or arriving later possibly with their own private 5G network (e.g., bubble 2), will need access to the provided PPDR services (in both bubbles). In such cases, SIM cards are distributed to them, and their devices can be registered to the AMAZING-6G network after providing information of the cards to the private network operator (purple part). If another private/public mobile network is 'still available' (yellow RAN), network connectivity can be established between this network and the initial private network (green RAN), to extend coverage and service provision in the affected area. Various options will be sought for this last RAN interconnection. The Figure 22 below illustrates interconnection of two RANs and PPDR services through CPEs while other options would be SIM registration and edge node direct connection.

Figure 22: P1b Context view.

Getting access to a Remote Control Center (light blue part), and other services from the Public Internet, would be highly beneficial for the campaign efforts. For such a purpose, an enabler will be developed to scan all the backhaul connectivity options and select the most appropriate one based on PPDR QoS requirements. Such options might include a *Non-Terrestrial Networks (NTN)* as depicted in the yellow part of Figure 23 below, a pre-existing fiber infrastructure or another 5G/6G network. End-to-end (E2E) slice delivery will be provided, deployed over multiple private and public B5G/6G networks, and extended from the (remote) emergency site to the Central Control Centre.

Figure 23: P1c&d-combined Context view.

4.4 P2 Context view

4.4.1 Actors and roles

- *Control & Command Supervisor (C&CS)*:
  - Instructs FR about eSLED itinerary (via C&CS);
  - Instructs FR about scanning/sensing a particular Entity of Interest (geographic area) via *Control & Command (C&C)*;
  - Responsible for decision-making about rescue operation based on analysis of "Live" situations compiled by the `sensorInstrumentation µS` and transmitted to the C&CC and historical data stored by the C&CC.
- *First Responders (FR)*:
  - Perform instructions received from C&CS.

4.4.2 Digital subsystems

- *Control & Command Centre (C&CC)* application:
  - Instructs FR about eSLED intinerary (via C&CS);
  - Instructs FR about scanning/sensing a particular Entity of Interest (geographic area) via C&C.
- *Mobile access points (MAP):*
  - They consist of a mix of drones and air balloons/airships;
  - They relay/extend communication from gNBs towards eSLEDs. Could be 5G-to-5G or 5G-to-WIFI (use of onboard CPE). Can involve at the architectural level *Integrated Access and Backhaul (IAB)* technology and IAB-ready MAPs.

4.4.3 AMAZING-6G+5G standalone and NTN support

- Provides optimal computation to the `sensorInstrumentation µS`;
- Provides optimal placement to the *Mission Critical Services (MCx)*, either at the tactical bubble side e.g. 5G-in-a-box or at the NTN side (e.g. inside the satellite payload in order to minimize the *Round-Trip Time (RTT);*
- Provides optimal placement according to QoS constraints (edge vs. cloud);

- Provides highly reliable and redundant communication to the C&CC and FR/eSLED (eventually relayed / extended by vertical-owned MAPs) relying on both *Terrestrial Network (TN)* i.e. a "tactical" standalone bubble and NTN which provides support to MCx hosting (eventually) and internet access;
- Provides automatic seamless handover between the networks involved.

4.4.4 µServices

- `sensorInstrumentation` µS: computes a data-enriched 3D model out of Lidar/Radar data, heat camera and GPS positioning.

4.4.5 UML diagrams
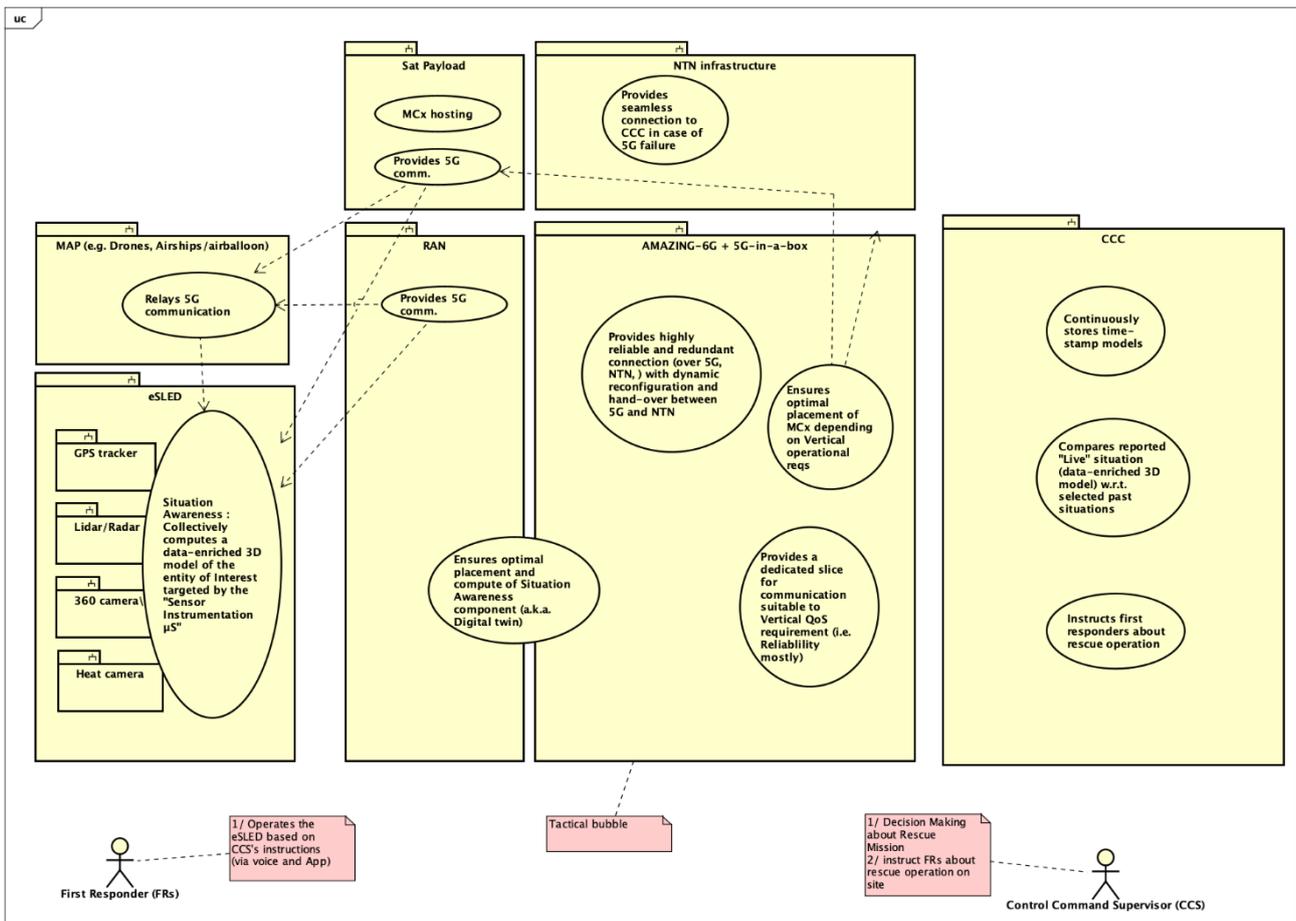
Figure 24: **P2 Context view.**

4.5 P3 Context view

The P3 Use Case differentiates from P2 (P4+NTN support) and P4 (the simplest version), in the sense it considers several tactical bubbles supported by their own 5G-in-a-box systems and own RAN serving the rescue mission actors only.

4.5.1 Actors and roles

The actors at run-time are limited to first responders, however the C&CC introduced in P2 is needed to configure the needed services (CaaS and AIaaS) before "deconnected" during Search & Rescue, leaving only (2 or more) technical bubbles linked through the supporting 5G mobile network.

4.5.2 Digital subsystems

- `MEC`: the MEC is preconfigured by the C&CC and AMAZING-5G framework to execute the needed software suites (MCx) and `Sensor Instrumentation µS;`
- `MAPs`: they consist of a mix of drones and air balloons/airships and relay/extend communication from gNBs towards `eSLEDs`. Could be 5G-to-5G or 5G-to-WIFI (use of onboard CPE). Can involve at the architectural level Integrated Access and Backhaul (IAB) technology and IAB-ready MAPs;
- `eSLED`: an eSLED is a sled equipped with various sensors used to analyze the scene (relying on `sensorInstrumentation µS`) and possibly detect victims;
- `5G-in-a-box`: a 5G private network with its own First Responder-dedicated RAN (one per tactical bubble).

4.5.3 AMAZING-6G+5G standalone

- Provides optimal computation to the `sensorInstrumentation µS;`
- Provides optimal placement according to QoS constraints (edge vs. cloud);
- Provides highly reliable and redundant communication to the C&CC for the sake of AIaaS and CaaS service configuration (remains disconnected at Search & Rescue time, leaving the cooperating tactical bubble fully autonomous);
- Provides automatic seamless handover between the networks involved.

4.5.4 µServices

- `sensorInstrumentation µS`: computes a data-enriched 3D model out of Lidar/Radar data, heat camera and GPS positioning.

4.5.5 UML diagrams
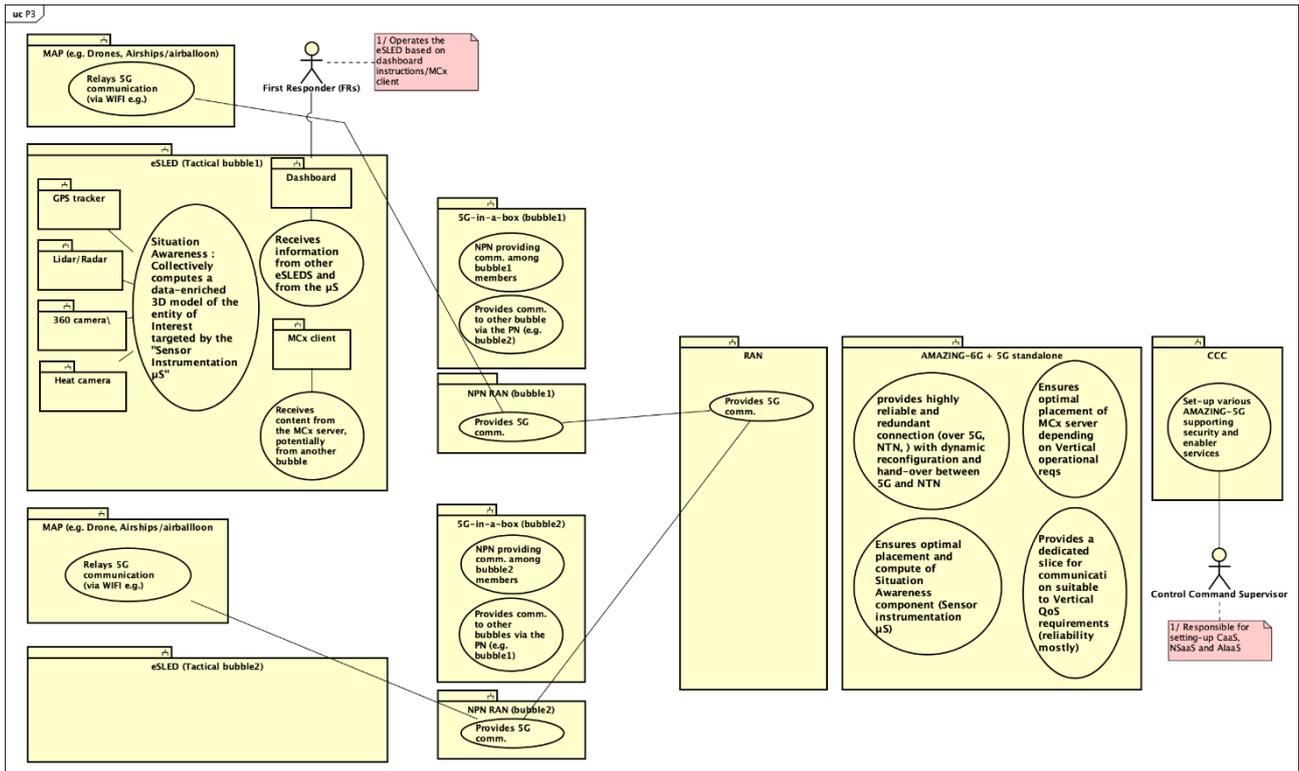
Figure 25: P3 Context view.

4.6 P4 Context view

We propose in this section the Context view that covers the P4 Use Case. As we can see in the next sections, it is very similar to the one covering the P2 Use Case.

4.6.1 Actors and roles

- *Control & Command Supervisor (C&CS)*:
  - Instructs FR about eSLED itinerary (via C&CS);
  - Instructs FR about scanning/sensing a particular Entity of Interest (geographic area) via C&C;
  - Responsible for decision-making relative to rescue operation based on analysis of "Live" situations compiled by the `sensorInstrumentation µS` and transmitted to the C&CC and historical data stored by the C&CC.
- *First Responders (FR)*:
  - Perform instructions received from C&CS.

4.6.2 Digital subsystems

- C&CC application:
  - Instructs FR about eSLED itinerary (via C&CS);
  - Instructs FR about scanning/sensing a particular Entity of Interest (geographic area) via C&C
- MAPs:
  - They consist of a mix of drones and air balloons/airships;
  - They relay/extend communication from gNBs towards eSLEDs. it could be 5G-to-5G or 5G-to-WIFI (use of onboard CPE). This can involve at the architectural-level IAB technology and IAB-ready MAPs.

- eSLED: a sled equipped with various sensors used to analyze the scene (relying on `sensorInstrumentation µS`) and possibly detect victims.

4.6.3 AMAZING-6G+5G standalone

- Provides optimal computation to the `sensorInstrumentation µS;`
- Provides optimal placement according to QoS constraints (edge vs. cloud);
- Provides highly reliable and redundant communication to the C&CC and FR/eSLED (eventually relayed / extended by Vertical-owned MAPs) relying on both TN and NTN;
- Provides seamless automatic handover between the involved networks.

4.6.4 µServices

- `sensorInstrumentation µS`: computes a data-enriched 3D model out of Lidar/Radar data, heat camera and GPS positioning.

4.6.5 UML diagrams
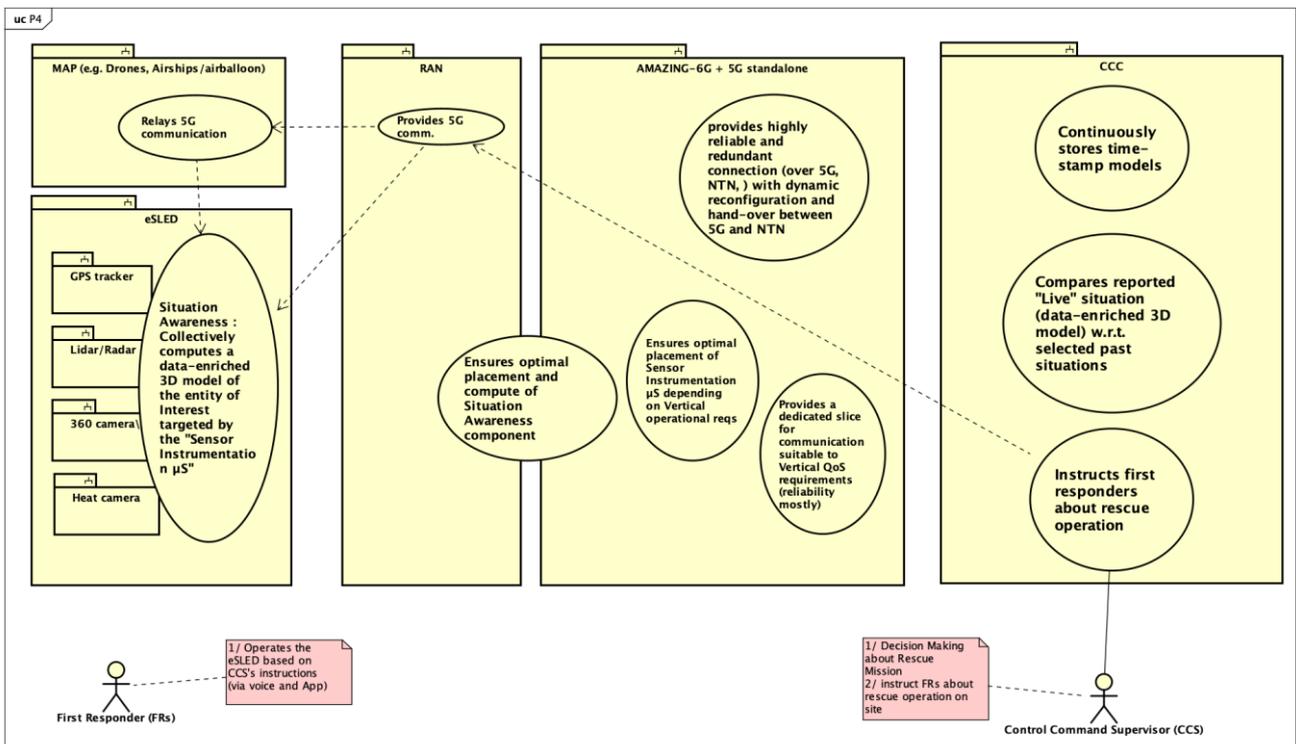
Figure 26: P4 Context view.

4.7 P5 Context view

4.7.1 Actors and roles

Three classes of end users are considered in this UC. They have different roles in the field and hence different QoS requirements in terms of network slicing. 3 different network slices will be deployed as shown in Figure 27 below:

- `HealthCare personnel:`
  - Medical teams use the system to communicate during emergencies, relying on secure and fast connections;
  - Use MCx services (e.g., MC-PTT, MC-Video, and MC-Data) to share real-time patient information and coordinate with other teams.

- `Safety personnel:`
    - Include public safety operators involved in emergency coordination and control;
    - Use MCx services to guide and support intervention teams with accurate, real-time information;
    - Monitor mission progress and maintain communication with other authorities.
- `Intervention troops:`
    - Include gendarmerie, firefighters, and military teams;
    - Use dedicated network slices for stable and secure communications during missions;
    - Rely on real-time updates, team coordination tools, and priority access for critical situations.

Each category of personnel connects to the local 5G system through their dedicated network subscription profile as depicted in the Figure 27.

4.7.2 Digital subsystems

This Use Case implements two digital sub-systems, in addition to those covering networking aspects:

- `Local Edge Compute Server`: this is an edge server deployed at the local tactical bubble side. It is responsible for executing a minimal set of necessary features in the event that the backhaul link to the main ORO Edge Server is lost. As such, it provides local personnel with communication service redundancy.
- `ORO Edge Server`: It is the main and most capable server for this use case. Services are executed there by default as long as the backhaul link is available.

4.7.3 AMAZING-6G+5G standalone (ORO side), NTN and local 5G bubble

The Use Case features a typical Disaster Relief networking deployment where redundancy and multiple access technologies are needed. Crucial and essential communication means (networking and supporting services) are required between personnel involved in the rescue mission (tactical bubble) but keeping communication available between the bubble and the outside world remains also very important (access to powerful computing, communication with other tactical bubbles if any, and communication with the overall rescue supervision team). Therefore, the following communication network, terrestrial and non-terestrial are considered:

- `5G-in-a-box`: this standalone down-scaled 5G system (including its local gNB) covers communication within the tactical bubble;
- `NTN platform` (StarLink^{TM}): this satellite system offers a backhaul link to the main ORO 5G standalone network (via Public Network) at a distance from the local bubble;
- `ORO 5G standalone` and its ORO RAN: deployed far from the operation theatre, they enable the tactical bubble to communicate with the outside world, as explained above.

Needed AMAZING-6G FCs are deployed at the ORO Edge Server and Local Edge Compute Server in order to provide optimized resource allocation and service execution. It could provide dynamic adaption of the network subscription profiles allocated to each of the three categories of personnel, offering superior priority to specific users by changing their QoS and *5G QoS Identifier (5QI)* parameters.

4.7.4 µServices

The following services are considered for the support of the rescue personnel activities:

- Full MCx suite consisting of:
    - *Push-to-Talk (`PTT`)*;
    - *MC-video (`Video`)*;
    - *MC-data (`Data`)*.
- Multicast Broadcast Service (`MBS`) – *optional;*

- `Network Control`: it is responsible to activate the MCx service via the cloud or locally deployed edge using an orchestration framework (e.g. Kubernetes pods migration).

Those services are deployed and executed at the ORO Edge Server side by default. The same set of services is also deployed at the `Local Edge Compute Server` for redundancy, in case the backhaul link is lost (as already mentioned earlier). Detecting the loss of communication with StarLink™ and therefore deciding to switch to local execution of MCx and MBS are the responsibility of the local tactical bubble intelligence.

4.7.5 UML diagrams
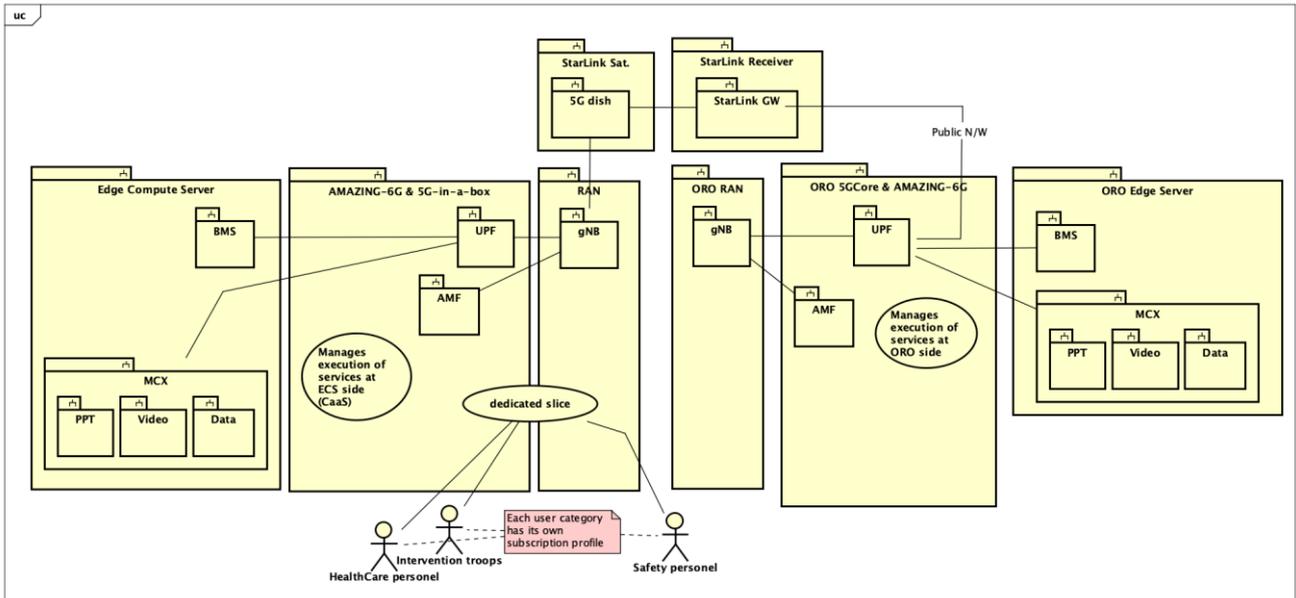
Figure 27: P5 Context view

4.8 E1 Context view

The following Figure 28 provides a conceptual model that describes relations between entities involved in the E1 Use Case. It was used to devise the E1 Context view Figure 29.
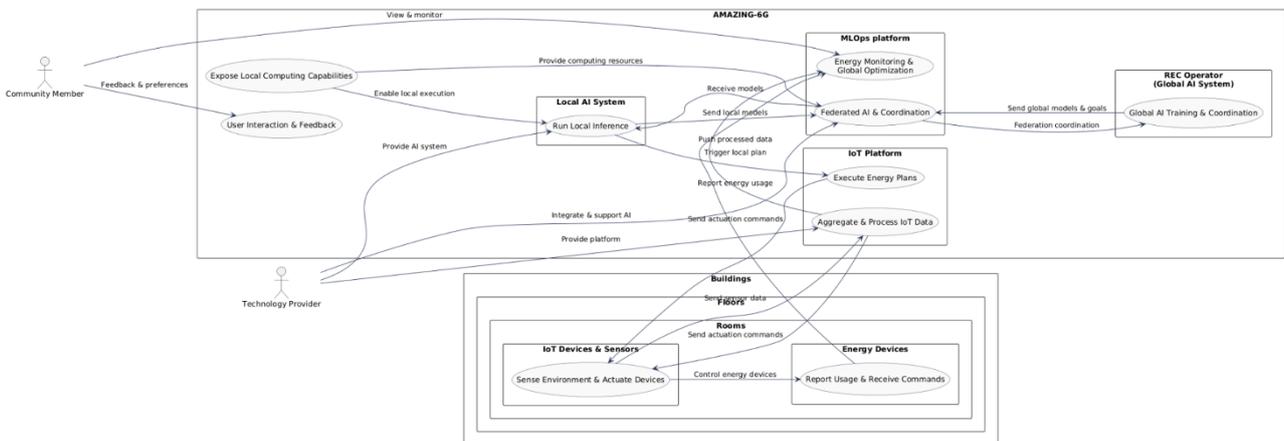
Figure 28: E1 conceptual model.

4.8.1 Actors and roles

- *"Prosumer" members of the REC:*
    - "Abstract" actors (households, smart building, smart campus, smart office, etc.) that produce (e.g., via solar PV or wind turbines) and consume energy;
    - They adopt 6G-enabled IoT platforms to managed smart meters, IoT sensors and actuators, appliances, etc., for real-time monitoring and control of energy consumption and production;
    - As option, they may:
        - Integrate batteries for energy storage;
        - Support *Electric Vehicles (EV)*;
        - Participate in peer-to-peer, intra-REC, energy trading;
        - Interact with the DSO and contribute to the local grid stability.
- *End-users, like citizens, smart buildings' inhabitants, etc. :*
    - They are the final consumers that benefit from the advantages offered by the smart energy management services at the buildings and at the REC level, in terms of environmental sustainability, reduced energy costs, level of comfort perceived in the buildings, and quality of life in general;
    - They interact with the system, via mobile applications or dedicate user interfaces, to monitor their energy consumption/generation, to receive notifications or suggestions on energy-efficient actions or building settings, to actuate and/or confirm these recommendations, as well as to generate feedbacks towards the system;
    - As option, they can participate in dynamic pricing or behavior-based incentives.

4.8.2 Digital subsystems

- *IoT Platform:* middleware platform at the edge that integrates device data and acts on AI decisions:
    - Aggregates and processes sensor and device data;
    - Executes energy plans based on global or local AI outputs;
    - Sends control signals to IoT Devices & Energy Devices.
- *Energy Devices (Producers/Consumers):* devices such as Heating, Ventilation, and Air Conditioning (HVAC), EV chargers, solar panels, and appliances that consume or produce energy:
    - Operate based on optimized control commands;
    - Execute control commands from AI-driven plans;
    - Participate in energy storage/consumption strategies.
- *Local AI System:* edge intelligent system deployed at building level:
    - Executes AI inference locally using distributed models;
    - Applies energy optimization decisions;
    - Participates in federated learning by sending model updates and receiving global models.
- *IoT Platform:* middleware platform, at the edge that integrates device data and acts on AI decisions:
    - Aggregates and processes sensor and device data;
    - Executes energy plans based on global or local AI outputs;
    - Sends control signals to IoT Devices & Energy Devices.
- *IoT Devices & Sensors:* sensors embedded in rooms and buildings (e.g., temperature, air quality):
    - Collect environmental and usage data;
    - Actuate devices based on control signals from optimization logic;
    - Send real-time metrics to the IoT platform for aggregation and preprocessing.
- *REC Operator (Global AI System):* cloud-based external intelligence orchestrator for the REC:

> o Trains and distributes AI/ML models across the community.
- *Technology Provider:* responsible for supplying and integrating the IoT platforms and AI components used in the REC.

4.8.3 AMAZING-6G+5G standalone

A standalone 5G system (Core+RAN) and a set of technological enablers installed across the infrastructure:

- Perform core AI/ML functions: monitoring, prediction, optimization and explainability;
- Coordinate EV charging, demand-response, energy trading, and feedback loops;
- Work collaboratively with both local systems and external operators;
- Expose computing capabilities at the infrastructure level to enable on-site execution of MLOps tasks such as AI training and inference.

In the following Figure 29 only the high-level features are mentioned (distributed among 5G RAN, 5G Core and AMAZING-6G).

4.8.4 µServices/services

- Data Aggregators;
- AI Models;
- Energy plan (not shown in the figure as µS).

4.8.5 UML diagrams
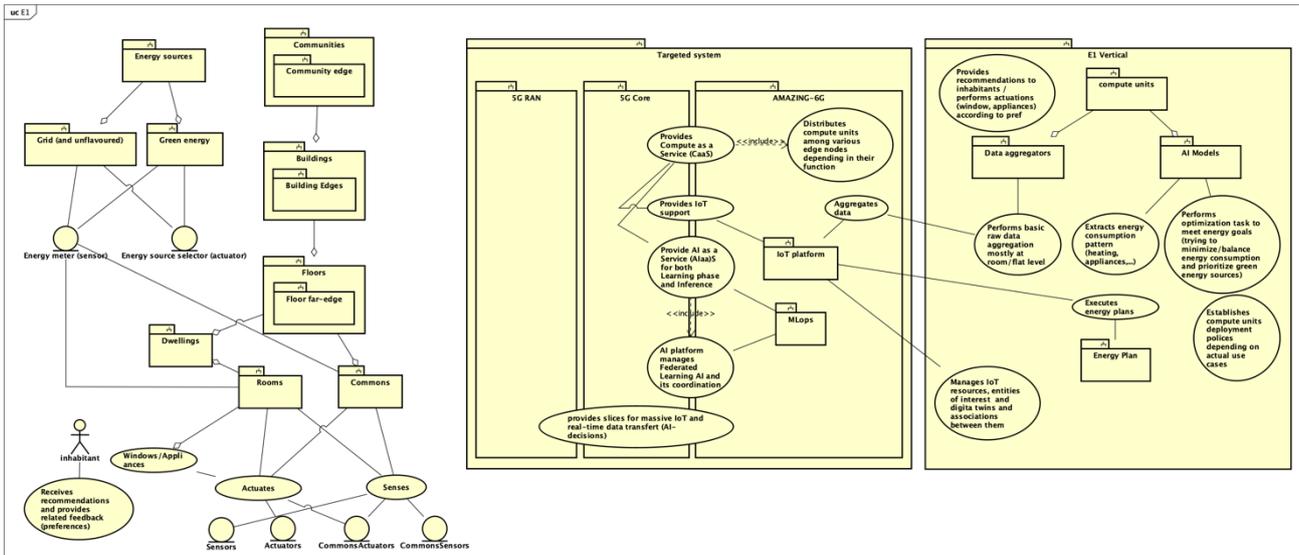
Figure 29: E1 Context view.

4.9 E2 Context view

4.9.1 Actors and roles

- `3D model analyst:`
  - o Can access wind turbine digital twin (constructed 3D model of a blade based on imagery) as part of a time series database (so that evolution of a particular blade structure can be assessed);
  - o Accesses blade 3D model and seeks structural anomalies;
  - o Must inform maintenance crew accordingly.

4.9.2 Digital subsystems

- `Drone`: it is equipped with:
  - `Ultrasound sensor`: images of the blade are taken, one by one until the entirety of the blade has been addressed;
  - `Drone actuation`: it allows to navigate the drone towards the blade, including landing;
  - `Positioning module`: it is used to determine the exact position of the drone on the blade;
  - `B5G/6G modem`: it is used to connect to the B5G/6G network and to transmit the blade ultrasound snapshots to the `Digital Twin μS`;
  - Scanning module: it drives the drone-attached sensors.
- `On-Shore Control Support (OSCS)` - it supports the following capabilities:
  - `Operation management`: responsible for setting up CaaS and security-related tasks;
  - `Data Storage`:
    - Collects 3D models of a wind turbine blades from the `Digital Twin μS` and stores them into a time series database, allowing to review the evolution of the wind turbine blade structure as historical data;
    - Provides the `Imagery Analyst` with access to database record.
- `Operation management`: manages the operation set-up with the different features of the platform (registration, NSaaS, CaaS,...) and data storage management.

4.9.3 AMAZING-6G+5G standalone

The `Targeted system`

- Provides optimal computation to the `Digital Twin μS` (especially CPU/GPU power);
- Provides optimal placement according to QoS constraints (edge vs. cloud);
- Provides highly reliable low latency/high throughput 5G communication between drone and `On-shore Control System`. A minimum throughput of 30Mbps is needed for high resolution images. For ultrasound data the throughput requirement will be significantly higher and will be determined later. The target latency shall be lower than 100ms.

4.9.4 μServices

- `Digital Twin μS`: build up a 3D models out of wind turbine blades imagery (ultrasound) and transmit them to the OSCS for storage.

4.9.5 UML diagrams
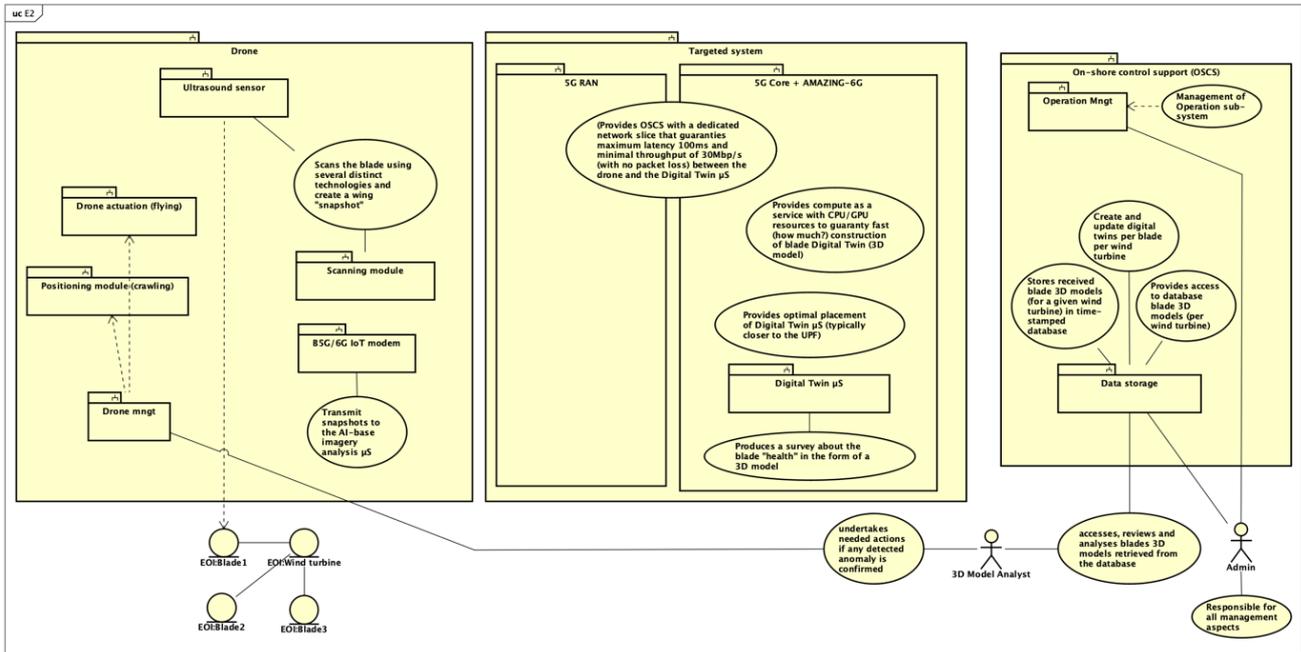
Figure 30: E2 Context view.

4.10 E3 Context view

4.10.1 Actors and roles

- `Solar Inverter`: measures the energy delivered by the solar panels and reports to the edge device;
- `Energy Storage`: constantly monitors the charging state of the battery and reports to the edge device;
- `Grid Sub-system`: connected to the solar plant;
- `NR RedCap modem`: connected to the Edge device and ORO's 5G SA network to transmit relevant data to the cloud computing software components.

4.10.2 Digital subsystems

- `Industrial Edge Gateway`: collects all the telemetry data from the solar inverter and energy storage units, does local data analytics and forwards the insights via the 5G SA network to the cloud-based software components;
- `ORO 5G Lab`: ORO's research testbed featuring a private 5G SA Advanced network featuring commercial equipment and being connected to a powerful edge-cloud computing facility that will host SIMTEL's software components; the network will be extended to cover the solar plants that will be in the scope of the project.

4.10.3 AMAZING-6G+5G standalone

Two slices are pre-configured in order to:

1. Convey control command issued by the Energy Management System and fine-tuning request issued by the energy grid authority (URLLC);
2. Convey telemetrics bulk data collected at the Field Layer side used by the prediction logic at the ORO L5G Lab (eMBB).

Besides communication aspects, the following capabilities of AMAZING-6G will be used:

- CaaS (Kubernetes based) for orchestrating the E3 services within the ORO 5G Lab Edge Computing facility;
- AI life-cycle support to CAPG's AI/ML models for predicting network conditions (RAN-metrics based) and take actions in the Core (network subscription profile updates – better QoS / 5QI if needed);
- AI life-cycle support to NXW's AI/ML models for energy predictions (performance comparison with the internally developed ones by SIMTEL/CSS).

4.10.4 µServices

- `Pre-processing`: data parsing, data normalization;
- `Energy Management System`: logic to control actuators in the solar system to optimize energy delivery parameters;
- `Prediction logic`: AI/ML algorithms to predict the solar plant energy production capacity and take management decisions based on the grid availability and real-time energy pricing.

4.10.5 UML diagrams
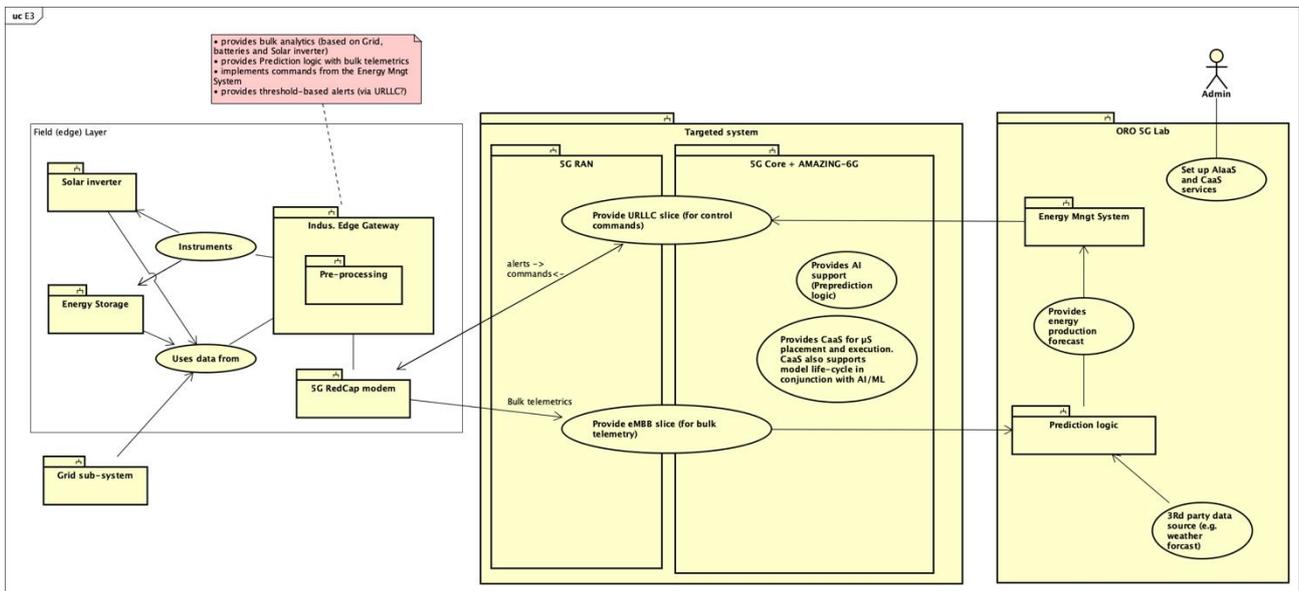
Figure 31: E3 Context view.

4.11 T1 Context view

4.11.1 Actors and roles

- `Technical Operator`: their role is to interact with the AMAZING-6G system in order to set up a vertical account, retrieve credentials and set up the various needed services such as CaaS, AIaaS and NSaaS;
- `Pedestrians`: carry UEs (see below) which 1/ provide pedestrians' GNSS coordinates to the RSUs and 2/alert them about any imminent incident;
- `Vehicles`: they onboard so-called *On-Board Units (OBU)* systems (see below). OBUs are used in similar ways than the above 1/ position transmission and 2/ imminent risk notification;
- `Admin`: technical staff responsible for operation setup (w.r.t AMAZING-6G system).

4.11.2 Digital subsystems

- `User Equipment`: smart phones are used to track down pedestrians' locations and to convey important/critical safety-related information to their users;
- `On-Board Units`: they are used to track down vehicles' position alongside other parameters. They are also used to communicate with drivers, the same way UEs are used;
- `Road Side Units`: they rely on solar panels and provide some computing capabilities too, meaning that some computation units can be offloaded and executed in such units. They are also equipped with a 5G model and sensors such as LIDAR and cameras which can be used to assess the current situation at some road segments or cross-roads. Their objectives are:
  - To track down pedestrians and vehicles;
  - To perform some computation tasks;
  - To monitor energy levels;
  - To communicate with the Control Command.
- `T1 Control Command:`
  - It is responsible for the set-up phase that includes in particular:
    - The registration to the `Targeted System` and provision of security credentials;
    - Initiating the set-up of a dedicated slice, either through the communication of various QoS requirements (via a dedicated web front-end) or by accessing directly the relevant network exposure API (thought it would require a highly trained member of staff);
    - Provisioning CaaS and providing deployment policies;
    - Provisioning a dedicated network slice (NSaaS);
    - Claiming AI/ML support (AIaaS).
  - It can also perform at the edge any computation task that the OBU can't maintain any longer, mainly due to lack of energy resource.

4.11.3 AMAZING-6G+5G standalone

- The `Targeted System`:
  - Provides the Vertical with a dedicated slice that fits QoS requirements;
  - Also provides the vertical with CaaS for the execution of the three µSs at the best possible location depending on energy level available at the RSUs. If not executed at the RSU side, those three µSs must be executed in such a way the latency is minimized, e.g. in the 5G cloud as close as possible from the UPF, or alternatively at the Vertical side.

4.11.4 µServices

- `Junction Safety µS`: based on the junction Digital Twins assesses potential risks for either pedestrians or vehicles and notifies them whenever any risk is detected;
- `Junction DT µS`: maintains in real time a junction digital twin, based on Pedestrian- and vehicle-related data collected at the `RSU` side or from the `OBU`;
- `Notification broker µS`: notifies `pedestrians` (through their UE) and `vehicle` drivers (through their OBU) about imminent danger. The broker is notified by the `Junction Safety µS`.

The three µSs should always be placed at the same location in order to minimize latency.

4.11.5 UML diagrams

The following Figure 32 provides an illustration of each Vertical sub-system roles (cloud and edge), in addition to the features which are expected from the targeted system.
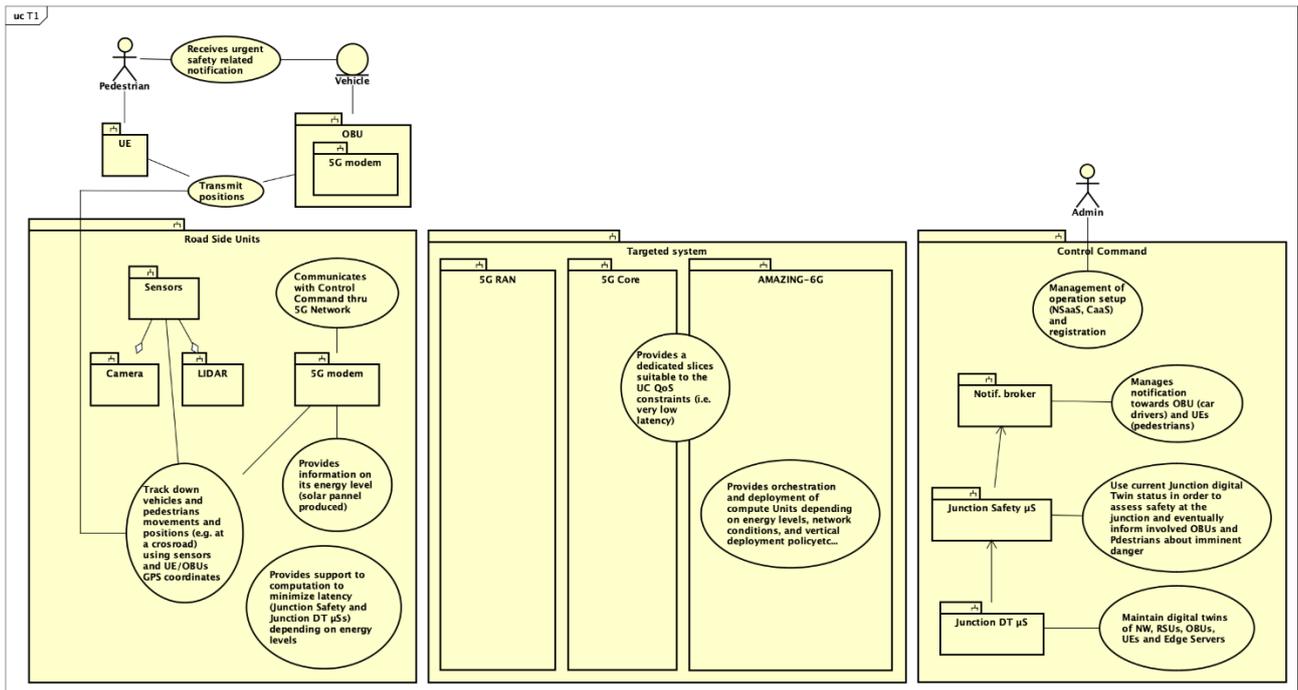
Figure 32: T1 Context view.

4.12 T2 Context view

4.12.1 Actors and roles

- `Technical Operator:` their role is to interact with the AMAZING-6G system in order to setup a vertical account, retrieve credentials and setup the various needed services such as CaaS, AIaaS and NSaaS;
- `Pedestrians`: they use an APP in order to request assistance. There current locations are also communicated to the T2 Control Command;
- `Tele-operator:` is located at the `T2 Control Command` side, (s)he can tele-operate the UGV in case of an emergency event (e.g. if the UGV should perform some specific movements to better understand the situation).

4.12.2 Digital subsystems

- `UE`: provides a city safety App which is used to 1/ request assistance or report situations and 2/ communicate the pedestrian's current location;
- `UGV`: is a robot that embeds an `OBU`, which is powered through battery and is equipped with a `GNSS receiver;`
- `OBU`: is a sub-system of the `UGV` that runs a 5G modem, monitors its own energy levels, embeds various sensors used to analyze a scene and is able to execute a µService responsible for analyzing the level of safety of an urban scene and identify risks. The execution of the µS can be transferred to the `T2 Control Command` (or AMAZING-6G cloud /5G Core) for the sake of saving energy. Finally, the `OBU` also provides an interface to the UGV navigation system which allows for tele-operation from the `T2 Control Command;`
- `GNSS receiver`: the coordinates of the `UGV` are used for tele-operation purpose;

- `Tele-operation`: is a module located inside the `OBU` that is communicating with the `Robot Control Command` located at the T2 `Control Command` side and operated by the `Tele-Operator`;
- `Navigation Module`: is a module part of the robot *Operating System (OS)* that allows for remote navigation;
- `Robot Control Command`: is the application by which the `Tele-operator` can remotely navigates the `UGV`.

4.12.3 AMAZING-6G+5G standalone

The `Targeted System` is responsible for:

- Providing set-up and access to the AMAZING-6G features (account setting/access to dedicated portal) such as AIaaS, NSaaS and CaaS);
- Orchestrating the execution of the µServices between the AGV and either the Vertical side or AMAZING-6G / 5G Core side;
- Providing reliable 5G communication between the `T2 Control Command` and `UGV` according to T2 functional and non-functional requirements;
- Supporting the Vertical for the execution of the µS with appropriate and dedicated amount of GPU power (AIaaS and CaaS combined).

4.12.4 µServices

- `Urban Safety µS`: provides an AI/ML-powered scene analysis upon pedestrian request (via her App). Depending on UGV energy level, this µS can be activated at the UGV side or in the cloud (`T2 Control Command` side or `Targeted System` side).

4.12.5 UML diagrams
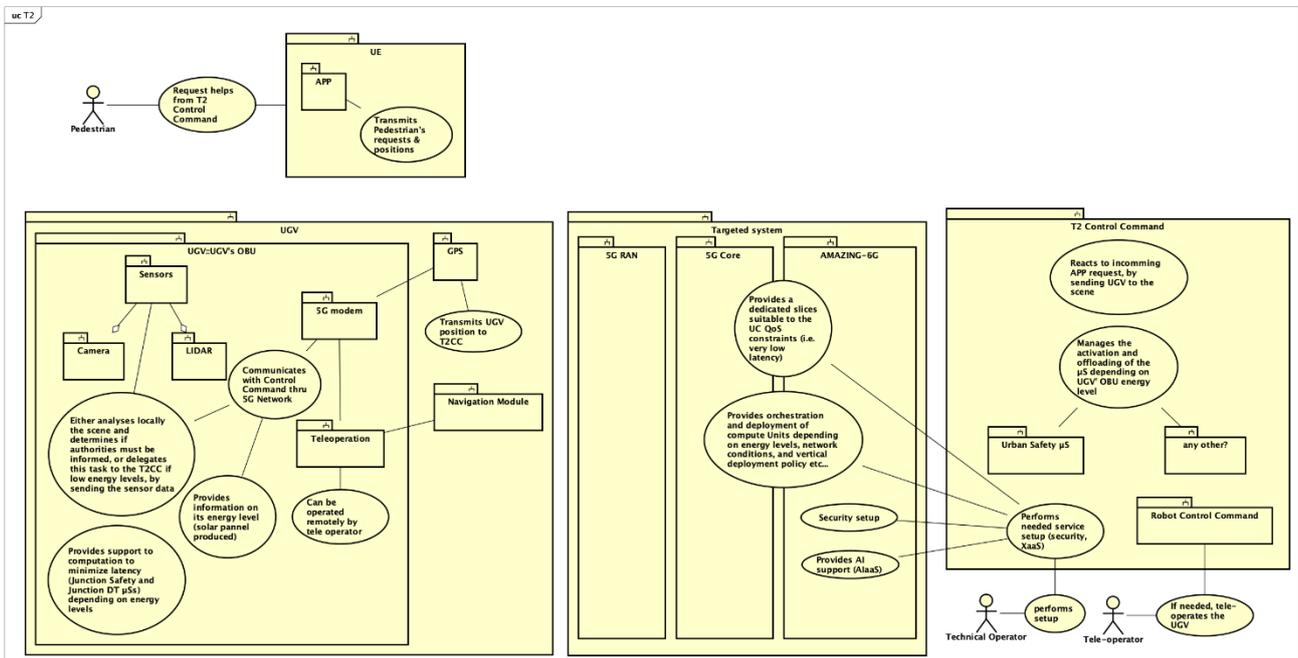
Figure 33: **T2 Context view.**

4.13 T3 Context view

The T3 Context view (see Figure 34) considers several key actors and components across the train, trackside, and network domains. The Train Driver interacts with the Train Dashboard, which is responsible for displaying alerts triggered either by the onboard ISAC Scanning Module or by messages from a preceding train. The ISAC Scanning Module, together with a Camera, collects data and forwards it via a 5G modem to the ISAC AI microservice (µS) for processing.
The ISAC AI µS, performs real-time AI-powered obstacle detection by fusing onboard sensor data with data provided by the Track Side Units. These units analyse and pre-process input from Track Side Cables and send their findings to the µS. The pre-processing allows for protection against distortions that may occur during the transmission of data and for reduced training time at the µS. Upon the detection of an obstacle, notifications are sent to the involved trains, allowing drivers to respond in real-time. Meanwhile, the Vertical Technician oversees configuration and service provisioning through the T3 Vertical subsystem, enabling seamless integration with the network via CaaS, AIaaS, and NSaaS capabilities.

4.13.1 Actors and roles

- `Train Driver`: beside being responsible for the whole normal train operation, applies all needed actions w.r.t. incoming notifications from the dashboard. Those notifications can result from the own inboard ISAC scanning module or being transmitted from the ahead train;
- `Vertical Technician`: is responsible for the interactions with AMAZING-6G such as account setting, service setting, CaaS and AIaaS services provision.

4.13.2 Digital subsystems

- `T3 Vertical`: this is the Vertical-owned sub-system primarily designed for interacting with the `Targeted System`. The actions undertaken by the `Vertical Technician` are performed from that sub-system;
- `Train`: the train sub-system provides a dashboard to the `Train Driver` and supports the operation of the `ISAC Scanning module`;
- `Train Dashboard`: the `Train Dashboard` is used to communicated notifications to the `Train Driver`. Such notification can be issued by the train ISAC system when an obstacle is detected or be issues by the ahead train when it detected a problem and had to stop or slow down. It is also responsible for communication notification to following train whenever the `ISAC AI µS` detects obstacle ahead;
- `ISAC scanning module`: uses NR for the purpose of detecting obstacles on the railway track. The data collected is sent to the `ISAC AI µS` for analysis (alongside images);
- `Camera`: captures images/video and send them to the `ISAC AI µS` for fusion and analysis (alongside ISAC data);
- `5G modem`: ensures the transmission of train data to the `ISAC AI µS` and then the transmission of its result back to the train;
- `Track side cables`: they are additional pieces of equipment installed alongside the railway tracks which are able to detect obstacles as well. The analysis of the received signals is performed within the `Track Side Units`;
- `Track side Units`: they are disseminated along the track and are responsible for performing signal processing based on signals received from the `Track Side Cables` and sending data to the `ISAC AI µS` for data fusion with the ISAC data transmitted by the `ISAC Scanning Module`.

4.13.3 AMAZING-6G+5G standalone

The `Targeted System` is responsible for the following:

- To provide ultra-low latency communication between the `5G modem` and the `ISAC AI µS`;
- To perform placement of the `ISAC AI µS` (CaaS/AIaaS) within the `Targeted System` in such a way the round-trip latency is minimalized;
- To provide the necessary GPU power that enable ultra-fast treatment of the sensor fusion data;
- The setup of dedicated network slice (NSaaS) that fits the latency/throughput vertical requirements.

4.13.4 µServices

- `ISAC AI µS`: this service relies on AI-powered data fusion and analysis (images, data from the `ISAC scanning module`) in order to identify incoming obstacles on the railway track. As this task is computation-intensive and requesting a lot of GPU support, it becomes paramount to rely on the `Targeted System` compute capabilities for its execution. The placement of the `ISAC AI µS` at the `Targeted System` should minimize as much as possible the resulting delay in receiving its result at the train side (ultra-short round-trip).

4.13.5 UML diagram
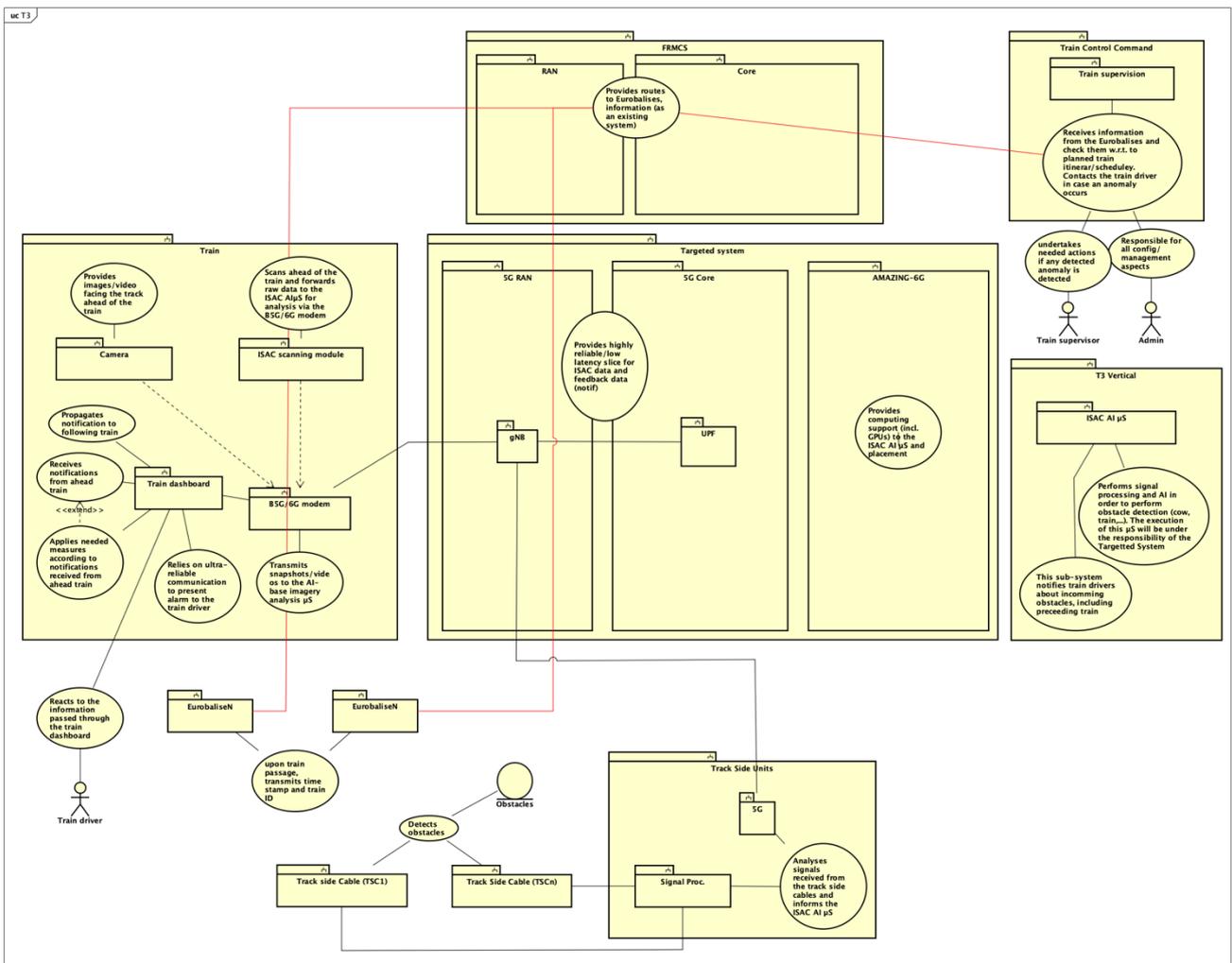
Figure 34: T3 Context view.

4.14 T4 Context view

The primary entities in this Use Case are the *Autonomous Vehicle (AV)* and the remote teleoperator. The AV is equipped with advanced perception, planning, control, and communication modules. The perception subsystem leverages multimodal sensor fusion (e.g., LiDAR, radar, cameras, and V2X inputs) to detect and classify safety-critical scenarios, including adverse weather conditions, infrastructure anomalies (e.g., poorly mapped or degraded roads), and complex traffic environments beyond the operational design domain of the autonomy stack. Upon detecting such conditions, the decision logic within the AV triggers a safe fallback procedure, notifying the control module to initiate a seamless teleoperation handover.

Simultaneously, the AV streams its situational awareness data to an edge computing node, including high-resolution camera feeds, LiDAR point clouds, and real-time vehicle state parameters (e.g., speed, heading, sensor health, and localization confidence). This edge node aggregates and preprocesses the data before securely relaying it to the teleoperation center's dashboard, ensuring low-latency, high-reliability visualization and control feedback for the remote operator.

The underlying B5G/6G network infrastructure dynamically provisions the required resources to guarantee real-time responsiveness. This includes adaptive uplink and downlink bandwidth allocation and the establishment of dedicated network slices to isolate mission-critical teleoperation control signals from high-bandwidth sensor and video streams. Additionally, AI-driven network orchestration algorithms operating at the edge and core domains continuously analyze the AV's telemetry and network conditions to allocate resources proactively, prioritize teleoperation traffic, and reconfigure existing communication flows to maintain *Ultra-Reliable Low-Latency Communication (URLLC)* performance.

This integrated approach enables a robust backup teleoperation mechanism that complements autonomous driving, ensuring safe vehicle operation even in challenging or unforeseen conditions.

The following Figure 35 provides a conceptual diagram meant to help understanding the UML diagram in Figure 36.
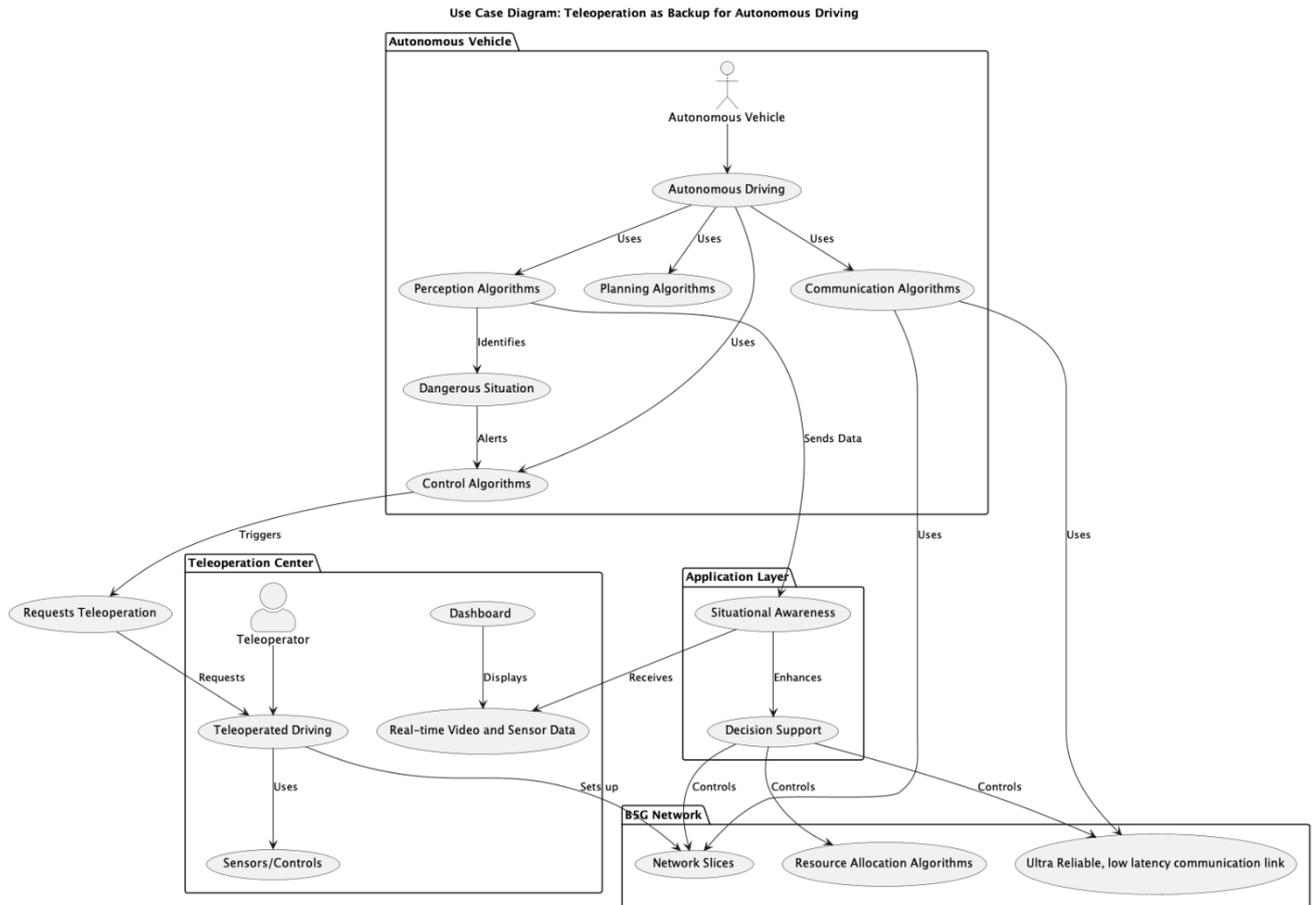
Figure 35: T4 conceptual diagram.

4.14.1 Actors and roles

- `Autonomous vehicle`: a vehicle equipped with an OBU that runs the services described below and a set of sensors enabling autonomous driving;
- `Teleoperator`: an operator who takes over the vehicle driving upon explicit request from the perception algorithm;

4.14.2 Digital subsystems

- `Teleoperation Center`:
    - `Dashboard`: the device by which the operator receives instructions and sensor data (including video feed);
    - `Teleoperation Console`: the actuation part that allows the driving teleoperation.
- `OBU`: located in the car it includes the `driving module` that operates the car either according to the outputs of the `Perception Algorithm` and `Planning Module`. In the Figure 36 below it also includes for the sake of simplicity, the various sensors, even though they are just devices connected to the `OBU`.

4.14.3 AMAZING-6G+5G standalone

This Use Case -like for T3- relies on a double 5G communication channel. The 5G located in Chemnitz features a dedicated slice providing:

- High throughput: requested for high quality imaging;
- Low latency: for obvious security reasons.

4.14.4 µServices/Services

Autonomous driving is composed of a few cooperating algorithms:
- A `Perception Algorithm` which relies on sensor to provide situation awareness;
- A `Planning Algorithm` that is responsible for the driving itself.

Additionally, a `Communication Module` is used to communicate with the `Teleoperation Center`.

The crucial part of this UC consists of the `Perception Algorithm` which also allows 1/ to identify such situations where autonomous driving put the passengers' life at risk and 2/ to subsequently to request immediate handover to the `Teleoperator`. When this algorithm decides that the situation becomes suitable to autonomous driving again, it reclaims control of the driving to the `Teleoperation Center`. The decision to request teleoperation and to reclaim autonomous driving is always the responsibility of the `Perception Algorithm`. (Remark: there are counterexamples to that rule in case of accident or fault).

4.14.5 UML diagrams

This UML Context view Figure 36 illustrates the tele-operation as a backup to autonomous driving Use Case (T4). At the center is the AV, equipped with perception, planning, and control modules. The AV interacts with several external actors: the `Teleoperator`, who remotely supervises and controls the `Autonomous vehicle`; the Edge Computing Node, which aggregates and preprocesses sensor and video data; the `Teleoperation Center`, which provides a real-time visualization and command interface; and the B5G/6G Network Orchestrator, which dynamically provisions dedicated network slices to meet URLLC requirements. The Use Case proposes two types of mobile networks, one owned by a public operator, which can provide an alternative, highly reliable, and high-throughput communication between the teleoperation center and the AV. The second one is a private mobile network, managed by TUC.

The autonomous vehicle continuously exchanges telemetry and perception data with an edge computing node, which forwards processed streams to the `Teleoperation Center`. The `Teleoperator` remotely supervises and controls the vehicle through a low-latency, network-sliced communication link orchestrated by the network. External environmental factors act as triggers for initiating teleoperation. This Use Case requires high-bandwidth uplinks for video streaming, strict URLLC for teleoperation commands, and seamless network orchestration across edge and cloud domains. This Context view highlights the main actors and system boundaries without detailing the temporal sequence of events. This Context view highlights the main actors and system boundaries without detailing the temporal sequence of events.
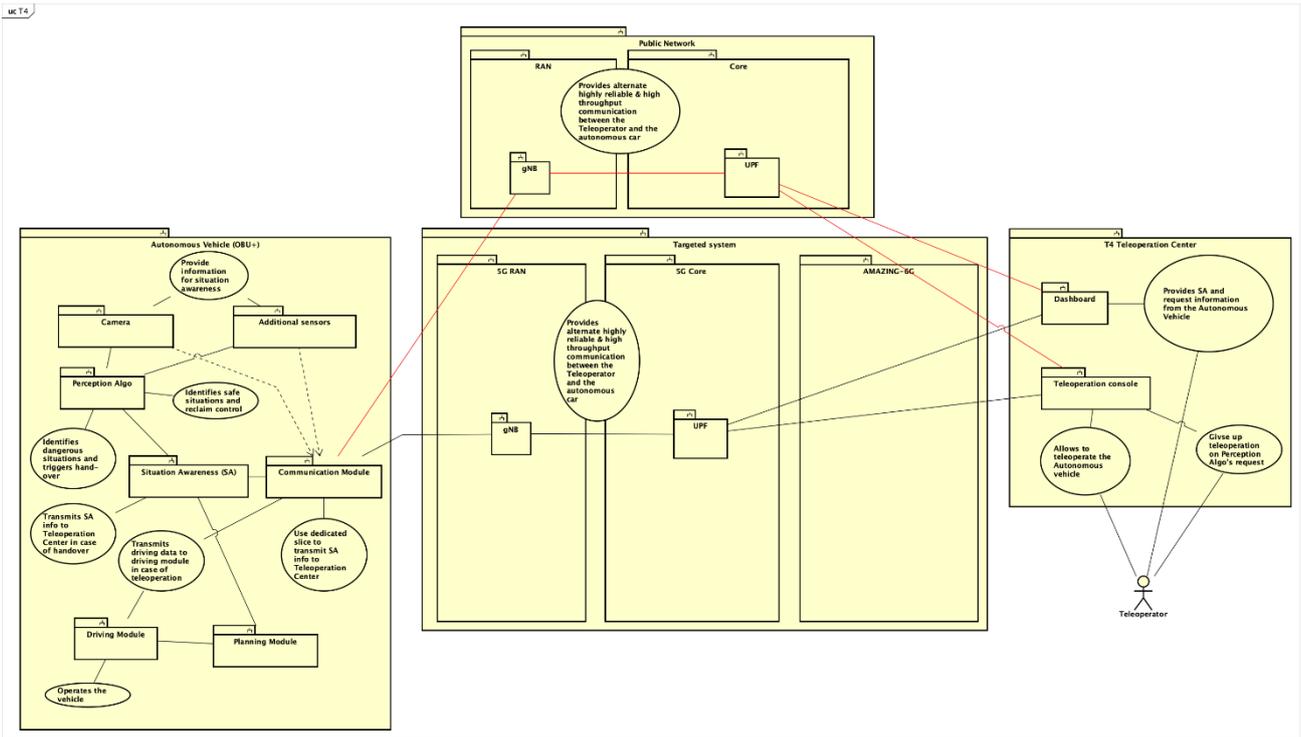
Figure 36: T4 Context view.

4.15 T5 Context view

4.15.1 Actors and roles

The expected actors that will interact with the proposed solution and their role are described below:

- `STS operators`: responsible for handling the equipment to load/unload containers to vessel or yard;
- `STS cranes`: are cranes used to unload container from the ship to the shore. During standard operation they are operated by STS crane operators;
- `Straddle Carrier`: they are responsible for moving containers at the shore towards the container yard and from the yard to the trucks. During standard operation they are operated by Straddle Carrier Operators;
- `Trucks`: they are used to remove the containers from the port and to transport them towards their final destination. At the port entrance they are allocated a loading bay number which then is used as a unique ID within the loading & routing plan;
- `Containers`: they are containers manipulated by the `STS cranes` and `Straddle Carriers`. They are identified by their location and row number (both at shore and yard).

4.15.2 Digital subsystems

- `Port Authority Edge Server`:
  - `AnyLogic Simulation`: is a simulation model that replicates real end-to-end process within the Port of Thessaloniki to serve as a playground for testing planning and operational strategies. A 3rd party extension will be provided in edge node of the port to allow manually design and extraction on-demand action-agents and strategic decisions impact measured via predefined KPIs;
  - `Port Management System`: software solutions that streamline and automate various operations within a port. Coordinates activities like vessel traffic and berth scheduling,

> cargo handling, resource allocation, and financial management to enhance efficiency and productivity;
>
> o `STS-TeleOperation`: is the application that allows a `STS operators` to operate an `STS Crane` remotely based on real-time video feed;
>
> o *`Terminal Operating System (TOS)`*: oversees end-to-end container terminal functions, such as berth & ship planning, yard management, equipment dispatch, billing & charges, etc. It transmits work orders to the container terminal equipment;
>
> o `Fleet Management System`: allocates equipment and surveils their status (values from PLC and subsystems).

4.15.3 AMAZING-6G+5G standalone

The following features are used for the execution of this Use Case:

- Dedicated slice(s) that matches the T5 requirements in term of latency and throughput;
- AI/ML support for both learning and inference phase;
- CaaS support for optimal and guaranteed optimal execution of the various systems.

4.15.4 µServices

The T5 UC will use a Anylogic Simulation Engine as the main µService as well as supporting planning and optimization models that will support the functionalities of management challenges of Thessaloniki Port. The services planned at this stage are:

- `AnyLogic Simulator µS`: the Simulation Digital Twin µService, which serves as the backbone of the Port's digital model, enabling the testing of strategic process changes and operational/planning algorithm configurations. This service provides a robust environment for scenario analysis, enabling stakeholders to assess various strategic and operational decisions without disrupting real-world operations;
- `AI-based Port Operation µS`: it aims to enhance container loading and unloading efficiency by optimizing the movement paths and scheduling of straddle carriers within the yard. This optimization will lead to significant improvements in operational flow, reduced congestion, better utilization of resources, and overall increased productivity of port activities.

4.15.5 UML diagrams
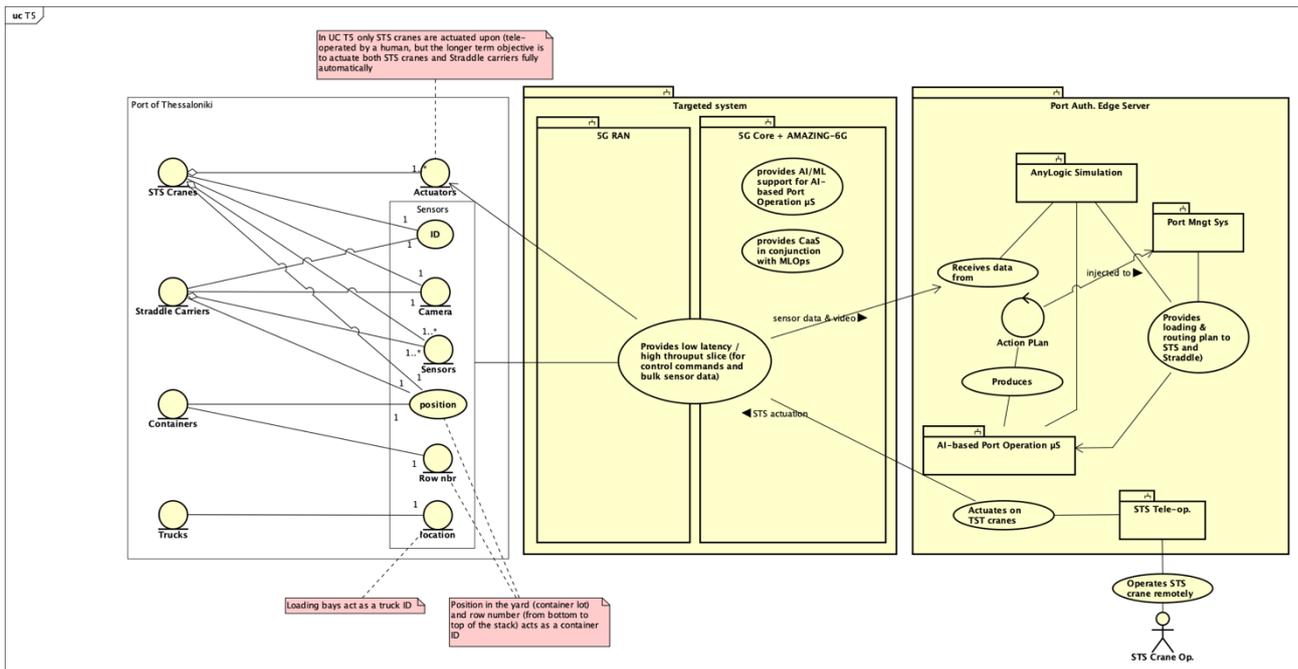
Figure 37: T5 Context view.

5   Functional view

The purpose of the Functional view is to organize per topic the functionalities identified during requirement analysis and place them into various vertical and horizontal layers. Intuitively functionalities put in vertical pillars interact with most (if not all) horizontal layers, while functionalities from horizontal layer N often relies on functionalities of horizontal layer(s) <N. In practice the rule is not that simple, as can be seen in Figure 39 below.

Having clustered functionalities into "boxes" (a.k.a. *Functional Groups (FG)*) and shortly described them (Section 5.1), another very important purpose of the Functional view is to describe in a fair level of detail, all functionalities, namely *Functional Components (FC)*, belonging to each FG (in Section 5.2).

Finally, and in order to challenge the architecture and verify its soundness and completeness according to 1/ the UC requirements and 2/ the expected usage of those FCs by the UC in WP 4,5,and 6, a third part of Section 5 elucidates some typical usage patterns, called *System Use-Cases (SUC) (see Section 5.3)*

5.1   Functional model
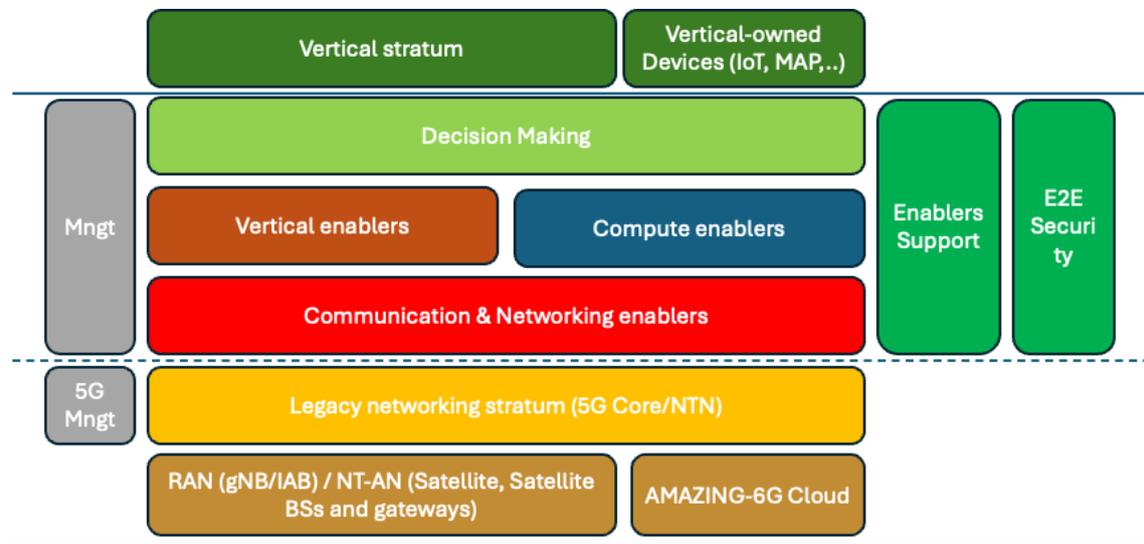
Figure 38: AMAZING-6G Functional model.

The AMAZING-6G Functional model (in Figure 38 above) consists of a set of layered FGs going from 1/ the upper plain line down to the dash line for a loose coupling architectural approach between AMAZING-6G and underpinning communication infrastructure or 2/ from the upper plain line to its bottom counterpart for a tight coupling architectural approach where all FCs part of the various FGs are tightly integrated with 5G networks and NTN as well. Loose and tight coupling and their related technical and business impacts are discussed further in Section 6.1.

In the following part of this section, we review briefly the different FGs and elucidate their main purposes, based on a "cutaway" (Figure 39) view of Figure 38 above.

> *Important note: the architecture we propose in this document is a proposal for a <u>logical</u> 6G architecture where FC descriptions mostly translate into textual description and interfaces (as 3GPP does).They won't be bound (in this document) to any specific implementations. There is no systematic one-to-one mapping between FCs and enablers described in WP3, although those enablers provide of course a vast majority of the technical inputs, functionality-wise.*
>
> *Because sometimes different topics are researched and developed by more than one partners in WP3, a one-to-one mapping often would not make any sense. In order to tackle the multiplicity of similar enablers, we tried to factorize and reorganise some enablers and even sometimes different aspects of a single enablers in order to finally propose a set of FCs which is optimal (no redundancy) and can serve more purposes than just those of the 15 project UCs. In none of the three iterations of the WP2 deliverables we will make assumptions or references on/to concrete (existing) implementations. On the contrary we will derive for each FC, logical interfaces that fit best, <u>concrete</u> interfaces of existing WP3 implementations of corresponding (even partially) WP3 enablers.*
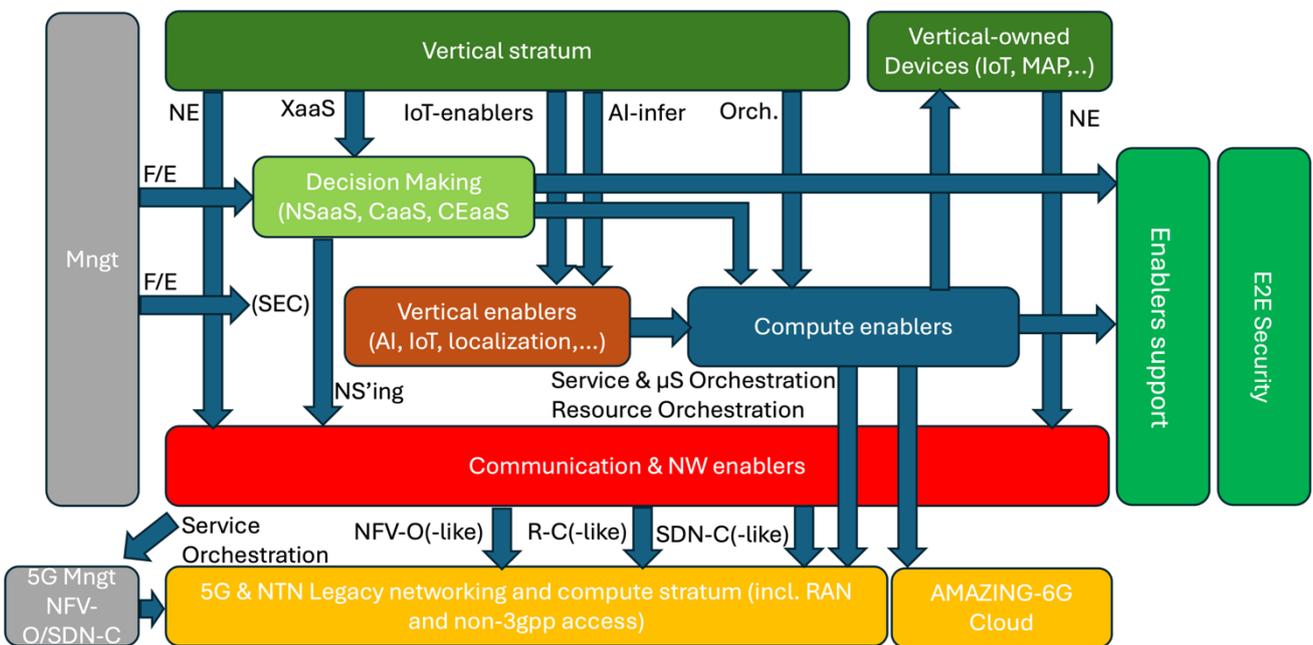
Figure 39: "Cutaway" of the Functional view.

5.1.1 Vertical Stratum FG & Vertical-owned Devices FG

The Vertical Stratum consists of all Vertical-specific applications and services. Those so-called compute units may be executed under the supervision and deployment choices of the Vertical, or alternatively be managed and deployed by the AMAZING-6G platform following deployment policies communicated by the Vertical. This later option is what we refer to as Compute as a Service (CaaS) in this architecture document.

This layer also includes any enabler that does not fall in the scope of the AMAZING-6G project either because being not part of one of the 4 innovation pillars of WP3 or being too much Vertical business-specific, to be considered as part of a 6G architecture meant to be as generic as possible.

Next to the Vertical stratum FG sits its "hardware"-counterpart: the Vertical-owned devices FG. This FG comprises edge and far-edge compute nodes, vertical-owned UEs , MAPs, AGVs, UAVs, RSUs, OBUs, etc.

Most of them can be addressed by AMAZING-6G in the context of CaaS providing they have reasonably powerful compute capabilities. It means they may be targeted by the dynamic service/application deployment process (later refered to as "compute task→compute node" allocation)

The Vertical stratum FG can access Coverage Extension as a Service (CEaaS), Compute as a Service (CaaS) and Network Slicing as a Service (NSaaS) by interacting directly with any related decision-making FC part of the Decision-Making FG (as explained below). This option implements intent-based approach to XaaS delivery.

Alternatively, a vertical may access enablers from the Vertical Enabler FG, Communication & NW enablers FG and Compute Enablers FG via their related exposure function (that consists of the public interfaces they provide to the Verticals, dedicating other interfaces to FCs interworking).

Vertical-owned services/application and devices (e.g. IoT nodes, MAP, edge & far-edge devices need being registered to the AMAZING-6G platform using different registries and repositories. This registration can be done explicitly or implicitly during the XaaS invocation and subsequent service parameter negotiation.

5.1.2 Decision Making FG

The XaaS features introduced shortly in previous sections rely -for their delivery to the invoking Vertical- on a decision-making component and many more components from e.g., the Compute Enablers FG, Networking & Communication FG or Vertical enablers FG.

While the decision-making is responsible for characterizing the invoked service based on Vertical's requests (later referred to as "intents"), the other components are responsible for implementing the decision-making "decisions". Decisions in this context heavily depend on the type of invoked service: a decision relating to dynamic network slicing (NSaaS) consists of a complete characterization of the NS to be commissioned, while a decision relating to CaaS invocation mainly consists of a "compute task→ compute node" allocation strategy. A quick presentation and summary of the decision-making FCs responsibilities follow:

- DM FCs take decisions, based on XaaS (NSaaS, CEaaS, CaaS) intent-based requests from the Vertical. Their roles cover the DECIDE part of the SENSE/AWARE/DECIDE/ACT loop. The decision implementation part (ACT) is performed by enablers from the Communication & NW enablers FG and Compute Enablers FG;
- Going into the detail of each XaaS we have:
  - Coverage Extension as a Service: deciding about extension dimensioning and characterization in term of needed supporting networking equipment, such as IAB nodes, MAPs (which sort and how many), TN vs. NTN (satellite e.g., StarLink), drones, airships, air balloon etc... based on the Vertical's requirements;
  - Compute as a Service: deciding upon placement and distribution of compute units (or tasks) over the available set of edge/cloud nodes, MAPs,... either part of supporting legacy infrastructure (5G Core / satellite payloads), part of vertical-owned devices (MAPs, OBUs, RSUs, TSUs & AGVs...). It takes into account constraints about energy efficiency (therefore considering energy sources), Verticals' deployment policies and individual execution requirements for all concerned compute units (µServices, applications,..) and provides a "compute task→compute node" allocation, filtering out typically nodes which don't provide GPU support or proper energy efficiency if such criteria are mandatory;
  - Network Slicing as a Service: capturing vertical requirements used to dimension and eventually provision a dedicated slice. The output of the decision process consists of *Network Slice Template (NST)* and *Network Slice Subnet Template (NSST)* templates as defined by GSMA [10].

> *Note: it is worth mentioning that decisions taken by the DM FCs are not mostly potentially temporary decisions. whenever circumstances change during the XaaS exececution and/or technical issue gets detected (e.g. execution of a vertical µService getting critical), it might be necessary to start again the corresponding DECIDE phase, involking the appropriate DM component for adjustement. The detection of such issues is made possible by using a set of digital twins (which cover the SENSE/AWARE part of the loop introduced above) which act as monitoring tools. More on those digital twins in the next section.*

All decision-making FCs are described in Section 5.2.1.

5.1.3 Vertical Enablers FG

This FG is dedicated to providing support to vertical IoT applications in the form of a complete IoT platform with semantic support (see Section 5.2.3.1 for more detail). And since an increasing number of vertical services and applications are relying on artificial intelligence (neural network) and machine learning techniques, we also provide in this FG an enhanced version of MLOps (which is described in deeper detail in Section 5.2.3.3. We provide now some more detail about the Vertical Enabler FG functionalities:

- Vertical with support for IoT application and AI-powered services;
- Support for IoT-flavoured application such as a digital twins and localization features;
- System-dedicated *Digital Twins (DT)*: they support context-awareness in the form of Network, Compute and Resource digital twins (respectivelly NDT, CDT and RDT). Those three DTs provide real-time information about network, compute and compute resource condition. They are a mandatory support to decision-making process since they provide at all time a near-complete snapshot of the system at run-time, for the purpose of detecting faults;
- AI/ML toolbox for MLOps (enhanced compared to the current 3GPP approach);
- In particular, provides an *AIML Exposure Function (AIMLEF):*
  - Access to (and discovery of) existing/reusable AI/ML models thru browsing/searching AI/ML model catalogue;
  - AI/ML model training, selection, management, performance evaluation & monitoring and updating;
  - Discovery and selection of similar pre-trained models to be used for transfer learning;
  - AI/ML functions registration, participation management, discovery and selection (including subscriptions and notifications);
  - Transfer of AI/ML tasks;
  - Split AI/ML operation, allowing to distribute the processing related to AI/ML models into multiple stages on different processing nodes. This is used to offload computation-intensive or energy-intensive tasks to network endpoints;
  - Support for *Federated Learning (FL)* operations, including FL members registration, FL member groups management, FL events subscriptions and notifications, selection, configuration and coordination of horizontal and vertical FL clients.
- Provide a complete IoT platform supporting Vertical IoT applications, and allowing the creation of a variety of digital twins, from the most basic ones exposing physical objects as *Virtual Entities (VE)* to the most complex ones orchestrating VE services in order to build large monitoring and management systems or simulations. It also:
  - Supports IoT resource and services catalogue with semantic descriptions (both sensors and actuators) to service registration and discovery;
  - Manages VEs and DTs catalogue to track identity, structure and binding between physical assets and their virtual counterparts;
  - Offers VE service discovery and registration, allowing metadata-based access to VE-specific services;
  - Provides orchestration for VEs to coordinate their services and interactions, ensuing alignment with real world-processes;

- o Provides and maintains a DT repository containing real-time and historical data to support state, inspection, simulation and decision making;
- o Stores outputs and artifacts from VE services in a repository to support analytics, traceability and reuse;
- o Enables scalable and event-driven communication between the message queues and time-series databases;
- o Supports the remote configuration and management of IoT devices, and exposes the IoT services and data through standardized APIs;
- o Connects non-IP or constrained devices to 5G/6G networks.

5.1.4 Compute Enablers FG

Those enablers are used to support -fully or partly- the XaaS features provided by the AMAZING-6G system to Verticals: *Compute as a Service (CaaS)*, *Network Slicing as a Service (NSaaS)* and *Coverage Extension as a Service (CEaaS)*. We provide below a list of functionalities with a very short description of their purpose and responsibility. They are further described as logical functional components in Section 5.2.2.

The main fonctionalities are:

- Support of the CaaS functionality, and more specifically the implementation of the CDM decisions concerning "compute task → compute node" allocation;
- Deployment and orchestration of services at the cloud/edge/far-edge and management of their life-cycle. Those services may 1/ originate from the Vertical and deployed wherever they fit best or 2/ consist of *Network Function (NF)* meant to be deployed at the supporting MNO side;
- Orchestration of compute resources to support computation of compute tasks (while the CDM relies of nodes capabilities and current resource availability status only). Typically, the resource orchestrator performs needed resource allocation adjustment at run-time, for a given *Execution Environment (EE)*, in order to maintain the optimal compute conditions for any hosted service within that EE;
- Allocation of compute resources by creating appropriate EEs (or customizating an existing EEs) that supports the optimal execution of hosted services; this includes the dynamic creation of clusters;
- Monitoring the execution of compute units using a compute digital twin (see REF below) and the status of compute nodes using a resource digital twin (see CEF below), both exposed by the *Compute Exposure Function (CEF)*;
- *Resource Exposure Function (REF)* which:
  - o Gives access to the overall catalogue (via discovery/search functions) of registered Edge/Cloud Nodes and their hardware/software characteristics, ownership, power source (power grid, self-powered, ...), max available Watt-age, current energy level and most importantly their internal organization in term of execution environments;
  - o Provides a repository that stores Services/μServices images (typically fed by Verticals invoking CaaS, but also AMAZING-6G FCs);
  - o Gives access to context *Resource Digital Twin (RDT)* which provides analytics snapshots of compute node status at run-time (% of capabilities used).
- *Compute Exposure Function (CEF)* which:
  - o Provides a registry that registers all APP/Service and μService characteristics and execution requirements;
  - o Gives access to compute contexts compiled by the *Compute Digital Twin (CDT)*. Such contexts provide analytics snapshots of application/service and μServices status at run-time.
- Service deployment policy repository (for Verticals but also for internal use), fed in particular by verticals when invoking CaaS.

5.1.5 Communication and Network Enablers FG

The main purpose of this FG is to provide the necessary components supporting the dynamic provision of a network slice through the NSaaS functionality. The following list provides its main responsibilities:

- It implements the NS dimentioned and characterized by the NSDM and manages its life cycle from commisioning to decommisoning after the NSaaS service has been fully completed;
- It covers the placement of *Network Functions (NF)* following the *NS templates (NST)* issued by the NS Decision Making component, and relies on the Service Orchestrator for that purpose. The placement can target both *Terrestrial Networks (TN)* and *Non-Terrestrial Networks (NTN)*. As far as terrestrial networks are concerned, it can also target any 5G-enabled MAP (RSU, 5G-enabled drone & robots and IAB nodes);
- It handles the creation of slice subnets;
- It may provide negotiation capabilities when deploying NS over multiple networks (access to resources);
- It relies on interfacing with *Management And Network Orchestration (MANO) Network Function Virtualization-Orchestrator (NFV-O)*, *Software-Defined Networking-Controllers (SDN-C)* and *Radio-Controllers (R-C);*
- It may provide additional supervision mechanisms in order to be able to address not only 5G *Radio Access Network (RAN)* and *5G Core (5GC)* but also NTNs and potentially multiple 5G networks.

In addition to the network slicing focussed features described above, it also provides:

- Communication channels to the upper layers (FGs) of the functional model (e.g. message buses for conveying IoT data towards IoT platform, etc.);
- *Network Exposure Function (NWEF)* which:
  - Creates a network abstraction layer between upper layer and legacy communication infrastructure;
  - Provides network slice selection function;
  - Gives access to underlying network topologies and associated compute resources for consultation or provisioning;
  - Gives information about the configuration of the existing network slices and their characteristics, including deployed NFs and subnets (e.g. using the native Slice inventory function);
  - Provides a *Network Digital Twin (NDT)* that informs in real-time about malfunctions or performance alarms. It may rely on the 5G native-*Network Exposure Function (NEF)* and *Network Data Analytics Function (NWDAF)* information;
  - Provides discovery functions for the above when relevant.
- *Integrated Sensing and Communication (ISAC)* support.

The FCs belonging to the Communication and Network Enablers FG are described in Section 5.2.4 and their interplay with FCs form the Decision-Making FG and Compute FG is elucidated in Figure 43.

5.1.6 Enablers Support FG

The Enablers Support FG provides additional support to Vertical by storing SLAs and enforcing them at runtime. Additionally, it provides a registry and repository for storing/searching 3rd party service descriptions (as provided by business service providers) and images, respectively:

- *Service Level Agreement (SLA)* storage & lookup;
- SLA enforcement.

These repositories and registries ensure that network functions and cloud-edge applications are deployed in compliance with agreed service delivery objectives.

5.1.7 Management FG

- Provides WEB-front ends that provides Verticals with easier access (easier than direct access through exposed interfaces) to the functionalities offered at lower layers of the functional model (e.g., DM FCs);
- Provides WEB-front end to the security features;
- Provides overall analytics dashboard (compute/network performance) and display of alarms;
- Accounting, ticketing and billing.

5.1.8 Security FG

The Security FG contains off-the-shelf components that provide basic functionalities like identity management, authentication and authorization. It also covers the creation and management of customer (vertical) accounts needed in the context of XaaS. The WEB front-end of those components are part of the management FG, as mentionned above.

5.2 Functional Components per Functional Group

FGs were described shortly in the previous section, with some of their main duties, but ultimately FGs are made of *Functional Components (FC)* (or so-called (logical) enablers). In this section we introduce for each FG, the individual FCs they are hosting. For the general purpose of each FG, please refer to the previous section.

We describe all FCs one by one, explaining as precisely as possible their roles and their place within the overall architecture, elucidating their relation to the other FCs, especially those belonging to other FGs.

The interplay of those FCs with FCs belonging to other FGs will be elucidated in the System Use-Case section (in Section 5.3), first informally (in this version of the document), then refined more precisely using sequence charts (in D2.2 & D2.3). Nevertheless, we provide a few diagrams in this section that elucidate parts of those interactions, however they are not time-ordered (see Sections 5.2.2.13 and 5.2.4.6).

5.2.1 Decision Making FG

5.2.1.1 Network Slicing Decision Making (NSDM)

This component has two distinct roles:

- An intent-driven component that is responsible for translating high-level intent expressions from Verticals, and translates them into actionable expectations and constraints (the NS requirements of a vertical willing to request a dedicated slice (subscribing to a NSaaS service)). These are then mapped to *Network Slice Templates (NST)* and *Network Slice Subnet templates (NSST)*. Those templates are meant to capture all information needed to actually provision a NS, relying on other components, typically from the Compute Enablers FG but also from the NF part of the 5G core or side 3rd party management platforms like MANO;
- As for the *Radio Access Network (RAN)* domain, it expresses intent expectations related to radio behavior (e.g, guaranteed throughput per slice, latency boundaries). These are then translated into actionable configurations and forwarded to RAN intelligent controller, which enforces and adapts policies for RAN slices, translating them into *Radio Resource Management (RRM)* policies and QoS flows.

5.2.1.2 Compute Decision Making (CDM)

An intent-driven component that is responsible for analyzing the compute requirements of a vertical and issuing as a result a "task → node" allocation table. Inputs received by the CDM from the Vertical willing to subscribe to a CaaS service are:

- A list of services to be executed and their characteristics (execution constraints);
- A list of Vertical-owned compute nodes and their characteristics;
- A service deployment strategy that sets constraints for services deployment such as favouring own-nodes compared to cloud-owned compute nodes.

Some of the information passed by the Verticals onto the CDM is then available through various registries and repository.

5.2.1.3 Coverage Extension Decision Making (CEDM)

The CEDM is an intent-based decision-making component which is used by a Vertical (via its front-end located at the platform web-based portal side) to request a momentary extension of the radio coverage based on the use of *Integrated Access and Backhaul (IAB)* nodes. Those IAB nodes can be deployed either using Vertical-owned MAP or MNO-owned equipment.

The CEDM responsibility is to understand the needs of the Vertical based on the characteristics of the needed CE.

5.2.2 Compute Enablers FG

Computing plays a crucial role in ensuring computing resources are used efficiently and intelligently. As devices and service become more distributed – especially at the edge, this Compute Enabler FG helps managing where and how Vertical services (refered to as µServices/µS) and FCs are executed. It determines which edge nodes are best suited to handle a task based on hardware specifications, energy levels, energy source, ownership and current workload. It also maintains a real-time view of the compute environment relying on various digital twins. That way, it can spot issues, monitor performance, and adapt quickly when execution conditions and status change, usually for the worse (e.g., degraded µService execution, equipment fault, etc.) Whether it is about powering smart cities, autonomous systems, or industrial IoT, this FG brings intelligence closer to where data is generated, making 6G networks faster, smarter, more responsive, and more energy efficient.

5.2.2.1 (Centralized) Service Orchestrator – cloud based

The overall service orchestration system, illustrated in Figure 40, represents a hierarchical setting with the *Centralized Service Orchestrator (CSO)* and *Edge Service Orchestrators (ESO)* as key elements. The orchestration process involves efficient resource allocation, service lifecycle management and adaptive scaling to minimize performance while minimizing resource consumption.These two orchestration layers have different sets of responsibilities.

The CSO (also called SO) is a centralized orchestration entity that oversees the entire Extreme Edge/Edge/Cloud continuum. As such, it is responsible for managing and optimizing resources across all edge nodes. In particular, within the AMAZING-6G architecture, the SO is the component responsible for implementing the "task→node" allocation decision taken by the CDM. It is therefore responsible for the actual placement of the compute tasks/vertical services into the allocated compute nodes, which Edge Service Orchestrators govern. The SO is a central component that relies on ESOs at the edge (edge servers, and far-edge compute nodes e.g., edge servers & MAPs) to perform life-cycle management of those placed services. To do so, it needs to keep track internally of any deployed ESO and is responsible for their respective life cycle.

The SO gets notified upon any addition/removal of a new/existing compute node to/from the Resource Registry (see below) and will deploy/undeploy ESO accordingly (and some other FCs most likely such as CDT (sensing-agents and aggregators), ...).

The SO gets notified upon any addition/removal of a new/existing compute node to/from the Resource Registry (see below) and will deploy/undeploy ESO accordingly (and some other FCs such as CDT (sensing-agents and aggregators), RDT, etc.)
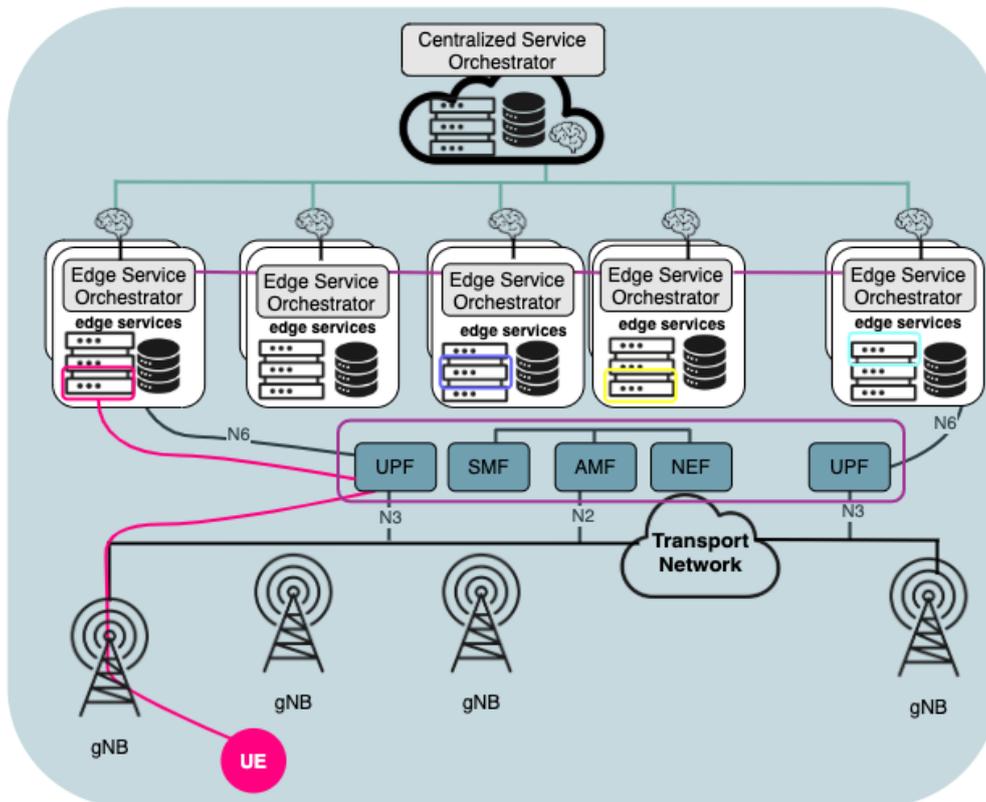
Figure 40: The service orchestration system consisting of one CSO and several ESOs.

5.2.2.2 Edge Service Orchestrator (ESO) – edge based (one per Compute Node)

The ESO(s) are responsible for orchestrating services at the edge/far edge as instructed by the CSO. ESOs are deployed by the CSO as its lightweight versions, towards the compute node prior to any Vertical service, FC or NF deployment, and their authority extends only within the operational boundaries of a specific edge node.

Each ESO is responsible for the lifecycle management of vertical services deployed on their respective edge nodes (by the CSO), i.e., performing operations such as scaling up/down/out/in and termination based on the changing requirements and conditions of the system. Therefore, it is responsible for the whole lifecycle of services, FCs, NFs, especially when their lifespan is pre-determined (e.g., for Vertical-owned services bound to an agreed SLA).

The operations bound to the specific node that ESO manages, such as scaling up/down and termination of Vertical services, can be performed entirely by the ESO. However, in the case of scale-out or service migration, the operation extends to other edge computing nodes and as such requires either support from the CSO or knowledge about adjacent ESOs and their respective edge nodes. To reduce the signalling overhead between ESOs and CSO, the ESO discovery mechanism can be employed, to ensure that adjacent ESOs are aware of each other. Once the discovery process is finalized, each ESO has an interface towards its adjacent instances, which can be used to communicate details related to required operation, including sharing of metadata necessary for operating (e.g., images needed for deploying a vertical service instance on the other edge node).

Depending on the AMAZING-6G Use Case, the diversity of roles ESO takes up may differ. In case of static service deployment, i.e., vertical service instance deployed once and consumed only by static users, only scaling up/down and termination are relevant for optimizing resource usage and service performance. However, in cases involving user mobility, the need for orchestrated service deployment across edges emerges, and as such the collaboration between ESOs and CSO is required.

5.2.2.3 Compute Resource Orchestration (CRO)

It maintains an up-to-date registry of computing resources, ensuring that service is deployed to the most suitable available infrastructure. The system is responsible for:

- *APIs availability:* allows the integration with other systems, enabling the onboarding of new infrastructure and providing real-time queries on resource status;
- *Application instantiation management:* it ensures that correct services are deployed to the right resources. It is also responsible for responsible for maintaining the appropriate execution condition of any service (w.r.t. their operational requirements) scaling resources up/down as needed, in such a way that: 1/ the compute node usage remains optimized and 2/ every single µS/FC is optimally executed.

During operation, the CRO relies on the CR-Reg (see below) in order to know about the maximum capacity of a compute node in term of compute and related networking resources.

5.2.2.4 Compute Resource Allocation (CRA)

The resource allocator interacts closely with the CRO to define and implement resource allocation strategies. This component *retrieves resource information* from the orchestration system to gain insight into the available computing resources and defines allocation strategies for services based on the request from the service *Life-cycle Management (LCM)* component. Several key developments and enhancements are planned to further enhance the capabilities of the CSO and CRA. These include:

- *Integration of constraints:* the allocation and orchestration process will be extended to integrate battery status and energy constraints into the decision-making framework. As edge devices and mobile terminals often operate on limited power, incorporating real-time battery status will enable the system to make more informed decisions about resource allocation;
- *Energy-efficient service placement and task allocation:* the resource allocation system will incorporate energy-efficient algorithms that consider device battery levels when making service placement and task allocation decisions;
- *AI-based constraints and models for resource allocation:* integration of AI-based constraints and machine learning models will enhance the resource allocation process.

5.2.2.5 Compute Resource Registry (CR-Reg)

The CR-Reg provides for each Compute Node known from the AMAZING-6G system, an inventory of:

1. Its maximum capability in term of CPU Core, GPU Cuda core, RAM, Disk space, available throughput, energy source (e.g. grid-powered, solar-powered)... and its current resource consumption status (% of MAX) including available energy level;
2. Its currently implemented *Execution Environments (EE)* and their configuration according to the criteria listed in 1. In addition to their current resource consumption status (% of allocated resources from the CN available pool).

This component (together with the S-Reg) is a crucial source of information to the CDM when it performs the initial "task → node" allocation and also to the SO/ESO when they ought to locally adjust resource allocation or task migration.

5.2.2.6 Service Registry (S-Reg)

The S-Reg FC stores vertical-owned and AMAZING-6G -owned service descriptions and offers a service discovery feature that allows querying and selecting services based on various criteria, as well as to retrieving their service handlers (used to fetch images from the Service Repository). Service description includes ownership, and all resource constraints pertaining to their optimal execution (as listed in 5.2.2.5 - .1). This later information is crucial for task→node allocation by the CDM, to the service orchestration, and for SLA enforcement.

5.2.2.7   Service Repository (S-Rep)

The S-Rep FC is responsible for storing Vertical-owned services (the services involved in the CaaS workflow) and FC images (in particular those that Verticals can deploy). It also offer the necessary look-up functions to search and retrieve service images (e.g., Docker images) for deployment.

5.2.2.8   Compute Digital Twin (CDT)

The CDT is an important component that aims to collect compute-related information at the service level at runtime and in near real-time. It provides analytics that characterize at runtime how well (or poorly) any EE-hosted service (either Vertical-originated or a Network Function) is executed. The CDT may be implemented as a layered group of components where each (n+1) layer brings additional information (typically meta-data) to information already received from (n) layers. The information ultimately conveyed to the CDT client (platform management function, SLA enforcement or CDM) includes % of used resource vs. allocated resource vs. needed resource (this later being registered in the service registry). Compute resources include the number of CPU & CUDA cores, the amount of RAM & mass storage space, available network throughput and energy consumption among others.

5.2.2.9   Resource Digital Twin (RDT)

While the CDT focuses on the execution of EE-hosted applications and services, the RDT focuses on the availability and usage of compute resources compared to those already allocated. It also provides insight into compute node energy consumption, which is a critical piece of information for e.g., solar-powered edge nodes.

The criteria used by the RDT are similar to those used for the CDT and will be fully described in the Information view of D2.2.

5.2.2.10 Resource Exposure Function (REF)

Following the Network Exposure principles, i.e., exposing the network to vertical applications, and allowing them to request additional network resources, the Resource Exposure is a paradigm that enables such applications to request compute resources on demand. If, for instance, a vertical service/application needs more CPU to execute certain tasks (while being placed within the edge-cloud continuum), the request can be sent to the network via the *Resource Exposure Function (REF)* (implemented as a resource exposure API). After the request is received via the compute exposure interface, the task of fulfilling the request is further handled by the resource orchestrator (based on the decision from the CDM). As a result, the application might be scaled up/out or moved/migrated to a different node.

5.2.2.11 Compute Exposure Function (CEF)

The CDT, being a purely internal component used by CDM, CSO and ESO to optimize resource allocation and service execution (either in the form of µService from Verticals or AMAZING-6G FCs), is complemented by the CEF, which exposes Verticals to the real-time execution status of their µServices.

5.2.2.12 Deployment Policy Repository (DP-Rep)

The DP-Rep stores the deployment policies provided by the Vertical after negotiating the service delivery characteristics with the CaaS service provider. It also stores the deployment policy pertaining to the FCs. A Vertical deployment policy encodes the preferences of the Vertical as far as its own services are concerned, especially when Vertical-owned edge or far-edge compute nodes are eligible candidate for Vertical-owned service deployment and execution.

A platform deployment policy also applies when a new Compute Node is inserted into the system to complement either, the AMAZING-6G compute eco-system or as a Vertical-owned compute node addressable by CaaS for service execution. In such a case, supporting FCs (monitoring-related like digital twins, or CaaS-related like (E)SO(s)) need being deployed too.

The structure of a deployment policy will be proposed in D2.2, within its new Information view, which will focus on logical interfaces and supporting data structures.

5.2.2.13 CaaS eco-system in a nutshell

Figure 41 illustrates the set of FCs involved when invoking CaaS, highlighting the relationships between these FCs. It is worth noting that CDT, NDT and RDT which are paramount to enable the decision-making full capability and SLA enforcement are part of the Vertical-enablers FG (IoT-related part). Additionally, the NEF and NWDAF NFs are part of the 5G core architecture and are used here to feed network analytics to the NDT, which is not only monitoring 5G networking performance but also encompasses all networking aspects, including AMAZING-6G cloud, edge and far-edge compute nodes.

Figure 41: CaaS eco-system.

5.2.3 Vertical enablers FG

IoT acts as the sensing and actuation layer at the 6G ecosystem, connecting the physical world to digital intelligence. This FG manages how devices are discovered, integrated, configured, controlled, and exposed across domains like mobility, energy, mission critical, a health. Ensures seamless communication, semantic interoperability and secure data exchange between diverse endpoints. Enables remote healthcare, autonomous transport, or energy aware buildings, and powers the data foundation of the system.

As far as the use of artificial intelligence and machine learning in 5G and B5G are concerned, 3GPP has introduced data analytics functions in support of network analytics services at the 5G Core Network [11], management analytics services at the *Operation And Management (OAM)* [12] and application analytics services [13]. As extension of application analytics, AI/ML services can be provided via 3GPP networks

to assist Application Service Providers and Verticals by exposing MLOps features and functionalities for AI-as-a-Service. This includes a wide set of procedures related to AI/ML models and operations, as well as mechanisms for handling custom AI/ML functions via open APIs.

In AMAZING-6G architecture, AI-related FCs are designed to guarantee the interoperability with 3GPP architectures for an easy integration in/with existing and future 5G/6G network deployments. For this reason, the *AIML enablement (AIMLE)* service defined in [14] (Functional architecture and information flows for AIML Enablement Service, rel. 19) has been considered as baseline for the exposure of AI/ML services from 3GPP-like domains (as the ones deployed in AMAZING-6G testbeds) to vertical-specific and edge applications.

5.2.3.1   IoT-related FCs

The AMAZING-6G IoT Use Cases are build on top of intelligent platforms that integrate devices, collect data and expose IoT services across diverse domains. These platforms support semantic modelling, monitoring, remote operations and scalable connectivity that goes from sensor-level integration to edge-cloud orchestration. The IoT sensing data is made accessible through registries and APIs, enabling real-time analytics, awareness systems and remote control of devices and actuators.

5.2.3.1.1   Digital Twin Framework

The *Digital Twin framework (DT-F/W)* represents a pivotal functional component for some Vertical Use Cases and leverages multiple FCs to deliver an intelligent, adaptive digital replica of the real-world system. In more detail, the different functional components are:

- *Data Collection FC (DT-DC)*: it collects data from the field independently from the transport protocol. The data are then formatted and checked to be then made available both in real-time and as historical data sets. While real-time data can be used to continuously analyze the behavior of the system, data sets are useful to post-processing and for training of new AI algorithms;
- *Simulation and Modeling FC (DT-SM)*: it simulates system behavior using multi-paradigm techniques (Discrete Event Simulation, Agent-Based Modeling, and System Dynamics), enabling predictive analysis, scenario testing, and behavioral replication of operational entities. This environment supports both high-level overviews and detailed, fine-grained modeling, ensuring realism and flexibility;
- *Decision Modeling and Optimization FC (DT-DMO)*: it applies advanced optimization algorithms and AI-based models—including Mixed-Integer Programming and Reinforcement Learning—to support dynamic, data-driven decision-making. These models learn from real-time and historical data to deliver robust, adaptive solutions for resource allocation, safety risk detection, and flow management. This FC sends feedback to the real world to timely respond to situation changing the behavior of the actors in the field;
- *Visualization and Interaction FC (DT-VI)*: it provides users with intuitive interfaces such as dashboards, 3D environments, and *Augmented Reality (AR)* tools. These allow operators to explore simulation and real-time outcomes from the field, interpret optimization suggestions, and respond proactively to system dynamics, enhancing decision-making and situational awareness.

The applicative digital twin is designed to analyze the real world to gain awareness and quickly respond to situations, thereby optimizing processes, enhancing safety and security, and, in general, leveraging its internal data to influence the physical environment.

5.2.3.1.2   VE service Orchestration (VE-SO)

The VE-SO FC enables the integration, coordination and control of digital representations of physical objects/entities (the so-called VEs), into business processes. VEs expose properties of their physical counter-parts, via VE services leveraging the underpinning IoT resources (e.g., sensors, actuators, or more complex systems). VE-SO ensures that these services are properly invoked, and composed in context-aware workflows, maintaining alignment with physical states. VE orchestration depends on several core IoT components such as resource registry, service registry, monitoring, message queue and others.

5.2.3.1.3   IoT Resource Orchestration (IOT-RO)

The IOT-RO FC is responsible for managing and coordinating the IoT hardware resources within the system, such as sensors, actuators and edge devices. It allocates device functions based on operational needs, context or policy (e.g., assign task to Drone A, or to vehicular robot). The IOT-RO is aware of device capabilities, energy constraints, and real-time availability and is responsible for selecting which devices are activated or assigned to specific sensing or actuation tasks. The component interacts with IoT Resource Registry to retrieve hardware capability descriptors and executes logic that ensures coordinated and efficient used o physical devices. It also manages the available resources in terms of capabilities such as CPU, RAM, storage to allocate and schedule IoT microservices dynamically across edge/cloud systems (e.g., OBU, MEC, etc.)

5.2.3.1.4   IoT Resource Registry (IOT-RReg)

The IOT-RReg FC maintains a detailed description of the physical and virtual IoT resources, including their types, capabilities, interfaces and metadata. This allows to know for example what type of data is returned by sensors or accepted by actuators. It serves as a foundational component for service discovery, orchestration and semantic reasoning. Each registered resource (e.g., devices, sensors or actuators) needs to include semantic descriptors such as supported measurement units, data formats, control types, and location. Especially critical for dynamic environments where sensors (e.g., ultrasound patch, ECG) or actuators (e.g., drones, eSleds) may be discovered and integrated at runtime. The IOT-RReg supports interoperability by aligning to reference ontologies (e.g., SAREF[7], NGSI-LD[8]). The IOT-RReg works closely with the IOT-SReg to connect devices to services and with orchestration logic to determine resource suitability.

5.2.3.1.5   IoT Service Registry (IOT-SReg)

The IOT-SReg FC keeps detailed description of IoT Services that can be invoked by internal or external actors. It stores detailed metadata about services provided by the IoT devices, such as reading sensor data, executing actuator commands or subscribing to environmental events. It enables direct lookup and discovery of services using identifiers, categories or semantic attributes. It includes information on how information can be accessed, specifying whether a service is available via on-demand polling (e.g., REST-GET), publish/subscribe (e.g., MQTT queue) or both. It also supports semantic discovery, enabling intelligent filtering or reasoning. This functional component acts as a broker between service requesters and the IoT infrastructure, ensuring clients can locate and interact with devices efficiently.

5.2.3.1.6   VE Service Registry (VE-SReg)

The VE-SReg FC provides service level descriptions and discovery capabilities for virtual entities, which abstract and semantically enrich physical devices. It enables context-aware applications to find and invoke VE services (e.g., risk analytics 3D modeling of blades, structural assessment) without directly interfacing with hardware. The VE-SReg stores semantic service models, behavioral descriptors and

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7 https://ngsi-ld.org/

8 https://saref.etsi.org/

capability mapping. It also stores for each VE service a handler which can be used to retrieve its corresponding image from the VE-SRep. The VE-SReg can be integrated with the VE-SRep and digital twin registries to create a cohesive virtual layer.

5.2.3.1.7 VE Service Repository (VE-SRep)

The VE-SRep FC is responsible for storing and retrieving VE Service images. VE-SRep can be invoked after a particular VE has been discovered and identified using the VE-SReg.

5.2.3.1.8 Digital Twin Registry (DT-Reg)

The DT-Reg FC manages metadata and identifiers associated with digital twins of physical entities. Includes information about the linked physical assets, current instantiation status, twin versioning and binding to data sources. It enables coordination between real-world systems and their digital counterparts by tracking active twins, synchronization models and updating their associations. It allows the discovery of twins based on entity type, context or deployment domain (e.g., wind turbine blade, building HVAC system). Like for VE-SReg, the DT-Reg also stores for each DT a handler used to retrieve its images from the DT-Rep. The DT-Reg interacts with VE-SReg and IOT-RReg to align virtual and physical entities.

It is worth reminding the main distinction we make between virtual entity and digital twins. While a VE is focused on a single object and the properties it is exposing (either linking to a sensor or an actuator), digital twins are meant to build complex IoT applications (like an IoT-based business process) by orchestrating VE Services (hence the VE Service Orchestrator introduced earlier). This distinction between DTs and VEs is elucidated in the Figure 42 of Section 5.2.3.2.4.

5.2.3.1.9 Digital Twin Repository (DT-Rep)

This repository is responsible for storing and retrieving digital twin images. DT-Rep can be invoked after a particular DT has been discovered and identified using the DT-Reg.

5.2.3.1.10 Digital Twin-Virtual Entity Time Serie Database (DTVE-TSDB)

The DTVE-TSDB FC stores both live and historical data associated with digital twins, including time series, simulation outputs, status updates, inference models. It serves as the knowledge base for each twin aggregating real-time sensor data. This allows retrospective analysis, decision support and AI model training. For example, in the wind turbine use case, it stores inspection, snapshots, model overlays and repair history. In healthcare, it retains patient vital trends, annotated images, and event timelines.

5.2.3.1.11 Message Queue Factory (MQF)

The MQF FC enables each vertical or system component to dynamically create its own message queue (e.g., a MQTT broker or Kafka topic) for managing specific data flows. These queues can be used for mission- or tenant-specific communication and may optionally include a linked time series database for persistent storage of sensor data. This allows producers and consumers to be decoupled, improving system flexibility and resilience in environments with unstable or delayed connectivity. The factory supports message buffering, replay, and real-time stream handling. It provides interfaces for queue configuration, lifecycle management, and integration with orchestration layers. This component is especially useful in mobile or tactical scenarios e.g., where a MEC node must route data from a Sensor Instrumentation microservice to a central command, or where BLE telemetry from a pacemaker needs to be streamed reliably to a clinical backend. It also supports scalable data ingestion within general IoT platforms.

5.2.3.1.12 IoT-Exposure function (IOT-EF)

The IoT-Exposure Function exposes internal IoT platform capabilities to external domains, applications or users through secure and abstracted interfaces. It acts as a gateway between trusted IoT subsystems and external consumers. It exposes data streams, event notifications, command APIs, or historical

repositories. It acts as a northbound interface between the IoT platform and external consumers such as clinical dashboards, teleoperations UIs, building management systems, or command control centers.

5.2.3.2 Localization and Positioning-related FCs

5.2.3.2.1 Position Acquisition Engine (PAE)

The PAE FC is responsible for acquiring raw geolocation data from various technologies such as GNSS, RTK or perception-based sensors such as LiDAR, radar and cameras. It incorporates network-assisted location, such as 5G NR positioning measurements or RSU-provided coordinates in cooperative systems. PAE abstracts the hardware-specific drivers and delivers synchronized, and quality data to the fusion engine or location logic.

5.2.3.2.2 Mobility Context Provider (MCP)

The MCP FC allows to obtain mobility insigths by analyzing position data streams over time. It determines states such as stationary, in transit, or approaching boundary, based on trajectory, velocity and heading. This capability is useful for teleoperation, dynamic path planning and collision avoidance. Finally, it enables geofencing logic by detecting entry and exit within/from predefined zones.

5.2.3.2.3 Cooperative Localization Engine (CLE)

The CLE FC enables precise, shared positioning by agregating and echanginf location data between multiple agents such as vehicles, drones and RSUs. It provides fused data from distributed sources including visual perception (e.g., LiDAR, cameras), GNSS corrections, and 5G NR-based coordination, essential in dense, dynamic or GNSS-degraded environments. The engine serves as a core enabler for scalable connected mobility in smart transportation and robotic systems.

5.2.3.2.4 IoT model

The following Figure 42 model shows the different concepts referred to throughout those different IoT functional components, and elucidates their roles and the relationships existing between them. It especially tries to make a distinction between VEs and DTs.

In this diagram, we have passive DTs which are mostly layered DT relying eventually on sensing agents disseminated throughout the system. The DTs introduced earlier, namely NDT, CDT and RDT are built according to that schema. They are passive because they exclude any type of actuation. On the contrary active DTs are layered DTs eventually orchestrating VE services, which in turn orchestrate IoT services, relating to typical IoT devices (actuators, sensors and tags), but also to digital artefacts. The three categories of IoT resources expose their capabilities via IoT services. IoT resources and IoT services are described and accessible via IoT Resource registry (characteristics, information to query the IoT service,...).
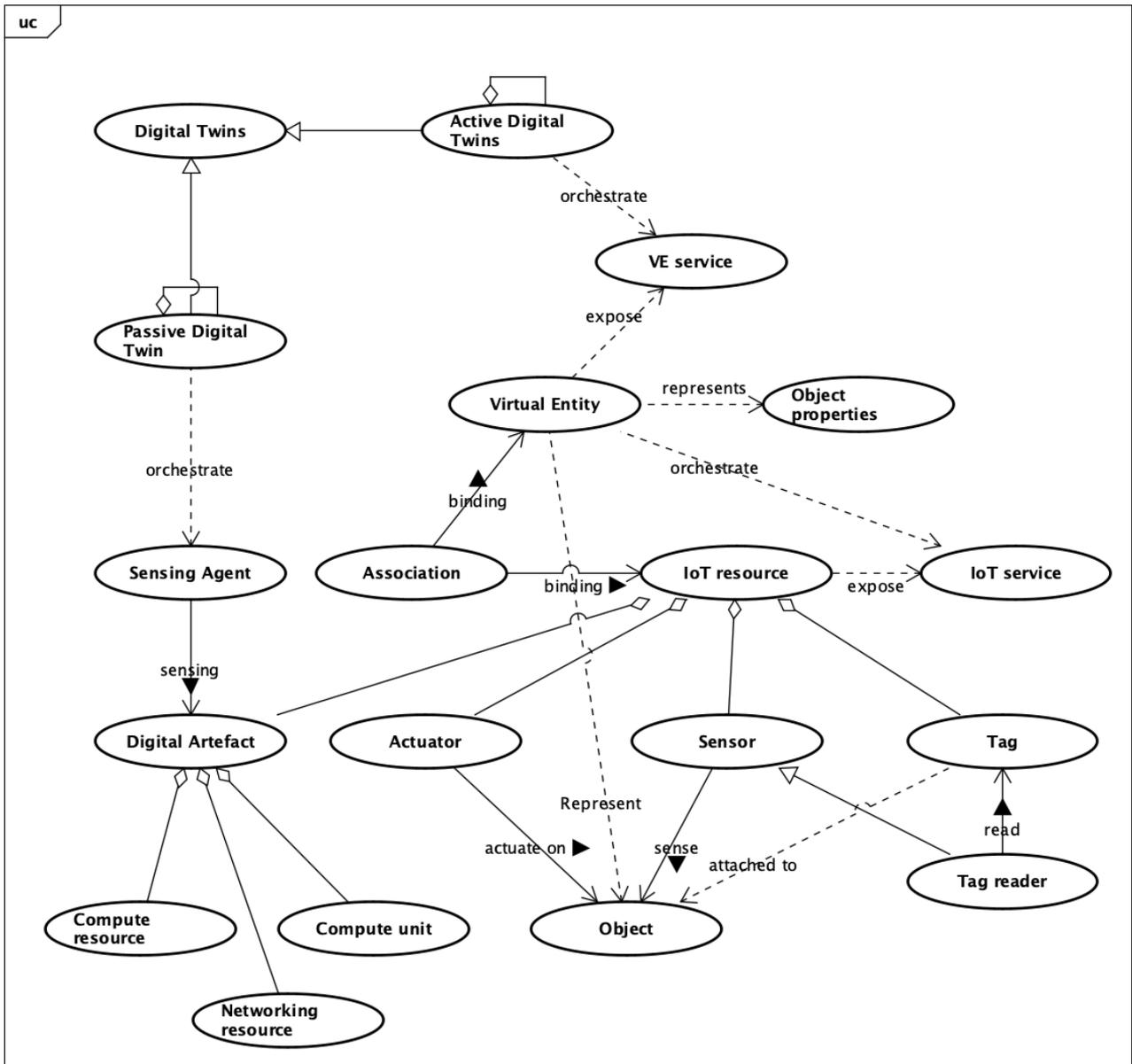
Figure 42: IoT model in AMAZING-6G.

5.2.3.3 AIaaS-related FCs

At the AMAZING-6G architectural level, the AIMLE service can be modelled as a set of functions (i.e., the AMAZING-6G AI-related FCs), typically implemented as cloud-native functions. These functions can be logically grouped in one or more AIMLE servers that can be deployed in a centralized cloud platform, in several edge platforms or with a hierarchical deployment with multiple collaborating AIMLE servers placed at the edge or in the cloud, depending on the target Use Case.

> *Note: it is worth mentioning that each UC relying on the AI/ML functionalities may implement only a subset of these following FCs, possibly extended with its own custom features, to meet the requirements of the UC itself. Cross-UC interoperability and re-usability will be guaranteed through the support of standard interfaces, compliant with the AIMLE APIs specified in 3GPP TS 23.482 for AIMLE server APIs, ML repository APIs, and AIMLE client APIs.*

We enumerate below the AI-related FCs that compose the AIMLE service:

5.2.3.3.1 *ML Model Catalogue (MLMC)*

The MLMC provides a centralized and structured repository for ML models, acting as a catalogue that enables storage, indexing, and discovery of models across different domains and Use Cases. It supports version control to ensure model lifecycle tracking, metadata tagging for efficient search, and performance indicators that allow users and systems to compare and select the most appropriate models.

5.2.3.3.2 *ML Model Training Engine (MLMTE)*

The MLMTE is responsible for orchestrating the entire ML training process. It manages data ingestion from multiple sources, preprocessing, algorithm selection, and the execution of training jobs in distributed environments (cloud, edge, or federated). The engine also supports model retraining using incremental datasets, feedback loops, or transfer learning mechanisms, ensuring continuous model improvement.

5.2.3.3.3 *ML Model Evaluation Engine (MLMEE)*

The MLMEE is dedicated to validating and assessing ML models during operational deployment. It applies testing and benchmarking procedures to evaluate model accuracy and compliance with defined performance metrics. Beyond pre-deployment testing, the MLMEE enables continuous monitoring of deployed models to detect performance degradation. This ensures that only reliable models are selected for inference and that deployed models remain effective over time.

5.2.3.3.4 *ML Model Deployment Engine (MLMDE)*

The MLMDE provides the functionality to package and deploy ML models in production environments, enabling inference execution at scale. Depending on the operational context, it can deploy models on cloud servers or at the network edge, ensuring compatibility with network requirements like latency, bandwidth, and energy efficiency requirements. MLMDE may integrate with cloud deployment managers or service orchestrators to automate provisioning, scaling, and rollback.

5.2.3.3.5 *ML Operations Management Engine (MLOME)*

The MLOME is responsible for the overall management and orchestration of AI/ML services. It handles registration and discovery of AI/ML functions, supports selection of appropriate services based on requirements, and enables subscription/notification mechanisms for lifecycle events. By providing these capabilities, the MLOME ensures that AI/ML services operate reliably and efficiently across different infrastructures and domains, while also enabling interoperability between different stakeholders and AIMLE instances.

5.2.3.3.6 *FL Management Engine (FLME)*

The FLME enables the coordination and management of federated learning (FL) processes, where participants (FL members) collaboratively train ML models without sharing raw data. It supports member registration, grouping, event subscriptions, and notification mechanisms to ensure dynamic participation and coordination. The FLME manages both vertical and horizontal FL scenarios, orchestrating training rounds, aggregating local model updates, and ensuring secure and privacy-preserving collaboration. By doing so, it allows distributed environments to benefit from AI/ML while respecting data locality, confidentiality, and regulatory constraints.

5.2.4 Communication and Network Enablers FG

The main objective of those FCs is to implement network slices characterized by the NSDM decision-making component.

5.2.4.1 *Centralized Service Orchestrator (CSO)*

In the context of network slice provisioning (NSaaS), The CSO –already introduced in the Compute Enabler FG (see Section 5.2.2.1)– is used for the deployment of needed network function(s) to their respective subnets.

5.2.4.2   NFV-O Connectors (NFVO-C)

The NFV-O Connector is responsible for propagating the requests targeting the NFV-O deployed at the MNO side, assuming that different versions of NFV-O may exist in the system featuring different interfaces. The role of this connector is mainly about request translation.

5.2.4.3   SDN-C Connector (SDNC-C)

The SDN-C Connector follows the same principle as the NFV-O assuming that different versions of NFV-O may exist in the system featuring different interfaces. The role of this connector is mainly about request translation.

5.2.4.4   Radio-C Connector (RC-C)

The Radio Connector acts as a gateway between network orchestration systems and the RAN. It translates and adapts commands and data flows for seamless interoperability. It enables real-time synchronization and coordination between core network functions and radio elements. This ensures efficient resource utilization and supports flexible network slicing and service customization at radio level.

5.2.4.5   Network Digital Twin (NDT)

The NDT provides insights on the networking aspects of the system (e.g., towards a particular EE, or edge node). The NDT provides digests about network status that can be used by the (E)SO(s), decision-making components and SLA enforcement in order to access the status of service execution from the networking standpoint.

5.2.4.6   NSaaS eco-system and relation to CEaaS FCs

The following Figure 43 shows the interplay between Compute-related, Network-related functional components and the supporting 5G system NF and components.

Figure 43: NSaaS and CEaaS shared eco-system.

5.2.5 Enablers Support FG

5.2.5.1 SLA related FCs

5.2.5.1.1 SLA repository (SLA-R)

The purpose of the SLA repository is to store an encoded service level agreement as agreed between the Vertical and service provider (AMAZING-6G & MNO combined) and to maintain its integrity.

Depending on the type of subscribed service (CEaaS, CaaS or NSaaS), the SLA keeps track of several different parameters such as:

- The agreed quality of service requested by the Vertical (throughput, latency, number of QoS flows, etc.);
- The agreed compute resources allocated to vertical service execution (amount of allocated RAM, number of assigned CPU/CUDA cores, available bandwidth, available disk space, etc.);
- The agreed coverage extension parameters such as capacity, extension perimeter, number of allocated IAB/MAP nodes, etc.

In a nutshell, the SLA encodes any information that is necessary to decide if the agreed terms of service delivery are met or not by the service provider at runtime.

5.2.5.1.2 SLA enforcement (SLA-E)

Following a service delivery (XaaS) contract agreement, the AMAZING-6G system will performs the requested service delivery according to agreed service delivery schedule. Depending on the nature of the

subscribed service AMAZING-6G may deploy Vertical's µSs, FCs, scaling networking resources up (typically provisioning a new dedicated network slice) according to the deployment policies and required QoS/QoE as captured in the S-Reg.

At the moment the subscribed service delivery starts, the SLA-E FC (as an independent component responsible for enforcing SLAs) starts monitoring all aspects of the service execution, based on the digital twins introduced earlier and then it continuously checks whether any violation of the SLA terms occurs.

Whenever a breach to the SLA contract is detected, it is reported to the responsible party (could be either the CDM, CEDM or NSDM FC depending on the nature of the SLA breach) so that appropriate countermeasures can be taken. At the same time the SLA breach is logged and eventually used in particular in the event of a dispute occurring between the service consumer (Vertical) and service provider (AMAZING-6G or AMAZING-6G + MNO for the special case of NSaaS).

5.2.6 Security Enablers FG

5.2.6.1   Identity Management (IdM)

Identity management covers the process of 1/ adding a new user account in the system, 2/ assigning her an identifier (login) and a list of role(s) (eventually only one) and finally 3/ defining and assigning access rights through *Access Control List (ACL)* per undertaken role. After registration, one credential per role, (e.g., password or token) is sent back for further use (e.g., for authentication, but also when accessing resources) to the new user.

5.2.6.2   Authentication (AuthN)

Authentication is used to get access to the system by presenting a login identifier, an assigned credential and possibly a role. Being authenticated by the system is a mandatory step before invoking any AMAZING-6G service. Access can be granted or denied according to the result of the authorization enforcement (see below).

5.2.6.3   Authorization (AuthZ)

Authorization is the process by which an attempted access to a certain resource by a certain entity (user, device, service) is granted or denied. AuthZ is therefore the service that enforces access to resources, based of identity, role and pre-assigned ACL.

5.2.7 Management Enablers FG

5.2.7.1   Decision Making Front End (DM-F/E)

The DM-F/E is a WEB front-end which exposes NSaaS, CaaS and CEaaS to the Vertical. Using this front-end the Vertical can 1/ express its requests and QoS constraints via intents and then 2/ engage into the negotiation process that ultimately leads to the establishment of a service delivery contract between the Vertical and AMAZING-6G (or the 6G network in the condition of a tight coupling[9] between AMAZING-6G and the supporting standalone 5G operator).

5.2.7.2   Security Front End (SEC-F/E)

The security WEB front-end is used for all aspects of Security management within AMAZING-6G. In particular this WEB interface provides the Verticals with the ability to create customer accounts including roles. Following this initial step, Verticals' crew members can register to AMAZING-6G (with their role) and get allocated authentication credential in return.

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9 See the difference between tight and loose coupling in Section 6.1

5.2.7.3   Platform Data Analytics (PFDA)

The PFDA FC allows to retrieve data analytics from the AMAZING-6G system based on data published by some of the most relevant FCs (xDM, system Digital Twins, etc.) using for instance the DTVE-TSDB or MQF FCs.

5.2.7.4   Platform Data Visualization (PFDV)

The PFDV FC allows to build a graphical dashboard and to display in real-time all sorts of data received by the PFDA (typically a component-off-the-shelf such as Grafana).

5.2.8 Non-AMAZING-6G Functional Groups

5.2.8.1   Vertical Stratum FG

The Vertical Stratum FG consist of two different sorts of Vertical-owned services:

1. Services (or applications) which are meant to be executed and underline managed by the Vertical in its own compute infrastructure (cloud or edge);
2. Services, the execution and management of which, is entrusted to AMAZING-6G. Those services owned by the Vertical but managed by AMAZING-6G are called µServices (µS), to distinguish them from the services of case 1. above. In this case, the Vertical must negotiate and subscribe one or several XaaS delivery(ies) (any combination of CaaS/NSaaS/CEaaS depending on its service execution and networking requirements).

5.2.8.2   Vertical-owned Devices FG

The Vertical-owned Devices FG consists of various sorts of devices:

1. IoT devices: the 15 UCs of AMAZING-6G features a large range of IoT device examples in the field of Health-Care, Public Safety, Energy or Transport;
2. Mobile Access Points (e.g., UAV with embedded CPE/IAB nodes, RSUs, TSUs, OBUs);
3. UAV, AGV, UGV, Robots, eSLEDs;
4. Any other (edge) compute nodes.

(Edge) compute nodes, but also devices from 2nd and 3rd categories above (depending on their compute capabilities) can be declared as potential µService deployment targets by the Vertical in the context of a subscription to CaaS. It means that the CDM can decide, in compliance with the Vertical deployment policy, to deploy some of the Vertical µSs towards their own compute nodes (the rest being potentially deployed to AMAZING-6G cloud e.g.

5.2.8.3   5G and NTN Legacy Networking FG

In this section we introduce the most important components used in the 5G and NTN systems, especially the ones which are going to be interacting with our AMAZING-6G FCs.

5.2.8.3.1   5G-related
5.2.8.3.1.1   5G Core

In this section we give a quick introduction to the main 5G core network functions, followed by -CP (resp. -UP) when they relate to the *Control Plane (CP)* (resp. *User Plane (UP)*). The NF capabilities are exposed through well-defined RESTful APIS, following a service-based architecture;

- *Access and Mobility Function (AMF)* -CP: the AMF is an utterly important component of the CP, it is responsible for managing access and mobility of UEs. It provides users (UEs) with secure access to the 5G network through credential verification and access policy enforcement. It is also responsible for managing handover between different network gNBs during UE roaming. Finally, it controls the UE access to the network and which resources it is authorized to use. The

gNB - AMF interface is denoted N2 and the communication protocol is NAS; More than one AMF may exist in the 5G system when several NS are instantiated;

- *Session Management Function (SMF)* -CP: the SMF is the central point for managing the entire user session lifecycle from connection, session creation to its termination. It also interacts with the PCF to enforce session-related network policies and manage the allocation of an IP address to the UE. The SMF works closely with the AMF (through N11 interface) and UPF (through N4 interface);

- *Network Slice Selection Function (NSSF)* -CP: the NSSF is a component that helps selecting the most suitable slice (among the eligible NSs existing within the 5G system) according to the user and service requirements in term of e.g., bandwidth, latency, reliability. It also assists the AMF in selecting the proper AMF instance in case the current AMF does not support the NS needed by the user or service. The AMF instances are linked via the N14 interface;

- *Network Function inventory (NRF):* it acts like a catalog, where all the network functions such AMF, SMF and UPF registers with NRF and declare they NF type and their S-NSSAI support;

- *Policy Control Function (PCF)* -CP: the PCF hosts network policies to create PCC rules to be forwarded to the SMF. It also provides policy rules for control plane functions, including network slicing, roaming and mobility management. It provides the management of subscribers, applications and network resources based on business rules. Interacts with SMF and AMF to enforce these policies;

- *Authentication Server Function (AUSF)* -CP: the AUSF receives authentication requests from the AMF (first component being contacted by the UE when establishing a connection) and relies on the UDM (see below) in order to verify the subscriber identity, to validate their subscription data, to determine their appropriate security context and to perform authorization;

- *Unified Data Management (UDM)* -CP: the UDM has multiple roles such as generating user credential, subscription management and user data management. It also participates to mobility and session management linked to respectively AMF and SMF. Finally, the UDM handles the subscriber slice authorization, and stores the allowed S-NSSAIs per subscriber. It is used during the registration to validate UE's slice access;

- *User Plane Function (UPF)* -UP: the UPF is a key component of the 5G core. It handles the forwarding and routing of user data traffic. Its placement within the 5G system is crucial for establishing low latency or high throughput, features which are essential for 5G-enhanced mobile broadband and emerging Use Cases such as Mission Critical services (PPDR), Health and Safety scenarios, and any throughput-critical vertical applications (e.g., HQ video broadcasting). The UPF (first in chain if multiple UPF are instantiated) is connected to the gNB (CU) through the N3 interface. Several flavors of UPF are implemented in the 5G architecture:
  - Internal-User Plane Function (I-UPF): interface between I-UPF and other I-UPF/PSA-UPF/UL-CL is N9;
  - PDU Session Anchor UPF (PSA-UPF): the UPF/Data Network interface is denoted by N6;
  - Uplink-classifier (UPF-UC): an uplink classifier is a function within a 5G UPF that directs incoming uplink (user to network) traffic from a UE to different locations or services based on traffic-matching rules provided by the SMF. This functionality can be used for instance to redirect specific UL requests towards some applications hosted at the satellite payload, e.g., a PPDR application (case of regenerative 5G enabled satellite) while the rest of the UL traffic goes to the ground station;

- *Network Exposure Function (NEF)* -CP: supports external exposure of capabilities of network functions. External exposure can be categorized as:
  - monitoring capability;
  - provisioning capability;
  - policy/charging capability;
  - network status;

- o reporting capability;
  - o Analytics reporting capability.
- *Network Data Analytics Function (NWDAF)* -CP: is a component that performs data analysis by collecting data from the NEF, from NFs, from Operation, *Administration and Maintenance (OAM)* and also from the UDR. Analytical results are made available to NFs, OAM and any *Application Functions (AF);*
- *Application Functions (AF)*: they cover a broad set of functionalities intended to support the 5G Core such as assisting in traffic routing, accessing the NEF, interacting in policy management, etc. Part of AMAZING-6G FCs could be recognized as AFs by the 5G Core for operation like network slice provisioning. Such aspects will be developed further in further releases of this document. AFs are connected to the *Service Based Interface (SBI)*.

5.2.8.3.1.2 5G RAN

- *Central(ized) Unit (CU)*: CU and DU deal respectively with the upper (lower) layer of the communication stack. There is one CU per gNB and it is running at the 5G Core cloud side. That CU controls all DUs implemented at the gNB side. CUs are connected between each other through the Xn interface;
- *Distributed Unit (DU)*: there can be more than a quite large number DUs in a single gNB, each of them supporting one or more cells. DUs are connected to their CU through the F1 interface;
- *NR RedCap:* (NR) RedCap stands for Reduce Capability and is a technology that targets small devices such as IoT devices (check the UltraSound patch in Use Case H1 for instance) which do not need the complexity and capability of 5G NR. NR RedCap modems feature better energy efficiency, reduced cost thanks to reduced capacity and offer a medium range throughput (typically ~200Mb/s DL and ~100Mb/s UL) using the same frequencies as 5G NR;
- *Donor-Distributed Unit (Donor-DU)*: the donor-DU is directly linked to the gNB Centralized Unit (the same way the gNB DU is). Note that the gNB must be IAB-enabled as IAB requires special hardware;
- *IAB-Mobile Termination (IAB-MT)*: the IAB-MT links to the up-link Donor-DU or IAB-DU;
- *IAB-Distributed Unit (IAB-DU)*: the IAB-DU offers an access link to UEs in radio scope and eventually to another IAB-node IAB-MT in range;

5.2.8.3.1.3 Other side components

- *Network Function Virtualization-Orchestration (NFV-O)*: the NFV-O deals with the management of virtualized network services by coordinating the deployment, scaling and termination of VNFs across the infrastructure. It interacts with various components to ensure service delivery, such as the SDN Controller. It provisions and manages network connectivity between VNFs to enable service chaining and traffic routing. As a key component on the orchestration, it allows the automation and lifecycle management of the network slices, ensuring the service quality and reliability. It consumes high-level intents expressed by operators and translates them into orchestrated service actions, supporting automated and policy driven operations;
- *Software-Defined Network – Controller (SDN-C)*: the SDN-C manages flow control for improved network management and application performance through a logically centralized control plane. It communicates with the underlying network infrastructure (switches, routers, and other devices) via southbound APIs such as OpenFlow, while exposing programmable northbound interfaces to higher-level applications and orchestration systems like NFV-O or intent-based systems;
- *Radio-Controller (R-C)*: the R-C acts as the central "brain" of the RAN, responsible for managing and optimizing its operations. It is typically divided into two types: the *Non-Real-Time Radio Controller*, which provides closed-loop control and optimization on a non-real-time scale, and the *Near-Real-Time Radio Controller,* which enables faster, near-instant decision-making. By introducing programmability into the RAN, the controller empowers self-optimizing network

capabilities and enhances flexibility. Through policy-driven, closed-loop automation, it supports faster, more efficient deployments and dynamic optimization of network performance.

5.2.8.3.1.4   Supporting databases

From the network operator's view, the registries are concerned with underlying infrastructure, network functions and domain orchestration. Since the network operator is responsible for the design, instantiation, control and assurance of physical/virtual networks and slice subnets there are key registries, such as:

- *Slice Template Registry (ST-Reg)*: it stores NSTs (Network Slice templates) and NSSTs (RAN, Transport, core);
- *VNF/NS Descriptor Registry (VNF-NS-Reg)*: it relates to orchestration metadata, it holds NSDs and VNFDs(VNF Blueprints) used by the NFVO and orchestrators. It holds the technical building blocks used within NSSTs, such as VNFDs: virtualized RAN (vDU, vCU), UPF, SMF, AMF, PCF, NRF,UDM, and NSDs: service chains of VNFs (e.g., core slice: SMF + UPF + AMF);
- *Core Compute Resource Registry (CCR-Reg)*: also related with the orchestration metadata, it tracks compute, storage and networking capabilities that are used by orchestrators to decide where to deploy slice components. It checks available capacity, ensures resource compliance, and maintains metadata about resource characteristics;
- *Inventory Registry (I-Reg)*: I-Reg in the OSS manages the lifecycle of slices (create, modify, delete), capacity and topology, and interacts with the ST-Reg. It acts as a central slice registry/inventory for planning, operations and assurance;
- *Network Slice Policy Registry (NSP-Reg)*: the NSP-Reg contains slice-specific rules: scaling, fault recovery, QoS slice admission control and global QoS objectives for the network slice. This registry fits at the slice manager's or the NFVO. It is managed by the PCF NF.

5.2.8.3.2   NTN-related

- LEO Satellite constellation: those satellite systems rely on a large constellation of small satellites placed in low earth orbit (500km~2000km). Those low orbits allow for lower latency (faster response time) and more stable internet connections. In the context of emergency B5G/6G communications, such satellite systems can serve as a reliable backhaul solution, especially in remote or disaster-affected regions where terrestrial infrastructure is compromised. When integrated with mobile 5G units, a satellite system enables real-time voice, video, and data services, ensuring uninterrupted mission-critical communication even in the absence of traditional connectivity options.

  Architecture-wise, we consider the satellite system to consist of two main components: 1/ the satellites themselves and their payloads and 2/ a large set of ground stations (satellite receiver + router) that collects & treats satellite signals and connects to Internet. As a side note P3 UC is partially based on a StarLink satellite sollution for backhauling.

5.2.8.4   *Overall view of the AMAZING-6G Architecture*

This following Figure 44 shows the detailed cut-away of the AMAZING-6G architecture. Detailed interactions between components can be found in Sections 5.2.2.13 and 5.2.4.6). Only 5G NFs interacting with AMAZING-6G system are shown (5G Legacy FG).
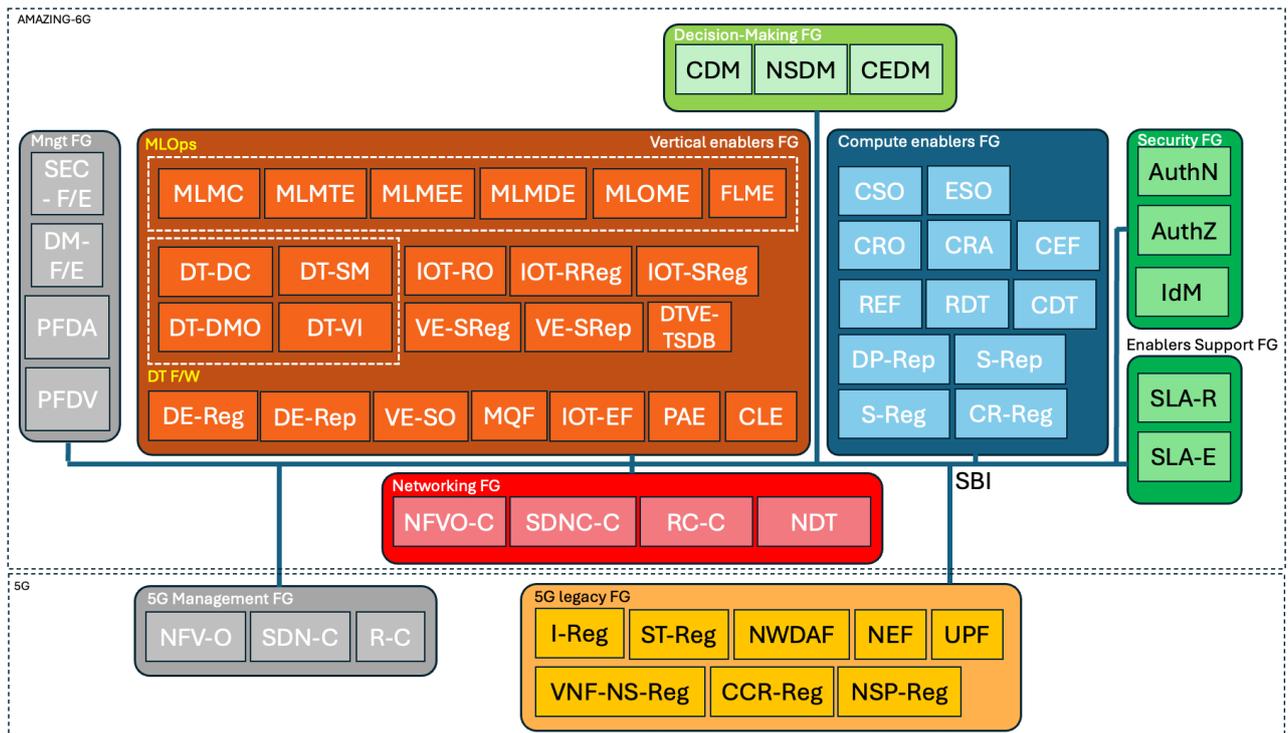
Figure 44: Proposed 6G (AMAZING-6G + 5G) architecture with Service Based Interface (SBI).

5.3 System Use-Cases

System Use-Cases (SUC) are meant to describe interactions taking place between the logical FCs within specific context (or execution patterns) such as the invocation of a XaaS by a vertical. They will ultimately show the sequence of messages exchanged by the components in a timely manner, using UML message sequence charts and precise abstract/logical interfaces.

5.3.1 A vertical registers to AMAZING-6G

Before invoking a XaaS feature or directly accessing exposed APIs, a vertical (ultimately an AMAZING-6G "customer") must be known from the system. A set of users can be registered alongside their role and affiliation and be allocated security credentials which can be used to securely access any exposed feature and service, e.g., invoking any of the XaaS which must be carried on by a vertical member of crew. The customer account is also used for all aspects relating to ticketing and billing.

When creating a customer account, one designated "administrator" user is responsible to register their company as a AMAZING-6G customer by providing all needed information relating to the Vertical (company). This ADMIN is also responsible for creating any additional user (the consumers of subscribed services) which in turn are assigned service-level credential (e.g., security token) and access rights depending on their roles.

Users can be either human or digital artefacts such as:

- IoT devices (which will have to access some communication features to communicate with e.g., communication services or μServices;
- Any MAP acting as a UE e.g., OBUs, RSUs and TSUs (authentication to the 5Gsystem is ensured via SIM cards but service-level authentication is based on additional credential as we saw earlier);
- μServices (those services that are handled by orchestrators and can migrate across different compute nodes) and Vertical services (whose executions are managed entirely by the Vertical).

5.3.2 A vertical requests coverage extension (CEaaS) - negotiation phase

The negotiation phase includes every interaction existing between the Vertical and the system where CE needs are analyzed, a solution is dimensioned and a service delivery proposal released by AMAZING-6G to the Vertical. This process involves the CEDM only, and a simple negotiation protocol -inspired from ContractNet[10]- implemented between the two parties. Whenever a proposal from the CEDM is denied by the Vertical, a counterproposal by the CEDM is issued. The result of this multiple-stages negotiation results into the Vertical accepting or denying the terms offered by the CEaaS provider (embodied in the CEDM).

Coverage extension can be achieved by:

1. Deploying additional gNB to the desired Vertical-designated location (backhauling towards the closest legacy gNB can be achieved by fiber wire or radio link);
2. Deploying IAB nodes (as many as necessary based on their radio range), with the first in-chainIAB node ultimately linked to a Donor-DU at the closest legacy IAB-enabled gNB;
3. A mixture of solution 2. and CPE if local WIFI coverage is needed;
4. Requesting 5G (Uu) satellite coverage (NTN), typically in extreme case such as disaster relief.

Since we decouple CEaaS from both NSaaS and CaaS (which can be complementary services to CEaaS) the provisioning of the CEaaS is rather simple and straightforward:

1. The Vertical invokes CEaaS thru a web-interface acting as a front-end to the CEDM (or directly via the CEDM interface);
2. The Vertical provides the information needed by the CEDM for the CE dimensioning and characterization:
   a. Needed throughput, capacity (number of UEs), latency, etc.;
   b. CE geographic characteristics such as latitude, longitude, altitude but also terrain characterization e.g., flat vs hilly vs rugged;
   c. Service delivery schedule including start and stop time and dates but maybe also some periods of pause;
   d. Radio interface (typically 5G or WIFI – in which case CPEs are to be involved).
3. Based on those requirements, the CEDM dimensions a solution in term of equipment to be deployed or to be planned (with possible involvement of NTN support) including incurred costs; the costs and justification are proposed to the Vertical;
4. The vertical may accept the proposal straightaway or denied it, in which case a counterproposal (where typically initial Vertical requirements could be downscaled (e.g., capacity, latency, or throughput) which in some extreme cases may require the provision of a dedicated network slice);
5. The negotiation process terminates with the Vertical accepting/denying either the preliminary proposal or counterproposal. At this stage a service ID is passed on to the Vertical. The service ID can be used when linking CE with additional CaaS/NSaaS subscriptions.

   Finally, the terms of the CEaaS delivery are encoded into an SLA and stored in the dedicated repository (SLA-Rep).

It is worth noting that this ContractNet-like protocol can be used with several service providers (which is outside the scope of this document) though some adaptations of the protocol would have to be implemented in that matter.

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10 https://en.wikipedia.org/wiki/Contract_Net_Protocol

5.3.3 A vertical requests coverage extension (CEaaS) - service delivery phase

The service delivery phase starts, assuming the CEDM proposal/counterproposal was approved (see Section 5.3.2 above), at the time stated by the Vertical, as part of its inputs to the service delivery negotiated schedule. The steps consist of:

1. If physical deployment is required, needed additional hardware (i.e., temporary loaned gNBs and/or IAB nodes) is deployed by MNO personal to the designed location prior to the start of service delivery;

2. If a dedicated slice has already been negotiated with the MNO (via NSaaS) the necessary configuration needs to be made within the 5G system so that the new hardware can be part of the new slice. It also means 1/ it must work with the SIM cards released when negotiating the new slice 2/ new SIM cards relating to the CEaaS must not be provided by the MNO to the vertical. Since the CEaaS service has been already linked to the NSaaS delivery schedule the following step 4 can be ignored;

3. Depending on the equipment type, delivery of SIM cards granting access to the additional gNB and IAB nodes must be made according to the service delivery schedule;

4. Connection to the extended network is accepted only according to the CEaaS delivery schedule.

5.3.4 A vertical requests network slicing support (NSaaS) - negotiation phase

The negotiation phase is part of the network slice lifecycle, and it is linked to the slice request and admission control. NSaaS offers to tenant's network slices as on-demand, customizable services. The tenant or customer requests a slice with certain characteristics, and the operator provisions it accordingly. The network slice negotiation is an early step where the tenant requests a slice, providing an intent with the slice blueprint described required resources, QoS and functionalities. This involves defining slice requirements, capabilities and constraints before slicing instantiation. The negotiation phase can be divided into different phases:

*   *Intent submission:* the tenant initiates the slice requests, where it contains the slice blueprint or template, with desired characteristics (e.g., bandwidth, latency, reliability, coverage), the *Service Level Agreement (SLA)* requirements and duration and scale of slice usage. Tenants use the interfaces provided by the MNO slice management system to submit the request, and the *Network Slice Management Function (NSMF)* is responsible for receiving the request and managing the slice lifecycle. Finally, the NFVO prepares to manage resources required for the slice;

*   *Evaluation & negotiation:* the NSMF evaluates the slice request against physical and virtual infrastructure resources, operator policies and business rules and existing active slices to avoid conflicts. If the resources or SLA parameters are not fully compatible, the NSMF proposes needed modifications. Here the NSMF translates the intent into network-specific parameters and initiates negotiations. Then the *Network Slice Subnet Management Function (NSSMF)* handles part of the slice such as RAN slice or Core slice. Next, the NFVO and *Virtualized Infrastructure Manager (VIM)* evaluate virtualized resource availability. The Policy registry evaluates the SLA with established policies and enforces relevant operational constraints;

*   *Agreement:* where a formal SLA contract is established, with slice characteristics, resource allocations and SLA terms;

*   *Admission control:* where the operator confirms resource reservation and ensures that instantiating the slice will not break other existing slices. Also, the slice is either accepted or rejected. If admitted, the slice delivery phase is initiated.

5.3.5 A vertical requests network slicing support (NSaaS) – service delivery phase

After a network slice is negotiated and granted, the service delivery phase begins, spanning instantiation, activation and ongoing management of the network slice.

The service delivery phase is composed of the main following steps:

- *Commissioning phase:* the agreed resources are provisioned and the *Network Slice Instance (NSI)* is instantiated along with its subnets:
    - it starts with the feasibility and resource reservation where the *Communication Service Management Function (CSMF)* of NSMF receives the SLA and forwards the request to allocate the Network Slice instance. The NSMF triggers a decision engine to verify the capabilities (in terms of required QoS, latency), and resources (compute, RAN, transport);
    - *creation of NSI and NSSIs:* is feasible the NSMF coordinated instantiation across domains, with RAN, *Core Network (CN)* and *Transport Network (TN)*. It can involve the NFV MANO for deploying VNFs or CNFs.
- *Activation:* the new instantiated network slice is activated so that UEs/services can use it. It involves activation across the different domains. The configuration needed to route UEs to the active slice using the *Single Network Slice Selection Assistance Information (S-NSSAI)* is performed. The slice becomes ready for tenant usage;
- *Operation:* it ensures that the slice meets the SLA requirements through monitoring, fault management, performance analysis and scaling. In this step, the NSMF periodically collects metrics from NSSIs and NSI to compute KPIs. Upon demand, the management can trigger the NSMF to scale the slice by resizing it. Finally, management data analytics and closed-loop automation enable proactive optimization of the intent.

5.3.6 A vertical builds up a Digital Twin (using DT-FWK)

The digital twin is designed as a functional component associated with a specific application or service logic. The deployment within the system architecture is determined by a range of operational requirements such as latency constraints, computational load distribution, scalability, and data locality and can typically be at the edge or in the core of the network. The DT acts as a logical endpoint capable of managing and integrating heterogeneous data flows coming from multiple physical or logical sources on the field.

- Once instantiated, the DT is automatically provisioned with all the necessary security policies to make it operational. In the standby phase, it is ready to receive incoming data streams from authorized on-field devices. These data producers can include static sensors, mobile users (e.g., vulnerable road users), connected vehicles, or infrastructure elements like traffic lights or RSUs. The DT becomes effectively active once devices discover its address and initiate data transmission;
- During the negotiation and bootstrapping phase, source devices must be informed of the DT's network endpoint (e.g., IP address or service URI). This is commonly facilitated via a dedicated *discovery API* exposed by the DT orchestrator. This mechanism is useful for mobile or nomadic devices such as UEs, VRUs, or vehicles, whose connectivity endpoints may dynamically shift because of user movement or handovers across network domains. In such scenarios, the DT address may be selected based on proximity, network load, or policy constraints, and updated transparently to the sender via the discovery interface;
- On the other hand, applications or services interested in consuming data flows (or historical data) through the DT must authenticate using secure interfaces. These consumers, often cloud-based or centralized applications, gain access to specific data streams, depending on their role and access rights. An access control mechanism ensures that only authorized applications can read or subscribe to selected subsets of the DT data, aligning with data governance and privacy

policies. Data is made available through topics or dedicated APIs that allow continuous data retrieval or the possibility to access historical data;

- During the operational phase, the DT performs a continuous ingestion of real-time data from the field. This data is normalized, contextualized, and stored or processed according to the application requirements. The DT acts as a mediator, enabling a high level, application-specific abstraction of the physical environment. Through this abstraction, other applications can interact with the physical layer in a decoupled manner, either for monitoring, analytics, control-loop feedback, or decision support.

A comparable mechanism applies to the NDT, which focuses on representing the virtual replica of the underlying network infrastructure. The NDT aggregates telemetry and performance data from various network elements, including the RAN, core elements, MEC nodes, and other programmable components. A distinction arises between static devices, such as gNBs or core routers, and transient entities like OBUs or UEs that may enter and leave the NDT's logical domain based on mobility patterns.

To maintain coherence, the NDT must dynamically adapt its data collection scope depending on the real-time topology. Devices that temporarily reside within the coverage area of a certain NDT instance need to dynamically register and expose relevant KPIs or contextual information. Endpoint discovery, security negotiation, and session lifecycle management are once again orchestrated through APIs that abstract the underlying complexity and ensure interoperability.

5.3.7 Network Slice selection

- The network slice selection from the UE follows a process that allows the UE to connect to a specific Network Slice tailored for a service or application (e.g. Enhanced Mobile Broadband (eMBB), URLLC, *Massive Machine-type Communication (mMTC)*:
- UE configures slice requirements:
  - ○ User or application selects or configures the type of service;
  - ○ UE maps this to a Slice/Service Type (SST) and possibly a *Slice Differentiation (SD);*
  - ○ The UE initiates a registration request to the network through the RAN. Along with UE-specific information, the request includes the *Requested N-SSAI (R-NSSAI)*, indicating the network slices the UE intends to access. Potentially a *subscribed NSSAI (S-NSSAI)* (if know from SIM or previous sessions).
- The RAN will select a serving AMF based on the R-NSSAI;
- The AMF performs NSSAI validation, where it validates the requested S-NSSAI is allowed for the UE. Then, it compares it with UE's subscription profile (stored in UDM). If some slices are not allowed, they are rejected;
- Upon receiving the registration request, the AMF sends a request to the NSSF to execute the network slice selection process. The AMF provides detailed information such as R-NSSAI, the *Public Land Mobile Network (PLMN)* ID of the *Subscription Permanent Identifier (SUPI)* and the *Tracking Area Identity (TAI)*;
- The NSSF performs the NS selection, using the information provided by the AMF. It determines which S-NSSAI the UE is eligible to use, and aggregates them into the allowed NSSAI. In addition, the NSSF may also identify the best AMF to serve the UE;
- The AMF updates the allowed NSSAI by including it in the registration *accept message*. This enables the UE to identify the network slices available for use. When the UE initiates a service, it sends a PDU session establishment request specifying the S-NSSAI. This ensures that the data traffic is associated with the correct core network slice;
- Network resource allocation follows, based on the S-NSSAI where appropriate SMF and UPF are elected. Finally, the session is established within the chosen slice.

5.3.8 A new Compute Node is added to the CRO

- Compute resources available in the newly added compute edge node;

- CRO updates the database with new resources associated with the edge computing node;
- CSO spawns up a new ESO for the newly added node, allowing it to deploy and manage new vertical services that will consume allocated compute resources.

5.3.9 A vertical requests compute support (CaaS) – negotiation phase

The general idea of CaaS is to provide Verticals with the ability to entrust the system with the optimal execution of their services, based on precisely defined execution requirements. The overall process involves the allocation of services to the most suitable compute node, either Vertical-owned, MNO-owned or AMAZING-6G system-owned. Several requirements of different nature are considered during the "task→node" allocation, such as the node's maximum available computing capacity, its remaining resources, and the characteristics of its energy source.

- The compute requirements are defined for each vertical service that needs to be deployed in the edge-cloud continuum, along with the network requirements, and as such they are described in the intent form. During CaaS invocation the verticals communicates the following information:
  - Its own compute node descriptions (their hardware capability, including energy source);
  - Its own service descriptions;
  - Its deployment policy (e.g. preferred compute node for specific services, alternative deployment according to varying criteria such as energy level, etc.);
  - The schedule for the service delivery e.g., starting and ending time/date, service suspend periods.

  A non-exhaustive set of compute and networking requirement parameters defining the service description is proposed in Section 5.2.2.6 as part of the S-Reg FC description.

- The CDM then processes the intent and generates a <u>test</u> "task→node" allocation. In order to perform this optimization function, the CDM relies on additional information such as 1/ static information about the compute node characteristics in addition of course to the service descriptions supplied by the Vertical in the previous step and 2/ dynamic information about the compute node status (current available resources vs. maximum available resources);
- If none of the compute nodes contains the required amount of compute resources, CDM invokes the CSO, which will consider the following options:
  - Adding new edge compute node to the CRO (as described in Section 5.2.2.3);
  - Terminating some of the existing services that are not actively used by end users (or not prioritized);
  - Denying the request as formulated but provides a counterproposal trying to find compromise on allocated resources;
  - Rejecting the request for a new service.
- If the service is granted the information returned by the CDM to the Vertical is basically a cost (and some justification, such as how many compute nodes have to be allocated to the vertical for CaaS on top of those owned by the vertical;
- Regardless to which proposal is accepted by the Vertical (either original or counterproposal), it is encoded into an SLA by the CDM and the CDM performs a pre-emptive resource allocation which is needed to guarantee that whenever the service starts, the pre-determined "task→node" allocation is still valid whenever the CaaS delivery actually starts;
- Finally, there is a need for the Vertical to upload service descriptions, service images, compute node descriptions and deployment policy to their respective registries/repositories.

This last action concludes the steps necessary to CaaS provision. At the end of this phase the services are not yet deployed to their respective target compute nodes.

5.3.10 A vertical requests compute support (CaaS) – service delivery phase

- The CDM performs a final task allocation, taking the latest compute node-related status information into account;
- Once CDM makes the placement decision, CSO instructs the corresponding ESO to deploy the vertical service and take up the role of life-cycle manager for that service;
- Vertical service is deployed on particular edge computing node within the continuum;
- ESO monitors the performance of the service based on the CDT, RDT and NDT digital twins, and compares it against the performance requirements stated in the intent;
- If the performance is affected by the lack of compute resources, ESO may decide to scale up the service or move it to the other node;
- In case of scaling up, more compute resources are assigned to the vertical service during its runtime.
- On the other hand, if a scale-out operation is necessary, ESO establishes peer-to-peer communication with the adjacent ESOs to ensure sufficient resources for the vertical service deployment in their domain;
- If a service is not actively used by the end-users or is not associated with a high priority during the high load conditions, ESO may decide to scale down the resources or terminate the service.

5.3.11 A Vertical is roaming across various Edge node domains

- *Precondition:* each edge node is considered as 'edge domain' where different vertical services can be deployed, although the definition of the 'domain' may vary depending on the use case deployment (e.g., some edge nodes might be grouped and considered as part of the same domain in case they serve as redundant nodes or are added to increase the compute power of a particular node);
- *Precondition:* when vertical service is used by mobile users (e.g., vehicles moving on the road), the same vertical service instance needs to be made available in the target edge domain. The target domain is considered the domain where the user is heading. This operation is essential for ensuring that user connects to the optimal service at any moment;
- ESOs utilize the peer-to-peer horizontal interfaces (west and east) to communicate necessary service deployment details (service metadata needed for service deployment and life-cycle management) with their adjacent ESO;
- If the target ESO is not the adjacent ESO, CSO intervenes and deploys service in the requested edge domain;
- Once the service instance is available in the target domain, the user is reconnected via N6, or to be more precise, the traffic from the user is being re-routed via UPF (and N6) to the new service instance;
- If the vertical service instance is not needed in the edge domain where it originated (there are no active users consuming the service), the associated ESO decides to terminate the service.

5.3.12 SLA enforcement detects an SLA breach

The SLA-E is an independent component responsible for tracking SLA breaches by constantly checking the status of execution of Vertical µServices and the networking parameters that relates to 1/ the (temporary) specially allocated network slice and 2/ communication that uses (temporary) specially allocated network coverage extension.

The SLA then queries information from the CDT, RDT and NDT that relates to the XaaS service subscribed to by the Vertical.

Whenever a breach is identified, such as when the allocated compute resources do not match the SLA or when the performance of µSs falls below the acceptable threshold, the SLA-E notifies the relevant DM components and records the breach (ideally on a blockchain). This ensures that the information is

securely stored, tamper-proof, and retrievable in case of a dispute between the Vertical and the platform.

Following the identification of the breach part of the DM FCs (if not all depending of the nature of the breach) need to take actions such as tinkering with the NS, allocating more compute resources etc.

It is important to note that the DM FCs always monitor DTs and take actions as soon as Vertical service delivery conditions start degrading. Therefore, in normal circumstances (excluding equipment breakdown), an SLA breach is not likely to happen.

5.3.13 Lookup/retrieval of an existing model

The MLMC exposes APIs that allow users or 3rd party systems to discover and retrieve trained ML models which have been previously onboarded on the catalogue, on the basis of functional needs, context characteristics, or capability constraints from target deployment environments.

Searching can be performed following different criteria and modes. Using a search on keywords or metadata, the users can query the catalogue using attributes of the ML model, e.g., name, type (e.g., classification, forecasting, …), knowledge domain, input and output format, licenses, performance metrics, etc. The attributes are defined in the metadata associated to the model and they can be used for filtering or prioritizing the results.

Models of the same type can be classified based on their version. This allows the system to keep track of different trainings or configurations, also ensuring the reproducibility and traceability of deployments. In some cases, the model metadata also provide a link to the dataset used to train the model for reproducibility purposes.

The result of a model query provides the ID of the model and its metadata, optionally with just a subset of attributes, together with the link to the model URL. The URL can be used to manually download the model from the file repository (local or remote) where it is stored or it can be referred to in further steps of an AI/ML pipeline, e.g., to deploy the model in a testing or operational environment for validation or inference phases. This latter case is typically used in MLOps workflows, where catalogue search via REST or gRPC APIs are integrated into CI/CD pipelines.

5.3.14 Training a model at the edge closer to the data source (FL)

The MLMTE is the MLOps platform function entity responsible for the training of an AI/ML model on a given dataset. The MLOps pipeline can be configured to train the model in a pre-defined location, e.g., in a centralized data center, or the selection of the target node can be done dynamically for each training request based on different criteria. In particular, for scenarios where bandwidth constraints or data privacy are particularly critical, it may be convenient to train the model at the edge, closer to where the data are generated or stored.

Raw data collected from sensors or devices on field are sent to edge nodes, where they are pre-processed and directly ingested in the training stage locally, reducing the transmission overhead and guaranteeing privacy. When combined with FL, the model updates trained locally are then exchanged with a centralized aggregator, usually running in the cloud, that merges the contributions from multiple FL clients and redistributes the models back to the clients until convergence. This approach has the advantage of enabling collaboration between multiple training points, while preserving data confidentiality and limiting the amount of traffic, since only model updates are exchanged, not the original datasets.

5.3.15 Querying an AI/ML model (inference)

In MLOps pipelines, the query and deployment of an AI/ML model allow to make trained models available for the inference in production environments. Trained models are packaged as containers (e.g., Docker) and deployed via orchestration platforms (e.g., Kubernetes or Kubeflow) in the target environment. The

containerization ensures the models portability across different settings, from cloud and edge, up to on-premises deployments. Once deployed, the models can expose APIs to allow third party applications to consume the inference services in a well-documented and unified manner.

The decision on where to deploy a model for the inference phase may depend on multiple factors and requirements, e.g., latency, privacy, bandwidth constraints, as well as placement of data sources and/or data storages and computing capabilities. The internal logic of the MLOps platform, in combination with the resource orchestrator, automates the placement based on service requirements and availability of computing resources in the edge/cloud continuum.

Once the models are deployed, they are continuously monitored for both resource-related performance (e.g., inference latency, throughput, resource utilization) and model-related performance (e.g., for accuracy to detect potential drifts). Feedback pipelines process these performance metrics and can trigger retraining or rollback where needed.

5.3.16 Discovery and invocation of IoT Services Through IoT Service Registry

A vertical IoT management application is deployed which, instead of being hardcoded to specific sensors, queries the IoT Service Registry to dynamically discover all sensors available within a given IoT environment. The registry, which maintains semantically descriptions of all registered IoT services, responds with a list of temperature sensing services that match the criteria, e.g., real-time data streaming, active status and location-specific context. The application selects the services and retrieves details such as APIs, supported protocols, and data formats. Using this, it subscribes to specific IoT services. This process allows the application to dynamically compose its monitoring functions based on available services, without prior knowledge of the devices. It ensures also interoperability across devices and domains, enabling adaptation to change such as new devices being added or others going offline.

The IoT service registry in coordination with the *IoT Exposure Function (IOT-EF)*, message queue factory and IoT resource Registry facilitated the discovery and invocation, supporting scalable and flexible IoT integration.

5.3.17 A vertical Registers IoT devices and services via IoT Exposure Function into IoT Resource Registry and IoT Service Registry

A Vertical registers its IoT devices and services through the IOT-EF, which abstracts device specific details and standardizes access. The registration populates the IoT resource registry with device details and the IoT service registry with service descriptions, allowing discovery, orchestration and server interaction across the IoT ecosystem.

5.3.18 Remote Actuation of IoT Devices

Remote actuation of IoT devices, such as cranes, robots, vehicles enable real-time control over distributed physical systems. At the core of this capability is the IOT-EF, which serves as a secure and abstracted interface through which external applications or control systems can interact with devices. The exposure function presents APIs or service interfaces that simplifies access. Before command control is issued, the system needs to determine whether the desired actuation capability exists within the available IoT infrastructure. This is handled by the IoT Service discovery which allows the system to query the environment and discover devices and supported functions. Once a desired device and function are identified the command is transmitted, and at the device end, the command is received though 5G enabled modem or gateway which may be embedded directly into e.g., the robot, crane or actuation control. The command is then parsed and executed by the device's control software, which has been identified by the IoT Service discovery. The message queue ensures that messages are properly sequenced, retained if necessary and acknowledged by the device. Digital twin components may be

used to simulate and validate actuation commands before execution. Running the actuation command in this virtual environment first, the system can detect potential problems.

5.3.19 Event-Driven Communication setup using Message Queue Factory

After registering through the IoT EF, IoT devices and virtual entities populate the IoT-RReg and IoT-SReg. This enables vertical applications to subscribe to specific data streams or events (e.g., temperature, motion detection). The request is handled though semantic discovery in the IOT-SReg. Then the message queue factory dynamically instantiate a queue (or event topic) tied to the relevant data source, using protocols like MQTT (or *Advanced Message Queue Protocol (AMQP)*), with support to time-series database when required. Then the data is used for different applications and is integrated with VE Service Orchestration that ensure that the data is forwarded to the right VE or service. This data is transmitted in near real-time, and the consumers can use it in DTs, for visualization or simulation, for AI/ML for anomaly detection or forecasting or to remote actuators to trigger automated control.

5.3.20 A vertical performs remote teleoperation over constrained network conditions via IoT Exposure Function

A vertical is performing remote teleoperation – controlling physical devices, (robots, drones, vehicles) from a distance where constrained or challenging network conditions (low bandwidth, high latency, intermittent coverage). In this scenario, the IoT exposure Function provides low-latency access to remote actuators using REST APIS, or pub/sub models. Network slicing is instantiated for the vertical with tailored QoS parameters. The feedback loop is established where commands are sent to the physical entity, and its real-world state is observed (via sensors) where is updated in the DT. The Digital twin and the feedback loop allow the mapping of a physical actuator to its software representation. The DT registry supports identification and binding of remote-controlled physical entities with their digital representation, enabling real-time synchronization and control coordination.

5.3.21 A vertical monitors mobility and proximity for dynamic service adaptation.

Using the *Position Acquisition Engine (PAE)*, the system tracks the movement of assets, e.g., vehicles, robots, mobile sensors). The Mobility Context provider interprets patterns (e.g., congestion) and shares context with cooperative engine. The engine enables adaptative behavior such as re-routing, of localized data processing.

6 Deployment view

We propose in this section two deployment views focusing on different aspects:

1. Platform deployment strategies and impacts on related business models;
2. A generic network deployment view which -as the name suggests- mostly focusses on connectivity aspects.

6.1 Platform deployment strategies

We develop and describe hereafter different deployment strategies for AMAZING-6G, with regard to 1/ the supporting 5G system and 2/ the Vertical.

6.1.1 Bound to 5G MNO in "loose coupling" mode

In this mode, the two systems are separated from the administrative point of view, however they collaborate in such a way the combination of the two bound entities behaves from the point of view of a Vertical, as a B5G/6G system; B5G/6G meaning here a 5G system which is augmented with smart additional Vertical-empowering enablers coming from AMAZING-6G.

Because the two systems are separated entities, acting as two distinct actors, any business model involving a Vertical, results into 3 occurrences of bi-partite collaborations with each of them having its own business impacts (typically, cost assessment, ticketing, billing):

- *Vertical ⟷AMAZING-6G:* AMAZING-6G acts as a front-end for NSaaS, CEaaS and main actor for any other services such CaaS, AIML and IoT support;
- *Vertical ⟷5G MNO:* Vertical's UEs (standard smartphone, 5G models and NR RedCap modems) have access to cellular communication via the MNO RAN (with SIM Cards delivered by the MNO as well) and eventually dedicated slices;
- *AMAZING-6G ⟷MNO:* when negotiating NSaaS with the Vertical, background negotiation takes place between the AMAZING-6G and the MNO. This happens because AMAZING-6G is not under the MNO administration, and as a consequence, AMAZING-6G should not be authorized to create network slices "at will" without proper negotiation, pricing establishment and authorization with/from the MNO, the owner of the 5G system.

From the deployment point of view, FCs are deployed to the AMAZING-6G own servers and possibly to Vertical-owned compute nodes depending on both 1/ the context (subscribed services, agreed terms,...) and 2/ deployment policies. Those compute nodes are also used for hosting any Vertical services (μS) that are subject to deployment by AMAZING-6G in the context of a CaaS subscription. As we saw earlier, based on a declared deployment policy, the CDM computes an optimized deployment of the Vertical μSs and as a result they get distributed towards different (edge) nodes, some of them (if any) owned by the Vertical, others owned and managed by AMAZING-6G.

Beside the deployment of μSs, some AMAZING-6G FCs must be deployed to the Vertical-owned (edge) compute node(s) as well, in order 1/ to support SLA-compliant XaaS delivery(ies) and 2/ SLA enforcement.

In order to deliver low-latency communication in loose-coupling mode, it is utterly important that AMAZING-6G system is deployed as close as possible to the 5G system UPF or connected to it through very high-speed networking.

6.1.2 Bound to 5G MNO in "tight coupling" mode

In tight coupling mode, AMAZING-6G and the supporting 5G system are -from the Vertical point of view- a single administrative entity: the B5G/6G system they will rely on to support their businesses.

Naturally, from the 3 bi-partite collaborations described above in the loose-coupling mode, only one survives:

- *Vertical ←→ 6G MNO (5G MNO augmented with AMAZING-6G):* Vertical UEs (standard smartphone, 5G models and NR RedCap modems) have access to cellular communication via the MNO RAN (with SIM cards delivered by the MNO as well).

As a consequence, the AMAZING-6G cloud disappears as a separate entity, and all AMAZING-6G enablers are deployed at the MNO cloud side. Of course, having µSs deployed closer to the UPF is no more an issue.

6.1.3 Deployed as a standalone and sizeable supporting enabling platform

The same way a Vertical business can deploy its own *Non-Public Network (NPN)*, deploying a subset (possibly the full set) of AMAZING-6G enablers can be done too, focusing on the services and related-FCs which matter to the Vertical business only.

The context view of Use Case P1 (see Section 4.3) shows a few PPDR-flavored examples of how AMAZING-6G can be deployed depending on the context involving NPN (5G-in-a-box), NTN and 5G systems in various configurations

6.2 Generic Network Deployment view

The following Figure 45 shows a generic deployment view of AMAZING-6G, focusing mainly of the 1/ integration with the legacy 5G system and supporting NTN and 2/ on networking (from the Vertical point of view). A short description of the main areas of the figure follows:

- *5G Core:* it shows the main network functions of the control plane and user plane. The Database plane shows a few registries used by the NSDM & CSO when provisioning Vertical-customized network slices;
- *5G RAN:* the RAN is made of three types of gNBs, standard gNB, IAB-enabled gNB and NR RedCap-enabled gNB. The two additional NR Redcap and IAB gNB can be respectively used by 1/ vertical needing modest throughput and energy efficiency and 2/ PPDR-related Vertical which need IAB-based coverage extension;
- *5G MANO:* the 5G management framework which is used to provision new network slices;
- *AMAZING-6G:* our system that augments the standalone 5G system with Vertical-empowering enablers (only the FCs interacting with the 5G Core are shown);
- *LEO satellite eco-system:* it has been included to this figure because it is used by one UC as satellite access solution providing alternate communication route and backhauling (cf: P1 & P3 Use cases);
- At the bottom, from right to left:
  - *A "generic" PPDR-flavored Vertical Edge Node deployed with three possible accesses:* 1/ 5G, via standard communication with a gNB (depicted with a plain black link), 2/ 5G via one distant IAB-node providing a relay to the (more) distant last standing gNB (shown as a red dash line), and finally 3/ 5G via a satellite (plain blue line). The figure also shows a CPE deployed by first responders, connected to the IAB node; it can provide WIFI-enabled devices or users with communication. In this example, distant users (e.g., User1) can receive notification messages from the PPDR application via normal gNB access, while local users (user0) receive messages via the IAB-node or WIFI, finally a robot gets connected via WIFI too;
  - *A Vertical-Edge Node (or cloud)*: grid powered, with good amount of compute power, able 1/ to run its own applications and 2/ µSs that it choses -through the deployment policy-to be deployed by AMAZING-6G CaaS to its own server. It typically represents a Vertical

back-end declared as "addressable" to CaaS, in addition to its own far-edge nodes too. For GPU intensive processing, some of its µSs can be deployed to AMAZING-6G cloud;

o *A Vertical (Far) Edge node:* it runs on portable battery (low capacity), requiring only modest throughput, therefore using a NR RedCap 5G modem, taking advantage of the NR RedCap technology to reach its energy-efficiency requirements.

The three compute nodes described in this diagram have subscribed to CaaS, which explains why the ESO has been deployed to them. Of course, other components (not shown) are also deployed by default, e.g., the CDT, RDT, NDT that are used 1/ to probe networking and compute efficiency and 2/ to report issues to the ESO, CSO and CDM. There is one deployed ESO per Compute Node made eventually of more than one execution environment(s).

It is worth mentioning also that some of the Context views in Section 4 show some sketch of more specific potential deployments (especially in P2-P4 where NTN is also involved, or E1 where far-edge nodes (dwellings) are used). Those Context views however do not show the deployment of FCs. Those aspects will be covered in next versions of this deliverable.
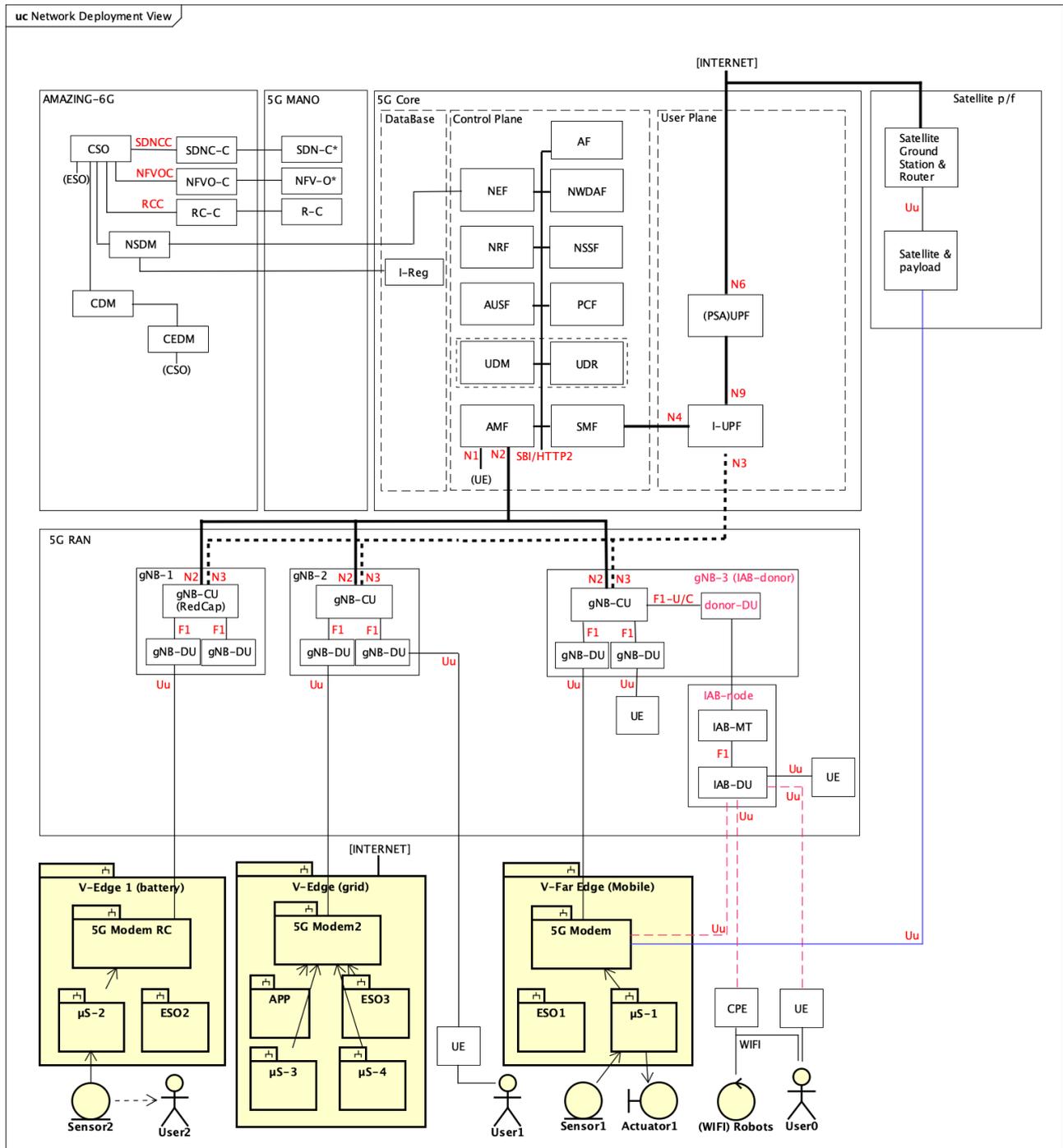
Figure 45: Generic Network Deployment view.

7   Perspectives

7.1   Performance

This first perspective is about system performance. We have identified six different tactics that can help to improve system performance, following five different angles (see the tactics below).

Table 4 below provides a general survey of the Performance perspective objectives, the FREQs it covers and, most importantly, the set of activities and tactics we followed in the AMAZING-6G project as far as performance increase is concerned.

Table 4: Performance Perspective survey.

Targeted System Quality	The ability of the system to predictably execute within its mandated performance profile and to handle increased processing volumes should this occur.
Requirement(s)	NF-1, NF-10, NF-11, NF-12
Activities	- Decrease latency and improve capacity; - Improve energy efficiency; - Improve computing effectiveness and flexibility; - Capture performance indicators; - Monitor performances and enforce SLA; - Keep decision-making and SLA enforcement roles separated; - Perform simulations.
Tactics	1. Providing vertical with a custom network slice that fits its QoS requirements; 2. Taking full advantage of Compute Continuum by balancing intelligence among Edge Nodes/Cloud and within Edge Nodes across multiple execution environments; 3. Migrating Compute unit to the most suitable compute node whenever QoS can't be maintained; 4. Placing Compute unit closer to the UPF for reduced latency; 5. Placing Compute unit in a satellite payload for reduced latency; 6. Ability to extend the network when requested (e.g. PPDR scenario).

7.1.1   Providing Vertical with customized network slice

For cases where Verticals have very specialized networking requirements, AMAZING-6G provides the NSaaS features. Based on the expression of intents, the NSDM component analyzes the networking requirements and provisions a dedicated network slice that ensures the requirements will be met during operations. Of course, this is a business transaction, and it naturally comes with a pricing and an SLA contract agreed between both parties. This SLA is enforced during service operation.

The following set of DCHs (Table 5) covers the 1st "tactics" bullet-point above.

Table 5: Design choices for Vertical-customized network slicing.

Design Choice ID	View	FG/FC	Technical description
PERF-1	Functional	Decision-making/NSDM	Analyzes the Vertical intents and creates NST and NSST templates.
PERF-2	Functional	Network Enabler/CSO	Central Service Orchestrator is used to implement the decision released by the NSDM; it interacts with the Radio, NFV-O and SDN-C connectors in order to provision the slice.
PERF-3	Functional	Radio-, NFV-O- & SDN-C-connectors	They interact with their respective counterparts for RAN configuration, and propagation to NFV-Os (NFs deployment) and SDN-Cs (subnets creation) respectively. Conjugated actions participates to the Network Slice provisioning.

7.1.2 Compute as a Service

CaaS provides intelligent placement of compute units among eligible compute nodes. It constantly monitors their executions and eventually re-distributes tasks depending on ever-changing compute conditions (including available energy).

The following set of DCHs (Table 6) covers the 2nd to 4th "tactics" bullet points.

Table 6: Design choices for compute as a service.

Design Choice ID	View	FG/FC	Technical description
PERF-4	Functional	Decision-making/CDM	The centralized component is responsible for deciding about the placement of tasks among compute nodes. Placement criteria include the type and availability of energy source. For example, if the energy level of a photovoltaic-powered compute node decreases, the system may trigger the temporary migration of a service to a grid-powered node until the original node replenishes its energy level.
PERF-5	Functional	Network Enabler/{CSO,ESO}	A centralized CSO and Edge Node- deployed ESO that are responsible for balancing compute tasks between EEs (inside a give Edge Node) and between Edge Nodes.
PERF-6	Functional	NDT, CDT, RDT	Three Digital Twins that are used by the CDM/ESO/CSO to monitor service execution.
PERF-7	Functional	DP-Rep	A deployment policy repository used to store intelligent deployment policies for Vertical services (used as an input by the CDM).
PERF-8	Deployment Functional	5G Core, Network Enablers	Deployment closer to the UPF as part of the CaaS (the 5G cloud can be addressed by the CDM).

7.1.3 Compute units as Satellite payload

Whenever satellite communication communication/backhauling is used due to a lack /disruption of direct UE-5G system communication, compute tasks (services/μS) can be placed as part of the satellite payload (subject to availability and scenario) to ensure service delivery continuity with minimum latency.

The following set of DCHs (Table 7) covers the 5th "Tactics" bullet-point.

Table 7: Design choices for compute units deployed as satellite payloads.

Design Choice ID	View	FG/FC	Technical description
PERF-9	Deployment	n/a	Deploying the 5G enabled services to satellite payload (in regenerative mode) – in conjunction with PERF-9.
PERF-10	Functional	Decision-making/CDM	CDM must detect the lack of connectivity with the UEs and trigger the deployment of compute tasks towards the payload (depending on available sat-embedded compute resources).

7.1.4 Coverage extension

The ability to extend coverage is a natural way to improve overall performance and availability of Vertical services. It can rely on different technologies, such as CPE for Wi-Fi/5 G bridging or IAB nodes for integrated access (sub-6 GHz) and backhaul (mmWave). They are natural ways of extending quickly network coverage for scenario which are mostly short-lived, such as PPDR or short-term events requiring a very large increase in capacity (e.g., music festival).

The following set of DCHs (Table 8) covers the 6th and last tactics for Performance perspective.

Table 8: Design choices for coverage extension.

Design Choice ID	View	FG/FC	Technical description
PERF-11	Deployment	n/a	Deploying the 5G enabled services to satellite payload (in regenerative mode) – in conjunction with PERF-9
PERF-12	Functional	Decision-making/CDM	CDM must detect the lack of connectivity with the UEs and trigger the deployment of compute tasks towards the payload (depending on available sat-embedded compute resources)

7.2 Energy Efficiency

This second perspective focuses on energy efficiency. We have identified three different tactics that can help to decrease energy consumption or to be energy efficient, following three different angles (see the tactics below).

Table 9 below provides an overview of the objectives of the Energy Efficiency perspective , the FREQs it addresses, and, most importantly, the set of activities and tactics adopted in the AMAZING-6G project regarding energy efficiency.

Table 9: Energy efficiency Perspective survey.

Targeted System Quality	The ability of the targeted system to handle energy consumption and energy source in compute or networking-related decisions, enabling vertical applications to maximize the use of renewable energy without compromising required performance.
Requirement(s)	NF-61 and also F-31 related
Activities	• Downscale 5G throughput to accommodate battery- or solar powered- small devices; • Optimizing energy consumption; • Light-weight protocols over same frequencies; • Use as much renewable energy as possible and rely on compute continuum features to palliate depleted renewable energy level, while maintaining service execution.
Tactics	• Energy level-driven compute task dynamic placement; • Use of reduced capability 5G radio (NR RedCap) in the RAN; • Use of NR RedCap enabled 5G-modem.

The 1st "Tactic" bullet-point is covered by PERF-4→PERF-7 above as 1/ energy levels are tracked down by the RDT and 2/ energy source/level is part of the compute decision-making (dynamic (re) placement of compute units, as explain in greater detail in DCH "PERF-4" above.

The following set of DCHs (Table 10) covers the 2nd and 3rd "Tactics" bullet points.

Table 10: Design choices for NR RedCap.

Design Choice ID	View	FG/FC	Technical description
ENEF-01	Deployment	n/a	Deploying NR RedCap software module to gNBs NR RedCap-enabled (no change in radio)
ENEF-02	Deployment	n/a	To equip small devices (like IoT boards) with NR RedCap modem. Using NR RedCap instead of LTE-M or NB-IoT, provides with higher data rates and advanced capabilities (e.g. robust connection, robust security with authentication, encryption, over-the-air updates, lower latency, etc.)

8 Conclusions

This last section concludes the document and makes a summary of its main achievements:

1. We provided an updated description of the 15 project Use Cases introduced initially in the project proposal (the initial HealthCare was split into two UCs respectively H1 and H2);
2. Those descriptions were complemented in the Context view section, with preliminary High-level design figures, which gave insights about possible designs and helped identifying functional requirements towards AMAZING-6G and 5G systems;
3. The requirement engineering process (collection, unification) was conducted, leading to the Volere template (available for consultation through a URL), that summarizes the project requirements (functional and non-functional) and current progress status. The requirement collection was complemented by the design of UC Context views;
4. A Functional view (Functional model + functional decomposition) was also devised as a result of the requirement engineering process, leading to a set of functional components organized in functional groups which constitutes the very initial AMAZING-6G 6G architecture, aligned with the project vision;
5. In order to complement the functional decomposition and to provide a consistency and completeness check, we identified and detailed a list of system use-cases (involving or not a Vertical), elucidating interactions taking place between components when achieving some selected system behaviors;
6. In the Network Deployment view we discussed two different ways (coupling) for AMAZING-6G platform to interact with a supporting standalone 5G provider, emphasizing some business-related implications. We also provided an overall network deployment figure showing a standalone 5G system and AMAZING-6G, side-by-side, interacting with Vertical applications through the 5G RAN. A simple (bentpipe) LEO satellite system was also introduced as additional connectivity support to PPDR applications;
7. Finally, we devised an initial version of the Perspective section, where perspective are used to process non-functional requirements.

Since this document is only the first iteration of the Requirement and System Architecture document out of three, more content will be available in its next iteration D2.2, the general objective being to always increase the level of detail and level of completeness from one iteration to the next.

Consequently, planned additions for D2.2 include the following:

- The Functional view will be revisited with additional components which were not considered yet in this version of the document. We will alo revisit the list of system use-cases and complement them with sequence diagrams;
- We will introduce an initial version of the Information view, where we will provide logical interfaces for selected functional components;
- We will extend the Deployment view, with more domain-focussed deployment scenarios (e.g., PPDR);
- We will provide an Instantiation view where will be shown how the enablers developed in WP3 can be mapped to the logical functional components of the logical architecture;
- We will extend the Perspective section with more non-functional properties (as only Performance and Energy-efficiency were addressed in D2.1);

As concluding remarks, we can emphasize that:

1. Despite the fact that this architecture is highly focused on the project technology pillars, namely, networking and compute continuums and AI/ML & IoT support, we took an holistic approach when designing the architecture, introducing aspects (therefore additional functional components) which are outside the scope of the project technical objectives. Those additional

       components will either stay at a logical level (no existing implementation, but existing logical interface) or be based on open source components (typically security-related functionalities);

2. As already discussed in the document, the architecture will not put any assumption or constraint on component implementations. However, it will ensure that the proposed logical interfaces are alligned with the concrete interfaces of the enablers implemented in WP3;

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