DEDICAT 6G: Dynamic coverage Extension and Distributed Intelligence for human Centric Applications with assured security, privacy and Trust: from 5G to 6G

Deliverable D6.2
Second Integration and
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List of Acronyms and Abbreviations

Acronym/Abbreviation	Definition
2D	Two-dimensional
3D	Three-dimensional
3GPP	Third Generation Partnership Project
5G	Fifth-generation wireless
5GC	5G Core
5GTN	5G Test Network
6G	Sixth-generation wireless
AGV	Automated Guided Vehicle
AI	Artificial Intelligence
a.k.a.	Also known as
API	Application Programming Interface
AR	Augmented Reality
ARM	Advanced RISC Machines
BLE	Bluetooth Low Energy
BS	Base Station
CAGR	Compound Annual Growth Rate
CE	Coverage Extension
CEaaS	Coverage Extension as a Service
CEDM	Coverage Extension Decision Making
CPU	Central Processing Unit
DB	Database
DDS	Data Distribution Service
DIKW	Data Information Knowledge Wisdom
DL	Downlink
DM	Decision Making
DMP	Data Marketplace
DoA	Description of Action
E2E	End-to-End
EC	Edge Computing
EE	Execution Environment

EN	Edge Node
eNB	Evolved NodeB
ESM	Emulated Shared Memory
FC	Functional component
FG	Functional group
FGPA	Field Programmable Gate Array
gNB	Next Generation NodeB
GNSS	Global Navigation Satellite System
GPP	General Purpose Processor
GPS	Global Positioning System
GUI	Graphical User Interface
HARQ	Hybrid Automatic Repeat reQuest
HLS	HTTP Live Streaming
HTTP	Hypertext Transfer Protocol
HW	Hardware
IAB	Integrated Access and Backhaul
IAB-DU	IAB-Distributed Unit
IAB-MT	IAB-Mobile Termination
ICMP	Internet Control Message Protocol
ID	Intelligence Distribution
IDaaS	Information Distribution as a Service
IDDM	Intelligence Distribution Decision Making
IoT	Internet of Things
IMU	Inertial Measurement Unit
KPI	Key Performance Indicator
LDM	Local Dynamic Map
LIDAR	Laser Imaging, Detection, and Ranging
LTE	Long Term Evolution
M	Milestone
MA	Mobile Asset
MAP	Mobile Access Point
MC	Mission Critical
MC-DATA	Mission Critical – multimedia Data service
MC-PTT	Mission Critical – Push to Talk

MC-VIDEO	Mission Critical – Video service
MCS	Mission Critical Services
MCX	Mission Critical Services
MEC	Multi-Access Edge Computing
MIMD	Multiple Instruction Multiple Data
MIMO	Multiple-Input Multiple-Output
MPEG-DASH	Dynamic Adaptive Streaming over HTTP
MQTT	Message Queuing Telemetry Transport
MSC	Mass Storage Class
NEF	Network Exposure Function (5G Core component)
NS	Network Slice
NSA	Non-Standalone
NF	Network Function
NFV	Network Functions Virtualization
NFV-O	NFV Orchestrator
NO	Network Operation
NODM	Network Operation Decision Making
NW	Network
NWDAF	Network Data Analytics Function (5G Core component)
OBU	On-Board Unit
PLR	Packet Loss Rate
PoC	Proof of Concept
PoI	Point of Interest
PPDR	Public Protection and Disaster Relief
PS	Physical System
QoS	Quality of Service
QR	Quick Response
RAM	Random Access Memory
RAN	Radio Access Network
RAT	Radio Access Technology
REST	Representational State Transfer
RISC	Reduced Instruction Set Computer
ROS	Robot Operating System
RSSI	Received Signal Strength Indicator

RSU	Road Side Unit
SA	Standalone
SDN	Software Defined Network
SDN-C	SDN - Controller
SDR	Software Defined Radio
SIMD	Single Instruction Multiple Data
SLA	Service Level Agreement
SNR	Signal to Noise Ratio
SUC	System Use Case
SW	Software
TCF	Thick Control Flow
UAV	Unmanned Aerial Vehicle
UC	Use Case
UDP	User Datagram Protocol
UE	User Equipment
UEDM	User Equipment (UE/BS/MAP association) Decision Making
UL	Uplink
UML	Unified Modelling Language
USB	Universal Serial Bus
USRP	Universal Software Radio Peripheral
V2I	Vehicle to infrastructure
V2V	Vehicle to vehicle
V2X	Vehicle to everything
VM	Virtual Machine
VR	Virtual Reality
VRU	Vulnerable Road User
XR	Extended Reality
µS	Microservice

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Executive Summary

This deliverable provides an intermediate status on the DEDICAT 6G platform integration, including logical perspective based on inputs from WP2 and components perspective based on inputs from WP3, WP4 and WP5, as well as the preliminary validation results.

The evaluation is done for the four use cases proposed in DEDCIAT 6G:

1. Smart warehousing covers the trustworthy automated real-time monitoring, surveillance, and optimized operation of a warehouse;
2. Enhanced experience provides live streaming applications that use enhanced data overlay in 360°, Augmented Reality (AR) applications and Virtual Reality (VR);
3. Public safety (Public Protection and Disaster Relief, PPDR) aims to showcase how resilience of critical communications can be enforced through DEDICAT 6G solutions and how human security can be protected in extreme situations;
4. Smart highway demonstrates how connected and autonomous mobility can benefit from Beyond 5G (B5G) and 6G connectivity.

This deliverable focuses on the updated integration of the mechanisms developed in WP3, WP4 and WP5 into an overall working DEDICAT 6G platform presenting the different use cases. Each use case presents an updated overview on implementation of novel interaction between human and digital systems offered to the end-users.

This document reports the first evaluations done of the different components of the DEDICAT 6G platform and comments on the preliminary results. The final evaluation and showcasing will be concluded in the deliverable D6.3 at M36.

1 Introduction

1.1 Scope

This deliverable D6.2 provides a status overview on integration of the mechanisms (developed in WP3, WP4 and WP5) based on the architecture (defined in WP2) and a status on intermediate validation results, which have started with the task T6.1 in month M08.

Deliverable D6.2 outlines first evaluation executed within the task T6.2 "Pilot studies execution and validation" which has started on month M15 and updates on use case specific software components definition and implementation.

It addresses the planning and operational requirements of the evaluation and the development, integration and deployment of use case specific software components and implementation of relevant simulations. The deliverable D6.1, entitles "Integration, pilot set-up, human-centric applications and validation plan", outlines the integration setup, the implementation of human-centric application and the planning of the project during the first period of the project. Finally, it defines the final validation plan for the pilots including the scope of the validation activities, the list of metrics/KPIs to be evaluated and the methods to get these measures for the third year of the project execution.

1.2 Structure

Section 2 provides a description of DEDICAT 6G platform integration overview described in D2.2 and a description of the overall logical platform architecture and its interaction with 5G systems defined in D2.4 [1]. It also summarizes the different mechanisms described in D3.2 [6], in D4.2 [7] and in D5.2 [8] and reports on first evaluation of these mechanisms.

Section 3, Section 4, Section 5 and Section 6 present an overall description of, respectively Use Cases, UC1 – Smart warehousing, UC2 – Enhanced experience, UC3 – Public safety and UC4 – Smart highway, scenarios and detailed stories. Furthermore, each of these sections describes for each Use Case the human centric applications/services by integrating innovative interfaces, such as robots. Each of these sections reports on first evaluation performed during the period M15-M24.

Section 7 describes the final planning for all Use Cases and the objectives of setup, showcasing and evaluation.

Section 8 concludes the deliverable.

2 Platform integration overview

2.1 Logical overview

In D2.4 [1], a Functional Model and a Functional Decomposition have been elucidated and proposed. While the Functional Model focuses on a layered approach, in organizing classes of functionalities with regard to their inherent focuses and roles they partake within the Platform, the Functional Decomposition provides a catalogue of *Functional Components (FCs)* that populated those layers (a.k.a. *Functional Groups (FGs)*). This functional decomposition offers a **logical** view of which functionalities are needed in the DEDICAT 6G platform in order to fulfil the project technical objectives. In addition, D2.4 provides precise interfaces for the vast majority of the FCs.

When it comes to implementing the platform, the resulting software classes / libraries / modules (say- entities) may differ from the catalogue of FCs introduced by the functional decomposition. Typically, there won't be a 1-to-1 mapping between FCs and implemented software entities, as in the scope of WP6. In DEDICAT 6G, we will primarily focus on essential FCs that are necessary to underpin the 4 project Use Cases; this, obviously, includes all functionalities which are part of the 3 project Pillars/Key Enablers as introduced in the project *Description of Action (DoA) (namely Intelligence Distribution (WP3), Coverage Extension (WP4) and Security, Privacy and Trust (WP5))*. However, the behaviours of those implemented functionalities must be compliant with the behaviours of the logical counter-part FCs they are implementing, as elucidated in D2.4v2 [1] *System Use Cases (SUC)*. The interface they implement must also be compliant with the logical interfaces described in the architecture document (which on purpose, remains language independent).

The aim of this Section 2.1 is then to illustrate and explain this functional decomposition and to introduce the reader to the principles and concepts followed in the DEDICAT 6G architecture work.

We will also refer in the following text to the *Data-Information-Knowledge-Wisdom (DIKW)* pyramid model[1] which is sometimes used to show how initial raw data can be enriched/enhanced before ultimately reaching the latest step where decisions are undertaken (Wisdom).

The general way the platform is operating complies with the well-known *Sense-Awareness-Analyse & Decide-Act* loop where:

- **"Sensing":** is undertaken mostly by agents scattered at the Edge/Far Edge, but also at the 5G System side (NEF, NWDAF), that aim at collecting raw Data (the D in DIKW), adding also some useful meta-data reaching the "I (information)" level of the DIKW model; that information is then forwarded to the next layer (see below);
- **"Awareness":** is about the collection, aggregation and analysis of information received from the myriad of agents introduced above. They aim to build contexts for the components of the *Decision Making (DM)* FG to use; here we reach the K (knowledge) level of DIKW model. It is worth noting also that different sorts of agents and aggregators are used depending on the nature of the initial raw data. Consequently, we will be dealing with *Network (NW)*, *Mobile Access Point (MAP)*, *User Equipment (UE)*, Edge Node, *Micro-services (µS)*/FC-related contexts which are in turn used by the various DM components depending on their roles and inner goals. Designing

[1] https://en.wikipedia.org/wiki/DIKW_pyramid

this layer and structuring contexts are paramount as they are expected to characterize the environment as a whole without discarding essential information to be used in the next steps of the loop;

- **"Analysing & Deciding":** is naturally undertaken by the DM components. Based on contexts that give an overall (but still precise with good granularity level) "picture" of the whole system being monitored (in that precise case, the DEDICAT 6G platform including the edges and the supporting legacy 5G network) the service logics embedded in the DM components take decision according to their inner objectives (reaching then the "Wisdom" level of the DIKW model). Such objectives are e.g., maintaining appropriate quality of service (QoS), palliating equipment failure, answering an optimization recommendation, providing a service to a vertical etc. What will make the difference between a proactive or reactive DM, depends on how the DM logic is built: if this logic is driven by recurring goals and issues actions (intents) based on internal beliefs embodied into contexts, the behaviour of the DM can be seen as "pro-active". If its service logic is driven by incoming events and implemented as a rather static set of rules, it would be considered "reactive". Of course, adopting a hybrid architecture approach -like we do in DEDICAT 6G- is also feasible and sound;
- **"Acting":** this final step of the loop implements the decisions undertaken by the DMs and is taken care of by several components that are either hosted in the cloud or deployed towards the Edge/Far Edge.

Figure 1 focuses on the DM components, elucidating most of the interactions existing between the "Analysing & Deciding" layer (hosting the DM FCs) and the underpinning "Awareness" (aggregators only) and "Act" layers. Other FCs which provide essential additional information (mainly registries) to the DM process are also shown.

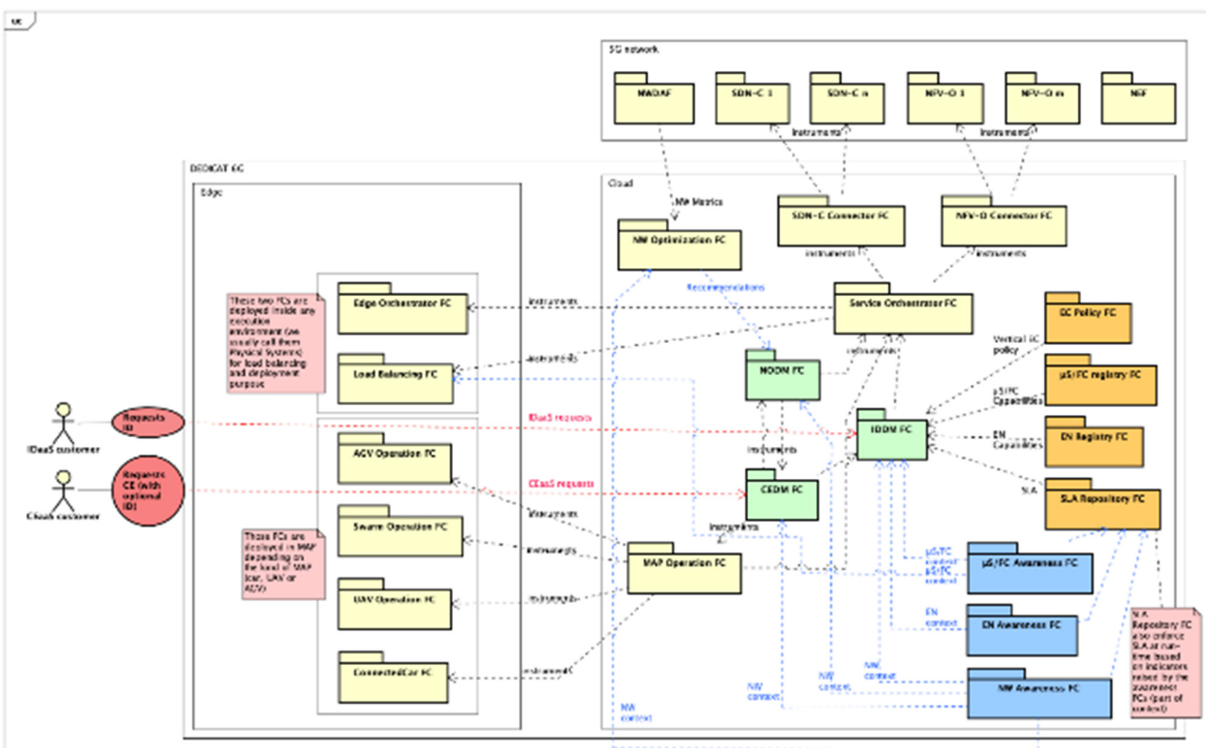


Figure 1: Decision Making and its interactions

In Figure 1 we can see that the three Decision Making (DM) modules (in green) are interacting with each other following a "separation-of-duties" principle. The reason for that is that if two different DMs taking their knowledge from the same source would perform independently and especially differently some Decision Making activities, most likely two different sets of actions would be issued, resulting in interferences.

Consequently, and as an example, whenever the *Coverage Extension Decision Making (CEDM)* FC is triggered by a *Coverage Extension as a Service (CEaaS*) request from a vertical, the CEDM FC will focus on *Coverage Extension (CE)* matters only and rely on the *Intelligence Distribution Decision Making (IDDM)* FC for the *Intelligence Distribution (ID*) part (if any) of the CEaaS request. In the same way, if the *Network Operation Decision Making (NODM)* FC detects some equipment failure which potentially needs CE, it will rely on the CEDM FC to cover that aspect. Finally, if a CEaaS request involves network slicing aspects, the MAP operation FC (which is ultimately responsible for implementing the decision taken by the CEDM) will be responsible for establishing a network slice (using the Service Orchestrator and NFV/SDN Connector FCs) and configuring the MAPs (from the NF point of view.

This next paragraph elucidates the various FCs involved in that figure and outlines their roles:

- **"Awareness"** (in blue): those components aggregate information into a context that can be used by the DM. It is based on information received from the relating agents:
  - µS/FC Awareness: focuses on µS and FC at run time (how much resources are used);
  - *Edge Node (EN)* Awareness: focuses on Edge Node and their status in terms of available resources (CPU, RAM, Disk...);
  - *Network (NW)* Awareness: focuses on networking aspects (throughput, capacity, QoS…);
  - *User Equipment (UE)* Awareness: focusses on UE-related information (e.g., perceived signal strength per Base Station (BS)/*Mobile Access Point (MAP))*.

  Typically, from the two first awareness components it can be deduced 1/ that a EN runs out of resources 2/ that an *Execution Environment (EE)* needs to be reconfigured or 3/ that some µSs/FCs need to be scaled-up and/or migrated to another EE.

- **"Analyzing & Deciding"** (in green):
  - *NODM FC:* the NODM is responsible for monitoring the networking aspects (based on context and Network Optimization-issued recommendations) and may trigger the CEDM if the result of its inner analysis suggests that CE is needed. In other cases, it will interact with the 5G legacy system;
  - *IDDM FC*: The IDDM FC primary objective is to find the optimal allocation of Tasks (e.g., FC or µS) to Edge Nodes depending mainly on µS/FC and EN contexts. It is also responsible for implementing an IDaaS request. Part of its duties is also the scaling-up or migration of already deployed tasks. Depending on execution indicators it can be decided, for instance, to duplicate or migrate a deployed µS or FC from one EE to another, which in turn can also involve changing from one edge Node (a physical system) to another;
  - *CEDM FC*: The CEDM FC objective is to decide about the physical deployment of 5G-enabled MAP in order to either implement a CEaaS service or to overcome an occurring problem relating to e.g., coverage, capacity, QoS (the WP6 features a quite comprehensive collection of scenarios where such issues can arise). The CEDM FC mostly relies on the MAP Operation FC which is the

entity responsible for implementing the CEDM FC's decisions. The MAP Operation FC in turn, relies from the CE operation point of view on various kinds of MAPs such as AGVs (Robots), UAVs (drones) and Connected Cars, as instructed by the CEDM FC. The CEDM FC delegates to the IDDM FC all aspects involving the deployment of µSs or FCs to those MAPs (which are also Edge nodes); The CEDM FC continuously monitors the network performance and therefore may reconsider and modify existing MAP deployments at any time;

  - *UE/{BS/MAP} Association Decision Making (UEDM):* the UEDM FC (not shown in the figures) is responsible for managing the multiple associations existing between a UE and its surrounding MAPs and BSs; this component is deployed in every UE.

- **"Acting"** (in yellow): those components are in charge of implementing the decision taken by the DM process.
  - *ID related*: Load Balancing FC, Service Orchestrator FC and Edge Orchestrator FC are responsible for balancing the execution load inside an EE, between several EEs in an edge Node or even between EEs belonging to different edge nodes; the goal being to provide an optimized and fair distribution of tasks between the EEs and to make sure all FCs or µSs are executed appropriately according to their requirements (see µS/FC registry) and the agreed *Service Level Agreements (SLA)* (if any).
  - *Network Slicing related:* the The MAP Operation requests the Service Orchestrator to characterize a new network slice in term of a set of subnets (with their own deployed Network Functions) and routing between subnets according to the performance requirements in term of latency, throughput, etc. The two NFV-O and SDN-C Connectors are used to support the Service Orchestrator FC when creating the new slice or expending an existing slice (more detail about that process is available in D2.4v2);
  - *CE related*: a collection of FCs is used to implement (at various stages) the CEDM FC decisions:
    - *MAP Operation FC:* as we have seen previously, this component is the main entry point to CE operation. It is responsible for the MAP configuration, as far as deploying Network Functions is concerned, and for the provisioning of needed network slice(s) (with the option of either creating a new dedicated slice or expending an existing one so that it can integrate new MAPs);
    - UAV Operation FC deals with drone operation where each drone is explicitly addressed;
    - Swarm Operation FC provides a high level of autonomy. Drones are able then to spatially organize themselves in order to provide better coverage of a designated geographical area;
    - AGV Operation FC: provides the basic management of robots and provides a basic palette of so-called atomic actions it can perform. Those atomic actions are then played with, in order to build more complex capabilities (e.g., in UC1 with identifying parcels and moving them from A to B with obstacle avoidance or performing quality checks);

- Connected Car Operation FC: basic management of a non-automatically guided vehicle.

Additional components (in orange) are used to assist the DM process:

- *SLA Repository FC*: encodes an SLA resulting from a negotiation between a DEDICAT 6G platform customer (either CEaaS or IDaaS) and the DEDICAT 6G Platform. This component is also responsible for enforcing SLAs, based on performance indicators brought by the various contexts;
- *EN Registry FC*: contains the characteristics of an edge node with the granularity of the EEs it manages;
- *μS/FC Registry FC*: this essential registry stores the execution requirements for all FCs and μSs that are candidate for deployment at the edge;
- Edge Computing (EC) Policy FC: set up constraints on μSs and FCs deployments (if any);
- *Network Optimization FC*: this component -that belongs to the Analytics FG- performs off-line network performance optimization and issues recommendations to the NODM FC.

We discuss now briefly additional components that are essential in any DEDICAT 6G scenario, but which do not interact directly with the DM components, especially agents, and the way they can be deployed towards the edge.

In the DEDICAT 6G architecture, agents come in different "flavours" still following similar deployment strategies. Some examples of "sensing" FCs are introduced below:

- *μS/FC Status Agent FC*: they are responsible for collecting information about the μS or FC execution;
- *EN Status Agent FC*: they are responsible for collecting information about a particular Edge Node and its execution environment;
- *NW Status Agent FC*: they are -likewise- responsible for collecting information about networking, focusing on performance and operation.

The information they provide to their Awareness FC counterparts is used to build-up contexts as explained earlier. However, they can also be deployed hierarchically (see Figure 2), meaning that before reaching out to their counterpart Awareness components (where the context is actually derived) they may propagate their information to an upper-level similar agent. In that case, that Agent ++ (as depicted in Figure 2) compiles a larger status, needed e.g., locally for Load Balancing purpose.

In the deployment example above, we can see several μS/FC agents (one per EE) reporting partial information from their own EEs to the μS/FC Agent ++ which aggregate it in the same data format. That one in turn provides a bigger view (still at the information level) to the Load Balancing FC which -in this deployment case- is responsible for balancing execution load in both *Physical Systems (PS)*, even if residing primarily in PS#1. Of course, there could be also one dedicated Load Balancing FC taking care of PS#2 alone.

Each μS/FC status agent senses any other executed entity within its own EE, including itself (and other agents) since it is an executed entity too and therefore consumes its own amount of computing resources.

A hierarchy of orchestrators is also illustrated in the figure above. The Service Orchestrator residing in the cloud -say the master orchestrator- is instrumenting Edge Orchestrators (only one in that figure) and also both *Network Functions Virtualization – Orchestrator (NFV-O) and*

Software Defined Network – Controller (SDN-C) connectors- Orchestrator which are then interacting with their 5G system counterparts for creating new network slices or extending existing ones.

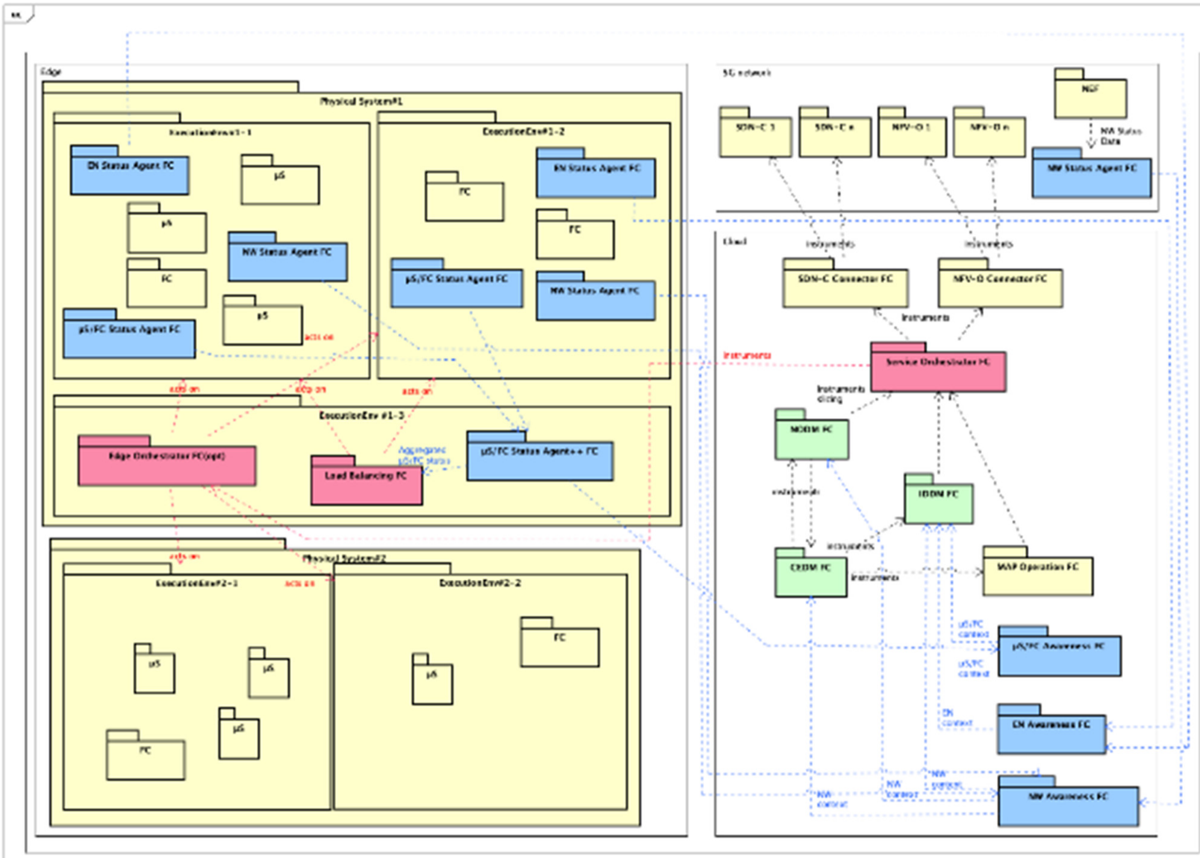


Figure 2: Hierarchies of agents as used for Edge Computing purpose

A 3GPP compliant figure in the Deployment view of D2.4v2 [1], shows in much more detail how DEDICAT 6G interacts with the existing 5G system for the sake of coverage extension.

As a final remark, it has probably been noticed that we have not explicitly shown Security Privacy and Trust components in the two figures above. As a matter of fact, most of those essential components work in the background and are not necessarily noticed by the Use Case, even if extremely important for its implementation and safe operation. However, we can mention a few components which are defined in D2.2 and also shown in some of the UML diagrams of D2.3 [2]:

- AuthN, AuthZ FCs: which respectively provide respectively both local or platform-wise authentication and access control (AuthoriZation). Local authentication and access control mean that those components would be deployed at the edge to serve a particular vertical;
- Logging FC: keeps track and store everything about occurring interactions either involving FCs and µSs only or involving human actors as well. In combination with the *Data Marketplace (DMP)*, which is built using a blockchain, non-repudiation can be enforced;
- Data Marketplace FC: it is present literally in any interaction and is used to provide in particular peer-to-peer authentication and access-control. Any interaction, either using *Representational State Transfer (REST) Application Programming Interface (API)* or

Message Queuing Telemetry Transport (MQTT)-like message queues (e.g., used by agents) goes via the DMP and is authorized by the DMP using a so-called dProxy component.

Having introduced the different FCs composing the architecture, we elucidate now some of the mechanisms which are shared by all UCs:

- CEaaS/IDaaS request: such services are requested by a vertical which requires the DEDICAT 6G platform to provide (respectively) Coverage Extension or dynamic intelligence distribution support. The process of requesting such services is widely explained in D2.4 textually and also using precise sequence diagrams. However –in a nutshell- this process consists of:
  1. Invoking the service using a web interface. All parameters which are characterizing the requested service are passed on to the CEDM (for coverage extension) or to the IDDM (when intelligence distribution support is needed but coverage extension not required);
  2. Decision Making FCs analyse the set of parameters (EN provided by the vertical, µS to be deployed, CE parameters like QoS…) feasibility and perform the needed dimensioning (EN, MAP…);
  3. Depending on the conclusion of the previous step, the service is either granted or denied.

  This phase is described in the context of the UC2 in D2.4 [1] Section 4.2.2.1 and in its generic form in the system use-case section of the Functional view (Sections 4.3.4.10, 4.3.4.11 and 4.3.4.12);

- FC and µS deployment: this phase is the result of the IDDM Task--> EN allocation procedure and relies on the Service Orchestrator for its execution. The deployment of FCs and µSs for all UCs is described as a UML diagram in D2.3 [2];
- MAP configuration and *Network Slice (NS)* provisioning: When a CEaaS is requested, DEDICAT 6G Platform needs to make sure that the CE guarantees that the QoS constraints (max latency, min throughput, number of UEs to serve) are compatible with the network capabilities. This is the CEDM responsibility to select a set of MAPs (eventually from different class and in different occurrences) that fits the requested CE characteristics. The CEDM relies on the MAP Operation for the configuration, execution and operation of the CE.
  1. As for MAP configuration the MAP Operation FC relies on the Service Orchestrator (and Edge Orchestrator) for the deployment of the needed network services into the MAP (I.e., IAB-MT and IAB-DU). Doing so, when deployed in the field, those MAPs (then IAB-nodes) are able to connect to their allocated IAB-Donor (located at the gNB side);
  2. As for Network Slice provisioning the MAP Operation FC relies on the service Orchestrator (in its second role) for establishing either the characteristics of a new network slice or the selection of an existing slice that fits the service constraints. In turn the service orchestrator interacts with 5G system components (NFV-O for NF deployment/config and SDN-Cs for subnet creation/config) via the two DEDICAT 6G NFV-O and SDN-C Connectors. As a result, the IAB-donor role (see Section 2.2.2.1) is activated in the gNB(s) that are nearby the MAP deployment site).

  Please refer to D2.4 system use-case Section 4.3.4.3 for detailed explanations concerning MAP configuration and NS provisioning.

- MAP and Network Slice activation/deactivation/termination: those three steps of the NS lifecycle (4^{th} one being provisioning) are controlled by the MAP Operation using the Service Orchestrator and SDN-C/NFV-O Connectors interfaces. Please refer to D2.4 Section 4.3.4.4 for details about the NS life-cycle;

- Dynamic intelligence distribution: the IDDM is responsible for optimizing the deployment of the µS and FCs over a set of edge nodes (typically provided by a vertical, and the characteristics of which are part of the request parameters). The optimization algorithm takes into consideration the EN characteristics, execution constraints from the µS/FC (CPU usage, needed memory, etc...) and various contextual information. The IDDM relies on the Service Orchestrator (in the cloud) and Edge Orchestrator (at the far edge) for distributing the FCs/µSs to the available Execution Environments;
- Load-balancing: this mechanism is implicitly used by all UCs and involves the Service Operation FG components and IDDM. Different scenarios are possible some involving the IDDM if it receives as part of the contextual information alarms relating to degraded execution condition for some FCs/µSs and some relying exclusively on the Edge Orchestrator/Load Balancing FCs (depending of the technologies used). Some FC/µS migration scenarios are shown for all UCs in the D2.3 Document using UML use-cases;
- SLA monitoring: when a vertical is granted a service (either CEaaS or IDaaS) the terms of the service are stored by the SLA Registry FC. This component is also responsible for monitoring independently the execution parameters of the FCs/µSs (and also the network condition) in order to detect possible SLA breach. When such breaches occur, they are logged into a blockchain, and a breach notification is sent to the IDDM and/or CEDM (that includes the proof of breach in the form of a context) in order to request corrective measures. When the conditions return to normal, the resulting context is logged into the blockchain too (as a proof of corrective action). The purpose of the blockchain is to serve as pieces of evidence in case of a dispute being raised between the Vertical and the Service Provider (the DEDICAT 6G platform operator).

2.2 Mechanisms overview

This section summarizes the different mechanisms for supporting dynamic distribution of intelligence described in D3.2 [6], the different mechanisms for dynamic coverage and connectivity presented in D4.2 [7] and the different mechanisms for security, privacy and trust depicted in D5.2 [8]. Those three classes of mechanisms constitute the three Pillars described in the DoA.

2.2.1 Mechanisms for supporting dynamic distribution of intelligence

WP3 addresses the design and development of mechanisms for supporting dynamic distribution of intelligence. It includes architectural techniques for supporting offloading, migration and distribution of computing and communication on processor, storage, and network levels. In order to fulfil the objectives of the project, the DEDICAT 6G platform must enable high availability and quality of service (such as imperceptible end-to-end latency for instance). To this end, it is necessary to move service and network intelligence closer to the end-users. In consequence, intelligence must be distributed towards the edge network, and in order to enable minimal resource consumption, it will be necessary to enable the migration of services at the needed times.

In order to support distribution of intelligence in the network, one needs to divide the intelligence (computation and related communication) to parts (threads, processes, services) that execute in parallel/concurrently in multiple execution units (be they different cores of a processor, different processors of a machine, different machines of a cloudlet, different edge servers of a region in a network, or different nodes of the network in general). The number of computational parts often exceeds the number of execution units introducing the need for multitasking, i.e., sharing one or more units between the parts. Efficient multitasking requires efficient *context switching* between the parts targeted to a single execution unit. If computational parts of a single service are executed in multiple execution units, there is need to perform intercommunication between these parts that can form specific *patterns of computation and communication*. There can be need for *balancing the computational (and communication) load* of the execution units in order to achieve better utilization. One way to do this is to *move computation (threads, processes and services)* between the execution units. Since moving computations translates to communication between execution units, *reducing the state of computation* can increase the performance. If there exist dependencies between the parallel/concurrent parts, one needs to perform *synchronizations* of computation to obtain correct results. If one chooses not to divide the intelligence into parts, the performance will be severely limited. Another dimension of distribution of intelligence is the way how it is done in practice. Does it, e.g., involve programming and if so, how difficult will it be? A metric related to this is called usability or *programmability*. Finally, the *means/algorithms for placing the intelligence* efficiently contribute significantly to how efficient distribution is.

In the following, architectural techniques for improving the behaviour of the system with respect to KPIs and the aspects mentioned above, are considered one by one:

Context switching – Typically, context switching in a *Central Processing Unit (CPU)* relies on interrupting execution of the current thread, waiting until all the operations under execution are completed, saving its registers to the thread table—a data structure keeping the state of the threads while they are not in execution—selecting a new thread for execution, loading the appropriate registers from the thread table and restarting the execution. If the context switching involves changing of the process too, writing to/reading from the process table, flushing resources keeping critical data and setting up memory spaces and privileges are needed.

While all CPUs are capable of executing multitasking operating systems support switching of threads, the latency of thread switching is typically a few hundred clock cycles. This is not a problem when executing independent threads. However, if the threads of the functionality at hands require dense intercommunication, the performance can be catastrophically poor.

The main mechanisms for accelerating context switching include *Multithreading* [9] and *Thick Control Flow (TCF)* execution [10].

Patterns of computation and communication - Patterns of parallel and distributed computation and communication refer to situations where multiple computational threads interact in a regular way that can be seen as a pattern. The most popular patterns include parallel execution, reduction and spreading and permutation. These are used, e.g., in parallel processing and communication, collection of data, multicasting as well as in certain mapping tasks. There exist a few techniques to speed up these patterns: multioperation [11], broadcasting/multicasting, flexible mapping.

Load balancing - Load imbalance is one of the most important reasons of poor utilization of the computational hardware. In a networked computing system, such as DEDICAT 6G, load imbalance can happen, e.g., between the user equipment and the network, between the cloud and edge, or between the edge servers of the same network region. The worst-case scenario for a region of edge servers occurs when a sole server executes everything. Then the execution time of a set of tasks in a region with N servers would be *N* times slower than perfectly balanced execution where all servers run with the full utilization. The main means for load balancing include work sharing, work stealing, moving threads.

Movement of threads - An essential part of computation offloading, functionality migration and load balancing are the movement of actual computational threads and processes.

These include the state of the computation in processor (context) and memory area containing data and executable as well as needed libraries. The baseline technique is to move everything in the computational node to another. The overall latency associated to movement of a thread, set of threads or a process includes the amount of data that needs to be transported, time to move the functionality from one computer to another, downtime needed before a program can be restarted in the target node. These are highly dependent on the part of the network (nodes, routers/switches and communication links) involved in computing and transferring the functionality. More advanced techniques for movement of threads include containers and moving threads [12] [13].

Reducing the state of computation - The state of computation at processor level is directly proportional to the latency of moving/migrating computation in the network. The smaller the state is, the faster the movement gets. The most popular model of Flynn's Taxonomy of parallel execution [14] is the *Multiple Instruction Multiple Data (MIMD)* model. In this model, multiple threads are executed in multiple processor cores in parallel. The main problems of the MIMD execution are that the state of computation is fully replicated for each thread of execution and that providing a (unique) program for each thread can be tedious if the number of threads is high. There exist, however, alternatives to the MIMD model, but they also come with limitations. The most interesting ones include *Single Instruction Multiple Data (SIMD)* [14] and TCF execution [10].

Synchronization - Synchronization is the key mechanism to ensure the correct behaviour of parallel and distributed software at hands in the case of inter-thread dependencies. Unfortunately, in current multicore systems the cost of synchronization can be very high. The main reason for this is the asynchronous nature of execution in multicore CPUs, computers with multiple processor sockets, clusters of computers and especially in the network. A notable fact is that the need for fast and efficient synchronizations is much more stringent in fine-grained parallel computing than in coarse-grained distributed computing that is not supposed to be able to execute fine-grained parallel algorithms efficiently. The low-level mechanisms to support synchronization include barrier synchronization and wave synchronization mechanisms [15][16].

Programmability - A processor can be said to have good programmability if the functionalities can be expressed compactly and naturally without unnecessary architecture-dependent constructs. An important factor of programmability is also portability and ability to retain speedup with respect to the number of execution units among a group of processors using the same paradigm/approach but having different hardware implementation parameters. The main challenges of current systems include the asynchronous nature of execution and sensitivity to non-trivial memory access patterns. Distributed systems, such as regions of edge servers, pose additional challenges to programmability since the latencies are much higher, throughputs much lower than those in clusters or parallel machines. Programmability is an important performance indicator since it is directly proportional to productivity of software development, and thus the cost of the software. A known method to address this challenge is to use *Emulated Shared Memory (ESM)* architecture [16][17].

Placement of data and functionality - The best performance is achieved when the right data is in the right place at the right time since moving both data and computation, i.e., execution of operations takes time. Additional complications come from the fact that the farther away data is from the place where it is needed, the longer time it takes to obtain it and the more dependencies there are, the longer it takes to execute if there are resource limitations. Even more complications can come from possible contention of traffic in the network caused by non-optimal placement of data and functionality in the network, reliability issues potentially requiring resubmissions, protocol issues, deadlocks, livelocks, race conditions, sequentialization, physical defects, noise etc. Current multicore systems are highly sensitive to data and functionality placement. These phenomena are augmented in the distributed computers such as cloudlets and regions of edge servers due to high latencies and limited bandwidths. The main software techniques to reduce the performance penalties are matching the software parallelism with the hardware one and the blocking technique [17].

Placement Algorithms - Another aspect of distribution of intelligence is the choice of where to place the computing tasks or the data. In addition, different services may have different requirements, so the placement algorithms must consider all the service requirements (such as maximum end-to-end latency, or minimum throughput, for instance), along with other constraints such as the limited capacity of the nodes. Finally, the placement algorithms must consider the KPIs defined in WP3, namely energy consumption, QoS, Mission Critical QoS, and Service Reliability, along with Use-Case specific ones.

Our plan is to test these techniques in order to see whether we can achieve any speedup/improvement here that would help us to achieve the ambitious KPI related goals of the project. According to our preliminary tests, many of these techniques appear to improve the performance and thus, allow us to achieve better utilization of edge servers/network nodes of the DEDICAT 6G system. We will report these techniques in more details in Deliverable D3.2.

2.2.2 Mechanisms for dynamic coverage and connectivity extension

DEDICAT 6G project develops dynamic coverage and connectivity extension mechanisms exploiting multiple types of MAPs for covering areas that cannot be easily reached (e.g. hard geo-morphology such as "forest cave"), where infrastructure, or additional capacity is required only for a finite, short amount of time (e.g. moving hotspots like festivals), or where regular network infrastructure has been damaged (e.g. after an emergency like earthquake, fire, terrorist attack). These mechanisms can be triggered by verticals using Coverage Extension as a Service.

Figure 3 illustrates the implementation of DEDICAT 6G framework for CEaaS. One important feature is the context awareness, the ability to monitor what is happening in the network and the system as a whole, to constantly deduce the current status and whether decision making is required. Another important aspect is related to decision making components, to enable the system to make decisions on the MAPs deployment strategies. This includes making decisions about intelligence distribution (i.e. service placement), network operation (i.e. MAP-UE association and RAT selection) and coverage extension (e.g. MAP and swarm operation).

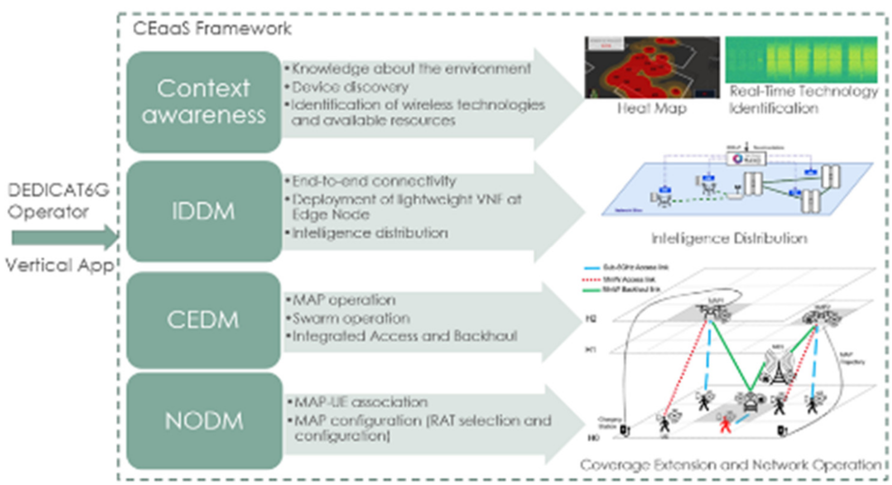


Figure 3: DEDICAT 6G framework for CEaaS

The context and situation awareness FCs contains several functionalities. These modules provide essential information for making decisions exploiting MAPs.

- Device discovery module is based on a new type of enhanced IoT devices estimating the number of users in a coverage area by short-range signal scanning techniques. Thanks to the information monitored and collected by the IoT sensing nodes, the backend of the micro-service generates detection chart reporting the history of device detections that have been performed by each of the nodes and real-time heat maps of the occupation by connected and non-connected users present in the area of interest.
- Technology recognition module can recognize a wide range of wireless technologies operating in the 5.9GHz ITS band (LTE, 5G NR, WiFi, C-V2X PC5 and ITS-G5) and can use the statistics of each identified technology to estimate and predict the traffic characteristics of each technology and to implement flexible and dynamic spectrum management and utilization.
- VRUs tracking module can track the movement of VRUs on the road or obscured subjects in real-time through camera sensors installed in the roadside unit located at an intersection and warns the driver of a hazardous situation via wireless vehicle-based infrastructure communication.

The network operation decision making FC proposes several approaches for MAP/UE association. The first option in a centralized UE association and MAP placement making a trade-off between the network cost minimization (number of MAPs) and user utility (spectral efficiency) maximization in a single framework where user utility is both an optimization constraint and optimization sub-objective. The second option is a distributed UE association and MAP placement deciding the number and the optimal location of MAPs, which maximizes the throughput and ratio of well-deserved users while minimizing the number of drones deployed and the execution time in sub6GHz and mm-wave bands. The last option provides heterogeneous MAP-assisted networks with machine learning to maximize the QoS satisfaction level and the energy efficiency by jointly optimizing user association and power allocation under wireless backhaul link capacity constraint in highly crowded areas with heavy traffic loads. Another network operation decision making functionality is the management and configuration of vehicular based MAPs (i.e. RAT selection and configuration based on MAP capabilities, applications/services traffic demands, and/or identified characteristics of the wireless environment).

The CEDM FC proposes MAP operation managing mobility, swarm operation and Integrated access and backhauling. The MAP mobility management FC proposes an algorithm for robot-based MAPs, finding the path or trajectory that each MAP should follow to reach the target position and the selection of nearby docking/charging stations. When using a fleet of cooperating UAVs, the Swarm Operation FC performs self-organizing functions as an ad hoc network (including access and backhaul links), UAV placement, UAV path optimization to achieve placement within the constraints of the CEDM coverage area, and self-management of resources, including autonomy (e.g. how often and where a UAV should return to its docking station).

The IDDM FC proposes an assistance to Intelligence distribution in the coverage extension. Intelligence is every software-based part that can consume computational resources available at the nodes of a B5G network scheme. Three types of intelligence can be defined: (i) DEDICAT 6G FC instances assisting the placement optimization and deploying concrete FCs instances along the network depending on the needs, (ii) NFV Orchestration of VNFs in the instantiation of network slices to enable end-to-end 5G/B5G connectivity and (iii) verticals apps impacting the coverage extension to guarantee the service.

This CEaaS framework can be optimized specifically for a use-case:

- The context awareness through sensing node network in shared traffic space will improve the network orchestration and increase the safety of people, helping to build reliable maps with the location of VRUs;
- The smart highway strategies will track vulnerable road users with roadside units for smart Highway scenarios and manage and configure vehicular based MAPs that offer multi-RAT capabilities. The objective is to guarantee safety of VRUs and to enable harmless coexistence and incumbent technologies protection;
- For enhanced experience of temporary events, different MAP placement and user association strategies are investigated according to the different characteristics of temporary events, multiuser interference scenarios, and different levels of network topology information;
- For public safety use case, a dedicated mission critical service strategy is investigated to bring critical communications close to the PPDR users and First responders. The objective is to provide on-demand and autonomous network management (i.e., self-configuration, self-healing and self-optimization).

2.2.2.1 Integrated Access and Backhaul platform

In DEDICAT6G, we investigate state-of-the-art mechanisms for dynamic coverage extension. In addition to the strategies presented in D4.1 [4], an additional mechanism is considered: multi-hop backhauling with Integrated Access & Backhaul (IAB). With IAB, both Access and Backhaul links share the same frequency bands. It provides an alternative to optical-fibre backhaul with a cost-effective and rapid deployment over a RAN network. It has been included in Release 16, in 2020 [25].

We can deploy IAB in order to ensure a minimum coverage for each user equipment even in a harsh and dynamic environment. Such approach is particularly interesting:

- To avoid RF blockages with dynamic deployment of APs,
- To quickly deploy a mmWave network over an uncovered area at limited costs,
- To temporarily densify the number of APs without the need of extra optical fibers.

IAB has been proposed with various levels of decentralization. In the project, we consider the standardized version which is depicted in Figure 4. IAB donors are directly connected the Core network and supports Control Unit (CU)-related functions. They usually correspond to fixed APs. IAB nodes support Distributed Unit (DU)-related functions and are linked with IAB donors with a backhaul link. IAB nodes can simultaneously forward the backhaul link and provide access to user terminals (Figure 5).

Considering IAB as a coverage extension mechanism in DEDICAT6G project makes sense as it relies on some project strategies [146/D6.1]. Indeed, first of all the performance achieved by IAB is highly dependent of the context awareness. The knowledge of the coverage quality in real-time is critical in order to anticipate the MAP (IAB donor) deployments. In addition to that, the implementation of IAB we propose rely on Multi-RAT technology with a sub-6GHz and a 26 GHz link. The sub-6GH can be either a WiFi or a 5G 3.5 GHz link and is used for control signals (mainly telemetry between IAB donor and IAB nodes and feedback on user locations) and for low date-rate signals. The feedback of user locations eases the beam steering and avoids the cell search when user equipment wakes up. On the other hand, the mmWave is used for demanding applications (such as HD video streaming). It requires proper beam alignment.

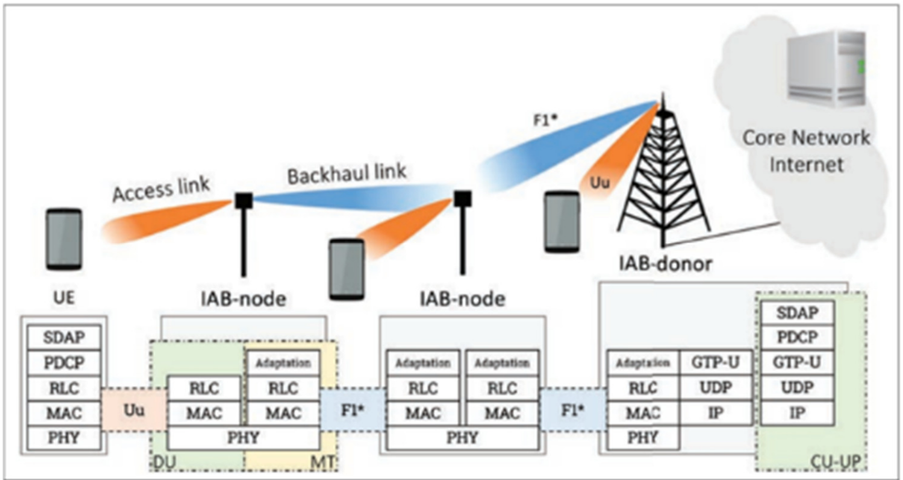


Figure 4: IAB Architecture (from Figure 5).

2.2.2.1.1. Development Status and overview

This paragraph describes the IAB platform developed in the framework of DEDICAT 6G project. The development of the IAB platform takes place into two stages: (i) standalone and (ii) integrated into UC pilots. The standalone version is finalized by end 2022. The last 12 monthes will be dedicated to the performance evaluation and the integration into UC pilots.

The overall set-up is illustrated in Figure 5.

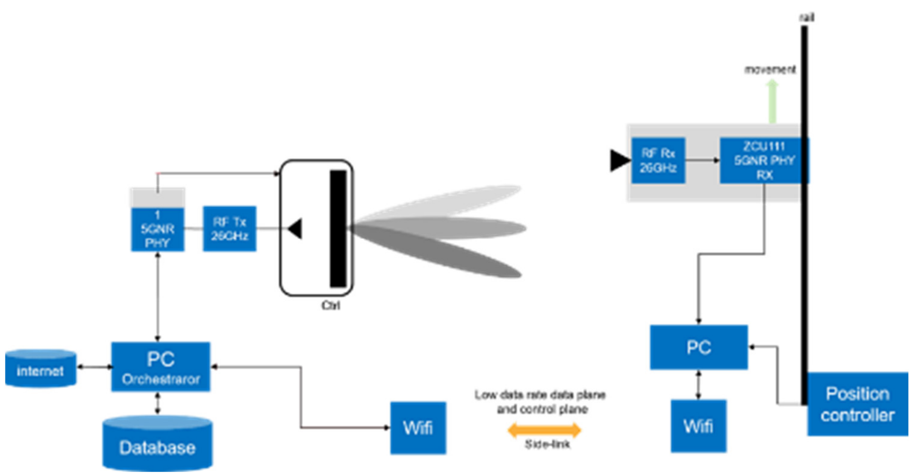


Figure 5: IAB platform overview

Figure 6 depicts the architectural overview of the platform. The Zynq ZCU111 boards, consisting of multicore ARM processors and built-in FPGA system-on-chip, are used to implement the transceivers (PHY-Layer related functionalities) and Linux computers are used to execute the MAC-layer related functions (IAB orchestrator, MSC selection and HARQ acquisition).

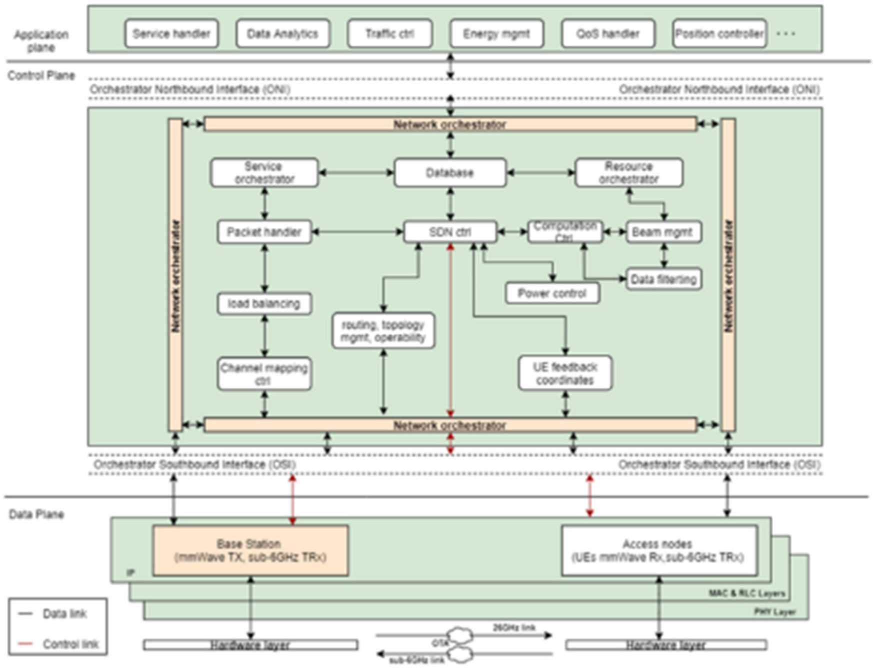


Figure 6: Multi-RAT IAB Architecture

The control plane transports and manages the DL and SL data packets as well as the control services of the network.

The Medium Access Control (MAC) layer from data plane maintains the Transmit (TX) and Receive (RX) coordination of the system's operability that shares the medium with both the northbound interface of orchestrator and southbound interfaces of Radio Link Control (RLC) and PHY layers. Figure 7 presents the data and control flow between each layer for Down-Link (DL), Side-link (SL), and Up-Link (UL) connections that transmits and receives the data packets and control commands. Link A dedicates to all the DL data packet transmission/forwarding to the lower layers, link B used for SL packet forwarding when emulated PHY is not available, the link switching. Link C designed for control-command operations by orchestrator on a given timer-routines in both northbound and southbound interfaces.

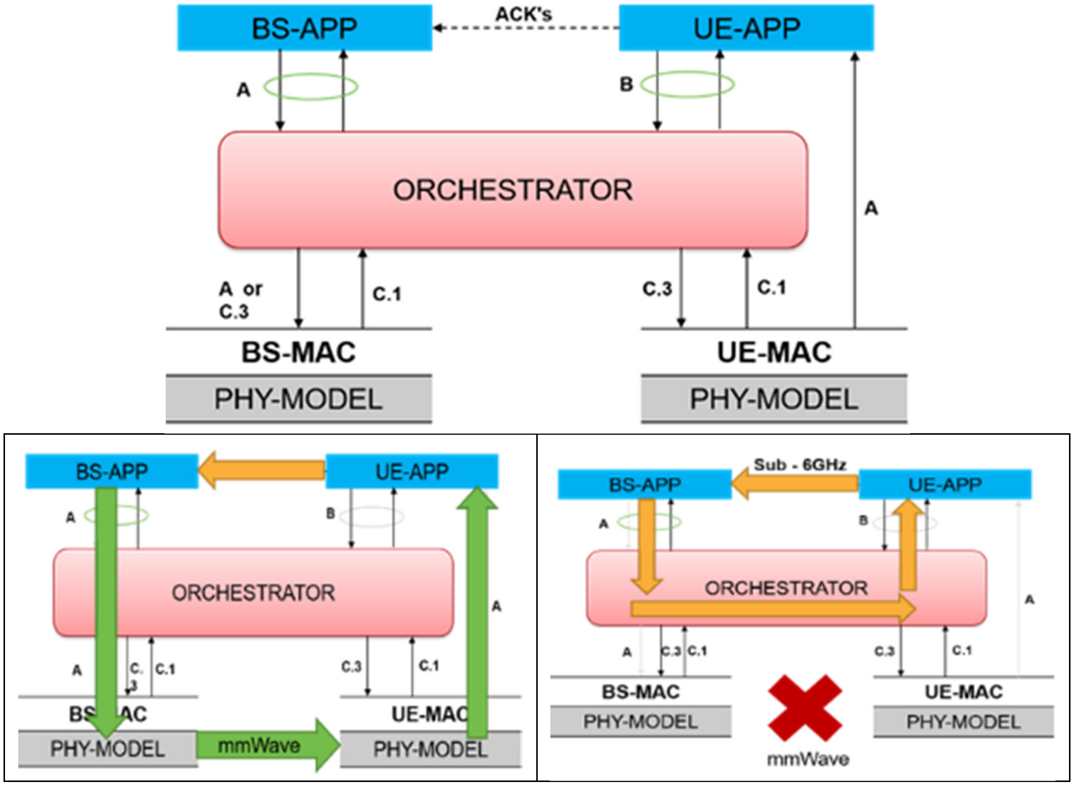


Figure 7: Control panel and Multi-RAT connections.

2.2.2.1.2. Integration

The implementation of networking protocol suite is now discussed. First, the software interfaces are described. Then the PHY-layer FPGA implementation and its features that is embedded on *Hardware (HW)* Zynq ZCU111 together with transmit-array antenna at 26GHz will be presented.

The implementation of northbound interfaces from Orchestrator dedicated for the application and side-link connections, as shown in Figure 8. The base-station application pushes a packet upon receiving through tunnel/Ethernet while adding it to the buffer. The orchestrator forwards the received packets to southbound interfaces of BS-MAC and PHY, it then transmits *Over-The-Air (OTA)* interface to UE nodes.

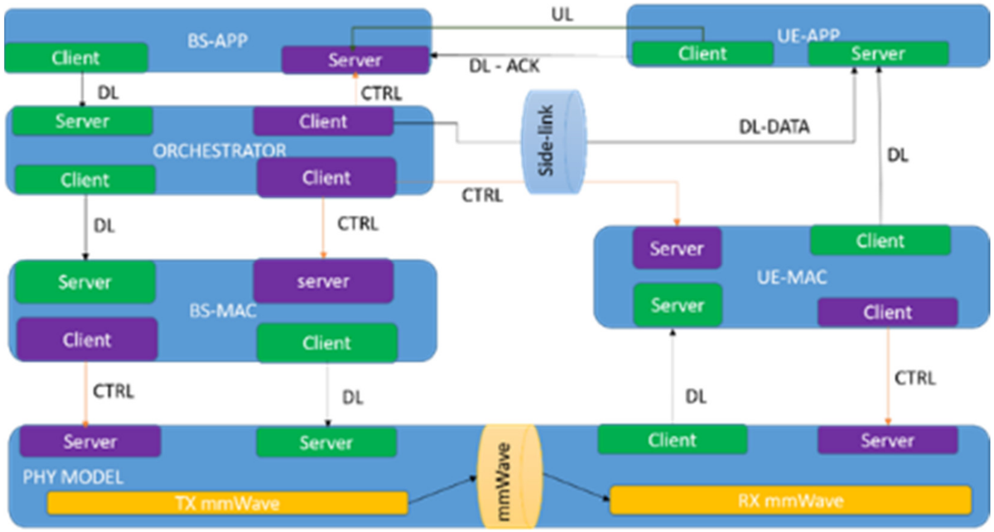


Figure 8: TCP connections

We implemented the network protocol stack in multi-threading model. Each layer contains one main server and several client's connections. Each layer of current TCP server can be a client to both upper and lower layers. Moreover, we assigned a unique server port numbers to each and all, and the same port numbers used as clients to others.

The Orchestrator timer routine gets the position coordinates of UE from UE-MAC and PHY, it then sets the preferred beam ID of BS from its current beam ID based on the coordinates of UE. The orchestrator then rechecks the sync status of UEs based on the decimal numbers of '0' and '1'. If the UE sync status equals to '1', the orchestrator forwards a packet to BS-MAC and PHY, otherwise it enables the SL connection to forward a packet to UE. The procedure is illustrated in Figure 9.

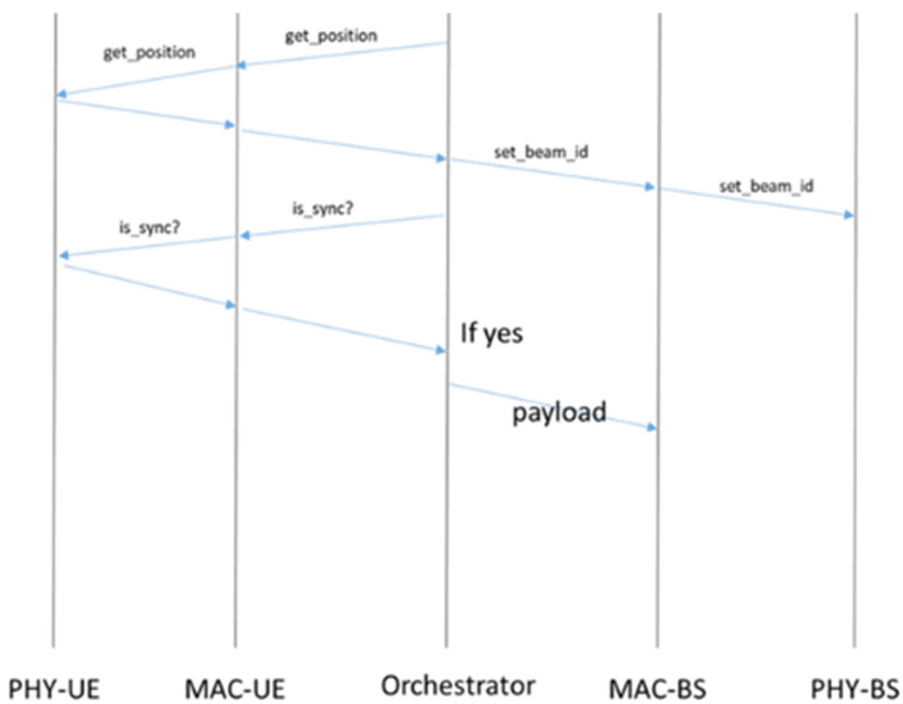


Figure 9: mmWave UE synchronization flowchart

The antenna structure used for the BS is a transmit-array. This array has not been developed in the framework of DEDICAT 6G and is an input to the project. Transmit-arrays exhibit higher antenna gain (17 dBi) than phased-array structures. It is the main reason which has motivated our choice. A transmit-array is composed of a lens (with 400 unit cells) and a set of feeding sources (4). It is capable of beamforming (120° coverage with 5° steps). A photography of our front-end structure and a block schematic are provided with Figure 10.

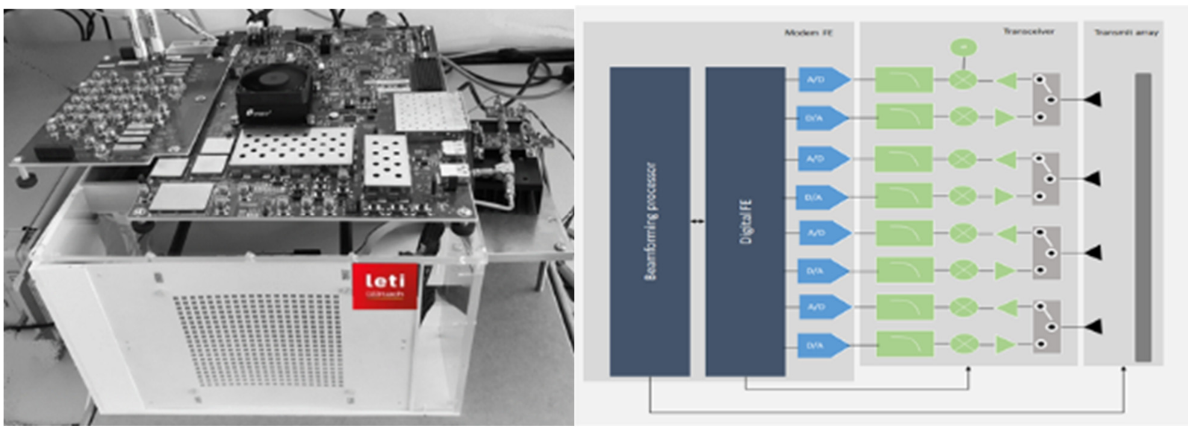


Figure 10: Transmit-array photo and schematics

2.2.2.1.3. Preliminary measurement campaign

In order to properly evaluate the achievable performance of the DEDICAT 6G platform, we developed a QT-based GUI. An illustration is given with Figure 11.

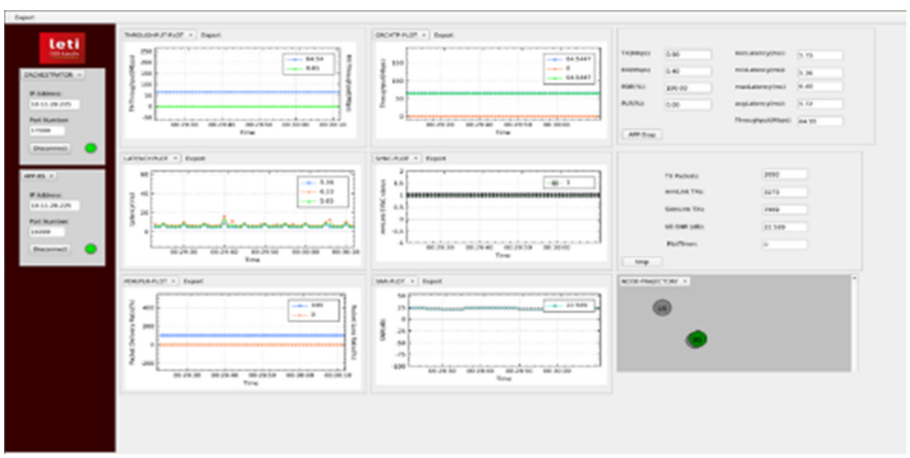


Figure 11: GUI main window

The idea now is not to fully describe this interface but to emphasize some metrics of interest and provide some preliminary results. A more detailed result presentation will be provided in further deliverables.

The performance of *Single User (SU)* MIMO transmission (OTA) between the BS node via orchestrator to UE and UE to BS, it was evaluated and tested to observe about the radio link conditions. The scenario is represented in Figure 12.

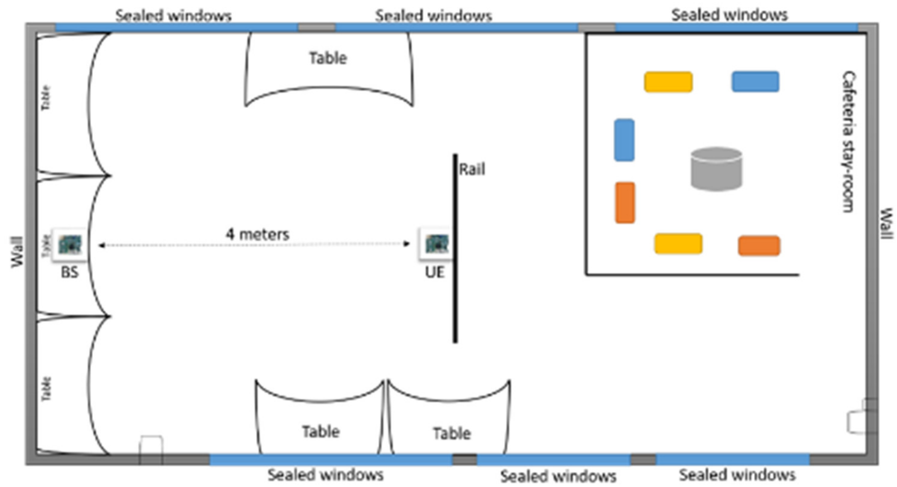


Figure 12: Evaluation scenario

Figure 13 represents user rate and end-to-end latency measurements.

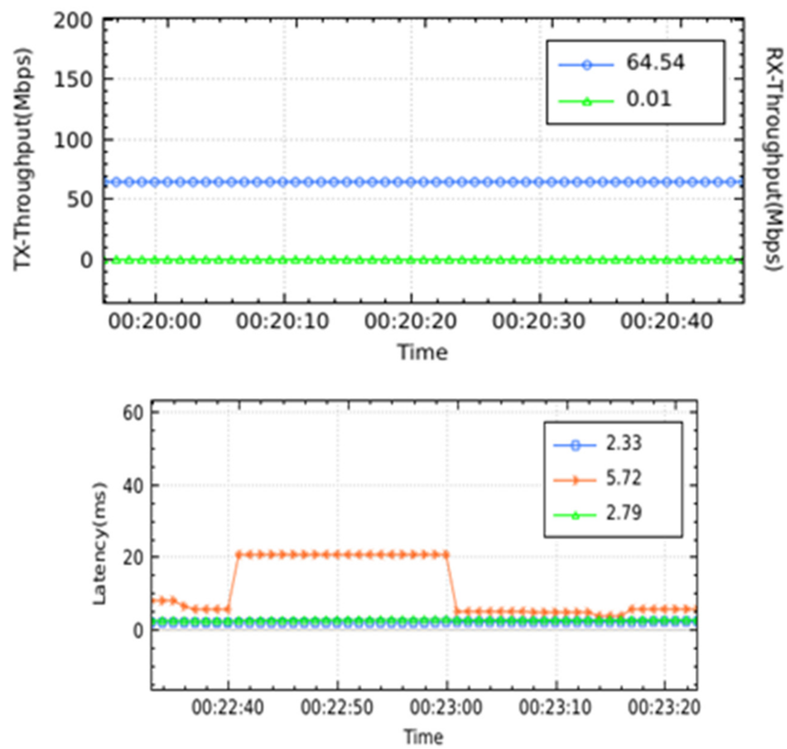


Figure 13: Evaluation of achievable user rate (left) and end-to-end latency (right)

Regarding the rate, we depict the rate of the DL mmWave (blue) and DL side-link (green). In this configuration the side-link is only used to transmit control signalling which explains the low SL rate. The achieved throughput should be at 1Gbps, as it has proven based on a PHY-mode. However, it is not the case due to some ZCU111 board limitations, which has been addressed the issue, and the implementations will be done in the next phase milestones.

Some issues have been encountered during the implementation and particularly when realizing the measurements. The PHY layer of the boards limiting the data rate to 80 Mbps regardless the packet size we push; this issue is addressed at the parallel processing level between FPGA and ARM-processor. We further need to investigate this issue for better throughput of 1Gbps by using Transmit-Array.

2.2.3 Mechanisms for security, privacy and trust

WP5 addresses Artificial Intelligence and blockchain-enabled security framework and trust management platform and mechanisms to provide security and trust. D5.1 [5] gives an overview of the interface provided by the framework and D5.2 discusses the initial implementation of the framework. The best practices are used to protect confidential data and the blockchain technologies are used to ensure trust between participants.

The DEDICAT 6G security and privacy protection framework will be based on a decentralized, blockchain-powered data marketplace for secure, automated processing and exchange of IoT sensors and digital assets data with policy-based data verification and protection.

The framework's unique features for exchange of data between arbitrary interested parties are:

- Private, permissioned blockchain technology which provides network security, data integrity, smart contract for fast automated transactions developed around token economy;
- Data access verification and policy-based access control through blockchain smart contracts and data encryption.

There are three main goals the framework is aiming to achieve:

Security - To protect sensitive data, the framework will rely on best cryptography practices for modern cloud-based applications. The sensitive user information such as passwords will be stored encrypted using best practices for hashing, so that potential data leak or direct access to the database won't reveal login credentials. Also, the framework does not require storing data streams from IoT sensors and edge gateways, but data can be kept on the data producer side and fetched by data consumer on request. When accessing protected data, data source location (as a *Uniform Resource Locators (URL)*) will be protected using best practices for symmetrical encryption.

Privacy - The platform provides not only data exchange, but also subscriptions to continuous data streams (potentially of infinite size) are supported. This is particularly useful for IoT use-cases where data is streamed directly by the edge gateways. All subscriptions are time-limited and access to data is denied upon expiration. To ensure access control over sensitive information, framework relies on attribute-based access control. Attribute-based access control enables creating fine-grained access control rules giving great flexibility to the framework. For some cases, however, role-based access control is a better fit due to its simplicity and long-time use in the industry. Role-based access control is using an artificial attribute(s) called role in the system to evaluate access control rights. The platform uses roles for determination of high-level access rights and attributes to provide more fine-grained control.

Trust - To ensure trust between parties, the framework uses blockchain technologies. Each data exchange is written to the immutable ledger. Decentralization, advanced consensus algorithms, and ledger immutability are three main properties of blockchain technologies. Support for smart contracts is used to automate the execution of an agreement so that both data consumer and producer can be immediately certain of the outcome. All these properties make blockchain a perfect fit to provide trust between parties who produce and consume data.

One practical use-case for security and privacy protection framework is data monetization in *Nokia Data Marketplace (NDM)* which is explained in D5.2. Tokens and Transactions are used to verify data transfer when creating data subscriptions. Tokens are digital assets stored in the blockchain and used for trading assets. The transaction is any exchange of tokens, including funding, defunding, and renting digital assets. Blockchain is used to store tokens in the form of smart contracts and each transaction results in a change of token balance for each participating party, platform included (platform can take a configurable fee from each transaction – also using fee smart contract). While this concept reminds us the real marketplaces where the real money is exchanged for real goods, tokens are not necessarily used as a monetization tool, but simply the asset that proves the transaction that results in enabling and disabling access to the virtual resource.

Two main benefits of using blockchain as the underlying technology are security and trust that come from its decentralized ledger nature. Blockchain acts as a source of trust between parties. Blockchain is also used to store users' terms and conditions of dataset/stream - that way platform can track eventual changes in data usage terms and condition and provide its integrity which is very important for the end-user.

Implementation of the Security framework for access control management is described in D5.1 and implemented in D5.2 and D5.3. It includes role-based and attribute-based access control to the resources, and data access control supported by blockchain.

In all project Use Cases, the security and trust framework has the same position: central source of identity and trust. All device interactions go through the framework where requested action is authorized against access control policies and allowed if policy evaluation is successful. Clients are authenticated using access tokens and authorized using access control policies. More implementation details can be found in section 3.1.1 of deliverable D5.2. Sensors and edge devices, as well as smartphones and web clients of all four project Use Cases, are providing data streams exchanged through the platform which is an implementation of the framework. Users are provisioned by the platform administrators, and users are able to add data streams to the catalogue of available streams. To make them accessible, other users need to generate cryptographically protected data streams out of the original using its location. Each access is recorded in the blockchain ledger, providing trust between client who provides and client who accesses the data.

3 UC1: SMART WAREHOUSING

3.1 Scenario and stories

According to the latest report by the IMARC Group, titled "Warehousing and Storage Market: Global Industry Trends, Share, Size, Growth, Opportunity and Forecast 2022-2027", the global warehousing and storage market size reached a value of US$ 451.9 Billion in 2021 and is estimated to reach US$ 605.6 Billion by 2027, exhibiting at a *Compound Annual Growth Rate (CAGR)* of 4.9% during 2022-2027 [18]. The COVID-19 pandemic has increased the need for warehousing and storage facilities to cater to the surging demand for numerous essential goods and healthcare products across the globe. Smart warehousing and logistics are key for the proper preservation of goods and consequently of the public health. Today, real-time tracking of vehicles and goods at the transfer points are much consolidated operations, for both end users and companies. However, the availability of data as well as functionalities such as augmented reality and remote-controlled operations, that can be supported by B5G/6G technologies along the warehousing and logistic supply chain, can enable much more advanced services reducing operational delays and wastes (due to disrupted products which do not reach the consumer market). This Use Case intends to demonstrate the feasibility and value of applying distributed intelligence in an overall Smart Warehousing context, for:

- Optimizing warehousing operations with increased performance and improved efficiency;
- Assisting training of new Warehouse Workers and maintenance of warehouse systems through application of 3D augmented reality, promoting human-robot interaction with 3D video-driven solutions;
- Enhancing the safety of personnel and goods;
- Enabling remote inspection and diagnostics;
- Identification and tracking of goods.

This will be achieved through an integrated state-of-the-art operational system based on AGVs, *Internet of Things (IoT)* systems and edge computation capabilities supporting deployment of DEDICAT 6G enablers through the DEDICAT 6G platform.

In the following more detailed stories are presented focusing on the tasks of key actors in the warehouse setting for showcasing the advantages of DEDICAT 6G enablers in a Smart Warehousing context.

3.1.1 Detailed Stories

The main actors in the smart warehousing scenario are Warehouse Workers focusing on their daily tasks and Warehouse Managers/Administrators focused on improving overall efficiency, performance, and safety by applying new processes, organizing personnel and resources, and remotely monitoring deployed systems. These main actors will interface with the deployed DEDICAT 6G systems and new technology in different ways. This is why the perspectives of 1) a Warehouse Manager and 2) a typical Warehouse Worker are described in the two stories.

Story 1: This story focuses on a Warehouse Administrator/Manager who is responsible for setting up the strategy for improving performance, efficiency and safety of personnel and stored goods. This person also performs monitoring of the deployed resources and configured processes in order to assess performance and derive necessary updates. Finally, a Warehouse Manager is also responsible for interaction of the smart warehouse systems with the outside world including the wider supply chain. The assumption is that a Warehouse Manager monitors the operations from a dedicated location/office which might or might not be at the same location as the warehouse itself.

Story 2: This story emphasizes how a typical Warehouse Worker utilizes deployed technologies to perform daily tasks (goods inventorying, goods shipment, training of a new worker, warehouse maintenance, etc.) more efficiently and safely. Warehouse workers are those who directly interact with the deployed AGVs, goods and other warehousing infrastructure. They perform all their activities within the perimeter of the warehouse.

3.1.2 Services – Human centric applications

The Smart Warehousing human-centric application essentially aims to address the needs of the Warehouse manager and the Warehouse worker fore mostly. In this direction, two applications are being developed: a dashboard for the Warehouse manager and a mobile application for the Warehouse worker.

Through the **Warehouse Manager dashboard** (Figure 14), the Warehouse Manager can:

- Configure daily tasks for the fleet of AGVs including product quality monitoring parameters, interaction rules with warehouse personnel and product offloading/loading schedule;
- View the overall status of AGVs and processes of the warehouse;
- Direct personnel or AGVs towards an area of interest or an asset;
- Configure safety rules for workers including social distancing and safety zones with configurable geo-fencing zones for different time periods and in line with offloading or loading schedule;
- Configure authorization levels for workers with respect to warehouse areas.

The Warehouse Manager dashboard also allows to view the overall status and processes of the warehouse through dedicated cameras, view notifications e.g., on completed tasks, view precise location of key assets, direct personnel or AGVs towards an area of interest or an asset, view AGV camera feeds, view real time data from the robots such as their status, battery level, availability and other statistical and historical data.

The Warehouse Manager is aware at all times of the robots within the system. In the "Smart Warehouse Context" panel (Figure 14 – left side), robots are constantly transmitting information about their status to the system. In the main window of the application there is an interactive virtual map, through which the movement of robots in the digital space can be observed as well as the positions of objects/products. The Warehouse Manager can supervise the robots in two-dimensional graphics or in three-dimensional space. Live video streaming of the robots' camera gives additional information about their position in space, and the tasks they are performing at that time. A Notifications panel & Progress window (Figure 14 – right side) provides the Warehouse Manager with additional information about the running processes. The Warehouse Manager can select a product from the list, and then the robots will work together to perform an automated process of delivering the selected product to a specific point. Information about the progress is provided.

Figure 14: View of Warehouse Manager dashboard

Through the **Warehouse Worker mobile app** (Figure 15), the worker can:

- receive a list of daily tasks as specified by the Warehouse Manager;
- direct AGVs towards a product or an area of interest if he/she is authorized to do so;
- View digital information on real world objects through the **Augmented Reality application** e.g., interact with the 3D model of an AGV or even watch a video explaining how the robotic arm works.

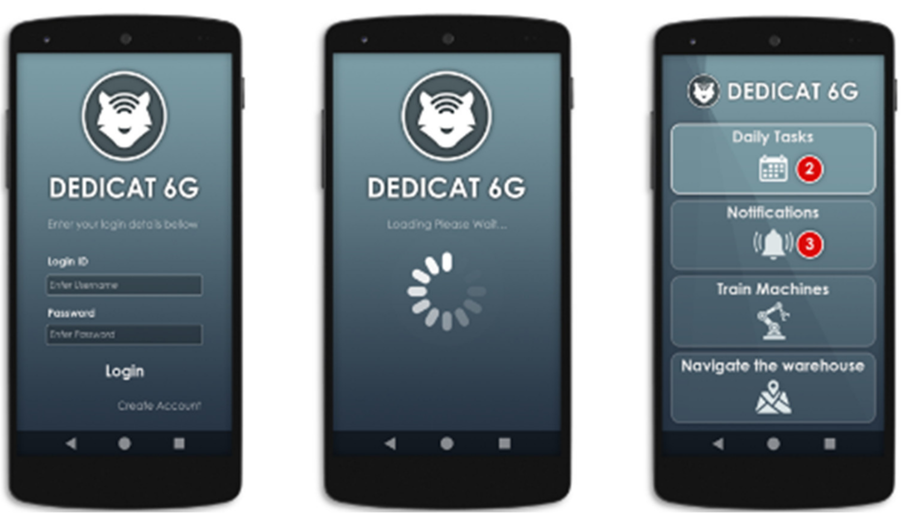


Figure 15: Warehouse Worker mobile application

The workers training Augmented Reality application combines real world objects with digital information. For example, a specific model of a robot has on its robotic arm a unique *Quick Response (QR)* code. The user will be able to target the QR-code with the camera of his mobile device (smartphone/tablet/AR glasses) and to get access to the robot's statistics in real time, to download the user's manual, to interact with the 3D model or even to watch video and animations explaining how the robotic arm works.

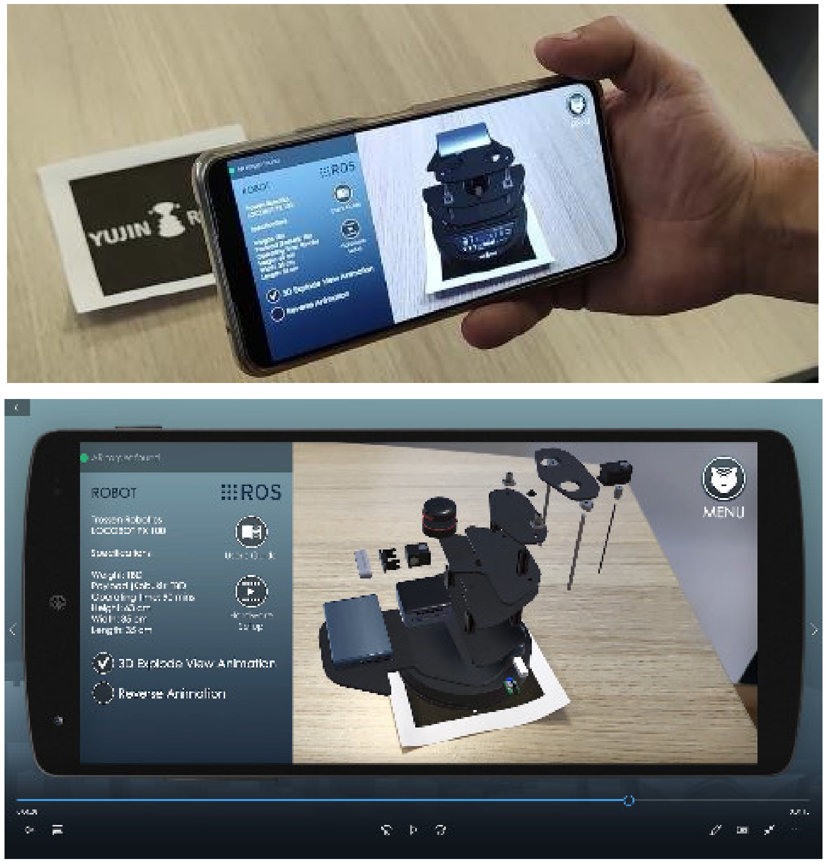


Figure 16: Warehouse Worker Augmented Reality application for training

3.2 Scenario Setup

This section aims to provide an overview of the pilot set up in terms of hardware and software components, while also outlining the relationship to the DEDICAT 6G architecture as defined in WP2 and the status of the integration of mechanisms from WP3, WP4 and WP5l.

3.2.1 Pilot setup

Figure 17 depicts the full setup considered at this time for realization of the Smart Ware-housing use case in the context of a pilot. This set-up considers the following:

- AGVs are deployed and configured to support smart warehousing tasks;
- IoT system is deployed and configured to support smart warehousing tasks;
- BLE (Bluetooth Low Energy) beacons are provided to *Mobile Assets (MA)*;
- IoT system for access control is connected to electric locks;
- Environmental sensors are connected to the IoT system;

- Personnel is registered and authorized;
- Smart warehousing layout/plan is digitalized;
- DEDICAT 6G mobile app is installed on personnel's mobile devices;
- DEDICAT 6G web-based dashboard is provided to the Warehouse Manager;
- DEDICAT 6G solutions for distributed computing, opportunistic networking and trust and security management are deployed and configured.

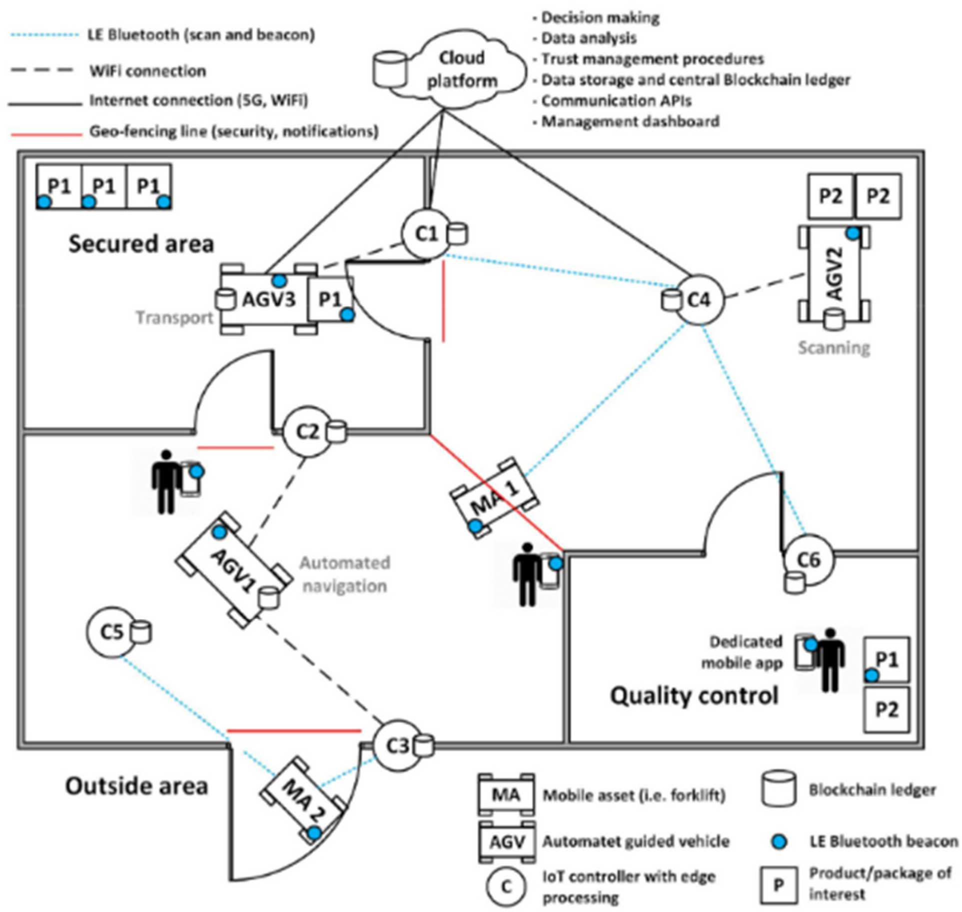


Figure 17: Smart warehousing use case setup plan

The **robots/AGVs** utilised in this use case are *LoCoBot WX250 6 DOF*. The LoCoBot (Figure 18) is a *Robot Operating System (ROS)* research rover for mapping, navigation and manipulation. Development on the LoCoBot is simplified with opensource software, full ROS-mapping and navigation packages and modular opensource Python API.

Figure 18: LoCoBot AGV

The rover is built on the Yujin Robot Kobuki Base (YMR-K01-W1) and powered by the Intel NUC NUC8i3BEH Core i3 w/ 8GB of ram and 240GB HD. An Intel® RealSense™ Depth Camera D435 sits atop an independently controlled pan / tilt mechanism (2XL430-W250-T) at the top of the platform which allows mapping and scanning. The 360-degree LIDAR can further improve both mapping and scanning (Figure 19).

The WidowX 250 is a 6-degrees of freedom manipulator with a maximum reach of 650mm and a working payload of 250g. The WidowX 250 is built using the DYNAMIXEL X Series servos from Robotis, which feature high resolution (4096 positions), user definable PID parameters, temperature and positional feedback and much more.

Kobuki Base	Intel NUC NUC8i3BEH Mini PC	Intel® RealSense™ Depth Camera D435	RPLIDAR A2M8 360° Laser Range Scanner

Figure 19: AGV hardware components

The **SmartAccess360 (SAC360)** Universal Internet of Everything Controller is specifically designed to offer smart solutions that maximize the performance of Smart Building services. The controller is an integrated multi-radio hardware and software system that acts as a gateway to connect networks of devices, collect data in real time, and monitor devices off-site from a smartphone app. SAC360 as an IoT system is responsible for door access-control and operation of the electric strikes.

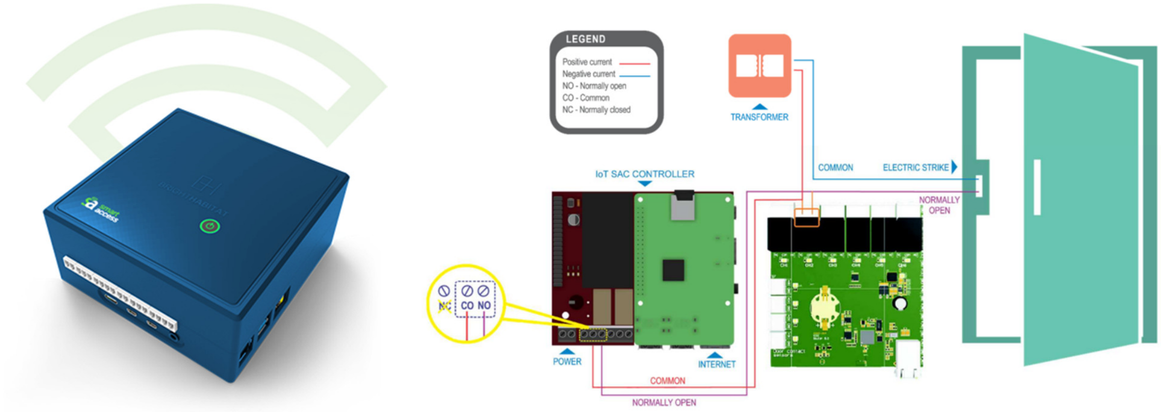


Figure 20: SmartAccess360 controller (left) and installation scheme (right)

Table 1: SmartAccess360 specification

Power:	802.3af/at Power over Ethernet (PoE) enabled (Alternative: 5V DC via USB-C connector (minimum 3A))
Physical size:	120mm x 120mm x 50mm (W x L x H)
SoC:	Broadcom BCM2711
CPU:	Quad core Cortex-A72 (ARM v8) 64-bit @ 1.5GHz
GPU:	Broadcom VideoCore VI
RAM:	2GB, 4GB or 8GB LPDDR4-3200 SDRAM
Networking:	Gigabit Ethernet, 2.4 GHz and 5.0 GHz IEEE 802.11ac wireless, Bluetooth 5.0, BLE
Storage:	Micro-SD card (8/16/32 GB)
Ports:	1x Gigabit Ethernet (PoE enabled) 2 USB 3.0 ports 2 USB 2.0 ports 2 × micro-HDMI ports (up to 4kp60 supported) 4-pole stereo audio and composite video port 2-lane MIPI DSI display port 2-lane MIPI CSI camera port 2x Contact sensor inputs 2x Push button inputs 40 General Purpose Input/Output (GPIO) pins, Serial Peripheral Interface Bus (SPI), I²C, I²S,[5] I2C IDC Pins at 3.3V; Not all 40 pins are available. Physical pin 5 (GPIO3) used for software reset/power off; Pins 8 (UART0_TXD), 10 (UART0_RXD) used by EnOcean transceiver; Pins 12 (GPIO18) and 13 (GPIO27) used for contact sensor input; Pin 32 (GPIO12 with PWM) used for FAN control; Pins 35 (GPIO19) and 37 (GPIO26) used

	for push button LED control; Pins 36 (GPIO16), 33 (GPIO13) used for driving relays; Pins 38 (GPIO20) and 40 (GPIO21) used for push button input
Relays:	2x embedded relays: Nominal switching capacity (resistive load) N.O. side: 10 A 125 V AC, 5 A 250 V AC, 5 A 30 V DC N.C. side: 3 A 125 V AC, 2 A 250 V AC, 1 A 30 V DC Max. switching power (resistive load) N.O. side: 150 W, 1,250 VA N.C. side: 30 W, 500 VA Max. switching voltage 250 V AC, 30 V DC Max. switching current N.O.: 10 A (125V AC), N.C.: 3 A (125V AC) Expected life: Mechanical Min. 107 (at 180 times/min.)
Environmental:	Operating temperature: 0°C to 50°C
Mounting:	Wall mounting
Power con.:	Idle: 2.85W Stress: 6.4W
Configuration:	Local Web User Interface (HTTP/S), CLI (Telnet/SSH), Cloud/Web based management and configuration
Monitoring:	Cloud/Web based monitoring
Software updates:	Over the air (OTA) updates
Frameworks and protocols:	AllJoyn, Project Haystack, SIP, Wireless mesh routing protocol - B.A.T.M.A.N. Advanced
Compliance:	RoHS3 and REACH compliant; FCC ID: 2ABCB-RPI4B; IC ID: 20953-RPI4B; Anatel: 06004-19-10629; KCC: R-C-P2R-RPI4B; NTC: ESD-GEC-1920098C; IFETEL: 2019LAB-ANCE4957; CMIT ID: 2019AJ10494; FCC, CE

The **Bluetooth Low Energy Microlocation Asset Tracking (BLEMAT)** system is a fog computing Internet of Things system based on VizLore's IoT Platform solution and UIoE family of IoT controllers.

In the warehouse, BLEMAT platform tracks AGV's Bluetooth beacons and calculates proximity and position of robots. Proximity information is the main trigger for further action. BLEMAT asset tracking capability refers to indoor tracking systems that need to continuously scan and monitor the assets/beacons over a period of time (Figure 21).

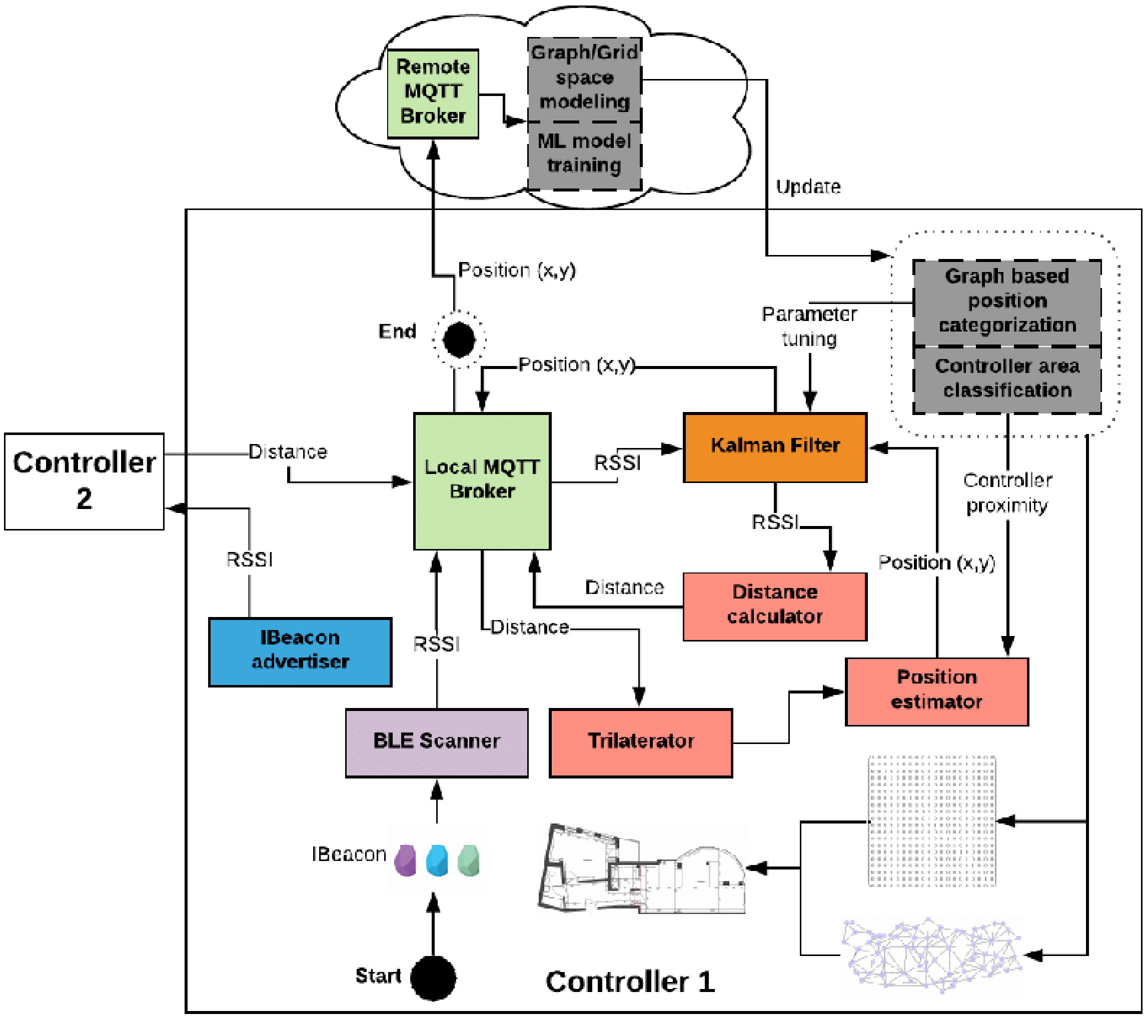


Figure 21: BLEMAT system workflow

Asset tracking utilizes trilateration to calculate the exact position of an asset in an indoor area. Where more than 3 controllers are deployed multi-lateration approach (combinations of more than three points) is used and then the position is averaged. Furthermore, position estimation is enhanced by context-learning and aggressive filtering of both signals and position estimations.

- Decisions are made at the fog level;
- Reactive decision making;
- Failover detection;
- Automatic handover of failing processes.

The cloud layer is used for deeper analysts, overall governance and policy enforcement should it fail at the fog level.

3.2.2 Smart Warehousing use case implementation

This sub-section aims to present the implementation of the use case with a key focus on UC specific components.

3.2.2.1 DEDICAT 6G architecture components

The detailed functional decomposition of the interconnection of this Use Case into DEDICAT 6G architecture and platform have been described in D2.3, D2.4 and also in D6.1. Table 2 provides a mapping of the functionality of the DEDICAT 6G architecture FCs to the current Smart Warehousing implementation of Figure 22.

Table 2: Mapping of DEDICAT 6G architecture FCs to Smart Warehousing implementation (Figure 22)

DEDICAT 6G architecture FCs	**Description**	**Smart Warehousing implementation** (Figure 22)
Edge Node (EN) Registry FC	Provides information on the Edge Nodes (including AGVs) that can be exploited for intelligence distribution	Kubernetes, ROS1/2 Bridge, DEDICAT 6G Controller, Warehouse Manager dashboard
µS/FC Registry FC	Stores the meta-data related to the microservices uploaded in the µS/FC Repository FC	MANO, Kubernetes
µS/FC Repository FC	Stores the uploaded microservices images related to the Smart Warehousing such as the Product Quality Check	MANO Kubernetes
Edge Computing (EC) Policy Repository FC	Stores the Edge Computing policies related to Smart Warehousing	MANO, Kubernetes, Intelligence Distribution algorithm
EN Status Agent FC	Provides monitored information about the current status of the edge nodes registered to the platform	Kubernetes, Warehouse Manager Dashboard, ROS1/2 Bridge, DEDICAT 6G Controller
µS/FC Status Agent FC	Provides monitored information about the current status of the microservices and DEDICAT 6G native FCs being executed in the use case infrastructure	MANO, Kubernetes, ROS1/2 Bridge, DEDICAT 6G Controller
NW Status Agent FC	Monitors the network of the Smart Warehousing infrastructure	DEDICAT 6G Controller
IDDM FC	Receives information about the ENs and the microservices and, as output, provides recommendations to the Service Orchestrator FC on the placement and deployment of microservices and FCs	Intelligence Distribution Algorithm
Service Orchestrator FC	Receives recommendations from the IDDM FC and acts over the ENs in order to deploy and orchestrate the microservices and FCs within the Smart Warehousing Physical Systems	MANO

μS/FC Awareness FC	Receives information from a group of μS/FC Status Agent FC then aggregates/enriches it and finally publishes it to the rest of the FCs available on the DEDICAT 6G platform (mainly Decision Making FC).	MANO, Kubernetes
EN Awareness FC	Receives information from a group of EN Status Agent FC and enriches/publishes it to the rest of the FCs available on the DEDICAT 6G platform	MANO, Kubernetes
NW Awareness FC	Provides information on the status of the network of the Smart Warehousing infrastructure	DEDICAT 6G Controller
AGV Operation FC	Provides the basic management of robots and provides a basic palette of so-called atomic actions it can perform. Those atomic actions are then played with, in order to build more complex capabilities (e.g., for identifying parcels and moving them from A to B with obstacle avoidance or performing quality checks).	ROS1/2 Bridge, DEDICAT 6G Controller, containerized microservices (docker/ROS)
Threat Analysis FC	Performs threat detection, identification and classification and is executed either in centralized or in edge processing nodes. Threat analysis is based on ML models trained and updated on collected system logs.	Security Mechanism Algorithm

3.2.2.2 UC specific components

This sub-section describes in more detail the UC specific components. The Warehouse Manager dashboard and the workers mobile application are implemented with Unity 3D game engine. Unity is a cross-platform game engine developed by Unity Technologies, first announced and released in June 2005 at Apple Inc.'s Worldwide Developers Conference as a Mac OS X-exclusive game engine. The engine can be used to create three-dimensional (3D) and two-dimensional (2D) games, as well as interactive simulations and other experiences. Unity provides best-in-class software tools to import, optimize and visualize 3D data and can be used to create 2D/3D, virtual reality, and augmented reality applications, as well as physical simulations.

Figure 22 presents a very high level, abstract, view of the smart warehousing implementation thus far. UC1 Smart Warehousing comprises of two AGVs (Locobots) having a custom lift ability for bringing ordered products to the user. Both AGVs have ROS1/2 bridges and containerized docker microservices running on them. AGVs communicate with the so-called DEDICAT 6G controller through fast *Data Distribution Service (DDS)* Discovery[2]. This controller essentially facilitates communication of the AGVs/robots with the user interfaces (i.e., the Warehouse Manager dashboard and the worker mobile app). For example, information sent to the Warehouse Manager dashboard includes AGV positioning/movement, camera feed and AGV status (e.g., battery level, CPU and RAM usage). The DEDICAT 6G controller is hosted in the cloud together with other auxiliary entities including an orchestrator based on

[2] https://fast-dds.docs.eprosima.com/en/v2.1.0/02-formalia/titlepage.html

open source ETSI *Management and Orchestration (MANO)*[3], the Kubernetes platform, an implementation of the intelligence distribution mechanisms from WP3 (specifically the algorithm for Placement of Intelligence described in section 2.1 of D3.2 [6]) and an implementation of the Threat identification and classification mechanism from WP5 (described in detail in section 6.1 of D5.2 [8]).

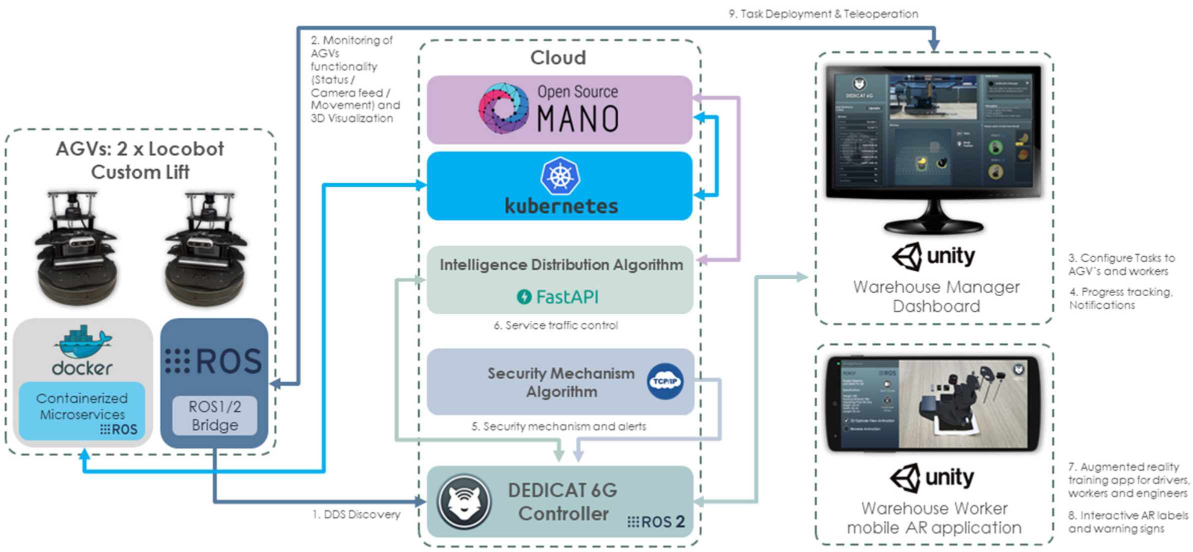


Figure 22: View of the smart warehousing implementation

The Intelligence Distribution Algorithm is responsible for (re-)distributing services dynamically to the network's nodes (AGVs, cloud nodes) for overcoming possible increase of network latency or possible unavailability of an AGV, while also considering power consumption of the involved nodes. This algorithm communicates with the DEDICAT 6G controller and the MANO orchestrator for receiving information related to AGVs, cloud and edge nodes status and services information. The output of the algorithm is sent to the MANO orchestrator, which deploys the corresponding containerized microservices as Network Services implemented by Kubernetes-based Network Functions (KNFs) at the entities/nodes where the algorithm suggests.

The Kubernetes master node deployed alongside MANO, instantiates the microservices on the robots registered as Kubernetes worker nodes. Figure 23 shows a view of the MANO dashboard displaying the status and location (node where they are placed) of the Functional Entities/services with the schematical representation on the bottom right corner of tasks completed per second and the deployment topology.

[3] https://osm.etsi.org/

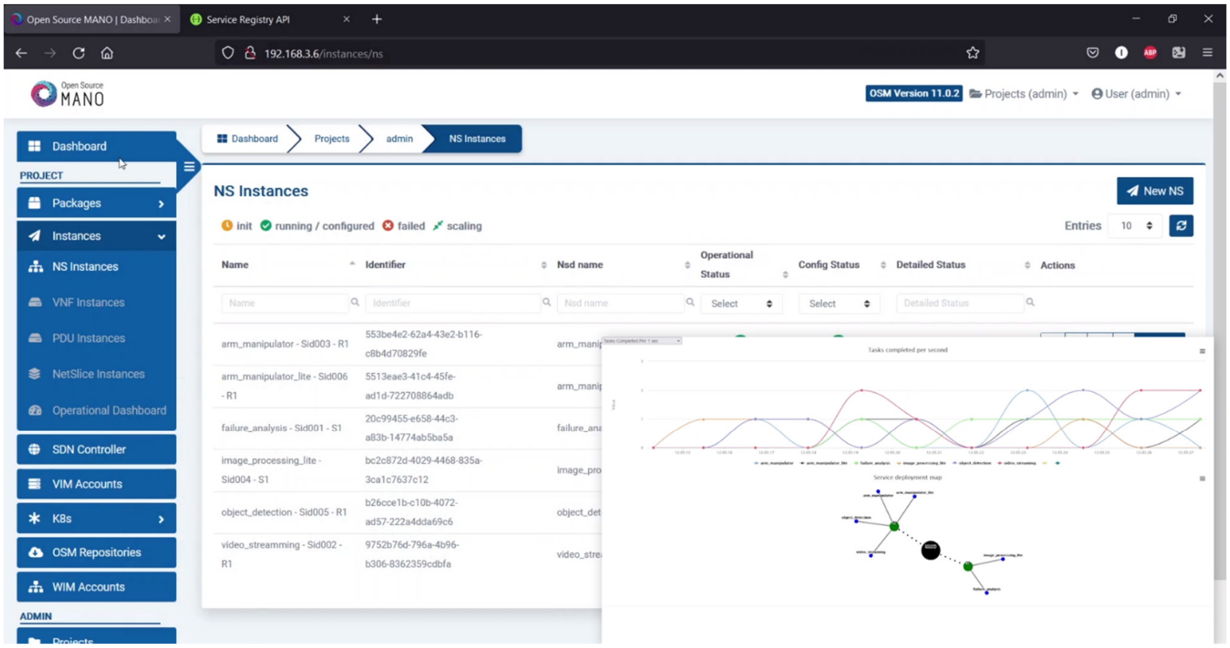


Figure 23: MANO dashboard

The Intelligence Distribution algorithm is a standalone, in-house developed component and communicates with the infrastructure and MANO components (with the help of the FastAPI web framework[4] to produce and apply management decisions regarding the placement of microservices (Figure 24).

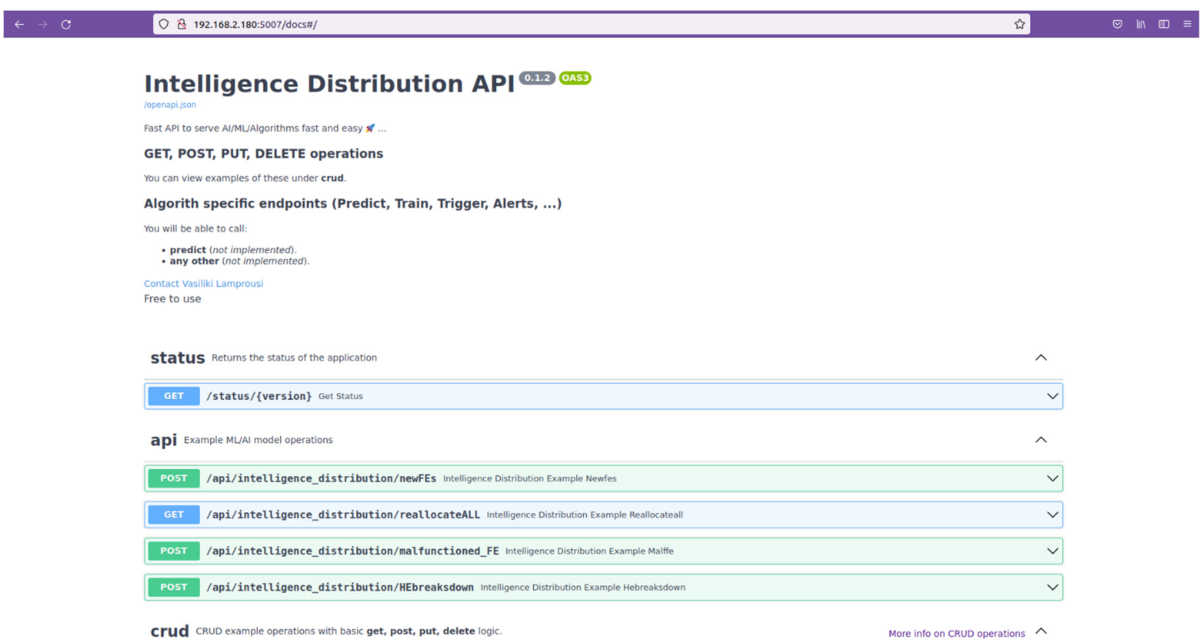


Figure 24: Intelligence distribution FAST API

[4] https://fastapi.tiangolo.com/

Furthermore, the implemented Security Mechanism for threat identification and classification monitors network traffic all over the smart warehousing infrastructure. In the case of a possible detected threat / cyber-attack, it alerts the DEDICAT 6G controller and a relevant notification appears on the Warehouse Manager dashboard. The security mechanism is implemented in Python. For the training of the algorithm UNSW-NB15 dataset was used. The algorithm uses a random forest classifier to classify the instances in 10 classes, depending on the type of attack it has been detected. The classes are: Normal, Fuzzers, Analysis, Backdoor, DoS, Exploits, Generic, Reconnaissance, Shellcode and Worms. Additionally, in order to be able to test the security mechanism, a simulator was developed. The simulator is also implemented in Python and produces instances of five types of attacks, based on the UNSW-NB15 dataset. Figure 25 shows the interface of the simulator. Every time the user wants to simulate an attack, the software writes in a csv file the values for every feature in the dataset according to the attack type that was selected. Subsequently, the security mechanism takes as input the last instance that was written and classifies it.

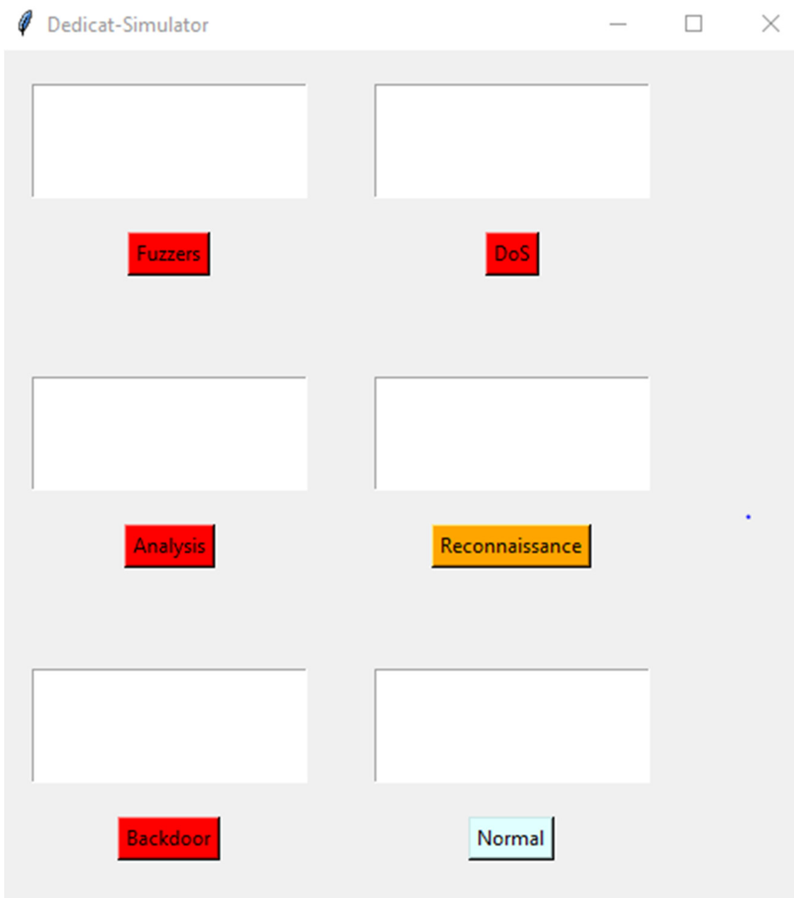


Figure 25: User interface for security mechanism testing

3.2.2.3 Interfaces

A view of the DEDICAT 6G interfaces relevant to this use case is provided in the UML diagrams for this use case in D2.3 [2] and further detailed in D2.4. An overview of the key interfaces between components that are implemented in the scope of this use case pilot are listed (see also Table 2):

- The EN Status Agent FC, µS/FC Status Agent FC and NW Status Agent FC interface with the EN Awareness FC, µS/FC Awareness FC and NW Awareness FC respectively;
- The EN Awareness FC, µS/FC Awareness FC and NW Awareness FC in turn provide input on the EN, µS/FC and NW context to the IDDM FC;
- The EN Registry FC, µS/FC Registry FC, µS/FC Repository FC and EC Policy Repository FC also interface with the IDDM FC;
- The IDDM FC has an interface with the Service Orchestrator FC;
- The Warehouse Manager Dashboard has an interface with the Warehouse worker app;
- The Warehouse Manager Dashboard and the Warehouse worker app have an interface with the AuthN FC and the AGV Operation FC.

3.2.3 Integration report

The paragraph below describes the use of WPs outcomes in the UC1 and the contribution per partner done during the period M15 to M24.

3.2.3.1 Description of WPs related outcomes in UC1

Mechanisms for Dynamic Distribution of Intelligence (WP3):

Intelligence placement of computation and content intended for B5G/6G networks that take account of the increasing service requirements as well as the demand of power and delay sensitivity of user devices.

Audit logging and analysis that enables collection and secure storage of all types of logs across the DEDICAT 6G system (with main focus on security) and implements blockchain technology to ensure logs consistency and trustworthiness.

Mechanisms for Dynamic Coverage Extension (WP4):

Context awareness module for device discovery. Enhanced Internet of Things (IoT) devices that will estimate the number of users and devices in a coverage area by short-range signal scanning techniques.

Coverage Extension Decision Making considers MAP (Mobile Access Point) operation and swarm operation. MAP operation includes managing mobility, adjusting orientation and tilt, and receiving status reports on ongoing operations.

Mechanisms for Security, Privacy and Trust (WP5): Similar to all the other use-cases, in UC1 the security and data protection framework designed and developed in the D5.1 and D5.2 are used for providing access control for resources and data. The framework is used for fine-grained asset control management, as well as data access control using underlying blockchain technologies. Threat identification and classification mechanisms developed for the WP5 as a component of the security and data protection framework are also used in UC1.

3.2.3.2 Description of contribution per partner in UC1

WINGS: Implementation of intelligence distribution mechanisms from WP3 (specifically the algorithm for Placement of Intelligence described in section 2.1 of D3.2 [6]) and implementation of the Threat identification and classification mechanism from WP5 (described in detail in section 6.1 of D5.2 [8]).

ORANGE: Implementation of Intelligence Distribution components, along with algorithm for placement of latency-sensitive tasks, described in Section 2 of D3.2.

VLF: Integration of smart access control and indoor positioning IOT solutions based on IoT platform and edge controllers. Implementation of audit logging and analysis from WP3, described in D3.2. Implementation of blockchain enabled security and trust management framework from WP5, described in D5.2

DIA: Provision of facilities for pilot execution of pilot and validation activities; feedback provision during the experiments and confirmation that the final attainable performance is satisfactory. Contribution to technical, functional and business requirements for the design of the DEDICAT 6G architecture capturing warehouse operations and optimization goals.

NOKIA: Implementation of security and trust management framework from WP5 by integrating NDM (Nokia Data Marketplace) with the proposed solution.

3.2.3.3 Description of external assets used in UC1

WINGS know-how and experience accumulated from the participation in projects such as Clear5G[5], One5G[6], 5G-EVE[7], and 5G-TOURS[8] has been utilised for the implementation of the UC1 prototype and the testing performed so far. The development and implementation of all software and hardware components for UC1 have been done specifically in the context of DEDICAT 6G, with no re-use of specific assets.

VLF will provide Bluetooth Low Energy Microlocation Asset Tracking (BLEMAT) solution for detecting location and mobility patterns of key mobile assets in a typical warehouse. Also, VLF will deploy Smart Access 360 – an IoT system for cyber-physical security managing flow of mobile assets and their access rights in context aware manner.

3.3 Evaluation and first results

Figure 26: View of Diakinisis warehouse deployment through robot cameras

[5] https://cordis.europa.eu/project/id/761745

[6] https://one5g.eu/

[7] https://www.5g-eve.eu/

[8] https://5gtours.eu/

An implementation of a Smart warehousing prototype is available including robots, the Warehouse manager dashboard and the AR training application for Warehouse Workers. This prototype has been demonstrated at EUCNC 2022, while corresponding videos have been produced (https://youtu.be/XKIq9AMywog, https://youtu.be/61yuMfEBBgs). The same set-up has also been **tested at the DIAKINISIS warehouse** (Figure 26).

This prototype is also **integrated with an implementation of intelligence distribution mechanisms from WP3** (specifically the algorithm for Placement of Intelligence described in section 2.1 of D3.2 [6]) and with **an implementation of the Threat identification and classification mechanism from WP5** (described in detail in section 6.1 of D5.2 [8]).

For demonstration purposes of the integration with the Threat identification and classification mechanism a panel for Alerts or Warnings has been added to the Warehouse manager dashboard (Figure 27 left side, middle panel).

Figure 27: Warehouse Manager dashboard displaying security threats and corresponding mitigation actions

3.3.1 List of KPIs, target values and gain

This sub-section describes the KPI related to the UC, specify the KPI target value, the measurement method and the gain with a comparison with t_0.

3.3.1.1 KPIs and target values

Table 3 presents the list of KPIs related to the Smart Warehousing use case, describing the evaluation methods and defining the target values and the baseline for comparison.

Table 3: UC1 – Smart warehousing KPIs list

KPI ID	Description	Target value	Baseline value
UC1_KPI1	**Latency.** Decreased latency (incl. mean delay and delay jitter) via intelligence distribution mechanisms by up to a factor of 10 in congested and faulty situations in order	End-to-end: 200ms *Uplink (UL)/ Downlink (DL)* network delay: 10ms	The baseline values range from less than 10 ms (augmented reality in human-machine interfaces), 10 to 100 ms (Human machine interfaces, Mobile control panels, Visualization of Control with periodic deterministic

KPI ID	Description	Target value	Baseline value
	to improve quality of experience.		communication), and 40 to 500ms (Service performance requirements for mobile robots, Periodic communication for standard mobile robot operation and traffic management) based on the "Service requirements for cyber-physical control applications in vertical domains" (3GPP TS 22.104).
UC1_KPI2	**Network energy efficiency and device energy efficiency.** Decreased energy consumption (incl. communication and computation) via intelligence distribution mechanisms by at least a factor of 10 in order to increase the operation lifetime of a mobile station or server.	<10 Mbit/J	Reduction of energy consumption by a factor of 10 (considering that intelligence distribution can contribute to increasing efficiency of Sleep Mode) [20],[21].
UC1_KPI3	**Service reliability** (application layer). Service reliability can be defined as the success probability of transmitting a layer 2/3 packet within a maximum latency required by the targeted service (ITU-R M.2410, cf. [17]). With the use of intelligence distribution mechanisms this should either improve or at least remain the same as the baseline	>=99.999	The baseline value is at least 99.999 based on the "Service requirements for the 5G system", (3GPP TS 22.261) and the "Service requirements for cyber-physical control applications in vertical domains" (3GPP TS 22.104).
UC1_KPI4	**Warehouse operation efficiency.** Advanced warehouse automation towards significant increase of operations' efficiency (elimination of time wastes", decrease of product damages) and safety, in a complex warehousing environment. Reduction of time required to complete processes such as quality assurance and order collection.	15% reduction	The baseline is usual operation of DIAKINISIS warehouse, without the use of DEDICAT 6G solutions.
UC1_KPI5	**Warehouse safety.** Enhancing safety in warehouses, as automation will reduce the collision risk by timely warning and/or anticipating in case of dangerous situations. An incident reduction is envisioned when a high	>=10%	The baseline is usual operation of DIAKINISIS warehouse, without the use of DEDICAT 6G solutions.

KPI ID	Description	Target value	Baseline value
	level of automation is deployed.		

3.3.1.2 Interim evaluation and results

This sub-section presents preliminary results derived from testing during the interim period (M15-M24]. It should be noted that **Table** 4 **only lists those KPIs from** Table 3 **for which measurements have been derived** in the scope of this document. For the rest of the KPIs measurements will be provided in D6.3.

Table 4: UC1 – Results obtained and gain

KPI ID and Name	Evaluation method	Result	Gain
UC1_KPI1 Latency	Measurements are collected at the application layer by adding timestamps to requests between functional entities/service components of an overall service. Then the difference in time is calculated between the request from one entity (e.g., client) and the response from the other entity (e.g., server). Measurements are also collected e.g., with the use of ping and iPerf.	Figure 28- Figure 32, section 3.3.1.2.1	From the various measurements latency is close to the target and baseline values.
UC1_KPI2 Network energy efficiency and device energy efficiency	The battery level of involved mobile nodes (e.g., phones, laptops, robots) has been measured with and without the use of intelligence distribution mechanisms for certain services/applications. The power consumption of involved servers may also be measured or at least estimated using various ways ranging from cheap watt hour meters for on premises servers.	Figure 33, section 3.3.1.2.2	5-10%
UC1_KPI3 Service reliability	The packet loss rate at the application layer (packets that arrive delayed or erroneous are considered as lost packets) has been measured.	Section 3.3.1.2.3	100% the target is met.
UC1_KPI4 Warehouse operation efficiency	Time is measured for completing product quality check and order picking with and without DEDICAT 6G solutions and in particular AGVs.	Section 3.3.1.2.4	Based on simulations and data provided by DIAKINISIS improvements in the time for order picking range from 7,27 % to - 49,66 %

3.3.1.2.1. Latency

Figure 28 presents results derived from running a ping to a random server (Google in this case) from the robot over WiFi, 5G with and without VPN, indoor and outdoor. It should be noted that a commercial 5G network was used for these experiments. As can be observed, Wifi offers the best latency performance, 5G seems to suffer from interference in indoor settings, whereas the use of VPN does not add a substantial overhead in terms of latency.

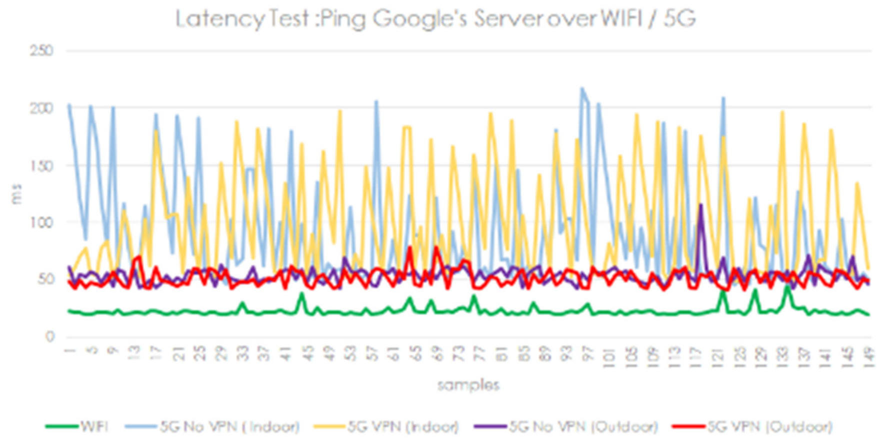


Figure 28: Latency performance tests (pinging a server)

In the robotic scenarios that we conduct, beyond the communication with an external server, there is a requirement for the devices to communicate between themselves. To achieve this, the use of a VPN is imperative. Figure 28 depicts results from a latency performance test (communication between devices), using the ping method. With ping, a data packet is sent to the remote computer, and then the computer that sent the packet waits for an echo reply, i.e., the response to the ping data packet. The packet sent with the ping is called an *Internet Control Message Protocol (ICMP)* echo packet. As can be observed the use of VPN does not add significant latency.

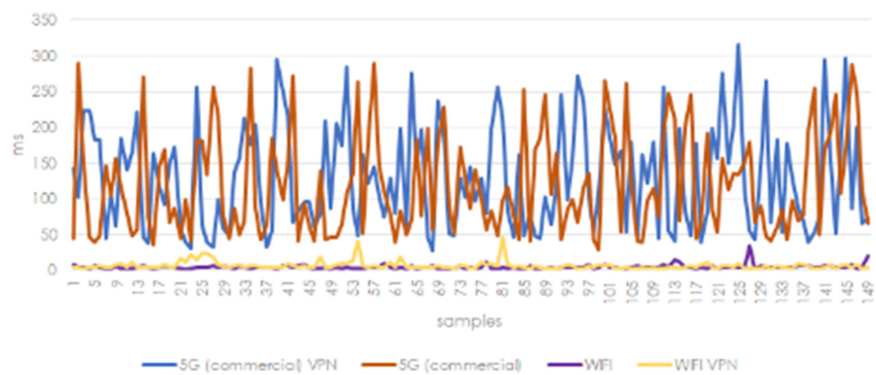


Figure 29: Latency from pinging between two robots

The implementation presented in Figure 29 includes processes/services that are enclosed in a docker environment with ros1_bridge, using ROS2 middleware. ROS2 has been selected over ROS 1 mainly due to two reasons. Firstly, ROS2 allows the creation of a fully distributed system, where each node is independent, whereas ROS1 requires a master node [9]. Moreover, ROS2 offers a rich variety of QoS policies that allows configuring communication between nodes. With the right set of QoS policies, ROS2 can be as reliable as TCP or as best-effort as

[9]https://roboticsbackend.com/ros1-vs-ros2-practical-overview/#Why_ROS2_and_not_keep_ROS1

UDP, with many, many possible states in between. Unlike ROS1, which primarily only supported TCP, ROS2 benefits from the flexibility of the underlying DDS transport in environments with lossy wireless networks where a "best effort" policy would be more suitable, or in real-time computing systems where the right Quality of Service profile is needed to meet stricter requirements[10]. ROS1_bridge is a network bridge which enables the exchange of messages between ROS1 and ROS2. Figure 30 aims to highlight the impact on latency when an application runs in an isolated environment (dockerized microservices). As we can see, there is a small increase in latency, while we pass from a bare metal environment to a dockerized one.

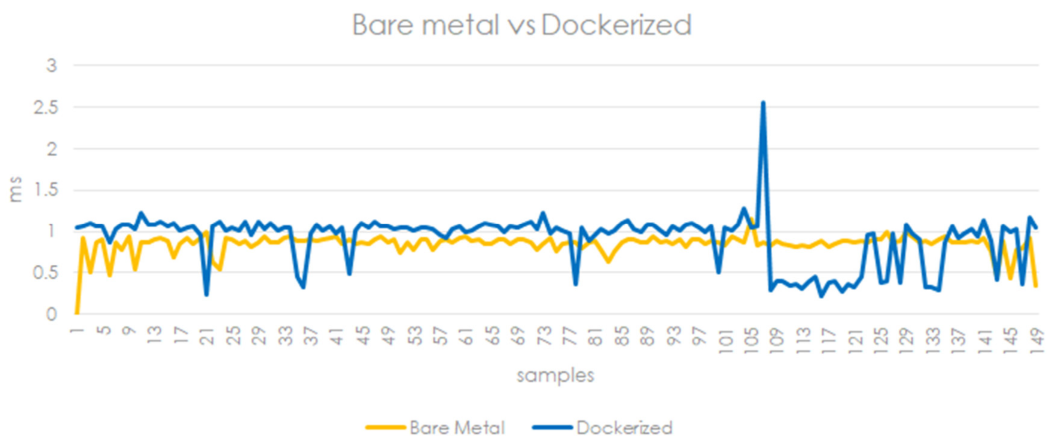


Figure 30: Latency when using dockerized microservices

A next step is to measure the latency caused by software. The majority of our processes are implemented in Python. Figure 31 shows a comparison of network latency as derived in Figure 29 with the latency of a service implemented in python and ROS, calculated as a round trip time.

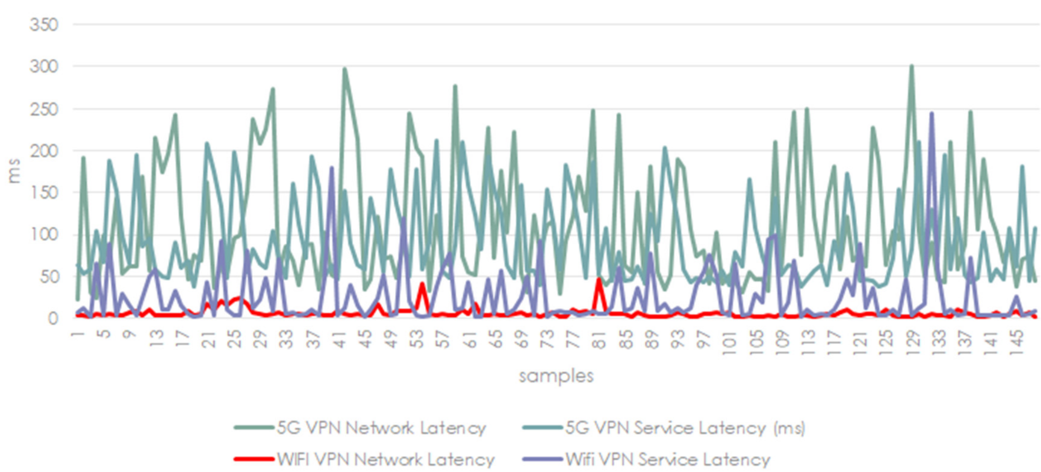


Figure 31: Comparison between network latency as derived in Figure 29, with the latency of a service implemented in python and ROS

[10] https://docs.ros.org/en/rolling/Concepts/About-Quality-of-Service-Settings.html

Figure 32 depicts a comparison between ROS1 bridged dockerized services with WiFi and 5G VPN. Non-bridged latency performance from Figure 31 is also included, in order to highlight the impact of ROS1_bridge to latency.

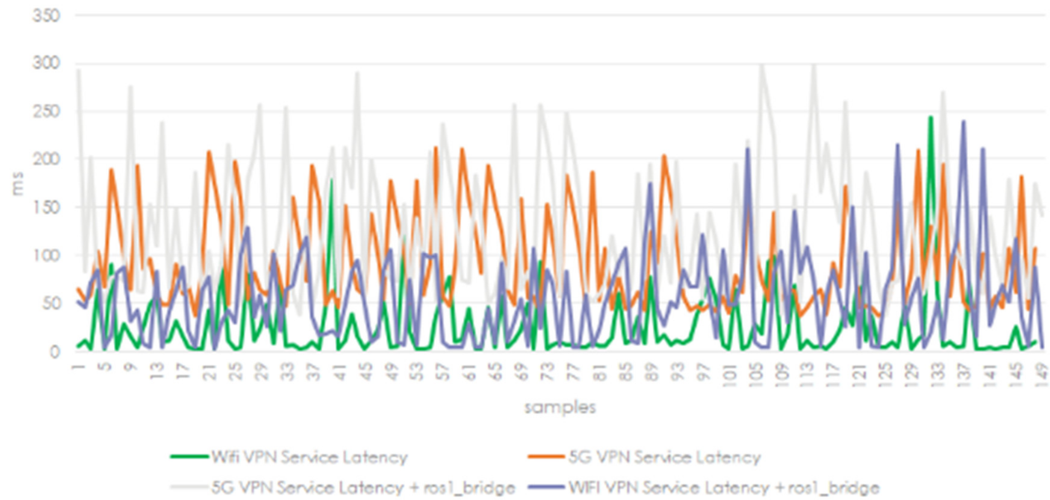


Figure 32: Latency comparison between ROS 1 bridged dockerized and non bridged services with WiFi and 5G VPN. N

The **average execution time for the intelligence distribution** integrated in the current proof of concept implementation is 2.31sec. This considers 4 hosting entities (2 robots and 2 servers) and 8 functional entities with various computational (CPU, RAM) and execution requirements (need of camera/arm/wheels, need of other Functional entities to be placed in the same node). Further results from lab testing of this implementation of the intelligence distribution mechanism can also be found in D3.2 [6].

The **average execution time for the implemented security mechanism for threat detection and classification** is 68ms for one data stream/row, 900ms for 40 streams, 2.4sec for 100 streams, and 23sec for 1000 streams. This average execution time also applies to the implementation of UC3 Public Safety.

3.3.1.2.2. Energy efficiency

Figure 33 depicts the level of battery of a robot for different levels of intelligence distribution. Specifically, the graph shows how the battery percentage evolves 75 % of nodes (i.e., services related to the Smart Warehousing) are hosted on the robot, all services are hosted on the robot and only essential hardware related services/nodes are hosted on the robot. As expected, the battery percentage is at its highest in the latter case, Figure 34 and Figure 35 present similar results for RAM and CPU usage respectively. These results aim to provide an indication of how intelligence distribution can contribute to energy efficiency.

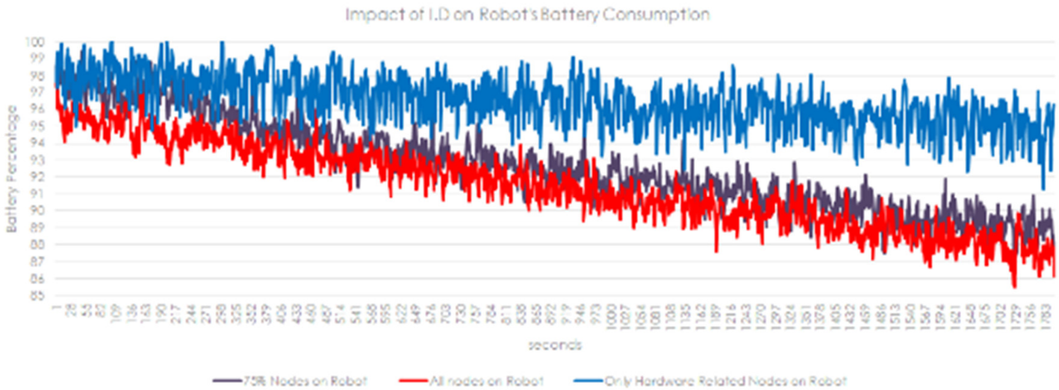
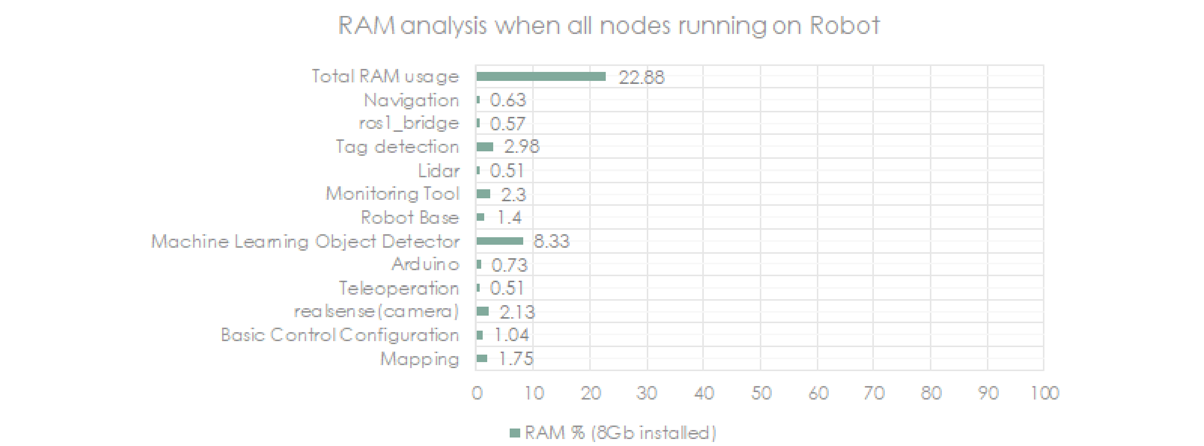
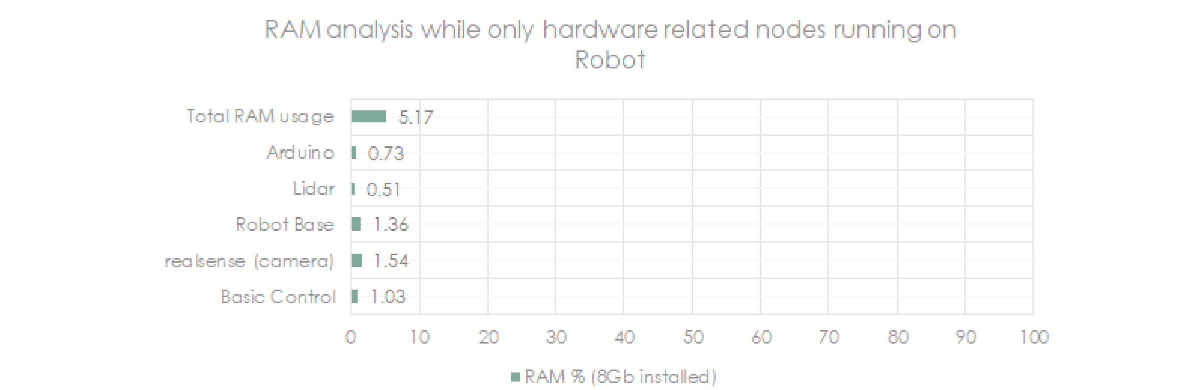


Figure 33: View of impact of Intelligence Distribution on battery consumption of robots

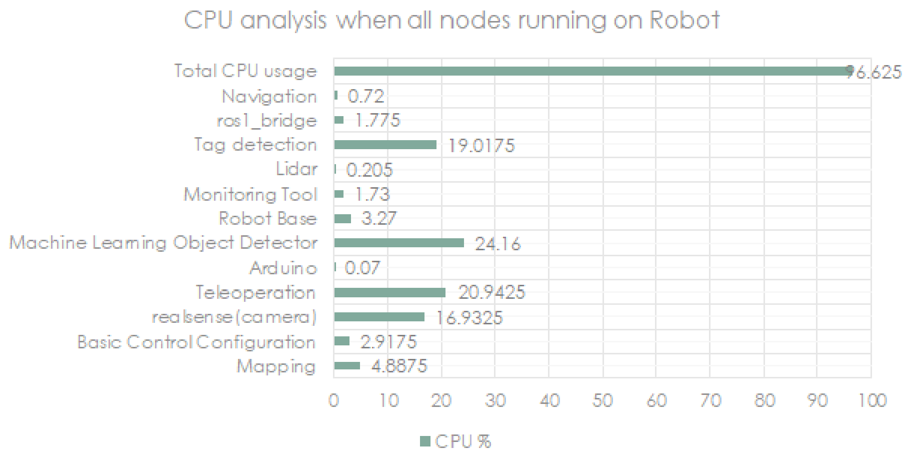


(a)

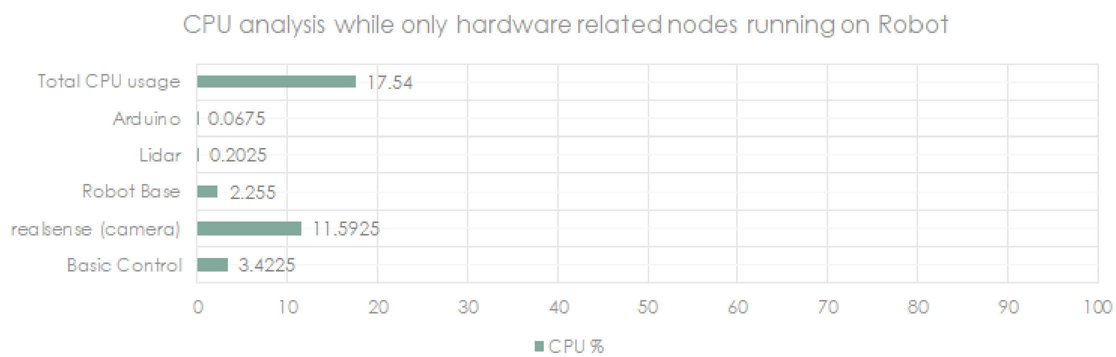


(b)

Figure 34: View of impact of Intelligence Distribution on RAM of robots:
(a) all services running on the robot;
(b) only essential hardware related services running on the robot



(a)



(b)

Figure 35: View of impact of intelligence distribution on CPU of robots: (a) all services running on the robot; (b) only essential hardware related services running on the robot

It should be noted that while the results presented here (Figure 28- Figure 35) are presented under UC1, essentially the measurements are also applicable to the UC3 Public Safety part based on a similar implementation architecture (Figure 67).

3.3.1.2.3. Service reliability

Packet Error Rate is measured continuously by sending test packets from a test sender to a test receiver, and back. No loss of packets was recorded and therefore service reliability is measured at a 100%.

3.3.1.2.4. Warehouse operation efficiency: order picking simulation

3.3.1.2.4.1. General information

Of all warehouse operations, order picking includes the most cost-intensive ones. It is vital to try lots of scenarios to clarify which one could lead to the best results (distance & time reduction). For this to happen, plenty of data is required such as storage locations, order lists, and the included products. We have created a simulator based on the historical data DIAKINISIS has provided us with. The way the simulator works and all the assumptions that have been made are described in this document.

3.3.1.2.4.2. Planning Problems

The planning and optimization of a warehouse can be split into three basic categories:

1. Storage location assignment problem;
2. Order Picking Strategies;
3. Picking Routing Problem (PRP)

3.3.1.2.4.3. Storage location assignment problem

This problem is about how incoming goods are stored in the warehouse. There are three main approaches:

- **random (chaotic)**: simply stored at the nearest available pallet location;
- **dedicated (slotting)**: goods are assigned specific storage locations;
- **class-based storage**: group by item characteristics and each group has a fixed storage location

3.3.1.2.4.4. Order Picking Strategies

Order picking strategies determine how picklists are generated.

- **single order picking**: One order at a time;
- **batching**: Pick more than one orders simultaneously (NP-hard problem);
- **zoning**: The picker only picks items stored in a specific area.

The literature discusses two methods for order batching. The **proximity batching** which uses the proximity of storage locations that need to be visited. In this case orders are not split between different batches. There is also the **time-window batching** in which all orders that arrive during the same time interval are grouped together in one batch. Finally is the **picking prioritization per area** in which orders for the same area are picked in order to increase the loading efficiency and not to miss the loading time window.

3.3.1.2.4.5. Picker Routing Problem (PRP)

PRP is a special case of the *Travelling Salesman Problem (TSP)*[11]. The literature outlines three approaches to pick-run routing optimization:

- Static routing heuristics, i.e., routing rules that human pickers follow;
- Scalable algorithms that either determine the optimal route, or approximate it;
- Hybridization of both picker routing heuristics and algorithmic approaches.

There is a strong connection between the order batching problem (OBP) and the picker routing problem (PRP). Solving these problems simultaneously results in a more efficient solution. This joint problem is known as JOBPRP.

[11] https://en.wikipedia.org/wiki/Travelling_salesman_problem

3.3.1.2.4.6. Simulation

Assumptions

- Workers can execute at least one order at a single tour. The single tour is defined as all the route steps a picker does before he goes to a checking station;
- Vendors that are stored at the left area of the warehouse have their orders checked at the checking stations also located on the left side;
- Vendors that are stored at the right area of the warehouse have their orders checked at the checking stations also located on the right side;
- For each one of the two areas (left-right), the checking station for each order is randomly selected. 3 checking stations available for each area;
- The quantity for each product is set to 1 (1 box);
- When a worker starts picking an order, the checking station for that order is already known so that the picking route can be calculated end-to-end;
- For each order the picker starts from one of the available checking stations (the one he put the last order collected), collects all the products, and then goes to one checking station;
- For the picking of each product a time interval (delay) is required. This is the time a picker needs to take the product from one shelf and put it in his/her carton on his/her pedestrian forklift:
    - We have set this value equal to 1 minute;
    - Currently all our metrics are about percentages of distance reduction, so the above delay does not affect our results;
- Another time interval (delay) is the time a picker needs to place the collected products at a checking station:
    - We have set this value equal to 30 seconds;
    - This variable also does not affect our results but is needed if we want to calculate time-based KPIs.

Workflow

Orders are created for each one of the 6 available vendors separately. The order creation procedure for each vendor is split into 3 steps:

1. Calculate the total daily orders for that specific vendor
    - This value follows the normal distribution (the average number of orders each vendor has daily based on the historical data provided by DIA)
2. For each order calculate the number of different products to be included (n different products)
    - The same technique is used: value follows the normal distribution (the average number of products each order has based on the historical data provided by DIA)
    - Different vendors have a different average number of products
3. Select randomly n products from the product list
    - This step is not exactly random, as the 'Lines' column (how many times each product has been picked) is used. Products that have been picked more times are more likely to be selected.

In the end, all the orders that have been created are merged. For a better understanding, the average values mentioned above are provided in Table 5. The order creation procedure is depicted in the diagram of Figure 36.

Table 5: Average values for each vendor

	PFIZER	UPJOHN	BGP	ARRIANI	GENERICS	MEDA
Average Daily Orders	245	130	108	114	37	35
Average products	5	7	6	7	9	6

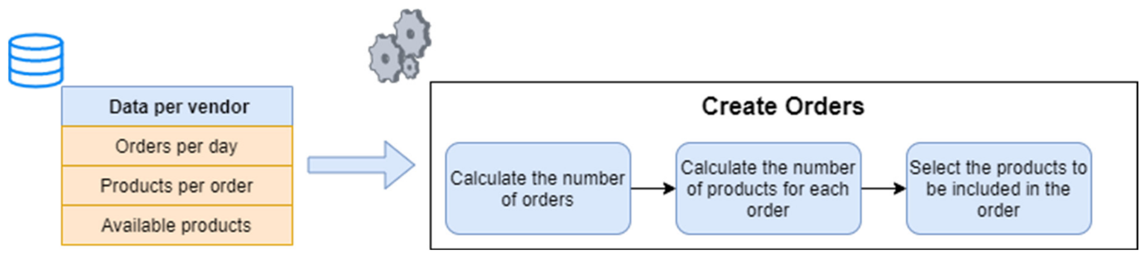


Figure 36: Order creation procedure

When all orders are available, the picking procedure starts. Half of the available pickers are responsible for the left area of the warehouse and the rest of them for the right. In the case that all the orders have been completed for one area, then all pickers operate in the same area.

Optimization

As described in the Planning Problems section 3.3.1.2.4.2, the optimization of the warehouse is based on the storage location of the products, the order picking strategies and the PRP. The first simulation uses the current state of the warehouse:

- Storage locations currently used by DIAKINISIS;
- Single order picking;
- Apply TSP algorithm to solve the picker routing problem (there is no other way to simulate the picking order).

This simulation is used as a reference point.

Storage Optimization

Each vendor has a specific number of storage locations which must remain the same (class-based storage, section 1) as shown in Figure 37. Different colours indicate different vendors.

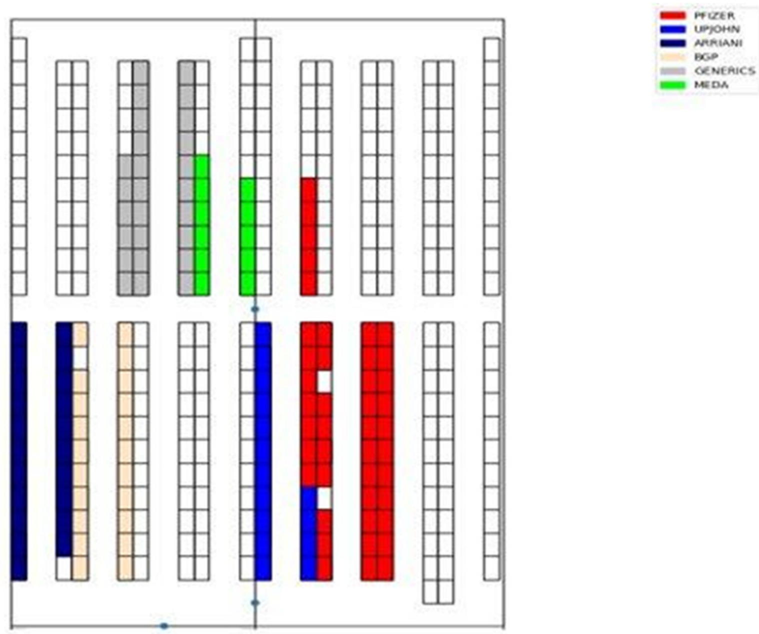


Figure 37: Storage locations per vendor

Our approach is to place most frequently used products near the checking stations to minimise the total distance required for each order. The checking stations are located near the end of the corridors. The products of each vendor are ordered based on their frequency and then placed at the storage locations with the lowest Manhattan distance[12] from the corridors as shown in Figure 38. This approach reduces the distance of high used products from both the checking stations and other products with similar order frequency. If we had historical order data, we could have found more patterns therefore have created an even more accurate storage optimization algorithm.

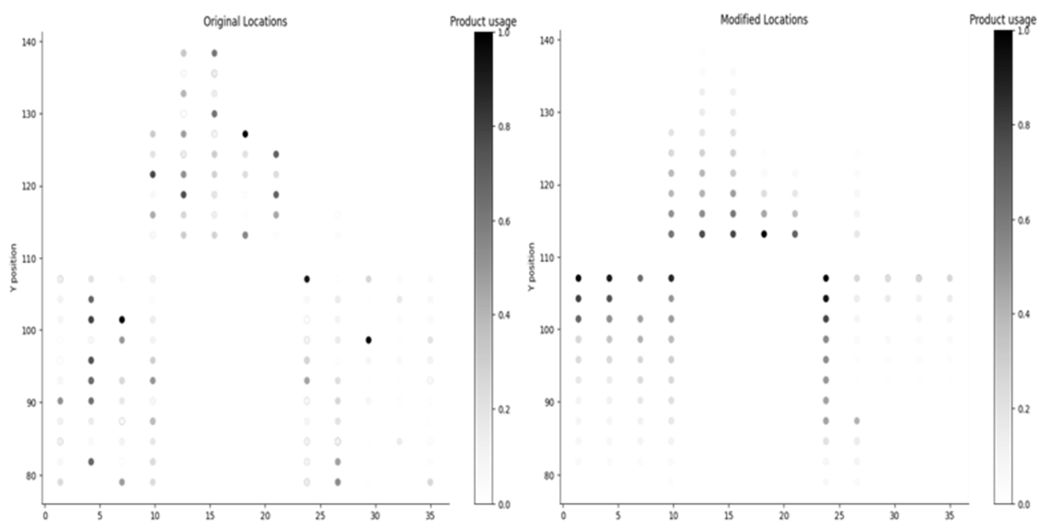


Figure 38: Original vs modified storage locations heatmap

[12] https://en.wikipedia.org/wiki/Taxicab_geometry

Order Batching

As mentioned in Section 3.3.1.2.4.4, for maximum distance reduction, similar orders are picked together, and the route optimization algorithm (TSP) is applied as if we had one single order (JOBPRP). Batching is applied to orders with common vendors. The order batching algorithm uses a combination of the seed algorithm and data mining. Data mining is used to extract the features that define the similarity of the orders. In our case the similarity is measured using the number of common products between orders. A high-level version of the order batching algorithm is shown in Figure 39.

```
while there exist unassigned customer orders do
   open a new batch;
   select an unassigned order as seed order;
   while orders exist which does not exceed the
      remaining capacity of the current batch then
      select an unassigned order;
      assign order to current batch;
   endwhile
   close current batch;
endwhile
```

Figure 39: Order batching algorithm

The similarity between the seed order and the remaining orders is calculated for each new batch. The most similar orders are assigned to the current batch till the capacity is full.

In our case the capacity refers to the total number of orders per batch. In most cases the number of products is used instead but this would add much more complexity to the algorithm.

3.3.1.2.4.7. Simulation results

The results of each simulation refer to the average daily distance reduction compared with the current state of the warehouse (first simulation). The total distance required for each order is the sum of the picking and checking distance. The picking distance includes all the route steps the picker does from the first to the last product. The checking distance includes the steps from his initial location to the first product and the steps from the last product to the checking station. Three different scenarios were simulated:

1. Update the storage location of the products based on our storage optimization algorithm without changing the picking strategy (single order picking);
2. Use the existing product locations (as provided by DIAKINISIS) but with order batching with 2 orders capacity;
3. Combine scenario 1 and 2.

The overall distance reduction is presented in Table 6.

Table 6: Overall daily average distance reduction

Scenario	Total Distance	Checking Distance	Picking Distance
Modified Storage Single Picking	**- 7,27 %**	**+ 1,66 %**	**- 18,35 %**
Original Storage Order Batching	**- 45,75 %**	**- 51,19 %**	**- 38,12 %**
Modified Storage Order Batching	**- 49,66 %**	**- 49,63 %**	**- 48,90 %**

Scenario 1

The impact of checking distance is high and cannot be easily reduced in single order picking. Storage optimization focuses on picking distance (low distance between similar products), while order batching deals with both checking and picking distance.

Although the picking distance was reduced by around 18%, the overall distance was not reduced that much. That is normal because picking and checking distances do not have the same weight. For instance, consider a vendor that is placed far away from the checking stations. Even if all products are placed together (small picking distance), the checking distance will be high as a lot of distance is required from the checking station to the area of that vendor.

The results may differ per vendor. As shown in Figure 37 the total number of storage locations per vendor is not the same. The more products a vendor has, the more the storage combinations will be. Small distance reductions indicate that the storage is already optimised.

Scenario 2

When two orders can be picked at the same time, there is a high possibility to find orders with some common products. In that way, a storage location is accessed only one instead of two times. It is vital to choose orders with as many common products as possible in order to get the maximum distance reduction. No matter whether similar orders are found, the distance between the checking stations and the vendor zones is reduced by around 50%. Order batching seems to smooth the distance weights, as the total distance now is the average of the checking and picking distance.

Scenario 3

When using both the modified storage locations and the order batching the results become even better. The checking distance is almost the same as scenario 2, but the picking distance is reduced even more. Order batching groups similar orders. Even if the orders do not have the same products, they may have products with high usage frequency. Due to the storage optimization algorithm these products have been placed nearby, thus the picking distance is reduced.

3.3.2 Next steps for the third period

The next phase will bring further integration of the partner's components and services. Also, focus will be on wider implementation of security policies and deployment of blockchain enabled trust management platform. Predictive mechanisms to support intelligence distribution will be added. Further KPIs will be measured such as UC1_KPI 5 Warehouse safety, while additional KPIs may be included as well.

The second integration functionality pilot demo is planned for the spring 2023 (Figure 40). We will have the final use case demo before end of the project, in September. The final pilot demo will demonstrate full components integration and evaluation in a real environment.

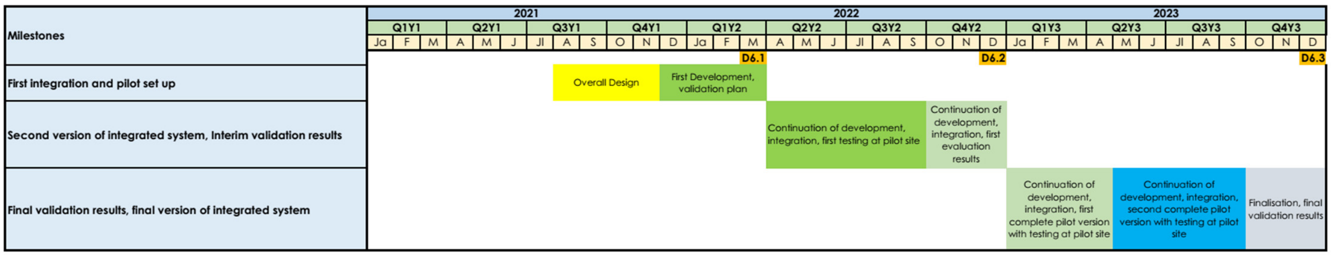


Figure 40: Milestones and planning for UC1 proof of concept

4 UC2: ENHANCED EXPERIENCE

4.1 Scenario and stories

The Enhanced Experience use case scenario focuses on live public events that are characterized by a dense number of local users (participants) as well as remote participants enabling virtual attendance. In such a use case, the underlying mobile network will be stressed by the users accessing their devices and even through live streaming from the site [19] as well as accessing the similar services. Especially in the event site, often more restricted mobile uplink capacity becomes the bottleneck when participants stream live content towards the social media or designated users. As a consequence, a large audience is vying for the same network resources within a small area [22], which creates a need for dynamic flexibility of the network. In addition, large crowds would move from one venue to another depending on the time and places (e.g., multiple stages attract varying size of audience). In this case, dynamic network coverage is needed to provide seamless connectivity [23], [24]. The DEDICAT 6G solution for Enhanced Experience focuses on these issues and strives to provide richer quality of experience to local spectators as well as delivering enhanced live experience to remote users using B5G/6G networking.

As the Enhanced Experience Use Case focuses on reducing the gap between local and remote participants for crowded events, several beneficiaries, a.k.a. stakeholders, can be identified depending on the physical location. In the actual event area, the main beneficiaries consist of the local audience. These users are equipped with DEDICAT 6G compatible devices that can enhance their live quality of experience via evolved navigation through smart glasses, real-time announcements of simultaneous shows in different areas (stages) and/or possibility for online streaming of these interests. The local users also possess the ability to become content creator by performing live streaming using the developed implementation architecture in DEDICAT 6G.

On the consumer side, remote participants are another group of beneficiaries who can possess remote experience of the live event from a remote destination i.e., from their home. This user group is also equipped with smart terminal technology able to get live announcements of live streams as well as browse through the different views of distinct camera sources of the event area. One of the content sources enables live view "see what I see" originating from the smart glasses.

Video service providers can also benefit from the DEDICAT 6G technology in this use case as the quality of service for remote consumers viewing the content has improved. The end users can obtain higher video streaming quality via novel proactive video adaptation against fluctuating network conditions. Mobile multicast can provide not only network resources savings and even other resources such as energy savings, but also improved quality of experience for the end users. Dynamic coverage extension introduced by Connected Car (MAP) according to the crowd movement will also ensure improved connection quality, especially on the UL side. Naturally, improved service quality can increase the financial value of the service(s). Virtual participation, especially during pandemic can increase the number of remote participants significantly.

4.1.1 Detailed Stories

The three stories planned for the Enhanced Experience use case, take place in two locations: on-site (public venue such as music concert) and in a remote location (user's home, etc.) considered as a means for virtual participation. The stories focus on providing a more efficient DEDICAT 6G-powered technology for on-site participants as well as narrowing the border between physical and virtual presence for such public events. To be precise, Story 1 concentrates on improving the on-site experience, Story 2 enhances the virtual experience remotely, and Story 3 combines the previous stories via live service for remote users. A so-called Connected Car has been pre-deployed at the beginning of the concert in order to increase B5G radio capacity in the event site.

Story 1: You are participating in a live public event, such as a live music concert with multiple stages, and you are glancing at the event brochure thinking about which artist to see next. Suddenly, your mobile phone alerts you and you receive a live video stream from your friend who has found a great position close to the stage where an artist you are also interested in, is currently performing. You begin the navigation according to the stream and find yourself quickly with your friend to watch your favourite band. After a while, you remember that some of your friends are not participating in the concert at all, and you decide to invite your friends. Since you are connected to a smart mobile network cell, which is enabled with the sophisticated DEDICAT 6G technology, you can easily launch a mobile video streaming service with your modern smartphone and high-definition camera even if there are a number of other mobile users competing for the same network resources.

From the brochure, you find that each event is scheduled on a different stage. Viewing the event-stage mapping information, you can move to the target stage and find places to watch the event. Since the network adopting the DEDICAT 6G technology will provide dynamic coverage for connectivity extension, you can connect to the network to share/send video streaming content from anywhere in the event venue.

Story 2: You are staying at home when your friend contacts you via mobile and live streams real-time video from a concert. You live through an enhanced remote experience as if you were amongst the members in the audience by using virtual presence through VR glasses. At some point you receive another stream notification from the event organizers, which is yet another access link to a live stream from the concert. Thus, the high-quality content from static cameras is distributed to a large audience for virtual participation in the event. COVID-19 is an excellent example of such a use case, where the event organizers are not necessarily postponing the event, but instead are live streaming the performances to paid users.

Story 3: This story takes place during a concert in an area (stadium, concert park, etc.) where the concert attendees gather and enjoy the shows (different scenes feature various bands and music styles). Then they engage in live streaming activities. Two actors are involved: the main actor –say user X- is a music concert enthusiast who attends a concert, and the second (category of) actor is one of X's FaceBook™ live followers.

4.1.2 Services – Human centric applications

The Enhanced Experience holds two main actors: local attendees in the event site and remote attendees in distance. The local spectators can act as content producers i.e., streaming the video from the site, or as consumers for playing the content provided by other users. The latter one can help to navigate stages of interest or watch simultaneously alternative content from their UEs. Thus, the virtual participants can locate as well nearby the event surroundings but still outside the area.

The content is pushed according to the stories to dedicated video streaming platform developed in the project with the connection to DEDICAT 6G platform for optimizing the service and visualizing the achieved gains in real demonstration. The dedicated remote users will have the ability to access these services in a secure way using Nokia Data Marketplace. It is also noticeable that on-site users relying on video streaming technology as content produces, may influence annoying audio latency, which emphasizes the technology usage mainly for remote attendees.

Different source cameras will be used for generating enhanced virtual experience for the end users. These cameras include normal 2D-cameras originating from USB-based cameras connected to UEs (such as integrated cameras with smartphones) or *eXtended Reality (XR)* capable cameras (such as 360°) for providing free viewpoint possibility and improved virtual experience. Thus, more complex HW & SW in XR devices can increase not only the *End-to-End (E2E)* latency compared to more traditional solutions, but may require higher data rate resulting also to high UL usage in the event site. Eventually, the solutions within DEDICAT 6G platform can enable network flexibility with this issue. Finally, the Smart Glasses that will also be utilized are depicted next.

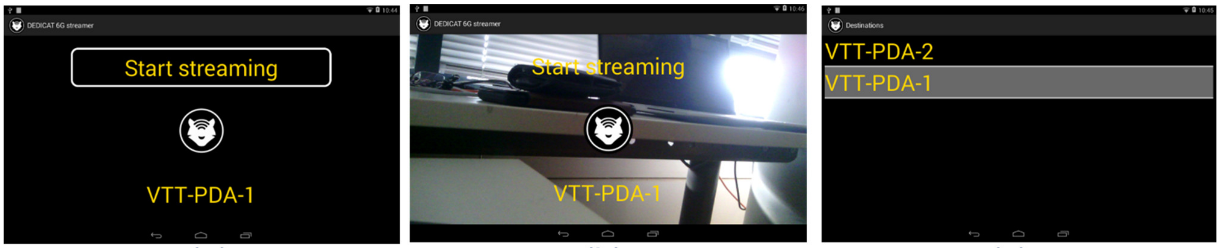
Optinvent will provide Smart Glasses in the event site illustrated in Figure 41, which will produce content for the end users. Optinvent will provide several ORA-2 smart glasses for the events. These devices are running on Android device platform and should be connected each to a local smartphone through a Wi-Fi/mobile hotspot to be able to connect to the Internet, since the glasses do not have 4G or 5G intrinsic connectivity. The glasses are standalone devices that allow users to see bright images while maintaining the transparency of outdoor scene. The glasses have embedded *Global Positioning System (GPS)* so that position of the user could also be tracked during the event if necessary. The ORA-2 smart glasses use KitKat Android version and are compatible with any existing application from Google Play. The streaming from the glasses could be either directly from the glasses or through the user smartphone (used also as a Wi-Fi/mobile hotspot). To interact with the glasses, a touch pad or joystick allows the user to go through a specific menu provided by the application that should be developed for this use case.

Figure 41: The components for the Smart Glasses to be used in the Enhanced Experience

In the second integration phase of the project, we have developed Android streaming application to be used in the Smart Glasses, which is visualized in Figure 42. In the first implementation stage, the application holds the basic functionality including features such as starting and stopping the streaming using the HW camera component as well as setting the destination for the live stream. The destination in this case, as depicted in WP2 architectural documents, is the edge server functioning as the video streaming platform. From the implementation point of view, the destination name field consists of the access network name together with edge server IP address introduced in the XML file. We also implemented logging and timestamping system inside the application for measuring the processing delay before video packet is sent to the network.

The implementation currently supports RTP/UDP streaming with 1280x720 resolution (camera HW limitation) and dynamic frame rate range 3-30 fps. Camera HW encoder in ORA-2 supports up to 20 Mbit/s, but in practice 5 Mbit/s outputs are measured.

The implemented Android application provides also scalability including functional support also the latest Android OS versions. In the current second phase of UC2 development, we have also integrated and tested the ORA-2 application in latest Android devices for comparing the Smart Glasses performance against the latest smartphones. These results will be introduced later in Section 4.3.



(a) (b) (c)

Figure 42: The developed Android streaming app GUI for the Smart Glasses. a) Basic view, b) Preview mode, c) Destination selection

As introduced earlier, the usage of 360° camera technology can enable XR-based experience for the end users and therefore providing improved virtual experience for remote participants. We have integrated the aforementioned components as part of UC2. However, as 6 different cameras form the final stream to be streamed through the network, it will consume the bandwidth significantly compared to traditional 2D cameras. This will emphasize the importance of UL in multi-user scenarios such as in UC2, where multiple users are vying from the UL resources and congesting the network. Therefore, intelligent DEDICAT 6G components are needed for increasing the capacity and extending the coverage into the borders of the existing network. Figure 43 below illustrates the aforementioned 360 camera with its view in VTT parking area.

(a) (b)

Figure 43: 360° streaming technology to be used within UC2. a) Insta 360 Pro 2 camera, b) Panorama 360° view of VTT parking area.

VTT will provide the latest 5GTN infrastructure for the pilots as well as the multicast/unicast video streaming platform with the necessary applications and UEs, which are needed specially to support the mobile multicast.

The unicast service and Facebook Live™ (see a sample photo, Figure 44 and Figure 45) can be accessed basically with all the modern smartphones, tablets, and laptops. The video transcoding unit associated with video streaming platform will generate the necessary formats (e.g., HLS, MPEG-DASH) for successful and supportive playback in various client devices. Figure 44 represents the sample tests using LTE/5G multicast streaming to three end user devices with pre-encoded content.

Currently the multicast is introduced in the 3GPP standardization [35] as *Multicast and Broadcast Services (MBS)* following the evolution of *Multimedia Broadcast/Multicast Service (MBMS)* [34]. The architectural enhancements towards 5G advanced and 6G include improving resource efficiency with the utilisation of inactive and idle states especially with broadcast mode. This would emphasize its usage also for energy-save optimizations.

Figure 44: A sample set of end user devices supporting mobile multicast.

Figure 45: A sample photo of Facebook Live session (Photo by Nicolas LB on Unsplash)

As the Enhanced Experience use case involves different scenarios for optimization, we started to implement real-life visualization as an animation of the UC2. This application is intended to perform as a compact demonstrator, which can take real-life measured values as an input and illustrate the system behaviour like a digital twin.

As an example, we have modelled VTT parking area under 5GTN, where several real measurements can take place and taken into the database for later usage in the visualization. Currently during phase 2 of UC2, we have completed the coverage extension scenario animation, where MAP (Connected Car) is brought near the DEDICAT 6G user(s) who are live-streaming from the event site using e.g., smart glasses or mobiles. With the visualization, we can illustrate which DEDICAT 6G components are taking the action in real time (upper left corner in Figure 46).

The actual implementation is done with C++ with assistance of Simple DirectMedia Layer (SDL2)[13], OpenGL Extension Wrangler Library (GLEW)[14], libcurl[15], ImGui[16], GLM[17], and Blender[18]. SDL2 is used for enabling OS-independent IO with graphics HW via OpenGL, which extensions are loaded run-time through GLEW. CURL (libcurl) is used for basic HTTP messaging, for instance, it can be used for fetching network information from the database. Finally, Dear ImGui forms the simple graphical user interface (e.g., inside the box for DEDICAT 6G components), GLM provides the mathematics library for graphics programming, and Blender is used for generating the 3D models in the application.

Figure 46: Real-life visualization application for illustrating UC2 scenarios.

4.2 Scenario Set-up

4.2.1 Pilot set-up

The site set-up includes ultra-high-definition video cameras, mobile devices, smart glasses and a B5G capable mobile network. The hidden network infrastructure contains dynamic intelligence implemented via enhanced AI algorithms, routing, and distributed computation processing. In addition, Mobile Access Points, namely as Connected Car as introduced in [2], are included to provide dynamic coverage enhancement of which the indoor protype is depicted in Figure 48. MAPs could be located dynamically.

Depending on crowded users' movement, the position of MAPs would be adjusted to provide robust connections to more users. In addition, considering that the base station can support users, user association to MAPs and BSs is arranged efficiently for traffic load balancing as well. During the evolution of the project this mobile prototype will be taken smaller to enable easier portability and mobility in different setups from which one main utilisation place will be onboarded to a car. Figure 47 illustrates the overall setup of the Enhanced Experience.

[13] https://www.libsdl.org/

[14] https://glew.sourceforge.net/

[15] https://curl.se/

[16] https://github.com/ocornut/imgui

[17] https://glm.g-truc.net/0.9.9/

[18] https://www.blender.org/

The on-site equipment comprises mainly of the components related to the human-centric services depicted earlier. These include mainly the end user devices capable of live streaming from the site with wireless connectivity. B5G systems are considered in the demonstration setup for form the connectivity starting from the 5G SA/NSA operability currently available in 5GTN.

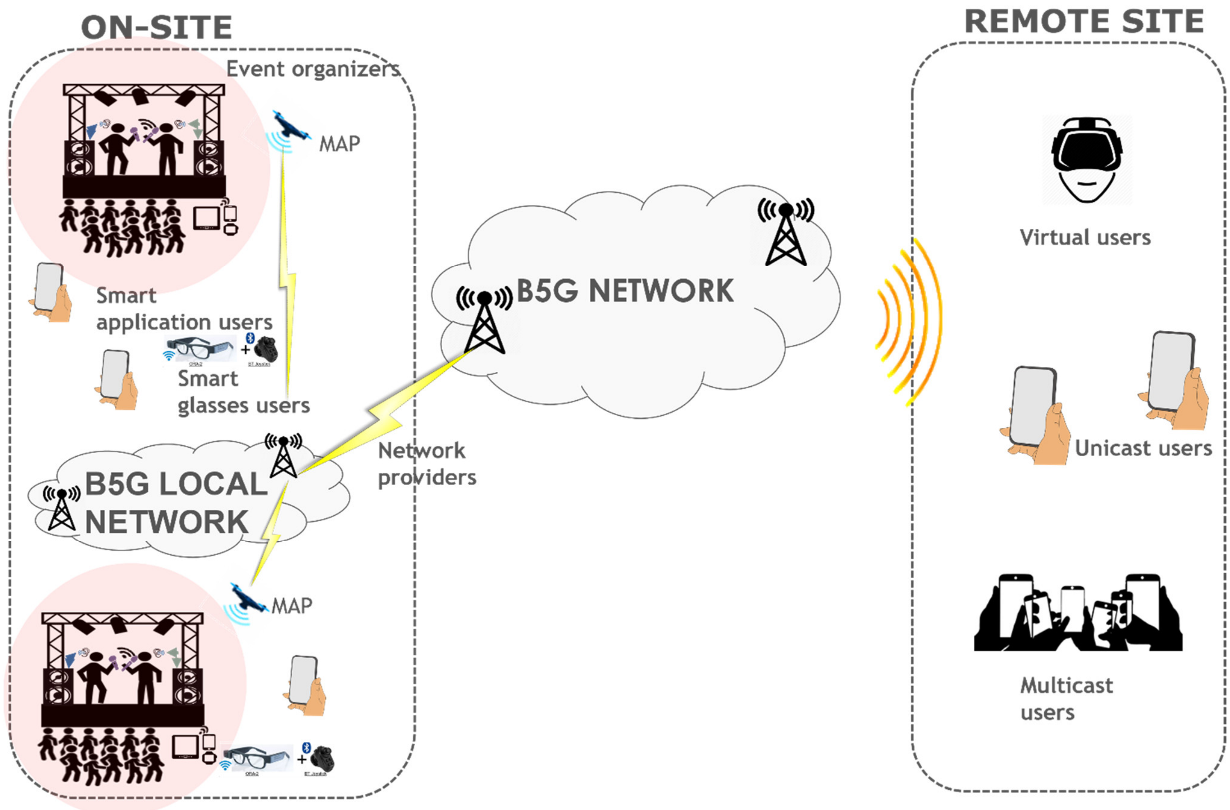


Figure 47: The set-up plan for the Enhanced Experience (UC2)

In overall according to Figure 47, the set-up considers the following:

- Smart Glasses and other sources (i.e., AR/VR capable cameras) in the event site;
- Smart devices with mobile connectivity (i.e., Smartphones) for providing the network access and necessary video applications for users including:
    - B5G connectivity support;
    - Mobile multicast both in middleware and playback application support;
    - Smart Glasses application;
    - Legacy video playback application(s);
    - Facebook™ native application.
- DEDICAT 6G video playback applications modified and developed for the project purposes for enabling optimised KPI targets;
- MAPs for providing dynamically enhanced coverage in the local B5G area;
- Edge (MEC) servers for providing live video database and video processing functions for enabling dynamic offloading, distributed computing, energy efficiency whenever possible, and load balancing in the setup;

- The DEDICAT 6G platform integration in terms for utilising necessary network parameters for network intelligence and optimisation, and trust/security management for secure system authorization;
- Nokia Data MarketPlace for providing security, trust and privacy for the video feed from the video streaming platform.

Orange will design decision-making algorithms for resource orchestration, depending on the service requirements and with isolation guarantees for security purposes. In particular, the algorithm will determine where to place the services on the different edge servers. The services include live video database, video processing functions, and any other function necessary for providing services to end-users. The placement has to find a compromise between uplink latency (for content production) and downlink latency (for content delivery), while being energy-efficient. Of course, the quality of the service must be taken into account by providing enough resources (computing, memory, storage) to the functions and keeping the latency within acceptable bounds, defined by the services. The available resources must be shared by all the functions fairly, so that all the services run within the accepted quality.

Figure 48: Indoor prototype of 5G MAP

4.2.2 Enhanced Experience use case implementation

4.2.2.1 DEDICAT 6G architecture components

The detailed functional decomposition of the interconnection of this Use Case into DEDICAT 6G architecture and platform is described in D2.3 and also in D6.1. During the evolution and revision of DEDICAT 6G architecture, one additional component has been introduced relevant also for this use case:

- MAP Operation FC: receives CE decisions from CEDM FC and is responsible for implementing them. It is also responsible for the provisioning of a dedicated network slice as described in detail in D2.4 (if required, depending on the QoS constraints and number of attendees).

4.2.2.2 UC2 specific components

Real-time network performance indicators alongside visualization of the system functionality plays a key role in this use case. The developed functionalities rely on gathering essential network data for directing especially the functionality and performance of the live streaming platform. These parameters include:

- Network delay (maximum accepted network latency);
- Glass-to-Glass latency (maximum accepted latency starting from camera capture ending to display in client screen);
- Throughput (minimum accepted throughput and the increased throughput by the use of MAPs will be also considered as the effect of traffic offloading);
- Number of connected users (needed for switch for multicast to unicast and vice versa);
- Packet loss;
- Signal statistics (e.g., strength, *Signal to Noise Ratio (SNR)*).

One of the used network performance evaluation tools includes Qosium, which *Graphical User Interface (GUI)* is depicted in Figure 49. This SW-based tool performs passive network performance evaluation and gathers the needed and essential network parameters in focus. Qosium holds two parts, namely Qosium Probes and Scope. The Probes are installed to different network nodes of interest. In video streaming scenarios such as in UC2, they will be installed in the network nodes related to the video transmission chain: source UE as for the content capture and streaming, edge nodes for content processing (transcoding), and client terminals for content consumption (video playback). During the second phase as an ongoing phase, it is still under investigation if Qosium Probe can be installed directly into the ORA-2 functioning as a rooted service. Alongside the Probes, Qosium Scope and Grafana are used for visualizing and/or gathering the results. During the measurements and piloting, we are sending the Qosium data real-time to the Influx database from which Grafana can retrieve the values for visualization. It suits also better for viewing long-term results and statistics regarding the system behaviour.

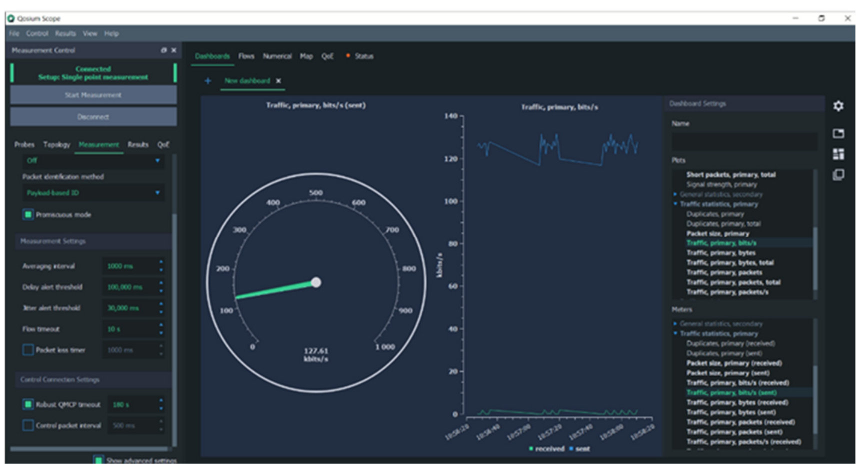


Figure 49: Qosium SW network tool for measuring and visualizing the KPIs

Carlo Gavazzi ET112 energy meters are used for determining the device power/energy consumption in reliable manner. The consumption is measured concerning the whole device, not only for specific SW processes.

4.2.2.3 Interfaces

The table of interfaces has been introduced in D6.1 (UC2- Interfaces for components on the Enhanced Experience). Additionally, during Phase 2, we have added security and privacy protection framework (*Nokia Data MarketPlace)* into the plan running as an edge service for protecting the video streams against external intrusions.

4.2.3 Integration report

The paragraph below describes the use of WPs outcomes in the UC2 and the contribution per partner participating in UC2, done during the period M15 to M24.

4.2.3.1 Description of WPs related outcomes used in UC2

Mechanisms for Dynamic Distribution of Intelligence (WP3):

Advancing the computation distribution in edge- and processor level. Finding the best practices for lowering the power/energy consumption in the video processing tasks (e.g. transcoding) with optimal real-time performance, which are relevant items for UC2. Testing and developing these distributed computing techniques into UC2 platform.

Mechanisms for Dynamic Coverage Extension (WP4):

Coverage extension algorithms and design for UC2 event scenario with dynamic/pre-deterministic MAP placement. Implementing and designing the actual MAP as a ConnectedCar into VTT premises in Oulu.

Mechanisms for Security, Privacy and Trust (WP5):

WP5 will provide security and trust and integrate it to the use-case. WP5 will provide access control on both producer and consumer sides. Evolving the security and trust framework via Nokia Data Marketplace, and integrating it with UC2 video streaming architecture especially in the downlink side between the video streaming platform (edge server) and end consumers.

4.2.3.2 Description of contribution per partner in UC2

UOS: Considering a group of UEs and multiple APs including MAPs and BSs, the efficient user association and resource allocation is required to provide robust connection to a group of UEs. During Phase 2, UoS has started to design how to associate UEs requiring different QoS to multiple UEs and allocate powers considering the power constraints. The algorithm has been designed for the case of pre-deterministic MAP placement. In the next phase, improvement of this algorithm will be carried out to include dynamics of MAP positions so that real-time mobility of UEs can be efficiently managed.

ORANGE: Orange has designed an algorithm for selecting the location of latency-sensitive tasks. In this way, the network resources will be shared among the different services, and the energy consumption can be lowered to its minimum while keeping the Quality of Experience at an acceptable level for users. This algorithm has been implemented as a proof-of-concept in order to perform lab evaluation. Later on, it will be integrated in the Decision-Making FC.

VTT: Selecting the right components during building the HW infrastructure in 5GTN and evaluating their current performance as a baseline both from device and network (5G) perspective. Integrating and evaluating Smart Glasses as a part of UC2. During Phase 2, VTT has also started to implement 3D-animation of UC2, which can visualize the scenarios by using the real-life values of the measurements in a way like digital twin. Distributed computation in the edge server(s) for enabling lower power/energy consumption in the UE, and also to load balance the access network. This is planned to be one part / one scenario of the UC2 pilot.

OPTIN: Optinvent and VTT have co-operated and developed an Android application suitable for live streaming in the ORA-2 Smart Glasses focusing on especially on the needs for integrating this device with DEDICAT 6G platform. A survey from novel versions of Smart Glasses has been also done in terms of introducing latest Glasses in the next phase. In addition, the preliminary performance of the application and ORA-2 has been done and will be reported in Section 4.3.

VLF: Implementation of private permissioned blockchain and collection of smart contracts for security and trust management framework, described in D5.2.

4.2.3.3 Description of external assets used in UC2

The test facility 5GTN in Oulu has been used, developed, and upgraded in various national and international projects during the last few years, and it is in continuous evolution phase for utilizing the actual HW and SW components in B5G. Generally speaking, past national projects (such as Finnish 5G-FORCE[19]) have been the basis for 5GTN, and nowadays it is updated and upgraded by the different vertical projects. H2020 projects 5G-HEART[20] and 5G-ENHANCE[21] have preceded the 4G/5G validation trials with live video streaming including also mobile multicast. Some of the streaming solutions developed and validated in these projects will be exploited in UC2 by enhancing and tailoring these solutions with DEDICAT 6G architectural components with increased intelligence and flexibility for adapting real-time video against the network fluctuations. In addition, 6G-XR H2020 project starting at the beginning of 2023 focuses partially on lowering the energy consumption in XR streaming, which can form synergies with UC2 following the work initiated in CONVINCE[22] project. UC2 will also evolve the Monica[23] work with the ORA-2 Smart Glasses for dedicating the applications specifically on enhancing the real-time end user experience from a large event. Furthermore,the ongoing Terminet[24] project also utilizes the Smart Glasses for real-time remote attendance, which can also form possible synergies from streaming application perspective.

4.3 Evaluation and first results

Next, we illustrate the current preliminary results across the different selected KPIs and focus on showing the baseline evaluation results. The more advanced solutions with results with full utilisation of DEDICAT 6G platform will be illustrated in the final WP6 deliverable, D6.3. The measurements in 5GTN test bed have been conducted by using the tools and techniques shown in 4.2.2.2.

4.3.1 List of KPIs, target values and gain

4.3.1.1 KPIs and target values

The key characteristics of this Use Case can be summarized as real-time video streaming services for heavily crowded users and local distant users by using dynamic coverage provision with MAPs. Thus, the performance evaluation is focused on effects of dynamic coverage

[19] https://5gtnf.fi/projects/5g-force/

[20] https://5gheart.org/

[21] https://cordis.europa.eu/project/id/815056

[22] https://www.celticnext.eu/project-convince/

[23] https://www.monica-project.eu/

[24] https://terminet-h2020.eu/

extension and impacts on real-time video streaming. Table 7 illustrates the KPI list with target and baseline values.

From the dynamic coverage extension perspective, service availability and edge offloading factor performance could be measured as well as decreased energy consumption mostly from the individual devices.

- Service availability: when the area of *Point of Interest (PoI)* is given for outdoor events, the video streaming service should be available for the whole area by either the ground base station or MAPs. Thus, the coverage where the service of required QoS is satisfied will be measured within the area of PoIs;
- Edge offloading performance: due to the surge of end users crowded for the event, it is expected that the ground BS (gBS) capacity is not sufficient enough for all users. Since MAPs can be deployed for traffic offloading, the effectiveness of offloading in the system will be measured. The performance is compared to the case of not using MAPs. Of course, this performance would highly rely on the number of deployed MAPs. In the final physical pilot a single MAP will be deployed and deployment of higher number of MAPs will be verified via simulations ;
- Decreased energy consumption: The developed solutions should contribute to decreased energy consumption in the network devices depending on the scenario especially when service users receive the content via multicast instead of unicast. We plan to implement a demonstration example with limited setup with the set of available energy monitoring devices.

From the perspective of the real-time video streaming, service reliability measured by *Packet Loss Rate (PLR)*, service latency, and throughput per each user can be measured.

- Service reliability (measured by Packet Loss Rate): it represents the ratio of the number of lost packets to the total number of sent packets. When video streaming data is transmitted, the PLR directly impacted the quality of experiences at the end users. Thus, end-to-end packet loss ratio will be measured;
- Service Latency: to make sure that the good quality of video streaming can be transmitted successfully, a low level of network delay performance needs to be guaranteed. The network delay comprises both uplink and downlink, but in the UC2 scenario especially the uplink delay is the more critical one. Along with the network delay, the overall end-to-end latency will be measured which comprises the whole transmission chain starting from camera capture ending to video playback in the UE display;
- Throughput per user: the scenario focuses more on fulfilling the needs of a large audience group as congested crowd rather than serving individual users with the limits of promised B5G network speeds. Adaptive streaming is a flexible option in terms of available network resources at an arbitrary point in time. The throughput target can also be identified in the window of square meters;

Table 7: UC2 – Enhanced experience KPIs list

KPI ID	Description	Target value	Baseline
UC2_KPI1	Service (video) Latency	Network delay (either UL or DL) < 10ms	5G as a baseline, shall be maintained / improved in congested scenarios using DEDICAT 6G architecture. The values are defined for live video transmission. "For live streaming in crowded areas, services for media production, augmented

KPI ID	Description	Target value	Baseline
			reality for collaborative gaming etc.: 20ms end–to-end (UL+DL) ([33], Annex A"
		E2E latency < 200ms	Motion-to-Photon or (Glass-to-Glass) latency; starting from camera capture ending to screen display. Literature indicates that higher latencies than 200ms affect negatively to QoE [32].
UC2_KPI2	Throughput for each user	Bitrate > 5 Mbit/s	Good bitrate for full HD video ranges from 3.5-6Mbits/s and we set 5Mbit/s as a target. For certain devices (i.e., Smart Glasses) some device-specific constraints apply. In [33], 3GPP standard, 50Mbit/s UL data rate is recommended for broadband access in a crowd in a confined area, such as in music concert with half million people / km^2 (30% of active UE users).
UC2_KPI3	Service reliability	PLR < 10^{-3}	Our target and baseline from the 5G/3GPP standard [33]. No need in our case to have higher reliability; even random packet losses are accepted.
UC2_KPI4	Service availability	99%	Service should be available within the whole event area, including its boundaries. Introducing the MAP(s) can also improve the availability.
UC2_KPI5	Edge offloading performance	> 50%	The use of MAPs in a heavy traffic load area can offload the traffic served by BSs. Compared to the case of no MAPs, the gain of traffic offloading is measured.
UC2_KPI6	Decreased energy consumption (servers / UEs)	<10 Mbit/J	In this use case we aim to reduce energy in UEs and edge server(s) using the intelligent mechanism for distributing the load between servers and computing architectures, and also via proper video parametrization. Furthermore, we show that latest HW/SW process the video bits more energy-efficiently than the baseline devices selected during the project proposal phase.

4.3.1.2 Evaluation and results

Table 8 summarizes the current evaluation results and preliminary gains. These are explained in details in the following sub-sections and will be elaborated also in the final WP6 deliverable, D6.3.

Table 8: UC2 – Results obtained and gain

KPI ID	Evaluation method	Result	Gain
UC2_KPI1	Service latency will be measured by placing the Qosium Probes to video source (smart glasses/smartphone), MEC, and in video client. By this both uplink and downlink network delay can be measured. End-to-end application latency will be measured by recording the millisecond chronometer, encoding, transmitting and displaying the chronometer value in client display, which results in end-to-end latency.	Figure 50, Figure 51 E2E latency in D6.3.	The first results show that 10ms network delay is reachable in low congestion scenario.
UC2_KPI2	Throughput will be measured by placing the Qosium Probes to video source (smart glasses/smartphone), MEC, and in video client. Qosium Scope can then measure and collect the sent/received throughput from the specific network interface.	Figure 51, Figure 52	5 Mbit/s video achievable, but it can mean higher energy consumption and latency.
UC2_KPI3	Service reliability will be measured by placing the Qosium Probes to video source (smart glasses/smartphone), MEC, and in video client. The service reliability is then monitored and collected using Qosium packet loss ratio indicator.	In D6.3	
UC2_KPI4	Service availability will be measured as a ratio between uptime and downtime. Dedicated scripts (e.g., Python) will be used for collecting the up- and downtimes, and for calculating the service availability.	In D6.3	
UC2_KPI5	Edge offloading performance will be measured with S/W simulation based patterns, where traffic over MAPs is divided by the total network traffic.	Figure 55, Table 9	124-207 % improvement depending number of users
UC2_KPI6	Energy consumption of different network nodes and servers will be measured by placing Carlo Gavazzi energy meters to desired devices and comparing the results with baseline values.	Figure 53, Figure 54	Currently baseline measurements.

4.3.1.2.1. Service latency

In the Phase 2 of UC2, two aspects of video latency were measured: Video processing delay for the developed Android Smart Glasses video application, and video network latency in the uplink using the latest 5G SA technology integrated in VTT facilities (5G NR TDD Rel-16 SA @ 3.5GHz (band n78), BW = 60MHz). These results introduce the current status of the implementation and reveal place for optimization in the third phase of the UC2 work. It is important to also identify the processing delay (video capture + encoding +packetization) in the application level before the packet is ready to be transmitted in the network, because it can have huge influence on total service latency (Glass-to-Glass) regardless of the used network. The results of the service E2E latency will be presented in the final deliverable, D6.3.

Figure 50 illustrates the processing delay with the target bitrates for the developed Android application. We tested the application against ORA-2 Smart Glasses by Optinvent running on Android Kitkat as well as with the latest Motorola moto 5G+ smartphone running on the latest Android 11. As can be seen, ORA-2 performs well when using lower video resolution. Thus, with higher resolution it is evident that processing delay increases due to low processing capabilities by the computing HW, which is acceptable for considering the actual small-size device. Even if ORA-2 camera has 5Mpixels AF, the ORA-2 display is a real 480p (display resolution of 800x480) and usually the glasses are used to receive video with this resolution for hands-free functionality. Then, if we consider 480p only, we are equivalent to Motorola smartphone.

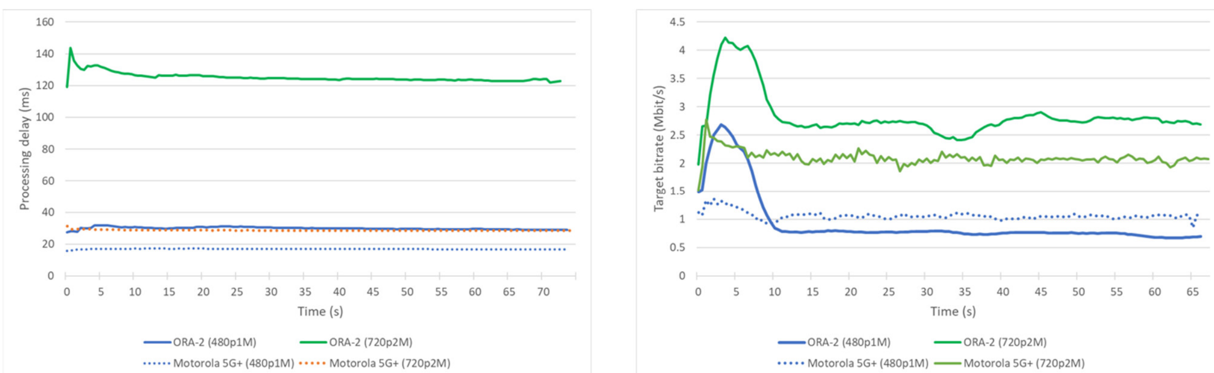


Figure 50: The processing delay comparison between ORA-2 Smart Glasses and Motorola moto 5G+.

As UC2 concentrates especially on live video streaming in crowded (congested) environment, we measured how additional data traffic, possibly from other users, affects to the video delay. Thus, the mobile uplink can be the bottleneck when live streaming from the event site. Uplink is relatively low even in commercial networks since operators don't see any real need for increase its volume. The results are illustrated in Figure 51 where blue line represents the UL video delay over 5G, and green the additional data throughput generated with iPerf over another 5G access point. As we used 1/4 data slot configuration for UL/DL share, the maximum UL capacity was measured approximately to 60Mbps by using Telewell modems. In this measurement, 4Mbps video at full HD resolution was used. From the curves we see that network congestion increases also the delay for the video user and eventually lead over 100ms delays (not visible in the curves) possibly alongside with significant packet loss rate. In Phase 3 after finalising the MAP, we aim to show that we can reach lower network delay even at congested and low coverage scenarios by utilising the DEDICAT 6G architectural components in the MAP placement.

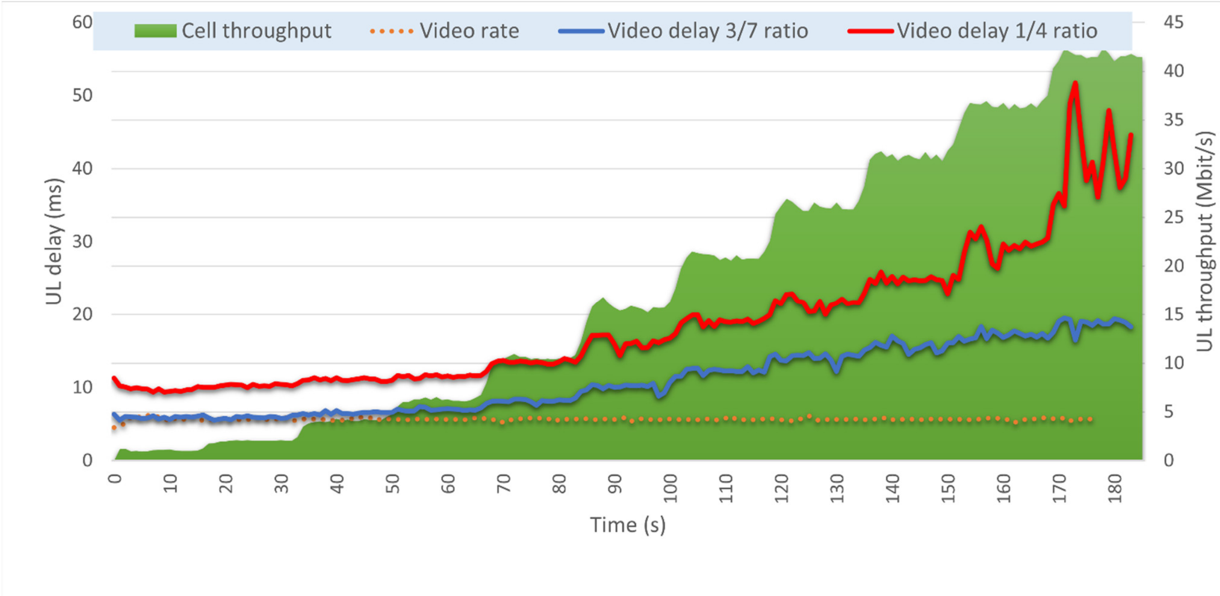


Figure 51: The effect of data rate to video uplink delay over 5G.

4.3.1.2.2. Throughput - Multicast vs unicast

The mobile multicast service is installed into VTT 5GTN and it has been currently tested against the Rel-14 version. In Phase 3 we are aiming at demonstrating the system against latest releases as well with measured energy consumption values. Thus, the MBS standardisation is active beyond Rel-17 and they are now boosting its importance in live streaming also from the commercial and sustainability point of view to be used not only for saving network load in the backbone, but also with less and efficient usage of resources. As UC2 tries to reach wide remote audience to access the live streams from the event site, possibly within the same radio cell, mobile multicast can do it efficiently by utilising the video streaming platform connected to the DEDICAT 6G platform. Figure 52 shows two benefits from the measurements conducted in 5GTN. On the left, it is seen that eMBMS can serve higher number of clients regardless of the multicast channel share allocation (during the measurements we had less DL capacity and bandwidth available than now). Secondly on the right figure, we see and validate how MBMS dynamic resource allocation functions; basically, it can reserve multicast resources in the base station real-time and narrowing naturally the unicast share as well. It is also notable that processor-based multicasting is also used as a spreading pattern for distributed communication, as introduced in D3.1.

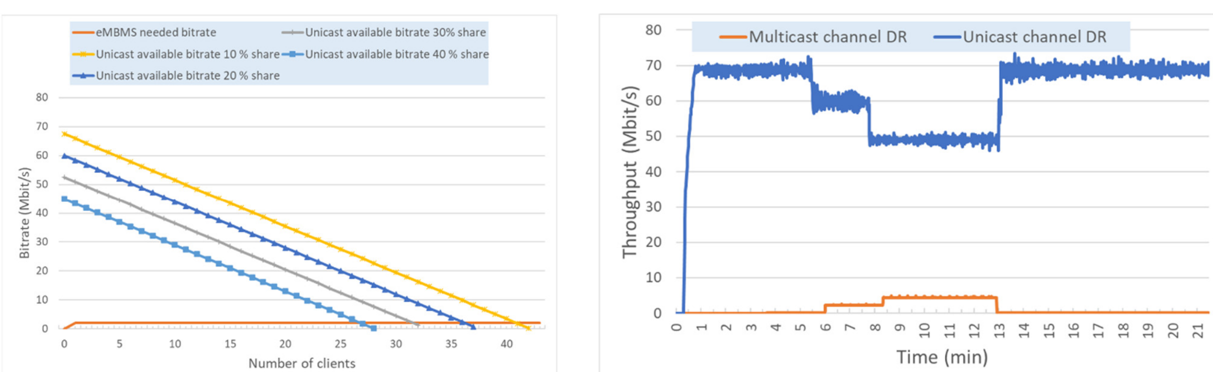


Figure 52: First results of MBMS benefit and dynamic resource allocation between multicast and unicast channels.

4.3.1.2.3. Energy consumption

One of the overall targets in DEDICAT 6G is to reduce the energy (or power) consumption during the live streaming. In UC2 context, we have identified that video parametrization and distributed computing can decrease the needed energy consumption. Video parametrization with less complex compression algorithms and optimal resolution selection (see also Figure 50) can lead to energy savings already in the capturing/sending device located in the event site, and novel processing schemes in the edge servers (needed especially for video transcoding to enable network adaptation against different client devices and access networks) can balance the load from centralized servers. There are already good results from the computation perspective presented in D3.1[3] and D3.2 [6].

Figure 53 illustrates real-time video encoding realized in an edge server for generating MPEG-DASH compatible 4-layered stream in order to enable adaptive HTTP streaming against network fluctuations and to enable flexibility for different client devices with varying playback characteristics. We utilize FFmpeg with x264 SW encoding, which is also needed in order to have dynamic, real-time configurability with the distributed offloading control. In this case, the resolutions and bitrates were selected according to the 5G XR specifications [37] for H.264. The red curve 'combined' indicates for encoding all the video representation layers simultaneously, and the others individually according to the series name. It is notable that nowadays widely used, although already quite obsolete, 720p (HD ready) and 1080p (full HD) can be encoded/transcoded relatively easily using powerful HW. As depicted also in D2.4, we use Intel Xeon E5-2860@2.5 GHz processor with 64-bit instruction set with 48 CPUs (2 threads for each core). In the final phase, we aim at utilizing the DEDICAT 6G platform in decision-making for selecting the best edge server candidate and directing the video processing towards the optimal location.

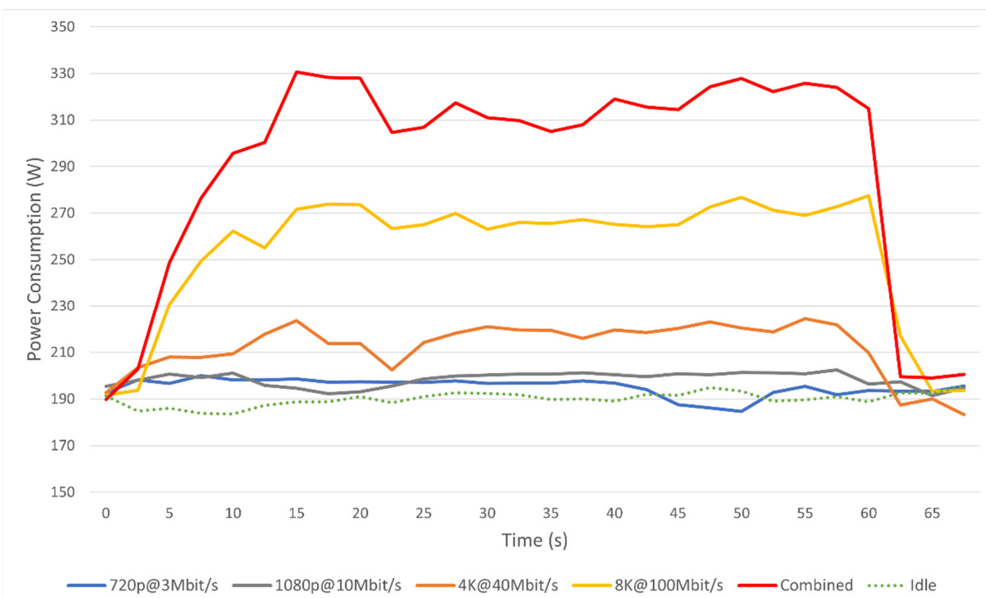


Figure 53: Power consumption of real-time encoding (centralized (combined) vs distributed).

By using similar encoding structures as above, we also tested the client side power consumption by using different mobile network technologies, illustrated in Figure 54. Dash.js player was run in Chrome browser, which were installed in Dell E6420 Core i7@2.7GHz laptop, and power measured using Carlo Gavazzi energy consumption meter. The video clips were streamed from the video streaming platform using the illustrated access network technologies. From the Figure 54 we see that a) access network technology does not have and influence to the in-device power consumption, b) video resolution and/or bitrate has significant influence also to the client, especially with higher resolutions. It is also notable that video client can adapt the stream towards lower quality in order to save energy. Thus, video adaptation can be also done in the server side in order to lower down the transmission energy (transmitted bits).

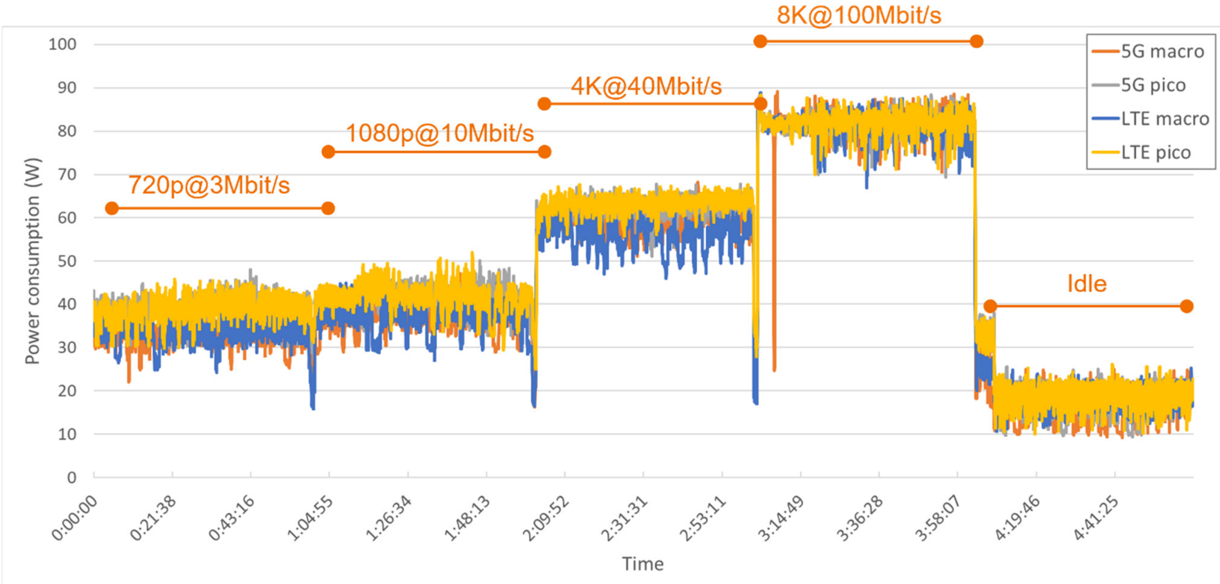


Figure 54: Client power consumption using different bitrates and mobile network technologies in live streaming.

4.3.1.2.4. Edge Offloading Performance

By using MAPs, we can expect the edge offloading effect. In the case that there are many UEs requesting higher data rate, the ground BS would not be able to satisfy all UEs by supporting their required QoS. Additionally, for UEs at the cell edge, the received signal level would not be strong enough even though a ground BS (gBS) has the capacity to support UEs. In both cases, by deploying MAPs for the function of additional BSs, traffic can be offloaded. The gain achieved by the use of MAPs is defined as the edge offloading factor and calculated as the ratio of data traffic sent by MAPs among the overall network traffic loads. Additionally, the area spectral efficiency is considered to show the effectiveness of edge offloading. By using two performance indicators, we measure the edge offloading performance of the proposed solution using MAPs and compare to the basic case that the only gBS provides the data service to UEs (without MAPs).

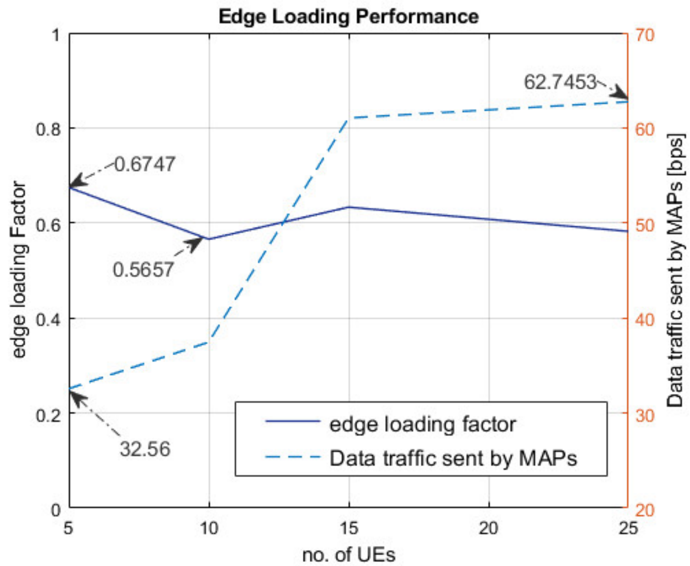


Figure 55: Edge Offloading Factor for different number of UEs.

As a ratio of transmitted data over MAPs among total transmitted data, the edge loading factor is illustrated in Figure 55. Two MAPs are assumed to be deployed with one gBS and the edge offloading factor is measured for different number of UEs. As the number of UEs increases, the amount of data traffic sent by MAPs tends to increase. For example, when there are 5 UEs, 32.56 Mbps can be transmitted via MAPs, then it increases to 62.7453 Mbps for the case of 25 UEs. Regardless of the number of UEs, the edge offloading factor could remain above 0.5.

Edge offloading factor is also measured in terms of *Area Spectral Efficiency (ASE)* as shown in Figure 55. Similar to the set-up forTable 9 Table 9, ASE is monitored for multiple number of UEs. For all cases of different number of UEs, deployment of MAPs leads to increase ASE.

Table 9: UC2 - Area Spectral Efficiency [bps/Hz/km2] for different number of UEs

No. of Users	5	10	15	25
Without MAPs	1.5701	2.8754	3.5362	4.7999
with MAPs	4.8262	6.6213	9.6408	10.7745
Improvement [bps/Hz/Km^2]	3.2560	3.7458	6.1046	5.9745
Improvement (%)	207.37	130.27	172.63	124.47

4.3.2 Next steps for the third period

Phase-2 evaluation contained both measurements in real mobile networking environment as well as simulation studies. Most of the measurement still concern the evaluation validation from integrating the individual components into the pilot environment and testing their current performance. In the final phase during the third year of the project, more advances with full utilisation of DEDICAT 6G functionalities and assets from other WPs are expected to show improvements with all the selected KPIs. Figure 56 shows the timeline for the development phases in the Enhanced Experience. It is basically divided into three main phases according to the WP6 milestones leading to three deliverables. In addition, we have set internal milestones during the phases in order to have certain checkpoints during the project. Dissemination via participation to demonstrative events helps to demonstrate different portions of the use case. The Enhanced Experience targets having visibility in several booths in different exhibitions, partially also in order to have smooth progress during the rest of the project. The main validation and experiments will be done in Finland, mostly in relation to 5GTN which have the needed facility for performing throughout evaluation in a closed environment. The final trialling event(s) during the last project year will be refined during this year.

As presented in Figure 56, we have differentiated the work for the video service part and communication. These parts will first progress individually to be integrated and evaluated together during Phase 2 and finally in Phase 3. The video streaming part focuses on setting the content production and delivery setup as a unity, which combines basically the Smart Glasses, 360° camera, multicast features, and playback applications with the video service architecture.

The current phase towards M24 contains revised integration of the partner's assets and components as well as individual development with the partners. Main components especially needed for streaming are ready and currently under evaluation and optimization with the preliminary results. Thus, some require dedicated planning for determining the required interfaces between the components, such as NDM, which has been introduced during Phase 2 in UC2 context. Naturally, this phase also involves the identification and implementation of the required DEDICAT 6G platform components via system-wide integration.

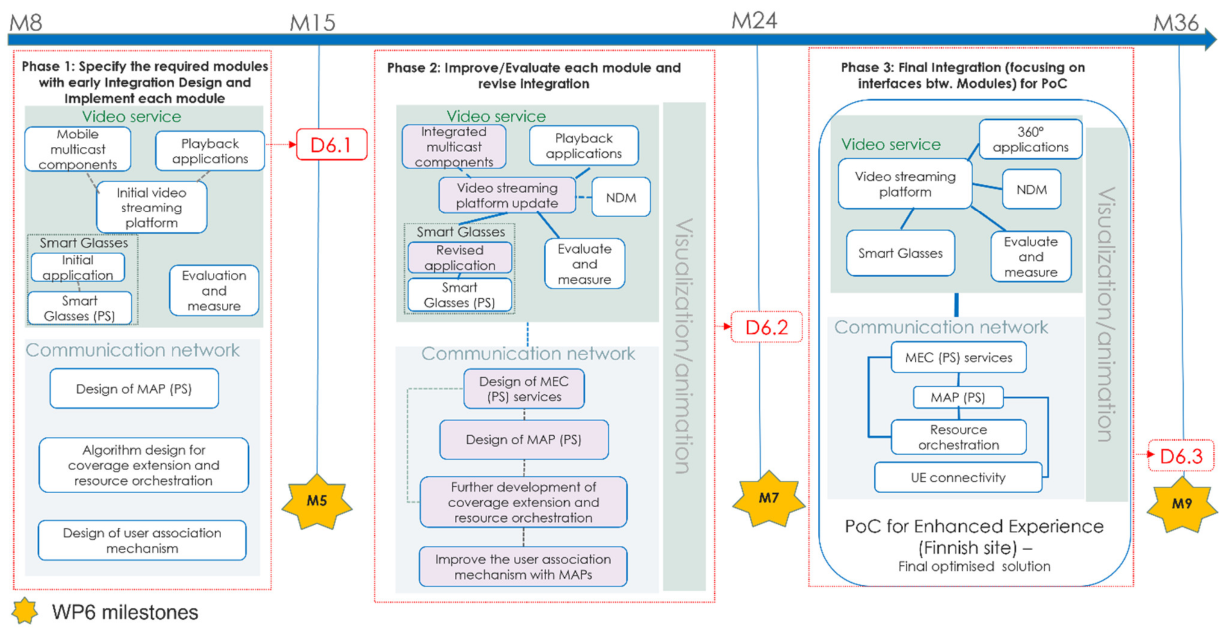


Figure 56: Validation and schedule plan for UC2.

Lastly, in Phase 3, we strive to integrate all components together and showcase the pilot via demonstrations. We will focus more on reporting the actual gains when using DEDICAT 6G platform. The first larger pilot is planned in the Spring 2023 with a public event at VTT Oulu. The third phase also contains evaluation and measurements of the developed component's performance using real mobile network connectivity. In addition, we will prepare for proof-of-concept demonstration video of this UC at the Finnish site to be completed before M36.

5 UC3: PUBLIC SAFETY

5.1 Scenario and stories

Public Protection and Disaster Relief (PPDR) and Public Safety organizations rely on reliable and efficient communications to respond to natural or man-made disasters. In most cases, PPDR and Public Safety organizations own their critical infrastructures which are operated at national level or small cell for tactical or urgent needs.

These infrastructures have to be available at anytime, anywhere and make all communications efficient for voice or data. With the beginning of 5G deployment, organizations are looking to apply their critical communications on this new technology and balance the choice of solution depending on the long term of investment.

DEDICAT 6G aims to deliver the high level of reliability expected by PPDR and Public Safety organizations by combining the use of operated connectivity (Public or Private) and the high-quality services of a dynamic and split architectures which deserve users on the field.

The Public Safety use case have been described in the deliverables D2.2 and updated in D2.4 through two contexts: connectivity lost after a natural disaster and network failure during a large event. The related stories have been described in deliverables D2.2, D2.3 and D6.1.

The following section completes the deliverable D6.1.

The Public Safety use case will showcase:

- **Dynamic coverage extension** via robots or cars combined with heterogeneous wireless connectivity options (Wi-Fi, 3G, 4G, 5G, B5G/6G) to ensure network availability, ultra-low latency and ultra-fast response times;
- **Distributed intelligence** to achieve a near-optimal efficient placement of computation and AI functions in the network with respect to selected multi-objective key performance indicators (energy consumption, latency, reliability, and availability);
- Interoperability to enable **efficient communication** with and among a multitude of devices and systems (e.g. cameras, drones, AGVs, smartphones, diverse sensors, etc.);
- **Complementing PPDR systems easily and cost-efficiently** with additional devices and functionalities, e.g., through the exploitation of drones/AGVs hosting diverse functions/services, analytics-driven and user-oriented feedback;
- **Context aware access control** for emergency personnel and context-based evacuation route opening through otherwise closed doors and inaccessible areas.

5.1.1 Detailed Stories

Public Safety and PPDR users rely on Critical Communications in two main environments:

- Non-urban or natural disaster: there is no, or a lack in, infrastructure to support critical communication;
- Urban environment: during a crisis, raises of connected devices and the use of social Medias for a live snapshot sharing from the event in real-time occurs failure or overloading of infrastructure when it matters.

Each story will precise what will be demonstrated and the components used from DEDICAT 6G platform and what will be measured during the pilot.

Context #1: non-urban or natural disaster

The first context demonstrates loss of connectivity after a natural disaster through three stories related to three phases which could be encountered during the crisis management:

- Connectivity recovery after disaster;
- Mission management capability with MCX;
- Allowing public communication for victims.

The first story will mainly address following components:

- Dynamic Coverage Extension: evaluation of time to deploy coverage (WP4);
- Distribution of Intelligence: evaluation of intelligence readability (WP3).

The second story will address following components:

- Dynamic Coverage Extension: evaluation of time to deploy coverage (WP4);

The third story will address following components:

- Distribution of Intelligence (WP4);
- Efficient communications.

Context #2: connectivity failure during a large event

The second context describes a connectivity failure during a large public event. Three stories related to three phases which could be encountered during the response to an incident:

- Support local connectivity;
- Welcome First Responders connection;
- Support video flow in real-time for leveraging situational awareness.

The first story will mainly address following components:

- Distribution of Intelligence: evaluation of intelligence readability (WP3);

The second story will address following components:

- Dynamic Coverage Extension: evaluation of time to deploy coverage (WP4);

The third story will address following components:

- Distribution of Intelligence (WP4);
- Efficient multimedia communications.

This second context is similar to the use case 2: "Enhanced Experience". The UC3 Context #2 differs in the priorization service offered to PPDR and Public Safety users comparing to consumer users. The 3GPP MCS define the capability to a Broadband system to priorize some resources than others, especially to support critical communications.

5.1.2 Services – Human centric applications

5.1.2.1 Mission Critical users' application

The *Mission Critical Services (MCS)* are integrated to the DEDICAT 6G cloud infrastructure. Based on the orchestrator and agent notification, the platform is able to deploy services where it matters to offer efficient and resilient connectivity.

Based on a cloud server – mobile client architecture, the MCX solution has been split into several components that support the different MCX services independently from others. This Edge Computing oriented architecture allows the system to automatically redeploy a component in case of a service loss, in order to support critical communications resiliency but also to deploy a specific component to leverage the service efficiency, e.g., MC-PTT in case of an overloaded audio service.

To benefit from mission critical services provided by the DEDICAT 6G Platform, users need to connect to the services by using a client application. All the critical features shall be delivered through the same application. This application will support the showcasing of access to the platform and performing evaluation.

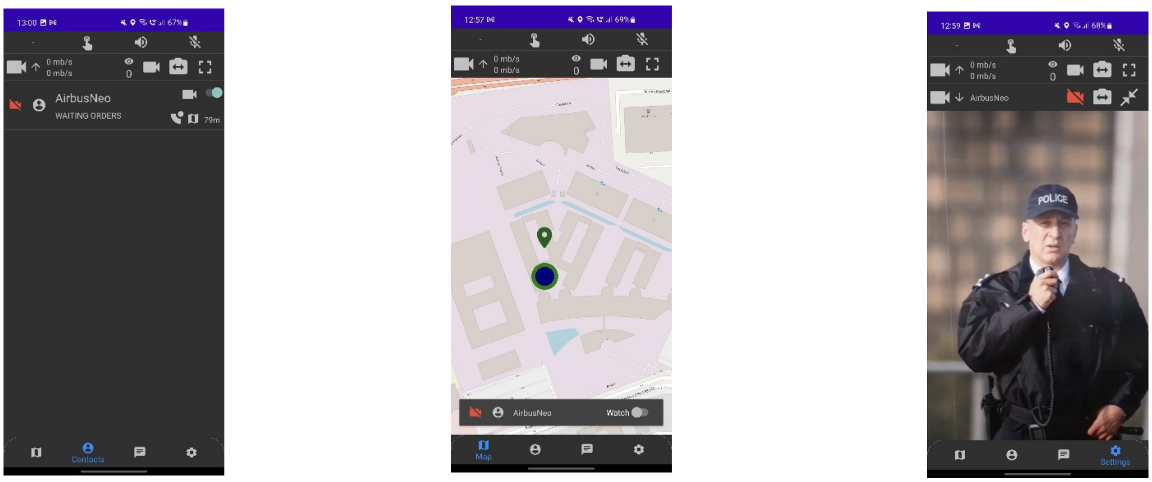


Figure 57: MCX Client application

The MCX Client application shall provide *Push To Talk (PTT)* (voice) group call, video call, video streaming and mapping (as shown on Figure 57).

To implement the MCX Client, the mission critical services will deliver interfaces allowing the use of main services (voice, video, or data).

5.1.2.2 Smart Glasses

Optinvent will provide several ORA-2 smart glasses for the scenarios. These devices are Android device platforms, and should each be connected through a local smartphone to a Wi-Fi hotspot to be able to connect to the Internet, since the glasses do not have 4G or 5G intrinsic connectivity. The glasses are standalone devices that allow users to see bright images while maintaining the transparency of outdoor scene. The glasses have embedded GPS so that the position of the user could also be tracked during the event if necessary. The ORA-2 smart glasses use KitKat Android 4.4 version and are compatible with majority of existing applications from Google Play. One option is to adapt Airbus MCX current API for rescue management that will be implemented in the glasses. Another option is to build a new Android application on the glasses. This point should be assessed in the incoming month to select the best way to build the application.

To interact with the glasses, a touch pad allows the user to go through a specific menu provided by the application that should be developed for this use case. However, to have better ergonomic of application and to let the user enjoy and concentrate on the event, an accessory Joystick with Bluetooth connection with the glasses will be used as depicted in Figure 58.

Figure 58: The components for the Smart Glasses to be used in the Public Safety use case

5.1.2.3 Coverage extension visualisation dashboard

In the scope of this use case pilot, a Clearpath Robotics Jackal Unmanned Ground Vehicle/AGV will be used as a MAP to reach a specific location with the aim of providing users with opportunistic wireless network for coverage extension. For demonstration purposes this is accompanied by a **coverage extension visualization dashboard** (Figure 59-Figure 62) that is connected to the robot and is also **integrated with an implementation of coverage extension mechanisms from WP4** (specifically the mechanism managing robot based MAPs described in section 4.5 of D4.2 [7]) and with **an implementation of the Threat identification and classification mechanism from WP5** (described in detail in section 6.1 of D5.2 [8]). The coverage extension visualisation dashboard allows the emulation of different user positions and consequently scenarios through the "new scenario" button. The virtual space of the application corresponds to the representation of an area of interest created for the lidar. In the current implementation this corresponds to an area in the parking of WINGS offices. The dashboard allows the configuration of the scenario by dragging and dropping users to different locations. For this scenario it is assumed that the coverage range of Access Points (green), and Mobile Access Points (Yellow) is one square (in each direction). Outside of that range users have connectivity issues that need to be solved. In this demo scenario two types of Mobile Access Points are considered: virtual (dummy) and one that corresponds to the actual Clearpath Robotics Jackal. The dashboard allows viewing robots/AGVs in two-dimensional graphics (Figure 60) or in 3D space (Figure 61). A location in the area of interest can be selected to view the coordinates. The Coverage Extension Decision Making algorithm (described in section 4.5 of D4.2 [7]) takes into account the scenario input and selects the optimal location for Mobile Access Points and the most appropriate allocation of users/mobile nodes to these Mobile Access Points. In this way all users have now access to the network. The dashboard also enables real space monitoring of the AGV mobile access point navigation to the given coordinates (Figure 62).

Figure 59: Overview of coverage extension visualization dashboard

Figure 60: Coverage extension visualization dashboard – 2D representation

Figure 61: Coverage extension visualization dashboard – 3D representation

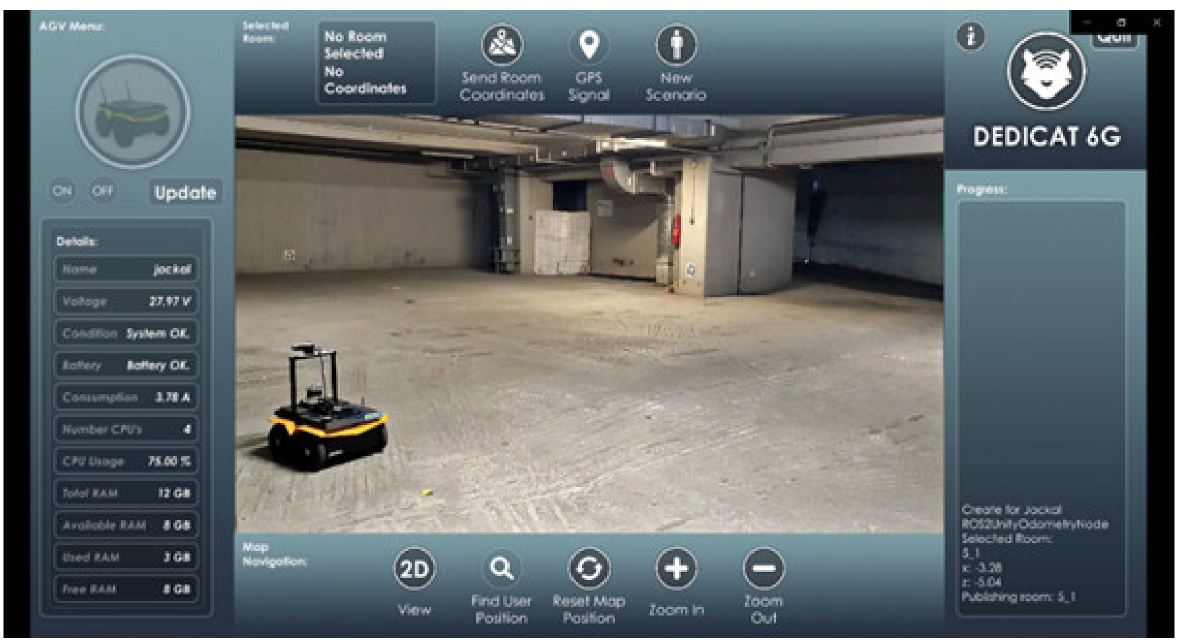


Figure 62: Coverage extension visualization dashboard – Real space monitoring

5.2 Scenario setup

The setup of the use case is the same for both contexts. The DEDICAT 6G will extend coverage and deliver mission critical services on the premise. Applications and equipment will be able to benefit from the connectivity delivered by the platform.

5.2.1 Pilot setup

Figure 63 illustrates the location of the pilot setup for the Public Safety use case.

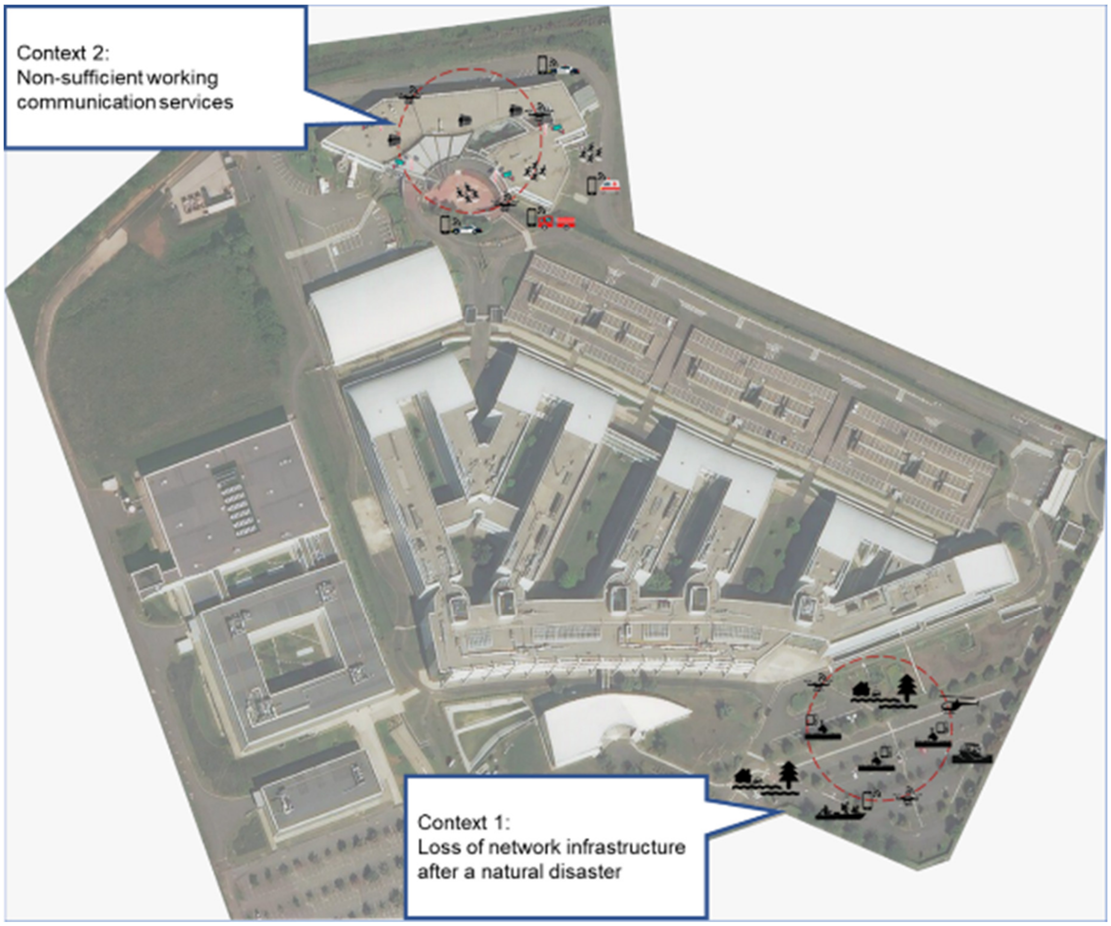


Figure 63: Location of Pilot Setup for Public Safety UC3

Mission Critical Components

The *Mission Critical (MC)* Services will be delivered as containers hosted in the Cloud part of the DEDICAT 6G platform:

- Container #1: MC-Audio;
- Container #2: MC-Video;
- Container #3: MC-Location;
- Container #4: MC-Registrar;
- Container #5: MC-Management.

An administrator of the MCX (or using automatic rules) is able to deploy all mission critical components by launching a script.

When deployed, all the services are running and managing by the DEDICAT 6G platform (new deployment, load balancing…).

MCX Mobile application and user device:

The MCX mobile application has been implemented to be executed in an Android environment compliant with the Android API level 7 (minimum Android 8.1 Oreo).

For the demonstrations and evaluations, the device which will be used will be a Samsung XCover Pro 6 5G (since 2022):

Figure 64: Samsung XCover 6 Pro with MC-PTT button

This device offers 2 programmable buttons. The one the left side will be used as a MC-PTT button through the MCX mobile applications.

The main characteristics of this device are:

- Ruggedized MIL-STD 810H et IP6;
- 5G Frequencies and Bands:
    - 5G FDD Sub6: N1 (2100 MHz), N3 (1800 MHz), N5 (850 MHz), N7 (2600 MHz), N8 (900 MHz), N20 (800 MHz), N28 (700 MHz);
    - 5G TDD Sub6: N38 (2600 MHz), N40 (2300 MHz), N41 (2500 MHz), N78 (3500 MHz).

AGV and Drone

Figure 65: Clearpath Robotics Jackal Unmanned Ground Vehicle

In the scope of this use case pilot, a Clearpath Robotics Jackal Unmanned Ground Vehicle/AGV (Figure 65) will be used as a MAP to reach a specific location with the aim of providing users with opportunistic wireless network for coverage extension.

Figure 66: Tarot Quadcopter Custom Drone

Jackal is a small, fast, entry-level field robotics research platform. It has an onboard computer, GPS, 3D lidar, camera and IMU fully integrated with ROS. Jackal's chassis is made entirely from welded aluminium and provides IP65 protection. The high torque 4x4 drive train gives Jackal maximum traction, with enough on-board power available to traverse obstacles or unconsolidated terrain.

In addition, the use of a custom-made quadcopter with PixHawk flight controller and a Raspberry Pi as a companion board will be investigated (Figure 66). Both the Jackal robot and the quadcopter can also be used as auxiliary sensing devices e.g., for video streaming over an area of interest.

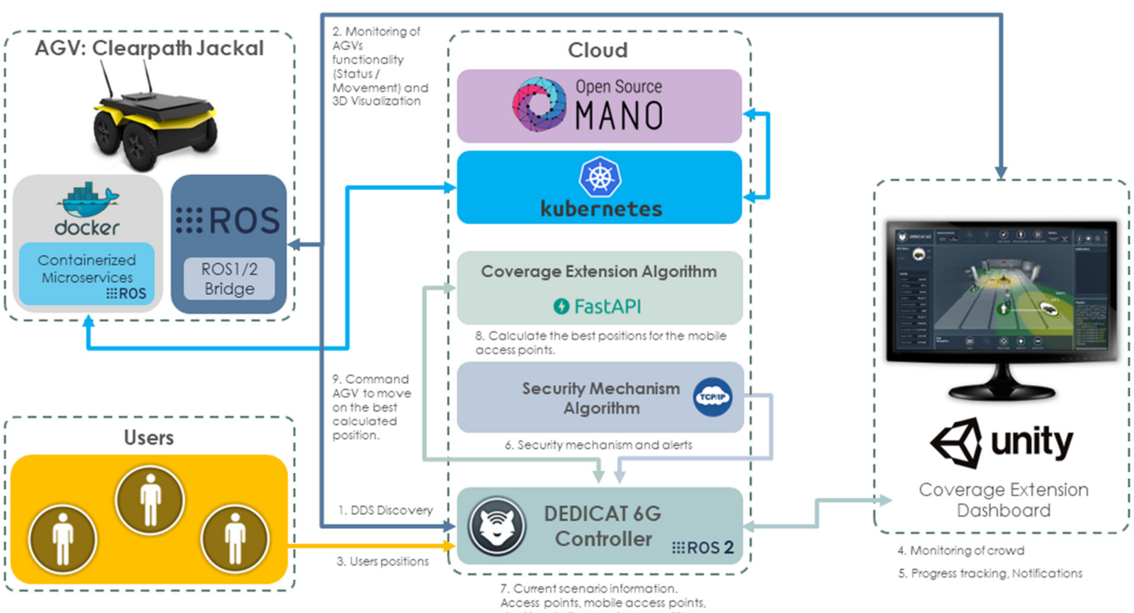


Figure 67: High-level view of Public Safety use case implementation with Clearpath Jackal being used as a MAP

Figure 67 depicts a high level view of the Public Safety use case implementation comprising the Clearpath Jackal AGV as a MAP. The AGV has a ROS1/2 Bridge and containerized Docker microservices running on it. It communicates via the DEDICAT 6G controller via Fast DDS Discovery[25] (Figure 68, see also section 3.2.2) with the coverage extension visualisation dashboard for sending AGVs' status, positioning/movement and camera feed. The coverage extension visualisation dashboard provides 2D and 3D visualization of the area, monitors crowd – users and AGVs' positions, progress tracking and provides various notifications. Users position is also sent via the DEDICAT 6G controller to the coverage extension visualisation dashboard. Hence, the DEDICAT 6G controller communicates with the AGV, the visualisation dashboard, user devices and the implemented Coverage extension algorithm and is responsible for distributing the information related to the position of robots and users to the coverage extension visualisation dashboard and the implemented coverage extension algorithm.

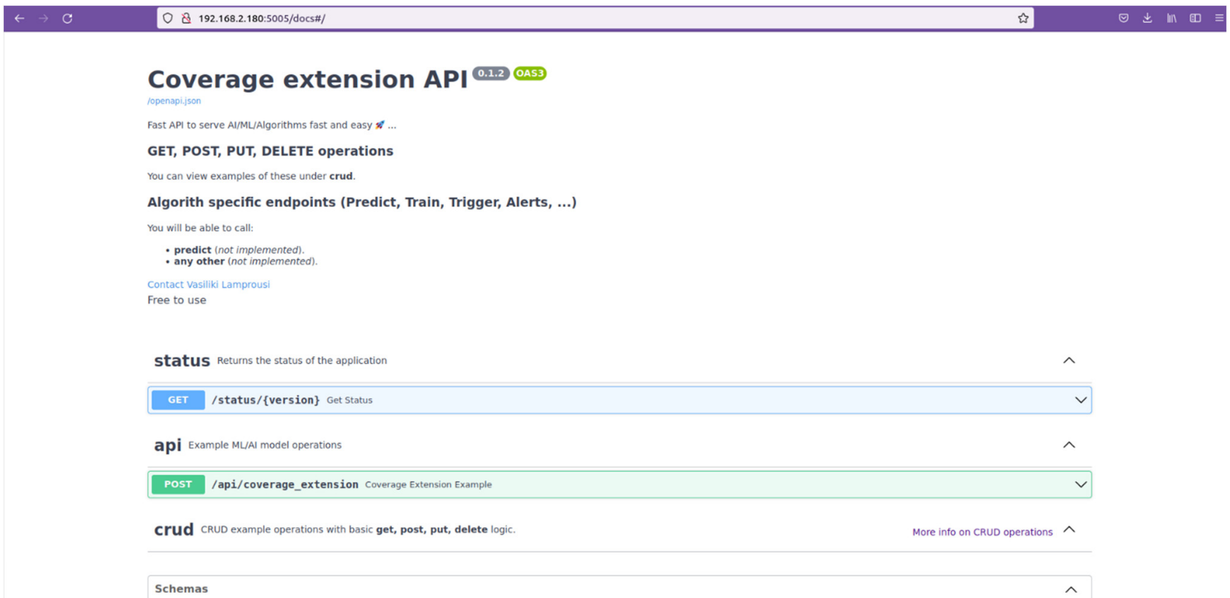


Figure 68: Coverage extension FAST API

Similar to the implementation of the Smart Warehousing (see section 3.2.2), the DEDICAT 6G controller is hosted in the cloud together with other auxiliary entities including an orchestrator based on open source ETSI MANO[26], the Kubernetes platform, the implementation of the coverage extension mechanism from WP4 ((specifically the mechanism managing robot-based MAPs described in section 4.5 of D4.2 [7])) and an implementation of the Threat identification and classification mechanism from WP5 (described in detail in section 6.1 of D5.2 [8]). The coverage Extension algorithm is responsible for optimally placing the MAPs to the available locations of the area of interest, aiming to provide coverage to all users with minimum number of utilized MAPs and minimum MAP traveling (this is also linked to energy efficiency). The implemented coverage extension algorithm communicates with the DEDICAT 6G controller for collecting and providing the input and output of MAPs, and users positions. Finally, as already mentioned previously (in section 3.2.2) he implemented Security Mechanisms are responsible for threat identification and classification and monitors network traffic over the public safety infrastructure. In the case of a possible detected threat/cyber-attack,

[25] https://fast-dds.docs.eprosima.com/en/v2.1.0/02-formalia/titlepage.html

[26] https://osm.etsi.org/

it alerts DEDICAT 6G controller resulting in a relevant notification appearing on Unity dashboard.

5.2.2 Public Safety use case implementation

5.2.2.1 DEDICAT 6G architecture components

The detailed functional decomposition of the interconnection of this Use Case into DEDICAT 6G architecture and platform is described in D2.3 and D2.4 and also in D6.1. Table 10 provides a mapping of the functionality of the DEDICAT 6G architecture FCs to the current Public Safety implementation of Figure 67.

Table 10: Mapping of DEDICAT 6G architecture FCs to Public Safety implementation (Figure 67)

DEDICAT 6G architecture FC	**Description**	**Public Safety implementation** (Figure 67)
μS/FC Repository FC	Stores the uploaded microservices such as video streaming platform	Kubernetes
EN Status Agent FC	Provides monitored information about the current status of the edge nodes registered to the DEDICAT 6G platform	Kubernetes, Coverage extension visualization dashboard, ROS1/2 Bridge, DEDICAT 6G Controller
μS/FC Status Agent FC	Provides monitored information about the current status of the microservices being executed in the use case infrastructure	MANO, Kubernetes, ROS1/2 Bridge, DEDICAT 6G Controller
Service Orchestrator FC	Orchestrate the microservices and FCs deployed over the Public Safety depending on information collected with Status Agent FC.	MANO
NW Awareness FC	Provides information on the status of the network of the Public Safety infrastructure	DEDICAT 6G Controller
Load Balancing FC	Load balancing and service orchestration functionalities for deploying and balancing Mission Critical services in the suitable edge	MANO, Kubernetes
EN Awareness FC	Status agents for reporting periodically the state of the services in edge nodes and network	MANO, Kubernetes
μS/FC Awareness FC	Receives information from a group of μS Status Agent FC and publishes it to the rest of the FCs available on the DEDICAT 6G platform after enriching it to the DM expectations.	MANO, Kubernetes
CEDM FC	Instructs physical deployment of MAPs	Coverage Extension Algorithm

AGV Operation FC	Provides the basic management of robots and provides a basic palette of so-called atomic actions it can perform. Those atomic actions are then played with, in order to build more complex capabilities (e.g., for identifying parcels and moving them from A to B with obstacle avoidance or performing quality checks).	ROS1/2 Bridge, DEDICAT 6G Controller, containerized micro-services (docker/ROS)
MAP operation FC	Responsible for implementing the decision taken by the CEDM	ROS1/2 Bridge, DEDICAT 6G Controller, containerized micro-services (docker/ROS)
Threat Analysis FC	Performs threat detection, identification and classification and is executed either in centralized or in edge processing nodes. Threat analysis is based on ML models trained and updated on collected system logs.	Security Mechanism Algorithm

5.2.2.2 UC specific components

In order to use MCX features delivered by DEDICAT 6G platform, a Human-Centric application will be implemented, and smartphones delivered to install the MCX Client application.

The MCX Client application will be available for setup on applications stores or as an installation file as "APK" for local installation.

A drone will be delivered to stream video from the field to Control Room and users on the field. A specific connector will be implemented to connect the drone to MCX services.

The detailed functional decomposition of the interconnection of this use case into DEDICAT 6G architecture and platform is described in D2.3 and also in D6.1.

5.2.2.3 Interfaces

A view of the interfaces is provided in the UML diagrams for this use case in D2.3 [2]. An overview of the key interfaces between components that have been implemented so far in the scope of this use case pilot are listed (see also Table 10):

- The EN Status Agent FC, µS/FC Status Agent FC and NW Status Agent FC interface with the EN Awareness FC, µS/FC Awareness FC and NW Awareness FC respectively;
- The EN Awareness FC, µS/FC Awareness FC and NW Awareness FC in turn provide input relating to the EN, µS/FC and NW as contexts to the CEDM FC;
- The EN Registry FC, µS/FC Registry FC, µS/FC Repository FC and EC Policy Repository FC also interface with the CEDM FC;
- The CEDM FC has an interface with the Service Orchestrator FC;
- The Service Orchestrator FC has an interface with Load Balancing FC;
- The CEDM FC has an interface with the MAP operation FC.

In addition, the interfaces offer third application the capability to use Mission Critical services. The MCX Client will use this interface to deliver MC-PTT, MC-Video and MC-Data features.

MCX features will be available through an "APK" application for integration with other components (e.g., Smart Glasses).

MCX UAV Connector: connection of drone camera in order to enable video streaming through MCX and to MCX Client app.

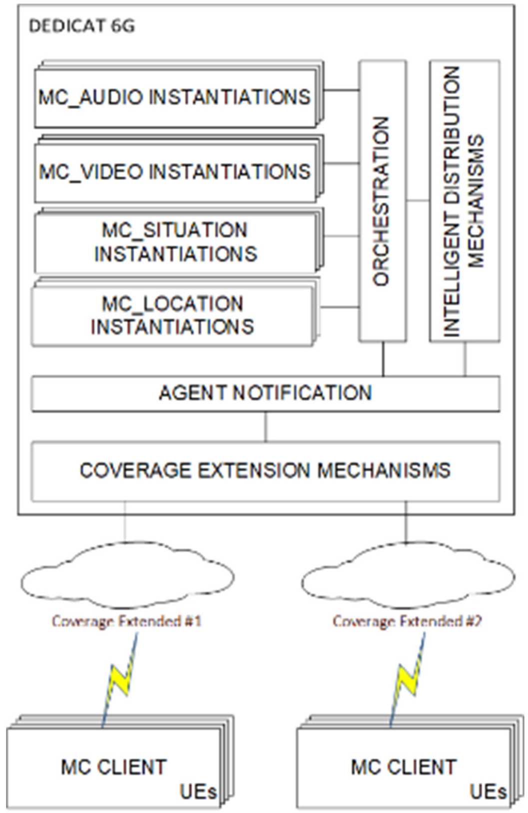


Figure 69: Connectivity Client applications with MCX services

5.2.3 Integration report

The paragraph below describes the use of WPs outcomes in the UC3 and the contribution per partner done during the period M15 to M24.

5.2.3.1 Description of WPs related outcomes in UC3

Mechanisms for Dynamic Distribution of Intelligence (WP3):

Outcomes of WP3 will be used in both contexts defined in UC3 "Public Safety" in order to support connectivity to resources, especially the mission critical components for communications between First Responders or PPDR users as described in section 2.2.1.

Mechanisms for Dynamic Coverage Extension (WP4):

Outcomes of WP4 will be used mainly in the Context #1 "Loss of connectivity in a non-urban environment" in order to showcase how DEDICAT 6G could establish a connectivity for PPDR users immediately after a natural disaster as describe in Section 2.2.2.

Mechanisms for Security, Privacy and Trust (WP5):

WP5 will provide security and trust and integrate it to the use-case. WP5 will provide access control on both producer and consumer sides as describe in section 2.2.3.

5.2.3.2 Description of contribution per partner in UC3

WINGS: Implementation of a coverage extension decision making algorithm from WP4 (specifically the mechanism managing robot based MAPs described in section 4.5 of D4.2 [7]) and an implementation of the Threat identification and classification mechanism from WP5 (described in detail in section 6.1 of D5.2 [8])..

UoS: Contribute to the mechanism how to associate UEs requiring different QoS to multiple UEs and allocate powers considering the backhaul capacity and power constraints in a network including MAPs with multiple UEs distributed.

CEA: CEA will contribute to the MAP deployment strategy to provide appropriate QoS connectivity to mobile nodes and demonstrate some features through simulation. Based on a background demonstration platform with bidirectional, dual RAT capabilities, CEA will provide a demonstrator for coverage extension assuming Integrated Access and Backhaul (IAB) with a moving IAB node. This includes Access and backhaul links management, Multi-Rat access (mm-wave and sub-6GHz bands) and multi-beam management.

Based on a background demonstration platform with bidirectional, dual RAT capabilities, CEA will provide a demonstrator for coverage extension assuming Integrated Access and Backhaul (IAB) with a moving IAB node. This includes Access and backhaul links management, Multi-Rat access (mm-wave and sub-6GHz bands) and multi-beam management.

AIRBUS: Implementation of a mobile client application which can connect to the different Mission Critical Services and, with several mobile applications connected, are able to join a mutlimedia group communication to make voice group call (MC-PTT), video group call (MC-VIDEO) or sharing operational statuses (MC-DATA). AIRBUS also evaluate novel features which could be supported by the DEDICAT 6G platform as drone or robot video streaming to a video group call (MC-VIDEO) and integration to other kind of rich features. Based on an existing clouded server architecture, AIRBUS has split and implemented specific architecture in order to deliver FCs and services to be deployed at the Edge/Far Edge or in the Cloud when necessary.

VLF: Implementation of private permissioned blockchain and collection of smart contracts for security and trust management framework, described in D5.2

OPTIN: Integration of a dedicated MC-PTT and MC-VIDEO application, in collaboration with AIRBUS, with smart glasses in order to showcase the use of such novel interactive application.

TUC: UC will contribute to a mechanism that provides a coverage extension by integrating MAPs based on RSUs and connected cars. TUC will implement a mobile client app to integrate VRUs into the local dynamic map even those located in areas undetectable by RSUs and Ego-vehicles. TUC will also provide the ability to predict dangerous situations within extended coverage and perform public safety-critical communication processes.

ATOS: Integration of Service orchestrator to manage the deployments of µServices required for intelligence distribution and coverage extension. Furthermore, the orchestration engine will be adapted to provide the functionalities of the NFV-O connector FC, which will serve as interface between the Service Orchestrator and the NFV-O to instantiate the required network slices.

NOKIA: NOKIA has contributed to UC3 through the work achieved in WP5 in order to provide security, trust and privacy to the DEDICAT 6G platform for the Public Safety use case.

5.2.3.3 Description of external assets used in UC3

WINGS: Know-how and experience accumulated from the participation in projects such as OneFiT[27] Clear5G[28], One5G[29], 5G-EVE[30], and 5G-TOURS[31] has been utilised for the implementation of the UC3 prototype and the testing performed so far. The development and implementation of all software and hardware components for UC3 have been done specifically in the context of DEDICAT 6G, with no re-use of specific assets.

AIRBUS: From the MCX solution used in 5G!DRONES[32] project, AIRBUS has splitted the architecture of in use MCX in order to make the new architecture addressing the requirements of DEDICAT6G. To measure some of the KPIs and make evaluation, AIRBUS will connect the MCX for DEDICAT 6G project to the 5G-EPICENTRE[33] platform.

5.3 Evaluation and first results

An implementation of a Public Safety prototype focused on coverage extension is available including the Jackal robot, the Coverage extension visualisation dashboard and the implementation of a coverage extension decision making algorithm from WP4 as outlined in section 5.1.2.3. A corresponding video has been produced (https://youtu.be/-QBJJTW0D8Q). This set-up has been tested at WINGS premises (Figure 62) while next steps include testing at AIRBUS premises in Elancourt (estimated around May 2023).

5.3.1 List of KPIs, target values and gain

5.3.1.1 KPIs and target values

Table 11 presents the list of KPIs related to the Public Safety use case, describing the evaluation method and defining the target values:

Table 11: UC3 – Public Safety KPIs list

KPI ID	Description	Target value	Baseline
UC3_KPI1	MC-PTT (voice) to MCX Audio service access time	Access time < 300ms 95% of request	The baseline values are based on the 3GPP MCS standards (ETSI Technical Specification 122,179 (2020)). The DEDICAT 6G project brings a new architecture for mission critical
UC3_KPI2	End-to-End MC-PTT (voice) access time for all MCX client under the same network coverage	Access time < 1000ms	
UC3_KPI3	Mouse-to-Ear (voice) latency	Access time < 300ms 95% of voice burst	

[27] https://cordis.europa.eu/project/id/257385

[28] https://cordis.europa.eu/project/id/761745

[29] https://one5g.eu/

[30] https://www.5g-eve.eu/

[31] https://5gtours.eu/

[32] https://5gdrones.eu

[33] https://5gepicentre.eu

UC3_KPI4	Maximum late call entry time	Late entry time < 150ms 95% of late call request	services and aims to not decrease the performances established by the standard. The final evaluation which will be done during the third year of the project will allow to compare and determine the gain regarding the standard.
UC3_KPI5	End-to-End MC-DATA (IP Data) and MC-VIDEO (video) request time for IP packets transmission	Transmission request time < 10ms	
UC3_KPI6	User Data Rate	DL user data rate shall be 100Mbps UL user data rate shall be 50Mbps	
UC3_KPI7	Successful packet transmission (Reliability)	Reliability indicator at least 99,999% of success for a 32 bytes IP Packet within 1ms	
UC3_KPI8	E2E Service Latency (similar as in UC1	10-100ms	The target values range from 10ms (augmented reality in human-machine interfaces) to 100ms having as a baseline the "Service requirements for the 5G system", (3GPP TS 22.261, Latency needs to support example use cases from vertical industries).
UC3_KPI9	Network energy efficiency and device energy efficiency	Reduction by a factor of 10	Reduction of energy consumption by a factor of 10 (considering that intelligence distribution can contribute to increasing efficiency of Sleep Mode) [20][21]

5.3.1.2 Evaluation and results

Table 12: UC3 – Results obtained and gain

KPI ID	Evaluation method	Results	Gain
UC3_KPI7	Measurements are collected at UE level.	Figure 74, Figure 75	What we can see, in case of loss of service, the system is able to reach the baseline in term of reliability.
UC3_KPI8	Measurements are collected at the application layer by adding timestamps to requests between functional entities/service components of an overall service. Then the	Figure 28-Figure 32	From the various measure-

KPI ID	Evaluation method	Results	Gain
	difference in time will be calculated between the request from one entity (e.g., client) and the response from the other entity (e.g., server). Measurements are also collected e.g., with the use of ping and iPerf.		ments latency is close to the target and baseline values.
UC3_KPI9	The battery level of involved mobile nodes (e.g., phones, laptops, robots) will be measured with and without the use of intelligence distribution mechanisms for certain services/applications. The power consumption of involved servers may also be measured or at least estimated using various ways ranging from cheap watt hour meters for on premises servers.	Figure 33	5-10%

As mentioned previously in this document results presented in section 3.3 and Figure 28- Figure 35 under UC1, essentially are also applicable to the UC3 Public Safety part based on a similar implementation architecture (Figure 22 and Figure 67).

In addition, measurements were derived on the time required from the triggering of the coverage extension algorithm up to the returning of the result from the corresponding decision-making process to the coverage extension visualisation dashboard and the Jackal robot as the MAP. The **average time for this coverage extension process** is currently measured at an average of 16 seconds. Details on the particular coverage extension algorithm implementation can be found in D4.2.

With respect to service reliability packet Error Rate is measured continuously by sending test packets from a test sender to a test receiver, and back. No loss of packets was recorded and therefore service reliability is measured at a 100%.

Regarding the Mission Critical Services, the first evaluation has shown that the split architecture and potential deployment at the Edge will have limited impact on the KPIs as defined in the 3GPP MCS standards, the first value measured show an increase latency for MC-VIDEO comparing to state-of-the-art technology based on Public 4G/5G operated networks.

5.3.1.2.1. Mission Critical evaluation

The following paragraphs describe the evaluation of such novel split architecture in Mission Critical Services.

The 5G network used for the preliminary evaluation was the Orange public operated infrastructure without prioritization for mission critical applications.

All the MCX components are available as containers in a Kubernetes environment which has been chosen for the evaluation. The evaluation has been executed related to the first context of the Public Safety use case, context #1 “Loss of connectivity in a non-urban area after a natural disaster”. A specific K8s context has been defined in order to support this Public Safety context with the automatic redeployment of a MCX component to support the MCX feature in use.

For the evaluation, two smartphone user devices have been used with a specific human-centric application implemented and deployed on them.

First step, after the initialization of the context, a script deployed all MCX components as shown on the figure below.

```
delmass@delmass-HP-ZBook-15-G2: ~/Kubernetes/M6/scripts
delmass@delmass-HP-ZBook-15-G2:~/Kubernetes/M6/scripts$ ./uc101connection.sh
Cluster "m6cluster" set.
User "ads-developer" set.
Context "m6context" modified.
Switched to context "m6context".
delmass@delmass-HP-ZBook-15-G2:~/Kubernetes/M6/scripts$ ./uc102deletedeployment.sh
deployment.apps "audiomedia" deleted
deployment.apps "audiosignalisation" deleted
deployment.apps "kpi" deleted
deployment.apps "registrar" deleted
deployment.apps "situation" deleted
deployment.apps "videomedia" deleted
deployment.apps "videosignalisation" deleted
deployment.apps "webapp" deleted
delmass@delmass-HP-ZBook-15-G2:~/Kubernetes/M6/scripts$ ./uc103startdeployment.sh
deployment.apps/audiomedia created
deployment.apps/audiosignalisation created
deployment.apps/kpi created
deployment.apps/registrar created
deployment.apps/situation created
deployment.apps/videomedia created
deployment.apps/videosignalisation created
deployment.apps/webapp created
delmass@delmass-HP-ZBook-15-G2:~/Kubernetes/M6/scripts$
```

Figure 70: "DEDICAT 6G - Mission critical components deployment"

On two user devices, the human centric application implemented to use MCX services is launched, and one device has started to stream the video from the user device camera to the other device which is able to display the video. The MC-VIDEO feature is supported by the MCX Videomedia component.

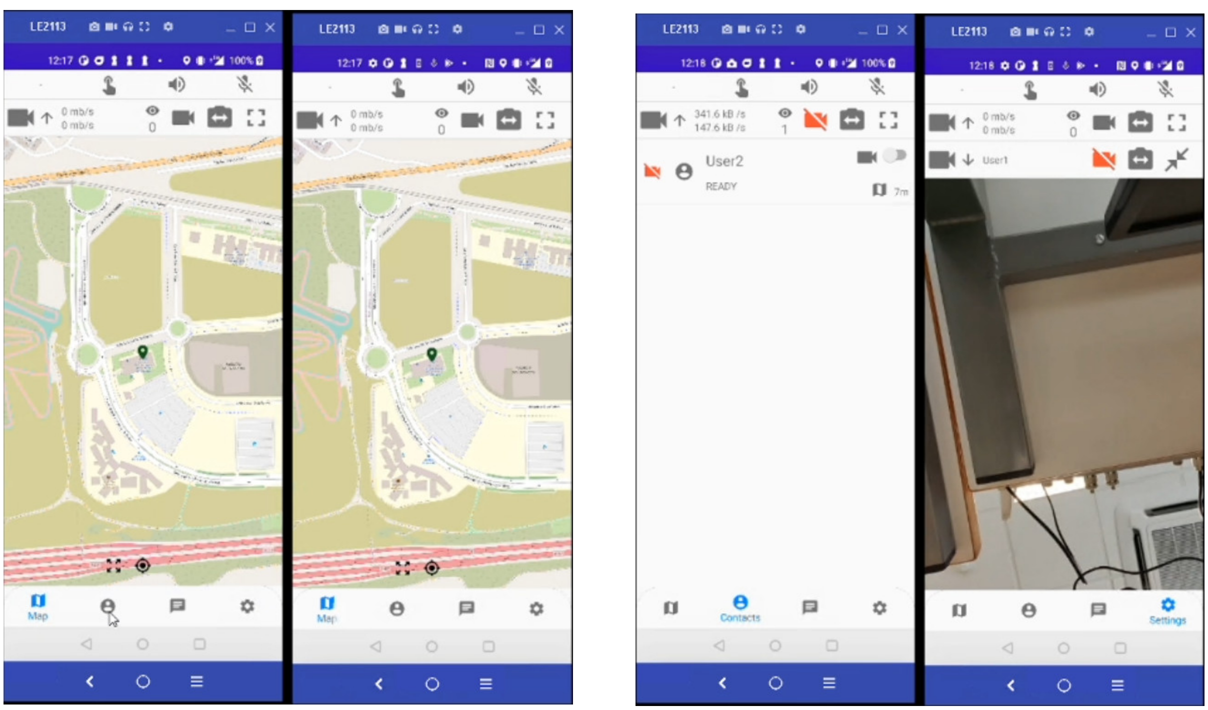


Figure 71: "Mobile Client applications on user devices with the video stream up"

The next step of the evaluation was to simulate the loss of the MC-VIDEO service. To do so, we have launched a script to kill the videomedia component

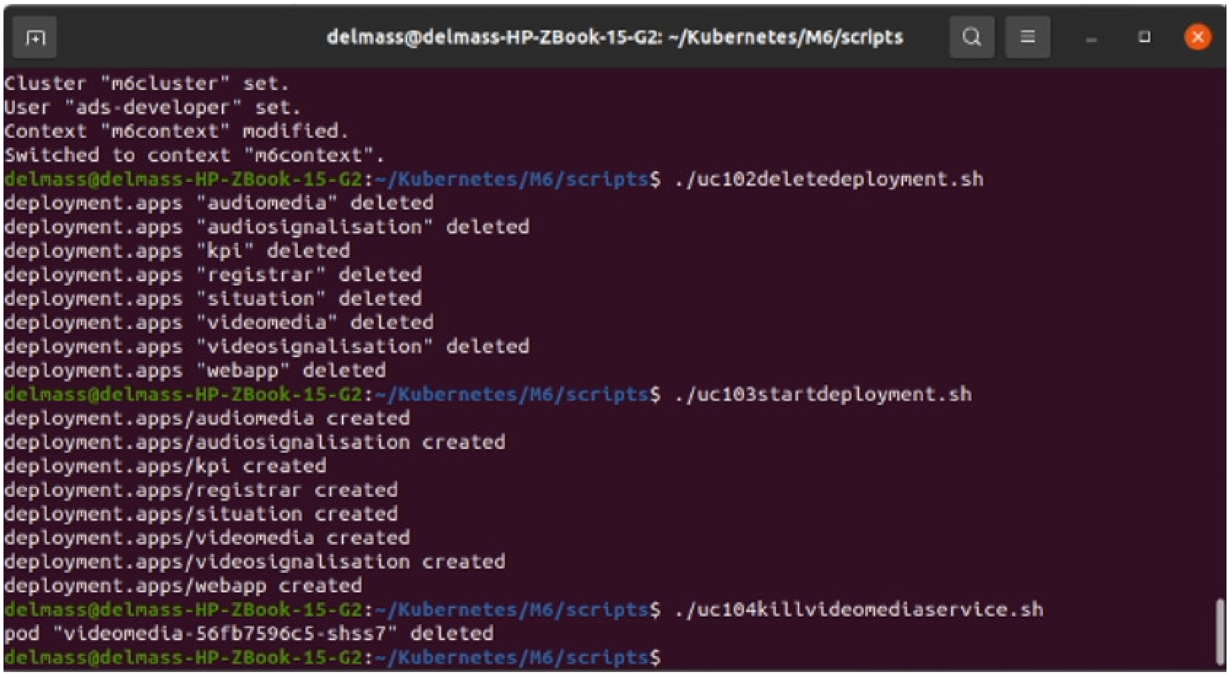


Figure 72: Simulation of loss of MC-Video service

The behaviour which has been noticed was the loss of the video stream on the second device (the right one on both pictures presented in Figure 73) before it reappears a few moments after.

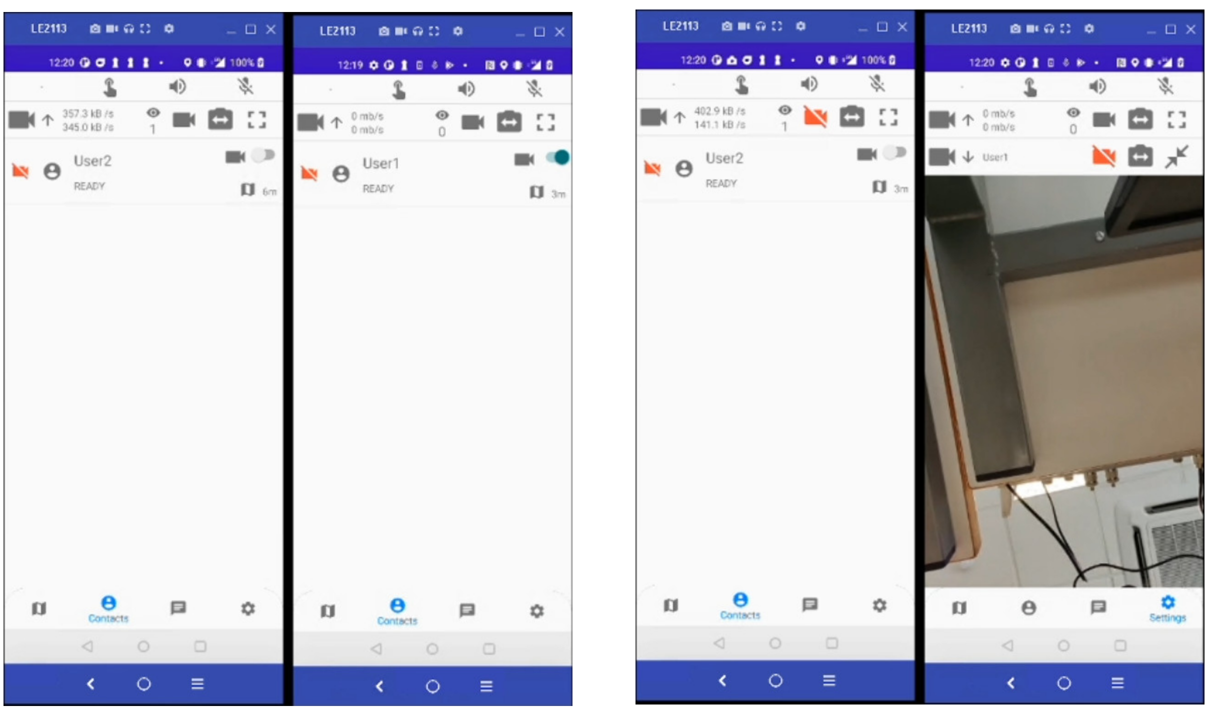


Figure 73: Mobile client (on right) losses video stream and a few instants later, the video stream is up

The system reacts as expected in the split environment. After the detection of the loss of one component which was in use. The orchestrator has created a new instance of the component and mobile devices have continued to deliver the information between them.

The data was collected and sent to an analyser component in order to measure the video latency.

The following Figure 74 explains the first KPI evaluation.

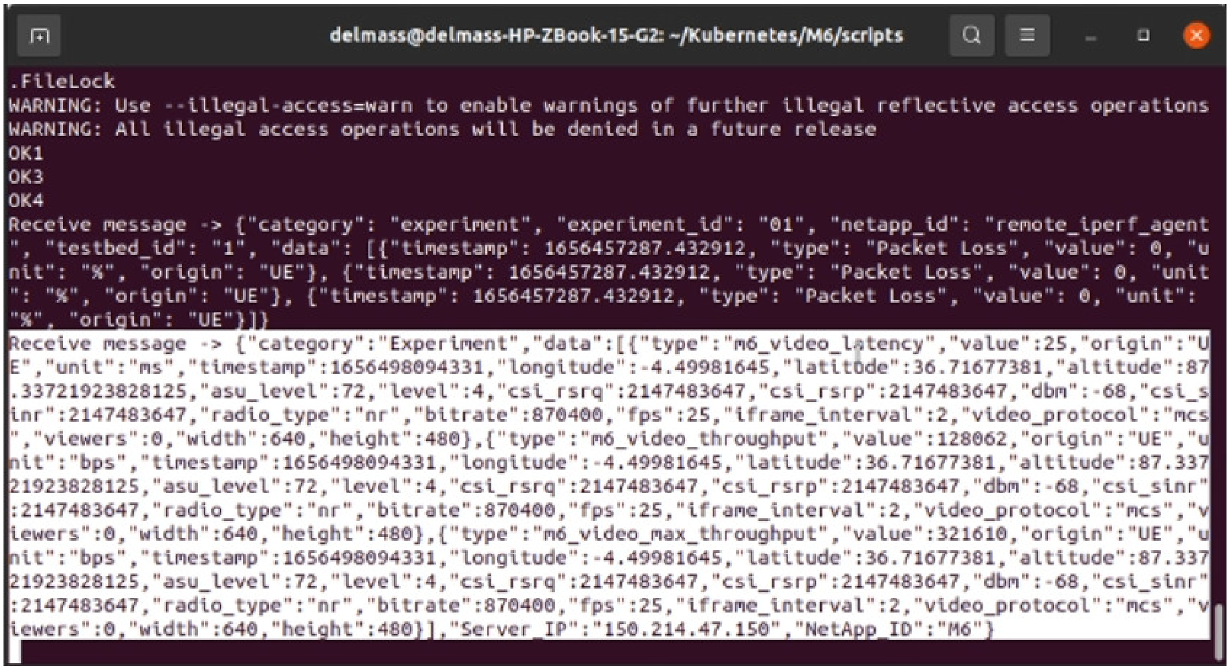


Figure 74: KPI evaluation for the recovery time of video media component supporting MC-VIDEO.

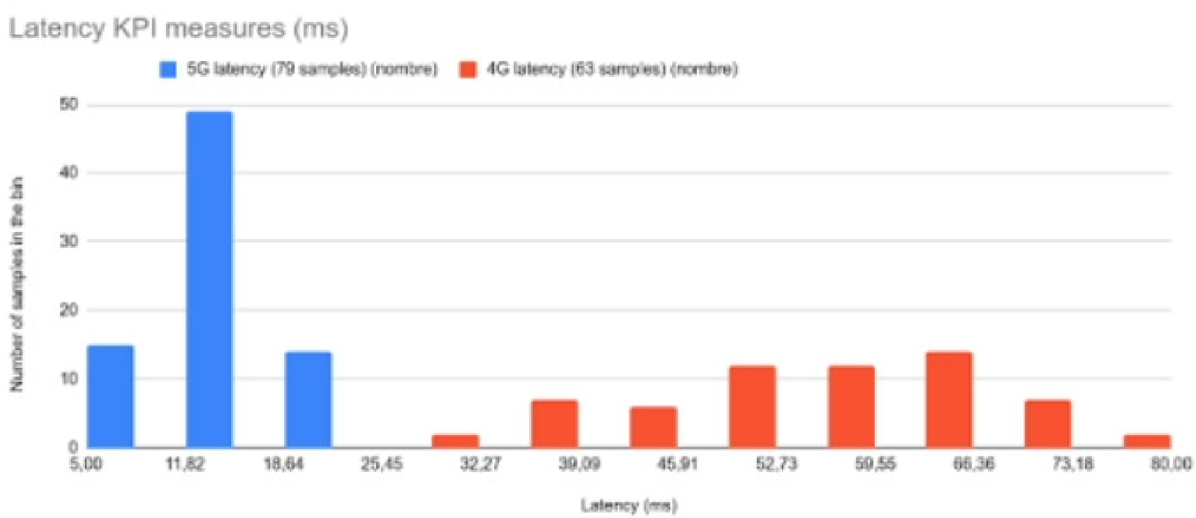


Figure 75: Video latency measured in 5G and results comparison with 4G.

The video latency was measured several times to have an average of the latency. In 5G network the video latency value measured was between 5ms and 25ms.

Some measures were performed on 4G in order to have some comparison with 5G as shown on Figure 75, all the video latency were more than 30ms.

5.3.2 Next steps for the third period

The following figure show the planning for the third year of the project with the setup of the Public Safety pilot around May 2023 and the execution of all KPIs measurements.

The results will be reported in the deliverable D6.3 at month M36.

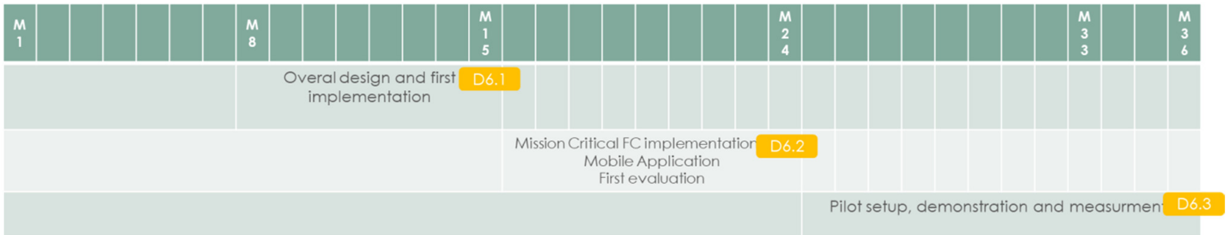


Figure 76: Milestones and planning for UC3 proof of concept

During the third period of the project, we will go through the integration of the different outcomes from WP3 to WP5 in order to measure the KPIs during the use of DEDICAT 6G and have comparison to the standards and evaluate all KPIs.

6 UC4: SMART HIGHWAY

6.1 Scenario and stories

Smart Highway use case is executed in the context of smart mobility. The goal of this use case is to research and experiment beyond-5G connectivity to enhance safety on the road. Communications between vehicles and Vulnerable Road Users (VRUs) are expected to have small delays and to be highly reliable. Cars and roadside infrastructures are used as edges that provide services closer to the end users as well as to load-balance the computational resources. Furthermore, this use case demonstrates the coverage extension to ensure that the connectivity is always covered in the area by having a car that is mobile being exploited as a Mobile Access Point (MAP).

6.1.1 Detailed Stories

The two stories planned for the Smart Highway use case take place in two locations: Belgium for Story 1 and Germany for Story 2.

Story 1 - VRU Detection at the highway exit: The story emphasised on the point of view of the driver of a car that is about to enter an intersection from the highway exit. The intersection is used by cars, as well as VRUs. All road users should be aware of each other so that navigational decision can be taken more carefully as well as to avoid any sorts of accident. The car that is exiting the highway can detect the presence of the VRUs by obtaining the information from the existing cars on the intersection that also forwards the information towards the roadside infrastructures, or the Road Side Units (RSUs). The car that is already in the area can capture the presence of the VRUs from LiDAR or camera. At the same time, the VRUs also send a beacon to all road users about their presence. In this sense, the overall vision about the scenario and any harmful situation is amplified, bypassing any obstacle (e.g., bridges, buildings, or trees) in the way.

Story 2 - Distributed situation knowledge in shared traffic spaces: This story focuses on the efficiently distributed situational awareness and knowledge through the exchange of (processed and/or raw) sensor information between vehicles and RSUs and VRUs to increase road safety and improve traffic flow in shared traffic spaces. In shared traffic spaces, VRUs are recognized through the vehicle's installed sensors (camera, LiDAR, etc.), the camera sensors are mounted on the RSU and the pedestrian's smart device app, and this information is shared with the vehicle and the RSU, which act as a Mobile Access Point (MAP). Then, the Local Dynamic Map (LDM) is defined based on the shared information. While analysing the VRU's movement and trajectory in real time on the LDM, it is possible to predict dangerous situations in shared traffic spaces and display warning messages on the vehicle's screen and the VRUs' app in real time to increase road safety.

6.1.2 Services – Human centric applications

The VRUs are equipped with a UE that can sense the presence of other road users. This UE will take the form of a lightweight device that can visualize a LDM that can pinpoint a real-time location of all the road users.

6.1.2.1 Story 1: VRU Detection at the highway exit

In scenario 1 that is referent to the story 1, we provide a human centric application which has the objective to generate dynamically a Local Dynamic Map of the exit of a highway located in Wommelgem, Belgium. This LDM application will have a server-side and a client-side component. In the server-side, the LDM application will process all the sensor data gathered by the Smart Cars and the VRUs and provide as output a single LDM to all involved users.

Moreover, the server-side application will identify potentially dangerous situations and trigger warning messages to the involved clients. In the client-side LDM application, depicted in Figure 77, the map of the specific location of the Smart Highway will show in which the Smart Cars and VRUs will be shown for the connected clients. Moreover, in case of a dangerous situation, a notification will be triggered to the connected users.

Figure 77: LDM App mock-up

The LDM application has the following features:

- VRU and Car detection and location information;
- Notification of obstruction, or warning between road users.

6.1.2.2 Story 2: Distributed situation knowledge in shared traffic spaces

In scenario 2 that is linked to story 2, the human-centric application basically aims to increase road safety by recognizing VRUs at the road-side and predicting dangerous situations. For this purpose, RSU application is being developed that runs on NVIDIA Jetson AGX Orin device serving as edge computing. And a mobile application for pedestrians that can be linked with RSU is also being developed.

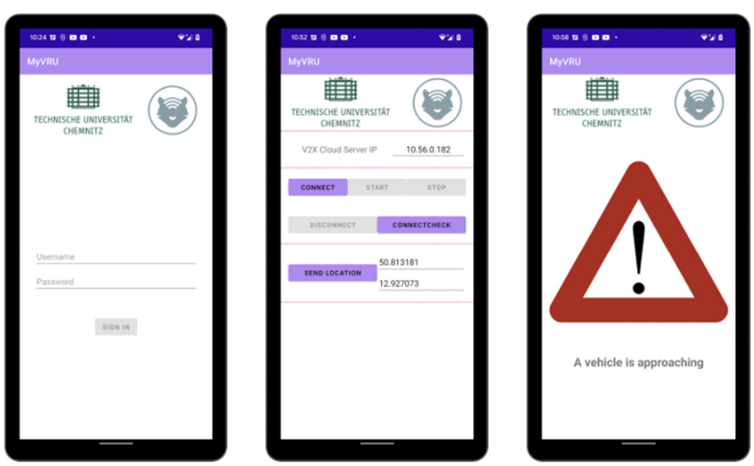
The initial implementation of the RSU application in D6.1 has been updated to version 2 as shown in Figure 78 with the following features:

- VRU detection and location information estimation on the road from the camera sensor installed in the RSU;
- Real-time integration of vehicle location received from OBU and VRU location information received from VRU app;
- Update LDM in real time based on integrated VRU information;
- Using the traffic information of LDM to predict situations such as collision risk and send appropriate warning messages to drivers and pedestrians.

Figure 78: The RSU application

The VRU mobile application based on Android OS, which is compatible with Android 6.0 or higher, has also been updated as shown in Figure 79 and has the following features:

- By logging in with a unique ID, RSU recognizes it as a unique VRU user;
- VRU (e.g., pedestrian, cyclist) location can be obtained using the Android smartphone's onboard GPS transceiver;
- The acquired location information is transmitted to the RSU in real time, including its unique VRU identifier;
- It receives a warning notification from RSU when there is a risk of collision predicted in LDM;
- A warning notification icon and a description of the situation are displayed on the screen.



(a) (b) (c)

Figure 79: VRU mobile application (a) login (b) setting (c) warning screen

6.2 Scenario Setup

6.2.1 Story 1 setup

6.2.1.1 Pilot setup

On the Belgian site, the execution will take place in Wommelgem, near the city of Antwerp. The intersection is a junction between a national road and E313 highway in the form of a roundabout, as depicted in Figure 80. The highway on top of the intersection is equipped with an RSU, as seen in Figure 81, capable of transmitting signals through short range communication towards road users. The roundabout connects to the exits of the highway.

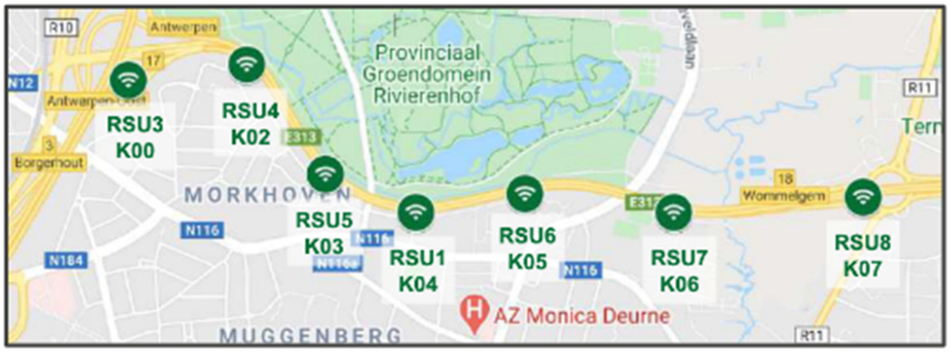


Figure 80: Location of the UC on map (Belgium site)

Figure 81: Physical location of the UC (Belgium site)

The use case will require several devices used such as:

- Cars with connectivity features (MAP and UE), sensors (LIDAR, GNSS) and computing capabilities (NVIDIA Jetson, general processing unit);
- Lightweight UE for VRUs;
- RSU with connectivity and edge computing capabilities.

As for the software, the UE and Cars will be provided with an LDM application that can visualize the situation of the environment.

6.2.1.1.1. Remote processing data centre

The remote processing data centre is located outside of the Smart Highway (Figure 82). This asset will give the experimenters the capability of hosting the LDM application in servers with more processing power than the hosts placed at the edge such as the OBU and the RSU. Besides having more computing power, the Cloud will provide a different setup network wise, since it will increase the network latency of the LDM application. Therefore, the trade-off between computing power and network resources can be used as input to the research of the project partners. For instance, the distributed intelligence algorithm could use hosts with different capabilities in order to maintain the QoS of the LDM application.

Figure 82: Remote processing data center (Belgium site)

6.2.1.1.2. V2X Platform

The V2X platform is composed of a car equipped with an *On-Board Unit (OBU)*, and a RSU located on E313, a highway located in Wommelgem, Belgium. The platform can be used for experiments on *Vehicle to everything (V2X)* connectivity and edge computing. The units on the platform have communication modules capable of transmitting signals via short range, either cellular V2X (C-V2X, via PC5 side link interface) or ITS-G5 (Wi-Fi based technology), and long-range, via 5G. Also, GNSS receivers are installed on the OBU in order to capture the location. In addition, both OBUs and RSUs can offer distributed computing features due to a powerful *General-Purpose Processor (GPP)*. More details about the RSU and the OBU are described below.

6.2.1.1.3. RSU

Figure 83 illustrates the RSU located on E313, a highway located in Wommelgem, Belgium. Each RSU consists of a large electrical cabinet which houses all the different modules of the RSU. These include modules for wireless communication, modules for local processing on the RSU and modules that allow the RSU to be managed and, if need be, recovered remotely. This RSU contains hardware and communication modules to provide V2X communication experience such as Ettus USRP N310, Mikrotik wAP LTE kit, and Cohda Wireless MK05 RSU.

Figure 83: RSU on E313 highway

6.2.1.1.4. Smart cars

The Smart cars of the Smart Highway are equipped with an OBU and a MAP. This MAP can be instantiated and activated automatically by an internal (e.g., GPS position) or external trigger, depending on the communication needs. In essence, the MAP acts as an access point that supports several wireless communication technologies, e.g., small 5G gNodeB system-in-a-box, to which other UEs can connect. This allows for high bandwidth data communication between vehicles, without the need for external infrastructure. The OBU is composed of processing capabilities and sensors that will enable environment monitoring by the cars. To enable the processing capabilities, the OBUs count with an Nvidia AGX Xavier. Moreover, the smart cars are equipped with LiDAR sensors, CAN-BUS, and GNSS receiver.

Figure 84: IMEC's experiment car with On-board Unit

6.2.1.2 Smart Highway – Story 1 implementation

6.2.1.2.1. DEDICAT 6G architecture components

While the architecture the components have been described in UML diagrams on D2.3 [2], herein we focus more on the functional components, i.e., the particular.

6.2.1.2.2. UC4 specific components

The UC specific components detail in this section were described in the UML diagrams present in D2.3 [2]. Below, we briefly present a table of the UC specific components identified during the UML diagrams specification.

Table 13: UC specific components in UC4 – Scenario 1

Component	Description
V2X Application µS	Part of the LDM application that is placed on the edge of the network for low-latency communication
V2X Communication Module	Responsible for sending sensor data for the LDM application in the cloud and also serving as client for the driver in the Smart car
GPS	Sensor responsible for informing geographical position of the Smart car or of the VRU
VRU App	Client application for VRU GPS information gathering, LDM and notification display
LiDAR	Sensor responsible for scanning the perimeter of the Smart car and sending the monitored data for the LDM application to be processed
LDM	Application responsible for building the Local Dynamic Map (LDM) and for dangerous situation identification

6.2.1.2.3. Interfaces

This section presents the hardware interfaces available in the Smart Highway testbed. More information about function components interfacing should be provided in WP2 deliverables and in D6.2. The interfaces group for this use case is composed of RSU, OBU, and the VRU Smartphone. Moreover, details for their interfaces are detailed in Table 14.

Table 14: Hardware interfaces for components on the Smart Highway – Scenario 1

Component	Hardware Interfaces
Roadside Unit	• Wi-Fi 802.11b/g/n network interface @ 2.4 GHz • SDR: Ettus USRP N310 • ITS-G5: Cohda Wireless MK05 RSU • LTE-V: Cohda Wireless MK6c EVK • 2x antenna connector (connected to 5.9GHz antennas) • Internal GNSS receiver (connected to a GNSS antenna mounted inside the RSU)

	• 1x 1GigE Ethernet port for data communication and management of the device • Mikrotik wAP LTE kit
Onboard Unit	• Wi-Fi 802.11b/g/n network interface @ 2.4 GHz • 8x 1Gbit/s ports • C-V2X PC5 (Qualcomm 9150), Bandwidth 10 MHz, 2 C-V2X antennas, 1 GNSS antenna, Security; SXF1800 FIPS 140-2 level 3 compliant • LTE Category 4 (150Mbps downlink, 50Mbps uplink), Internal antennas with support for optional TS9 external antennas
Smartphone	• Wi-Fi 802.11b/g/n mobile hotspot @ 2.4 GHz / (5 GHz) • B5G modem support as network interface (currently @ 3.5 GHz)

6.2.2 Story 2 setup

6.2.2.1 Pilot setup

The demonstration will be structured and implemented as follows, starting with the RSU platform.

6.2.2.1.1. RSU platform

Hardware

The RSU prototype hardware configuration is shown in Figure 85. RSU acts as an edge AI computing where AI algorithms can be processed locally, making independent decisions in milliseconds without the need for internet or cloud connectivity. NVIDIA Jetson AGX Orin, an embedded device equipped with a GPU core to process AI algorithms, and BASLER acA2440-35uc is configured in the RSU to recognize and detect VRUs on the roadside. In addition, the RSU prototype hardware includes the USRP N321, a software-defined radio for communication between the cloud server, the VRU, and the vehicle, and an Intel NUC connected to handle the communication of the USRP N321. That is, the AI part and the communication part are processed in parallel by Jetson AGX Orin and Intel NUC, respectively. The main specifications of each device are described in Section 6.2.2.2.2.

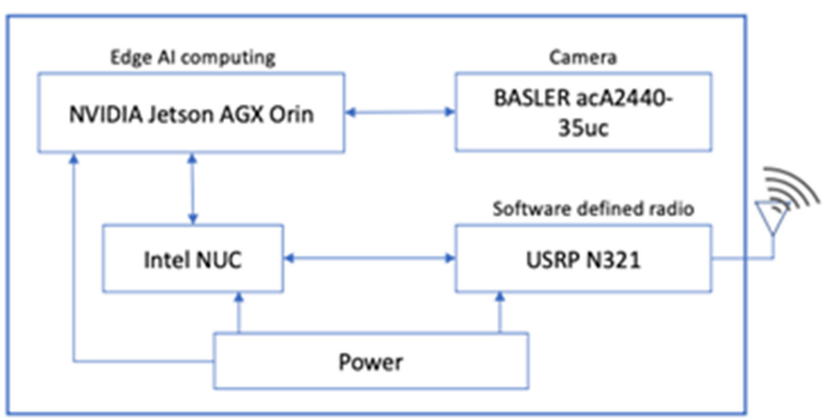


Figure 85: RSU prototype hardware configuration

Software

Figure 86 summarizes the overall software structure of the proposed RSU. Information between RSU, vehicle and VRU apps is transmitted through USRP (N321). The cloud server classifies the vehicle's location received from the vehicle's OBU and the VRU location information received from the VRU app and delivers it to the RSU. In RSU, the location information transmitted from the cloud server and the VRU location information detected by the RSU's camera sensor are integrated in real time. And RSU's core software analyses the integrated information to estimate the location of the VRU and vehicle, and then updates the LDM in real time. It predicts situations such as collision risk from traffic information from LDM and sends appropriate warning messages to drivers and pedestrians.

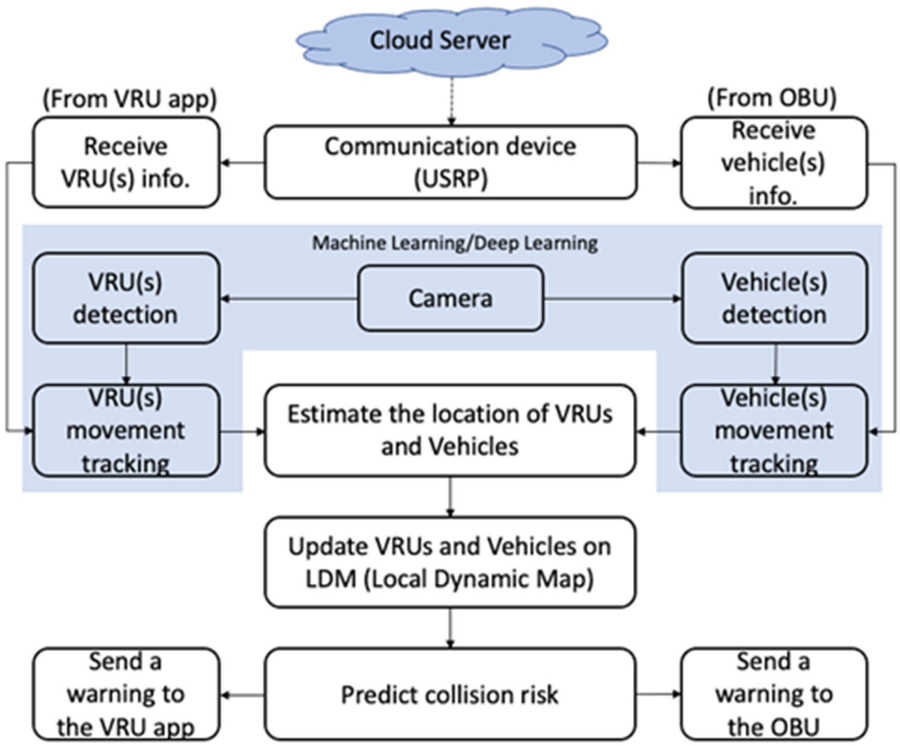


Figure 86: The overall software structure of the proposed RSU

The GUI of the software RSU (version: 0.2) running on edge computing is based on Qt5 and is shown in Figure 78. From the initial version of D6.1, the categories of the current GUI have been expanded to 10 groups, and the roles of each group are defined as follows:

- Camera View: it displays the VRU object detected from the single camera image mounted on the RSU;
- Bird Eye View: it converts the four positions specified in the single camera image into Bird Eye and displays the VRU locations located within the area. From this location information, VRU's GPS coordinates are calculated so that layer 4 of LDM can be constructed;
- LDM: LDM [27][28] can be represented in four different conceptual layers. In RSU, only Layer 1 and Layer 4 can be active. Layer 1 receives the map information of the RSU area from OpenStreetMap [29] and Layer 4 is generated from the GPS coordinate information of the VRU calculated from bird eye view;

- Map Layer: it can activate the layer visible on the LDM;
- Coverage of VRU detection: the VRU located in the LOS (Line of Sight) within the coverage of the camera viewer area can be tracked, and in conjunction with the VRU mobile app that transmits the VRU's current location to the RSU, it can be tracked up to the NLOS (Non Line of Sight) area. And it can extend a coverage for tracking VRUs that located outside the camera view;
- VRU (Vulnerable Road User): it can select the type of VRU displayed on the screen;
- VRU tracking: only moving VRUs are visible to LDM;
- VRU detection (Camera view): The VRU type and accuracy detected in the camera view are output in log form;
- VRU location – GPS coordinates (Bird eye view): The GPS coordinate values tracked by the VRU calculated from Bird Eye View are output in log format;
- Communication: it provides a button to connect to a *Universal Software Radio peripheral (USRP)* device for communication and a button to enable the RSU as a MAP.

6.2.2.1.2. VRU application

VRU represents a set of vulnerable road users such as pedestrians, cyclists, etc. Between 2010 and 2018, more than 51,000 pedestrians died in the EU [30]. Pedestrian accidents are mainly caused by driving and pedestrian negligence, and in recent years, the use of smartphones and other devices has made pedestrian fatalities worse every year [31]. Additionally, most road accidents involving VRUs occur because road users fail to detect the presence of VRUs in a timely manner and respond appropriately [32]. Pedestrian road safety can be either a sensor-based or communication-based solution and can be addressed by considering an infrastructure-based approach that typically relies on sensors, cameras, wireless tags, RSUs, and smartphones. In UC4 (German site), it aims to solve the safety problem of VRUs on the road-side based on *Vehicle-to-Infrastructure (V2I)* by developing a dedicated smartphone app.

An initial version of the VRU app has been implemented on Android OS. This VRU app utilizes the onboard GPS transceiver of any Android smartphone to obtain a pedestrian location sends the GPS coordinates of the user's current location to the RSU in real time. And the VRU app can receive notifications from the RSU about dangerous situations such as risk of collision. Then, a warning message is displayed on the screen, sounded, or vibrated. As shown in Figure 79, the VRU app screen currently under development consists of V2X cloud server IP, V2X cloud server access control, current location (GPS coordinates), and warning message viewer.

6.2.2.1.3. Local Dynamic Map

The concept of LDM, which is now being standardized in Europe, is data aggregation for use in *Intelligent Transport Systems (ITS)* introduced in 2010 with the SAFESPOT [28] project. It defined a four-layer structure as shown in Figure 87 [28] The first layer consists of static data such as map data with road topology, the second layer consists of transient static data such as traffic signals, buildings, and roadside infrastructure, the third layer consists of transient dynamic data such as congestion and other traffic conditions, and the fourth layer consists of dynamic data such as vehicles, pedestrians, and cyclists. In UC4 (Germany site), it notes that only the first and fourth layers out of the four layers are active because the RSU application focuses on the trajectory of VRUs.

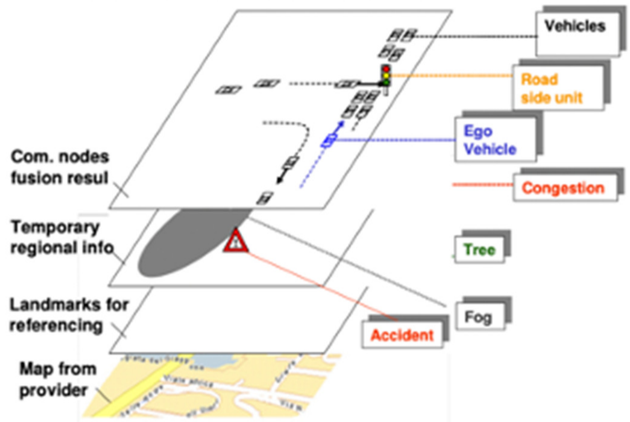


Figure 87: The four layers of the LDM

We set out to implement LDM on NVIDIA AGX Orin, which acts as RSU's mobile edge computing. LDM's database management systems are built based on MariaDB and PHP. We used Python 3 to create an *Application Programming Interface (API)* to access LDM.

The architecture of the LDM is illustrated in Figure 88 and is defined based on the following components:

- LDM database: It is built with a MariaDB-based database to store dynamic data for the fourth layer;
- LDM database interface: It is a PHP-based database interface for performing *Create/Read/Update/Delete (CRUD)* operations for *Structured Query Language (SQL)*-type DB;
- LDM application programming interface: It is implemented in Python 3 with a set of functions to interact with the database, including input and output interfaces.
    - Add VRUs: It is new or updated information about VRUs received from the RSU, VRU app, or Vehicles;
    - Load static map: It loads a static map for the first layer. OpenStreetMap data are used;
    - Gt VRUs: It retrieves real-time information about VRUs at certain time instants or intervals;
    - Predict collision risk: It estimates the collision risk between VRUs within a coverage area.
- VRU Input: The VRU information is added through the RSU's sensors (e.g., camera), the vehicle's OBU, and the VRU app;

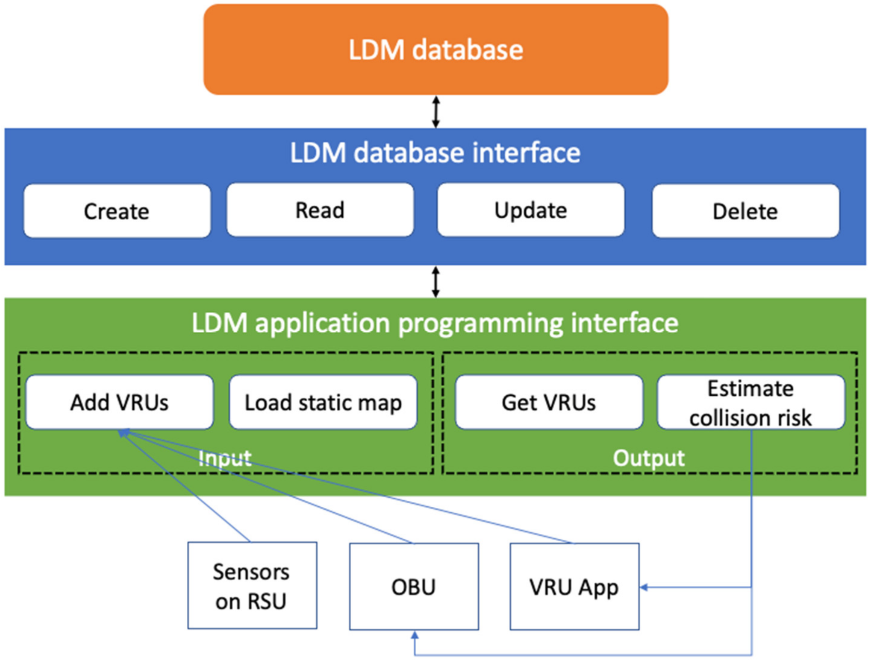


Figure 88: Architecture of the LDM

6.2.2.1.4. Vehicle platform

As shown in Figure 89, TUC research vehicles are Volkswagen Tourans, BMW i3 and Volkswagen ID4. The vehicle is equipped with an OBU and sensors such as RADAR, LiDAR, FIR, NIR, MobileEye, and GNSS for autonomous vehicle implementation. The current vehicle platform is currently being updated to be able to cooperate with RSU application in the third period.

Figure 89: TUC vehicle platform

Figure 90 shows that vehicles are equipped with SDR-based communication devices to extend their reach to V2X applications and can connect with mobile ITS research stations.

Figure 90: SDR-based V2X communication device on TUC vehicle platform: (a) installation setup (b) UE (c) CN+eNB

6.2.2.1.5. End-to-End Network

Connected vehicles and RSUs can utilize IEEE 802.11p for *Vehicle-to-Vehicle (V2V)* and V2I communications. The widespread deployment of connected vehicles and RSUs on the road and the introduction of autonomous driving applications will significantly increase the bandwidth and scalability demands of networks. In order to address these challenges, heterogeneous V2V communication based on multi-RAT will be adopted in UC4.

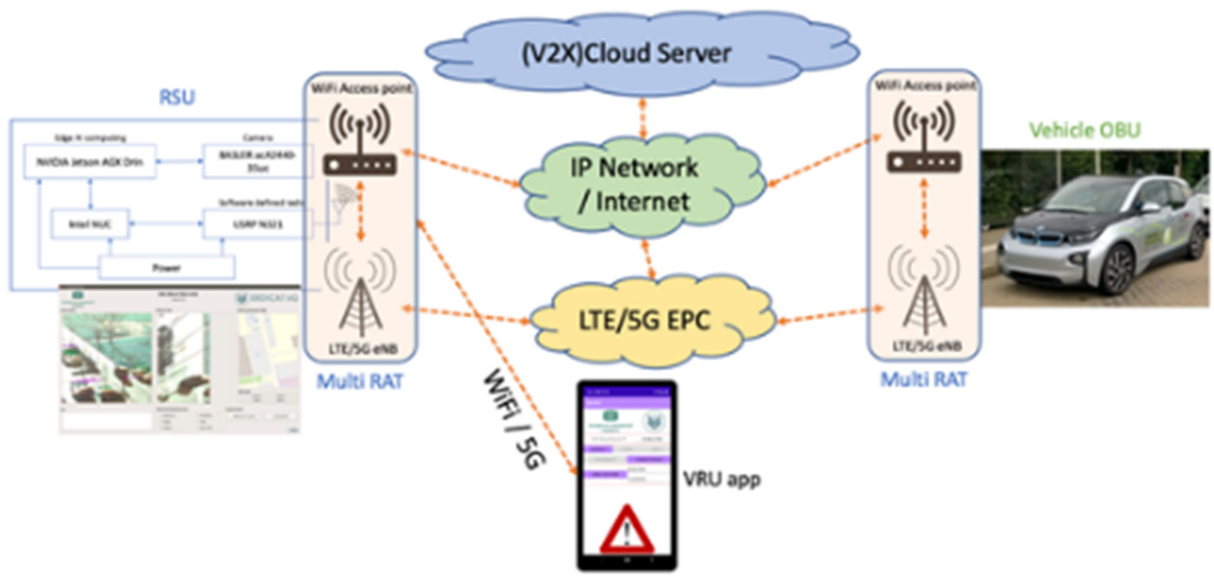


Figure 91: End-to-End Network for UC4

As shown in Figure 91, USRP devices capable of performing the MAP role based on Multi RAT will be installed in RSU and OBU to form an end-to-end network between vehicle, RSU, VRU, and V2X Cloud Server. The detailed network configuration and implementation based on the USRP devices will be completed in D3.3 and D4.3 of the third period. And the core parts of RSU and Mobile App have been implemented from D6.1 to the present D6.2. The OBU, V2X communication, and the cloud server parts are currently partially implemented, and will be all integrated in the third period. Then, the integrated practical application is used for UC4.

6.2.2.1.6. Sensing node network

This subsection describes the sensing node network and their components.

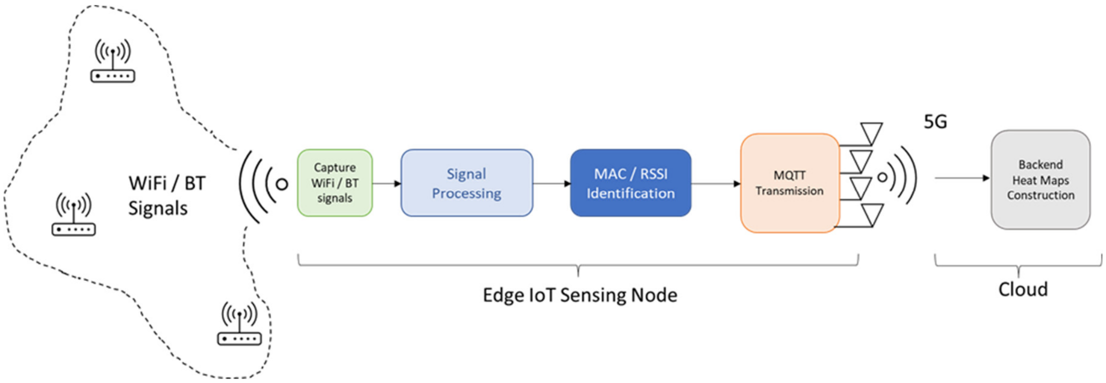


Figure 92: High-level view of a IoT Sensing Node Architecture

The Figure 92 describes the general architecture of the system considering the IoT nodes in the Edge and the algorithms for processing the information and the construction of the heat maps that are processed in a cloud backend.

The sensing nodes act as edge devices where they act as listening devices capable of detecting devices in the coverage area that use short range radio technologies, such as Wi-Fi or Bluetooth with the intention of determining or estimating the number of VRUs (assuming that most of them will carry devices that make use of these technologies, such as smartphones or connected wearables in the shared traffic zone). The sensing nodes network will generate occupancy heat maps in the area that can collaborate in the construction of a global map of VRUs and cars present in a given area (LDM) to give a greater awareness context to prevent risk situations for VRUs and vehicles. In addition, VRUs that need a backup connection to send location information can query connectivity information about the sensing nodes with availability to use their connectivity resources.

Each sensor node consists of an enhanced people counter and a 5G connectivity device, whose connectivity resources are centrally controlled through the Sensing Node µS dashboard. Sensing node prototype hardware configuration is shown in.

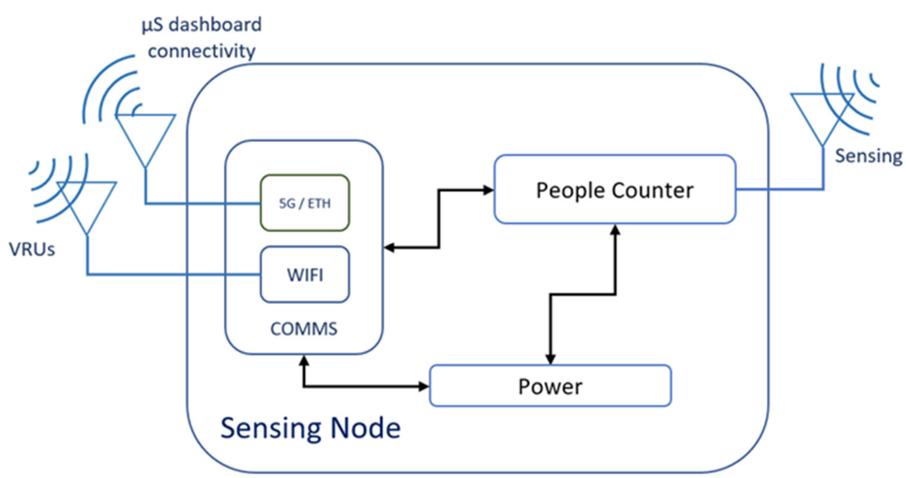


Figure 93: Sensing node architecture

The final assembly of the sensing nodes shown in Figure 93, where we can distinguish the communications board, where there is a 5G and a WiFi interface, the board in charge of capturing the WiFi and BT signals, signal processing and extraction of RSSI/MAC characteristics.

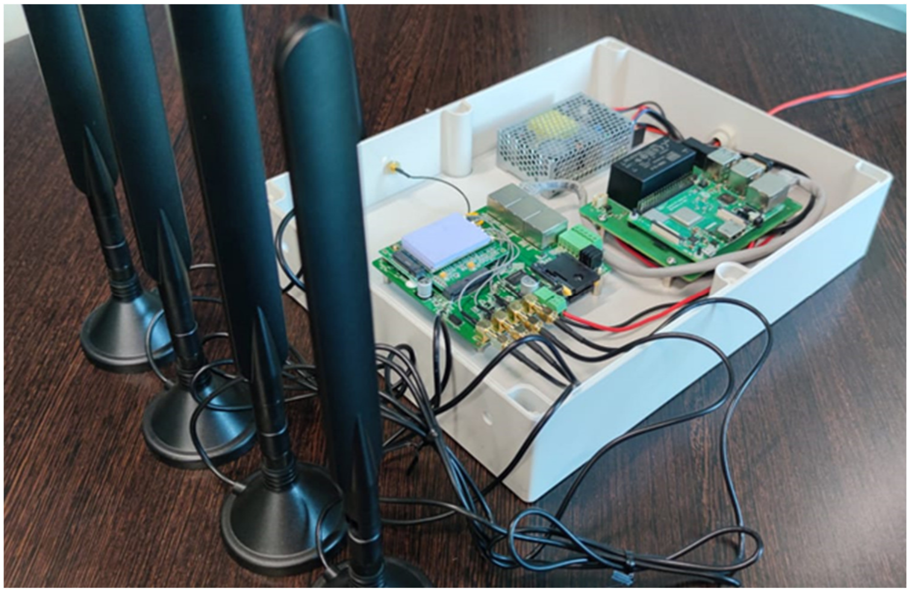


Figure 94: Final sensing node prototype

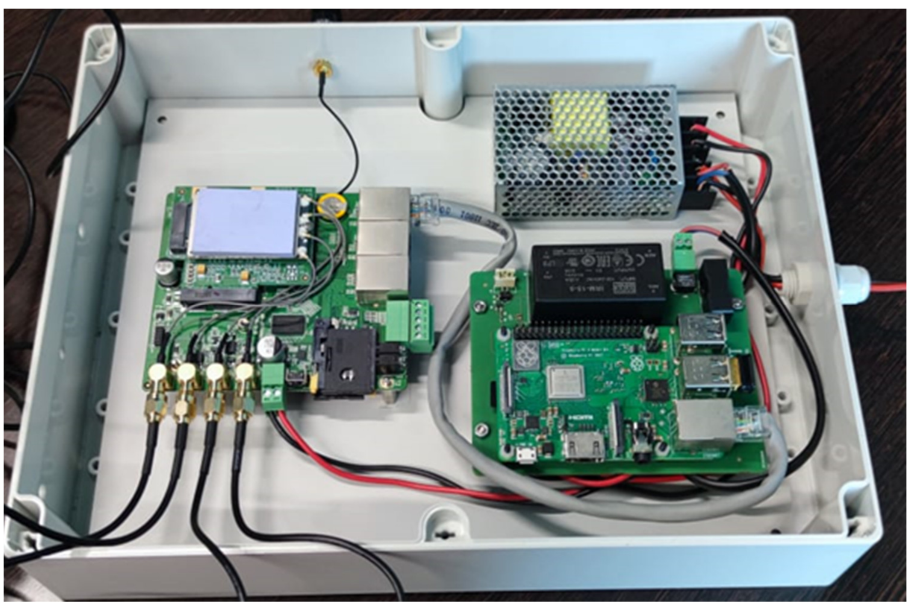


Figure 95: Detail of different components of the sensing nodes

The sensing node process board function is to capture and filter messages exchanged by the Wi-Fi and Bluetooth interfaces of the generalist devices that are expected to carry most of the VRUs (connected and non-connected to DEDICAT 6G) in order to extract information about the number of devices present in the area shared by the traffic.

The information extracted by the sensing nodes is the MAC information of the radio interfaces and the *Received Signal Strength Indicators (RSSI)*, as shown in the frame structure depicted in Table 15.

Table 15: Sensing node frame structure message

SN@WIFI@$DATE@$TEMPERATURE@$NUM_WIFI_PKTS@$NUM_WIFI_DEVICE	MAC@RSSI
000000006956C35F@WIFI@20192208-22:41:55@65.53@12076@5	8C:F7:10:07:AE:C2@-71
	B8:27:EB:71:FF:F5@-57
	00:16:9D:F5:0B:80@-85
	CC:4B:73:64:59:66@-41
	44:07:0B:E9:4D:30@-35

The information that is extracted by the sensing nodes is the MAC information of the radio interfaces and the received signal strength indicators, as shown in the Table 15.

The MQTT protocol is used to send the information collected by the nodes. So, they are published in an MQTT broker hosted in a cloud server, which allows to extract the data and use such information to feed a database used by the Sensing Node µS dashboard to generate heat maps with estimates of the coverage area occupancy and to generate statistics and trends.

Figure 96: Sensing Nodes DB MACs detected

Through the microservice dashboard it is possible to manage and visualize the detections of each of the sensing nodes collaborating in the network.

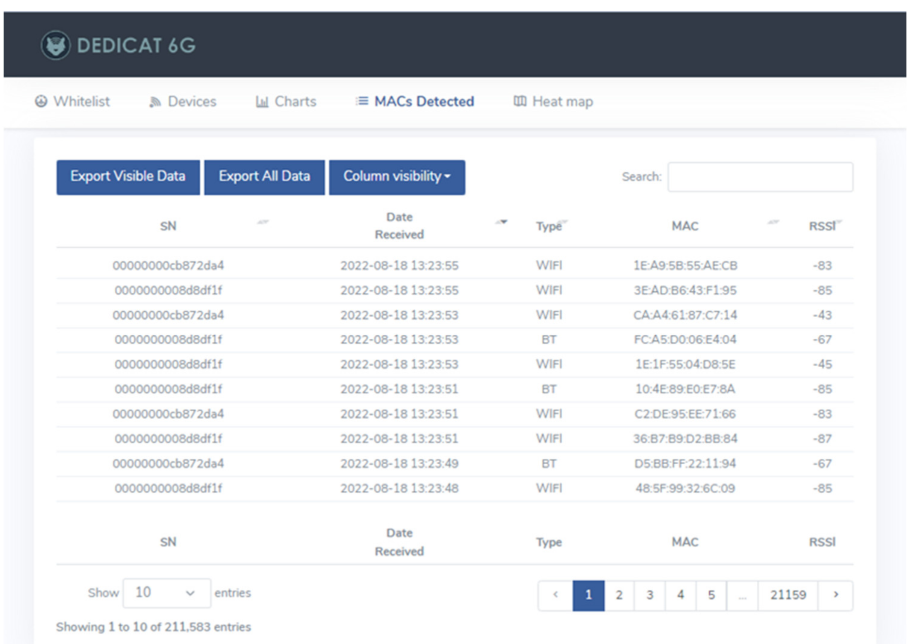


Figure 97: Detail of MAC Detected Dashboard

With the information collected by the IoT sensing nodes, the backend of the microservice generates, on the one hand, detection charts in which the history of device detections that have been performed by each of the nodes.

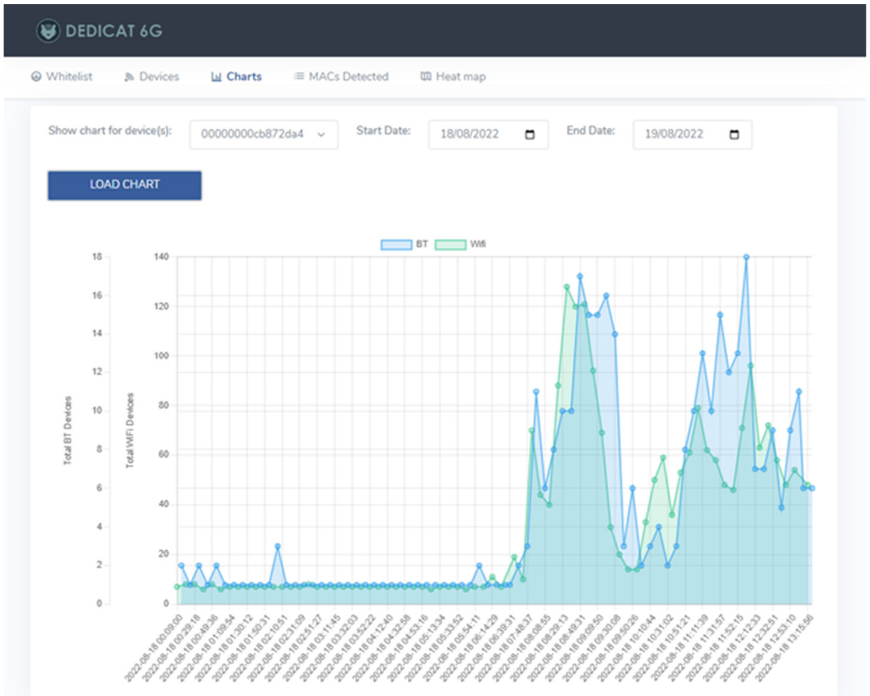


Figure 98: Device detection graphs

On the other hand, this information is processed to build a heatmap around each node to estimate the VRU occupancy and to visualize a dynamic global heatmap of VRUs of the shared zone with the traffic of the entire network. That information generates a context awareness that it could facilitate coverage extension tasks.

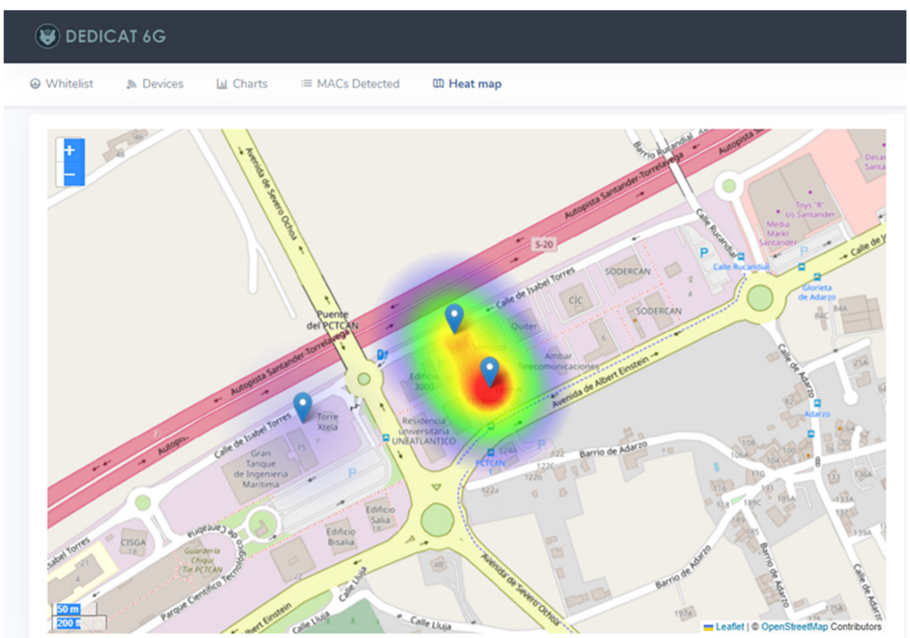


Figure 99: Heat Map Visualization of device occupancy

Also, the information collected by the nodes is processed in the cloud and it could send to collaborate in the construction of a global map of VRUs and cars present in a given area (LDM). Thanks to this, the LDM can be completed so that problems can be discovered with a crowd that may be accumulating in the shared traffic zone and cannot be discovered by other sensors of the DEDICAT 6G system (because it is outside its sensing area) making DEDICAT 6G safer through a more complete context awareness.

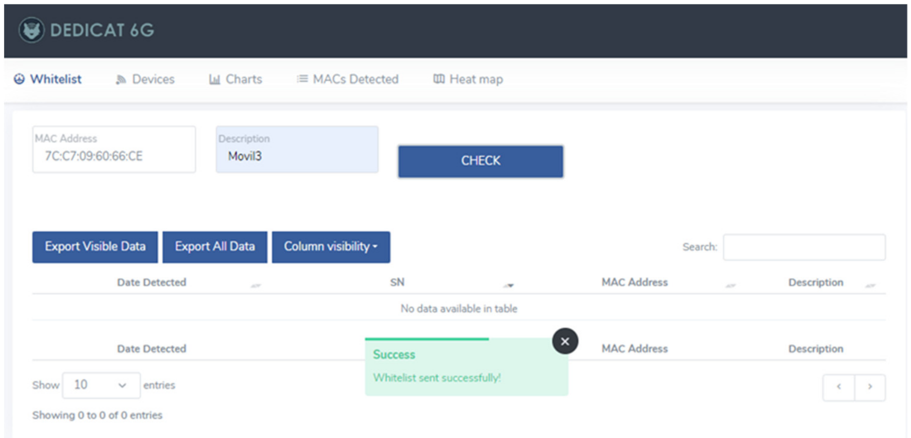


Figure 100: Device whitelist registration

In addition, for the management of connectivity resources, which can be used by VRUs that need to send their location information from time to time, the information available from the VRU devices connected to DEDICAT 6G will be used to allow them to connect to the sensing nodes to send the information in case they need it. The connection to the nodes will be controlled through the dynamic generation of whitelist of allowed VRUs based on their location.

To make use of the network resources, two conditions must be met. The users must be registered through the microservice dashboard and must have been detected by the sensing node in their coverage area. When both conditions are checked, the microservice backend includes the user in the whitelist for a certain period of time.

```
Nov 18 00:00:43 log_dedicat6g [14034]: LINEA 0 : ~@@@00000000cb872da4@WIFI@30:E3:7A:FF:C1:ED@-51@@@~
Nov 18 00:00:43 log_dedicat6g [14034]: DeviceId found in database. UPDATE
Nov 18 00:00:43 log_dedicat6g [14034]: insertamos pc_log_macs
Nov 18 00:00:43 log_dedicat6g [14034]: LINEA 1 : ~@@@00000000cb872da4@WIFI@28:7F:CF:25:29:DE@-85@@@~
Nov 18 00:00:43 log_dedicat6g [14034]: DeviceId found in database. UPDATE
Nov 18 00:00:43 log_dedicat6g [14034]: insertamos pc_log_macs
Nov 18 00:00:43 log_dedicat6g [14034]: LINEA 2 : ~@@@00000000cb872da4@WIFI@90:06:28:CF:41:D3@-85@@@~
Nov 18 00:00:43 log_dedicat6g [14034]: DeviceId found in database. UPDATE
Nov 18 00:00:43 log_dedicat6g [14034]: insertamos pc_log_macs
Nov 18 00:00:43 log_dedicat6g [14034]: LINEA 3 : ~@@@00000000cb872da4@WIFI@B8:03:05:13:37:24@-81@@@~
Nov 18 00:00:43 log_dedicat6g [14034]: DeviceId found in database. UPDATE
Nov 18 00:00:43 log_dedicat6g [14034]: insertamos pc_log_macs
Nov 18 00:00:43 log_dedicat6g [14034]: LINEA 4 : ~@@@00000000cb872da4@WIFI@C2:C9:E3:03:0B:76@-71@@@~
Nov 18 00:00:43 log_dedicat6g [14034]: DeviceId found in database. UPDATE
Nov 18 00:00:43 log_dedicat6g [14034]: insertamos pc_log_macs
Nov 18 00:00:43 log_dedicat6g [14034]: LINEA 5 : ~@@@00000000cb872da4@WIFI@74:DE:2B:B0:BB:0B@-55@@@~
Nov 18 00:00:43 log_dedicat6g [14034]: DeviceId found in database. UPDATE
Nov 18 00:00:43 log_dedicat6g [14034]: insertamos pc_log_macs
Nov 18 00:00:43 log_dedicat6g [14034]: LINEA 6 : ~@@@00000000cb872da4@WIFI@80:A5:89:7E:EE:78@-51@@@~
Nov 18 00:00:43 log_dedicat6g [14034]: DeviceId found in database. UPDATE
Nov 18 00:00:43 log_dedicat6g [14034]: insertamos pc_log_macs
Nov 18 00:00:43 log_dedicat6g [14034]: LINEA 7 : ~@@@00000000cb872da4@WIFI@40:A3:CC:E4:14:20@-43@@@~
Nov 18 00:00:43 log_dedicat6g [14034]: DeviceId found in database. UPDATE
Nov 18 00:00:43 log_dedicat6g [14034]: insertamos pc_log_macs
Nov 18 00:00:43 log_dedicat6g [14034]: LINEA 8 : ~@@@00000000cb872da4@WIFI@B4:69:21:8B:C4:AA@-93@@@~
Nov 18 00:00:43 log_dedicat6g [14034]: DeviceId found in database. UPDATE
Nov 18 00:00:43 log_dedicat6g [14034]: insertamos pc_log_macs
Nov 18 00:00:43 log_dedicat6g [14034]: LINEA 9 : ~@@@00000000cb872da4@END_WIFI@20211711-23:00:43@590728@1@10@@@~
Nov 18 00:00:43 log_dedicat6g [14034]: DeviceId found in database. UPDATE
Nov 18 00:00:43 log_dedicat6g [14034]: insertamos pc_log_init
Nov 18 00:00:46 log_dedicat6g [14034]: ******************************************************************** Connected from :
Nov 18 00:00:46 log_dedicat6g [14034]: RECIBIMOS
Nov 18 00:00:46 log_dedicat6g [14034]: ~@@@00000000cb872da4@INIT_BT@20211711-22:50:37@585834@1@0@@@~
```

Figure 101: User in microservice backend

6.2.2.2 Smart Highway - Story 2 implementation

6.2.2.2.1. DEDICAT 6G architecture components

Figure 102 shows the mapping of the DEDICAT 6G Functional architecture components for PoC on the Smart Highway use case at Germany Site.

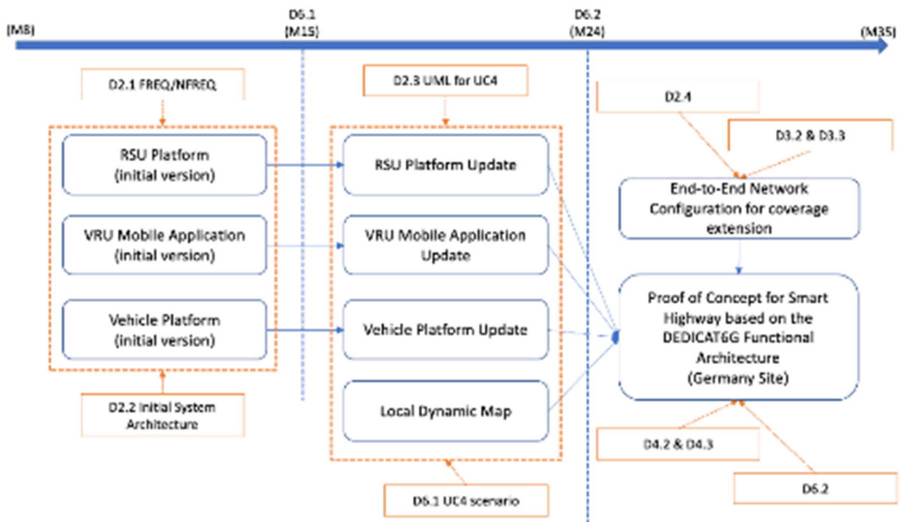


Figure 102: The mapping of the DEDICAT 6G Functional architecture components on Smart Highway at Germany Site

The detailed functional decomposition of the interconnection of this Use Case (Germany site) into DEDICAT6G architecture and platform have been described in D2.3, D2.4 and D6.1. Table 16 provides a mapping of the functionality of the DEDICAT 6G architecture FCs to the current Smart Highway implementation as shown in Figure 92.

Table 16: Mapping of DEDICAT 6G architecture FCs to Smart Highway (Germany site) implementation

DEDICAT 6G architecture FCs	Description	Smart Highway implementation (Germany site)
Dashboard FC	Used to interact with Operation Manager to manage the deployment and management of DEDICAT 6G components.	RSU, OBU
AuthN FC	Responsible for granting the RSU, OBU, VRU apps access to the DEDICAT 6G platform.	Cloud server
CEDM FC	Communicates with NODM FC to collect network status information and to enable and disable MAP of RSU and OBU to perform the coverage extension.	In D6.3
IDDM FC	Receives information about ENs and µS and then provides results to Service Orchestrator FC and Dashboard FC.	In D6.3
µS/FC Repository FC	Stores the uploaded µS related to the Smart Highway such as the V2X Application µS and the Sensing Node µS	RSU, Cloud server, OBU

EC Policy Repository FC	Stores the Edge Computing policies related to the Smart Highway.	Cloud server
μS/FC Registry FC	Provide information on the V2X Application μS and the Sensing Node μS	RSU, Cloud server, OBU
EN Registry FC	Provides information on the Edge Nodes such as RSU, OBU that can be exploited for intelligence distribution.	RSU, Cloud server, OBU
Service Orchestrator FC	Receives recommendations from the IDDM FC and acts over the ENs in order to orchestrate the μS and FCs deployed over the Smart Highway.	In D6.3
EN Status Agent FC	Provides monitored information about the current status of the edge nodes registered to the platform.	RSU, Cloud server, OBU
μS/FC Status Agent FC	Provides monitored information about the current status of the μS being executed in the use case infrastructure.	RSU, Cloud server, OBU
NW Awareness FC	Provides information on the network status in the Smart Highway infrastructure.	In D6.3
NW Status Agent FC	Provides monitored information about the current status of the network in the Smart Highway infrastructure.	In D6.3
NW Optimization FC	Optimizes the network for the coverage extension component based on the current status of RSU and OBU.	In D6.3
Load Balancing FC	Receives monitored information about the edge nodes and the microservices and acts over the Smart Highway infrastructure in order to balance the network and processing load over the multiple hosts available	In D6.3
NODM FC	Receives recommendations from NW Optimization FCs in order to reconfigure the network and meet the desired objectives for V2X communication	In D6.3
μS/FC Awareness FC	Receives information from a group of μS/FC Status Agent FCs and publishes it to the rest of the FCs available on the DEDICAT 6G platform	RSU, Cloud server, OBU
EN Awareness FC	Receives information from a group of EN Status Agent FCs and publishes it to the rest of the FCs available on the DEDICAT 6G platform	RSU, Cloud server, OBU

6.2.2.2.2. UC4 Story 2 - Specific components

The UC-specific components detail in this section were described in the UML diagrams present in D2.3 [2]. Below, we briefly present a table of the UC specific components identified during the UML diagrams specification.

Table 17: UC-specific components in UC4 – Scenario 2

Component	Description
Sensing Node μS	Sensor responsible for scanning the coverage area of the sensing node, discovering connected and non-connected VRUs and sending the estimated crowd data for the LDM application to be processed
V2X Application μS	Fusion of collected sensor values as part of an LDM application that is placed on RSU and OBU networks for low-latency communication.
V2X Communication Module	Responsible for transmitting real-time collected sensor data for LDM applications and also serves as a client for the driver in the vehicle.
GPS	Provides information for V2X Application μS as a sensor that collects the geographic location of smart cars
LiDAR	Provides information on V2X Application μS with a sensor that scans the surroundings of a smart car
VRU App	Client application to collect GPS-based location information of VRU and display notifications
LDM	Application responsible for building LDM (Local Dynamic Map) based on data collected from RSU, OBU, and VRU App and identifying dangerous situations

The main specifications of each device that make up the RSU prototype in Figure 85 are as follows:

- NVIDIA Jetson AGX Orin:
  - GPU: 2048 NVIDIA CUDA cores and 64 Tensor Cores;
  - CPU: 12-core ARM Cortex-A78AE v8.2 64-bit CPU 3MB L2 + 6MB L3;
  - Memory: 32GB 256-Bit LPDDR5 204.8 GB/s;
  - Storage: 64GB eMMC 5.1 + 512GB NVMe M.2 SSD;
  - DL Accelerator: (2x) NVDLA v2.0;
  - Vision Accelerator: PVA v2.0;
  - Video Encoder: 2x 4Kp60 | 4x 4K30 | 8x 1080p60| 16x 1080p30 (H.265);
  - Video Decoder: 1x 8K30 | 2x 4K60 | 6x 4K30 | 12x 1080p60 | 24x 1080p30 (H265).
- Intel NUC:
  - CPU: Intel Core i7-6770HQ 2.6gHz 8 Cores;
  - Memory: 32GB;
  - Graphics: Intel Iris Pro Graphics 580 (SKL GT4);
  - Storage: 1.0 TB.
- BASLER acA2440-35uc:
  - Interface: USB3.0;

- Resolution: 2248(H) x 1088 (V);
- Sensor type: CMOS;
- Pixel size: 3.45 x 3.45;
- Shutter mode: Global shutter;
- Frame rate: 35fps;
- Pixel bit depth: 10 or 12 bits.

- USRP N321:
  - CPU: Dual-core ARM A9 800 MHz;
  - FPGA: Xilinx Zynq-7100 FPGA SoC;
  - DRAM - DDR3 memory size: 2,048 MB (PL) / 1.024 MB (PS);
  - Transmitter;
  - Number of channels: 2;
  - Frequency Range: 3MHz to 6GHz;
  - Maximum instantaneous bandwidth: 200 MHz;
  - Maximum output power (P_{Out}):

Table 18: Maximum output power (Pout) at USRP N321

Frequency	Maximum Output Power
3 MHz – 450 MHz	+10 dBm
450MHz – 1000 MHz	+20 dBm
1GHz – 4.25 GHz	+18 dBm
4.25 GHz – 6 GHz	+15 dBm

  - Gain range: 0 dB to 60 dB (1 MHz to 6 GHz)
  - Gain step: 1dB
  - Noise figure: Tx Phase Noise (dBc/Hz)

Table 19: Noise figure: Tx Phase Noise (dBc/Hz) at USRP N321

Frequency Offset	1.0 GHz	2.0 GHz	3.0 GHz	5.5 GHz
10 kHz	-117dBc/Hz	-110 dBc/Hz	-108 dBc/Hz	-103 dBc/Hz
100 kHz	-117 dBc/Hz	-110 dBc/Hz	-108 dBc/Hz	-104 dBc/Hz
1 MHz	-145 dBc/Hz	-137 dBc/Hz	-135 dBc/Hz	-130 dBc/Hz

  - Supported I/Q sample rates: 200 MHz, 245.76 MHz, 250 MHz00 MHz, 245.76Hz, 250
  - Output third-order intercept (OIP3)

Table 20: Output third-order intercept (OIP3) at USRP N321

Frequency	Output Third-Order Intercept (OIP3)
3 MHz – 450 MHz	> 15 dBm
450MHz – 1000 MHz	> 28 dBm
1GHz – 4.25 GHz	> 25 dBm
4.25 GHz – 6 GHz	> 23 dBm

- Tuning Time: 245 us
- TX/RX Switching Time: 750 ns
- Filter Banks: 450 – 650 MHz / 650 – 1000 MHz / 1000 – 1350 MHz /1350 – 1900 MHz / 1900 – 3000 MHz / 3000 – 2100 MHz / 4100 – 6000 MHz
- External LO Frequency Range: 450 MHz – 6.0 GHz

- Receiver
  - Number of channels: 2
  - Frequency Range: 3MHz to 6GHz
  - Maximum instantaneous bandwidth: 200 MHz
  - Gain range: 0 dB to 60 dB (1 MHz to 6 GHz)
  - Gain step: 1dB
  - Maximum recommended input power (P in) 1 dB: -15 dBm
  - Noise figure

Table 21: Noise figure at receiver

Frequency	TX/RX Port Noise Figure	RX2 Port Noise Figure
< 800 MHz	11.0 dB	10.0 dB
800 MHz – 1.8 GHz	6.5 dB	5.5 dB
1.8 GHz – 2.8 GHz	7.0 dB	6.0 dB
2.8 GHz – 3.8 GHz	7.5 dB	6.5 dB
3.8 GHz – 5.0 GHz	8.5 dB	7.5 dB
5.0 GHz – 6.0 GHz	11.0 dB	10.0 dB

  - Third-order intermodulation distortion (IMD3)

Table 22: Third-order intermodulation distortion (IMD3) at receiver

Frequency	RX Input Third-Order Intercept (IIP3) (dBm)
450 MHz – 1.0 GHz	> 13 dBm
1.0 GHz – 4.5 GHz	> 17 dBm
4.5 GHz – 6.0 GHz	> 16 dBm

  - Supported I/Q sample rates: 200 MHz, 245.76 MHz, 250 MHz
  - Tuning Time: 245 us
  - TX/RX Switching Time: 750 ns
  - Filter Banks: 450 – 650 MHz / 650 – 1000 MHz / 1000 – 1350 MHz /1350 – 1900 MHz / 1900 – 3000 MHz / 3000 – 2100 MHz / 4100 – 6000 MHz
  - External LO Frequency Range: 450 MHz – 6.0 GHz

The main specifications of the sensing node prototype presented Figure 103 are as follows:

- People Counter Board
  - Raspberry Pi 3B+:
  - CPU: Broadcom BCM2837B0, Cortex-A53 (ARMv8) 64-bit SoC
  - SDRAM 1GB PPDDR2
  - Gigabit Ethernet
  - 2.4GHz / 5GHz IEEE 802.11.b/g/n/ac
  - Bluetooth 4.2, BLE
  - Shield Quectel M66 2G IoT modem
- Communication board
  - CPU: Industrial 32 bits CPU
  - SDRAM 128MB
  - FLASH 16MB
  - Interfaces: RS232, RS485
  - Wi-Fi support 802.11b/g/n. support AP
  - LAN: 3x 10/100Mbps Ethernet ports
  - WAN access methods, including static IP, DHCP, PPPOE, 5G (sub-6GHz), ETH 10/100Mbps Ethernet port
  - MIMO DL 4x4/ MIMO UL 2x2
  - Power range: DC 5~35V
- AC-DC power supply – 12V 25W

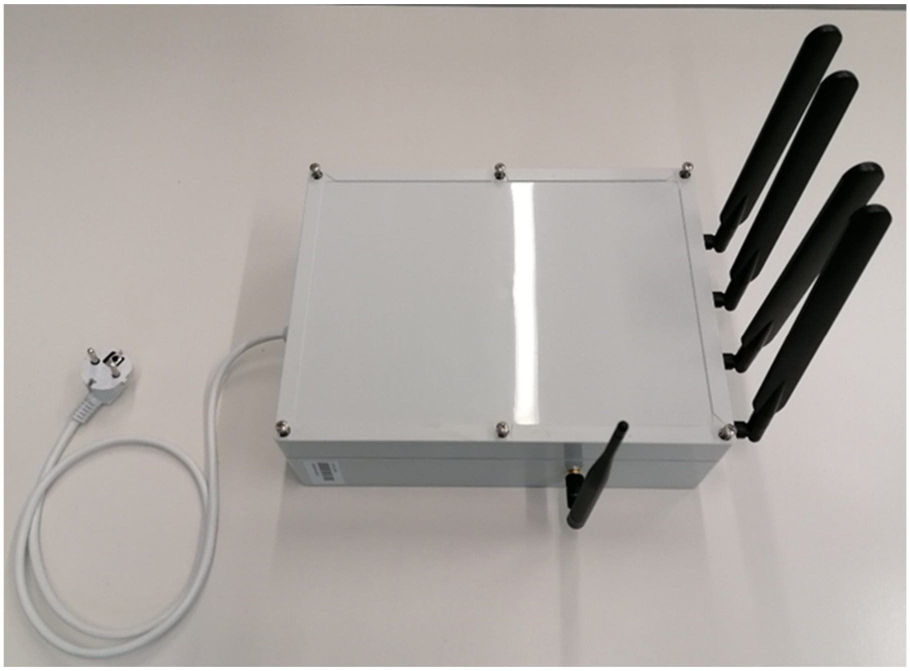


Figure 103: Sensing Node appearance

6.2.2.2.3. Interfaces

This section describes the interfaces between components implemented for UC4 related to Scenario 2.

Table 23: Interfaces for components on the Smart Highway – Scenario 2

Component	Interfaces
Roadside Unit	HW: • Wi-Fi 802.11b/g/n/ac network interface @ 2.4 GHz / 5GHz • SDR (Software Defined Radio) using USRP N321 • Camera sensor interface SW: • Python 3 and C++ based implementation • GUI (QT5) • Local Dynamic Map
Vehicle / Onboard Unit	HW: • Wi-Fi 802.11b/g/n/ac network interface @ 2.4 GHz / 5GHz • SDR (Software Defined Radio) using USRP N321 • Camera sensor interface • LiDAR sensor interface SW: • Python 3 and C++ based implementation • GUI (QT5) • Sensor fusion interface for LiDAR and Camera
Smartphone / mobile devices	HW: • Wi-Fi 802.11b/g/n/ac mobile hotspot @ 2.4 GHz / (5 GHz) • 5G modem support as network interface SW: • Android OS • Java or Kotlin based implementation
Sensing Node devices	HW: • Wi-Fi 802.11b/g/n/ac mobile hotspot @ 2.4 GHz / (5 GHz) • Bluethooth 4.2, BLE • 3G/4G (possible 5G) • ETH 10/100 Mbps SW: • Linux OS • Java / Python based implementation

6.2.3 Integration report

The paragraph below describes the use of WPs outcomes in the UC4 and the contribution per partner done during the period M15 to M24.

6.2.3.1 Description of WPs related outcomes used in UC4

Mechanisms for Dynamic Distribution of Intelligence (WP3):

The distributed intelligence research has been applied to this use case in order to optimally find the best placement for the LDM application components. Furthermore, a custom monitoring system provides periodically metrics for the Distributed Intelligence Decision Making in order to maintain the Quality of Service (QoS) for the vehicular application in means of network latency, jitter and throughput.

Mechanisms for Dynamic Coverage Extension (WP4):

Context awareness strategy for tracking VRUs. Implementing and integrating to work with a local dynamic map running on RSU.

Mechanisms for Security, Privacy and Trust (WP5):

WP5 will provide security and trust and integrate it to the use-cases.

6.2.3.2 Description of contribution per partner participating in UC4

CEA: CEA will contribute to the MAP deployment strategy to provide appropriate QoS connectivity to mobile nodes and demonstrate some features through simulation. Based on a background demonstration platform with bidirectional, dual RAT capabilities, CEA will provide a demonstrator for coverage extension assuming Integrated Access and Backhaul (IAB) with a moving IAB node. This includes Access and backhaul links management, Multi-Rat access (mm-wave and sub-6GHz bands) and multi-beam management.

IMEC: IMEC will contribute to the research network slicing mechanisms for enabling the dynamic connectivity required for the distribution of intelligence. Furthermore, we will provide distribution of intelligence algorithms to optimize the utilization of resource as well as the network service requirements.

IMEC will provide research on coverage extension applied to the smart highway use case by publishing papers on the area of spectrum sensing and mechanisms to trigger the extension of the coverage to users of the network that are not in good network coverage.

TTI: TTI will provide research on context awareness using people counting techniques based on sensing characteristics of short-range radio technologies of the general-purpose devices to assist in coverage extension tasks.

TUC: Implementation of a VRU tracking strategy from WP4, which described in D4.2, and Local Dynamic Map in RSU application.

TUC also contribute to integration of LDM mechanism that can extend coverage for tracking VRUs in conjunction with VRU mobile app.

ATOS: ATOS will contribute to orchestrate the deployment of FCs/µServices (Intelligence distribution) in the Edge Nodes by using the Service Orchestrator-Edge Orchestrator Interface (K8s). ATOS will contribute to orchestrate the establishment of network services/slices (OSM interfacing) to enable 5G-based connectivity when coverage extension is needed. This will be done adapting the orchestration engine developed in the project to provide the functionalities of the NFV-O Controller, defined in D2.4.

VLF: Implementation of private permissioned blockchain and collection of smart contracts for security and trust management framework, described in D5.2

6.2.3.3 Description of external assets used in UC4

The vehicle platform ("CARAI"), from TUC partner, has been used, developed and upgraded in various domestic and international projects over the past few years. The platform is continuously evolving and has developed from three individuals, stand alone and unconnected vehicles to an increasingly integrated platform where all three vehicles as well as the RSU are connected via V2X.

In the context of DEDICAT6G and in particular in UC4, a range of software and hardware components are being specifically developed and implemented. These components were developed from scratch and do extend the pre-existing CARAI platform.

TUC has also set up the "Smart Rail Connectivity Campus (SRCC)", at the core of which is a Cellular Testbed covering a Research railway line over a 25km stretch with a dedicated slice, in the 700MHz Band, on a commercial 5G-SA Network and comprising of two smaller (~6km and ~2km, respectively) campus networks that provide a highly adaptable cellular research infrastructure with two SA cores and OpenRAN capabilities. The aim is to deploy the CARAI platform in the SRCC testbed once the DEDICAT6G extensions have been finalised and tested.

Moreover, IMEC has deployed a smart highway testbed (and a smart car) over the past few years that will be used in an overall fashion for UC4 and the 5G portable testbed used specifically for the coverage extension mechanism.

6.3 Evaluation and first results

6.3.1 List of KPIs, target values and gain

6.3.1.1 KPIs and target values

Table 24 presents the list of KPIs related to the Smart Highway use case, describing the evaluation method and defining the target values:

Table 24: UC4 – Smart highway KPIs list

KPI ID	Description	Target value	Baseline
UC4_KPI1	5G Vehicular-Based MAP Downlink/Uplink Throughput	>= 16 Mbps	In accordance with ETSI Technical Specification 122 186 V16.2.0 (2020) [38] related to Service requirements for enhanced V2X scenarios (Video sharing be- tween UEs supporting V2X application): 10Mbps
UC4_KPI2	5G Vehicular-Based MAP Latency	<= 20 ms	In accordance with ETSI Technical Specification 122 186 V16.2.0 (2020) related to Service requirements for enhanced V2X scenarios (Video sharing between UEs supporting V2X application, Lower degree of automation): 50ms

KPI ID	Description	Target value	Baseline
UC4_KPI3	LDM Response time from identifying dangerous situation until emitting warming message	<= 100 ms	The V2I target network latency will be 100 ms taking as baseline the work done by Petrov et al [39].
UC4_KPI4	LDM network throughput downlink/uplink usage	>= 16 Mbps	The target throughput both in downlink and uplink for the usage of the LDM application is 16 Mbps as experimented in the laboratory with the current LiDAR sensor and application developed.

6.3.1.2 Evaluation and results

Table 25: UC4 – Results obtained and gain

KPI ID	Evaluation method	Result	Gain
UC4_KPI1	Tests will be set up where a known data stream will be sent over UDP (e.g., using iperf) from the MAP to the UEs over 5G link. At the UEs, the throughput of the received data streams will be measured at the application over a small time window (e.g., per second)	In D6.3	
UC4_KPI2	Tests will be set up where data packets will be sent (over UDP or ICMP) from the MAP to the UEs over 5G link. The timestamp will be logged at the sender when the packet is transmitted and at the receiver, when the packet is received. The sender and receiver should be time synchronized within 1ms accuracy	In D6.3	
UC4_KPI3	The logging of the timestamp of the dangerous situation identification on the LDM application will be crossed with the receiving of the notification on the VRU application and in the V2X communication module	In D6.3	
UC4_KPI4	The downlink and uplink throughput will be monitored on the components of the Smart Highway such as OBU, RSU and Cloud in order to validate that the minimum throughput for the use case is being met by the network solutions	In D6.3	

In D6.2, the UC4 partners focused on updating the features implemented in D6.1 and adding some new features, e.g., as the new local dynamic map feature. Implementation of a V2X communication module based on USRP N321 for coverage extension is currently in progress and will be completed in D3.3 and D4.4 completing WP3 and WP4. Then, the implemented V2X communication module will be applied to UC4. The KPI evaluation and results in Table 24 will be provided in D6.3.

6.3.1.2.1. Coverage extension evaluation

Figure 104 shows the demonstration setup diagram for spectrum sensing based IMEC's 5G MAP configuration in this use case. The figure shows an interference generator, a smart car that is equipped with a 5G portable unit, and another car with a 5G UE. The interference generator is used to demonstrate the spectrum sensing based RAT configuration capability. This can be done by using ITS-G5 and/or C-V2X PC5 transmitters.

In the first smart car, a USRP connected to a host machine is used to sense the spectrum. The technology recognition, traffic characterization, and multi-RAT controller described in Section 6.1 are used to sense the spectrum and avoid interference with incumbent V2X transmissions. The RAT controller is used to select a channel based on the interference traffic characterized by the knowledge building process.

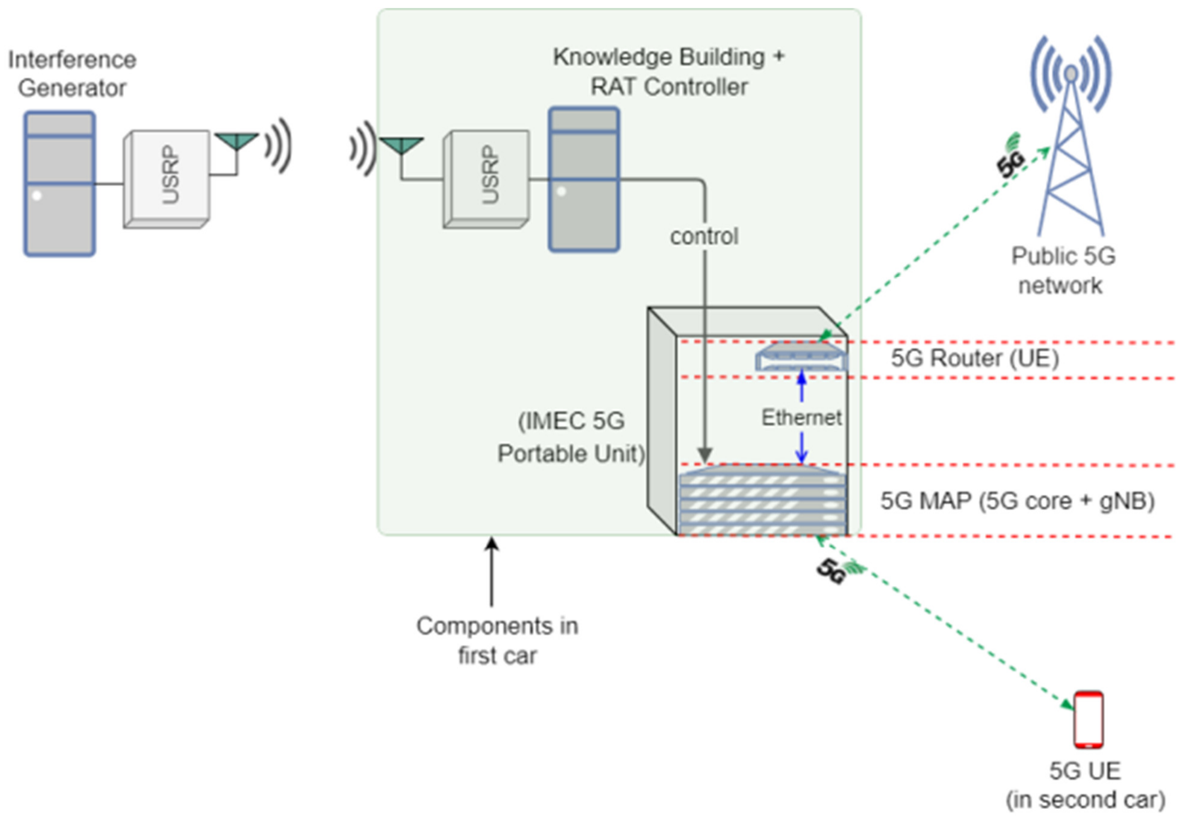


Figure 104: Demonstration setup layout for spectrum sensing based 5G MAP configuration in UC4

The smart car is also equipped with the IMEC portable 5G unit, which is used as a 5G MAP. IMEC has designed and built portable 5G units that allow testing, experimentation, and novel research based on 5G and beyond network technologies. These 5G units consist of both commercial off-the-shelf (COTS) and software defined radio (SDR) equipment, enabling flexibility for extensions and customization beyond the features offered in 3GPP releases and the capability for end-to-end experimentation involving business-critical and/or mission-critical applications with demanding QoS requirements in dynamic wireless environments.

The portable 5G units can be used both as User Equipment (UE) and as an open-RAN (O-RAN) compatible base station (small cell) in combination with the 5G core network, either as a system in a box or running the 5G core on a central data server.

As shown in Figure 105, the 5G units include:

- The Accelleran O-RAN solution, which provides the Accelleran dRAX lab kit consisting of the software for the Central Unit (CU), the Distributed Unit (DU) and the near real-time RAN Intelligent Controller (RIC)
- The Benetel outdoor Radio Unit (RU) that is O-RAN compatible
- COTS 5G router (5G UE)
- A powerful computing unit with GNSS support and accurate timing synchronization
- A power unit that allows the equipment to run over a battery or the power grid
- An SDR USRP 2943R that can be combined with open-source LTE/5G solutions, such as srsRAN and OAI

Figure 105: IMEC portable 5G unit hardware components

6.3.1.3 Distributed Intelligence evaluation

For evaluation, a use-case was crafted of 10 devices and 10 tasks, providing 1010 possible different placements. The networks and additions were built using RLLib [18]. Four objectives were evaluated: Energy, Worst Case Execution Time (WCET), Latency and Bandwidth. For the Deep-OLS ap- proach, Energy and WCET were scalarized as device objective, and Latency and Bandwidth scalarized as network objective. Due to instability and slower convergence, the vector Q-values, proposed by Mossalam et al. [16] were not used. We expanded on the existing approaches of the Deep-OLS and Conditioned networks by building them using a Double Dueling DQN, which improves general stability and convergence. The hyperparam-eters used are found in Table I. The results were compared with a Non-dominated Sorting Genetic Algorithm II (NSGA-II) approach, as proposed in previous research [19]. This algorithm was configured with a population size of 100, running for 1000 iterations. Additionally, a com-parison was made with a standard random search, iterating over 1000 possibilities before finishing.

Table 26: Hyperparameters

γ	0.95
lr	0.00001
ϵ	150 000
batch size	32
buffer size	20 000
weight change interval	10 000 steps

All algorithms were generally able to find solutions that satisfied all constraints. Figure 106 represents the average time required to find a single solution. We pooled the MORL algorithms, as they had similar networks and consequently similar inference time. The Cloud solution refers to placing all possible tasks on the cloud, showcasing the traditional approach. The log scale showcases that the proposed MORL approaches outperform the traditional NSGA-II algorithm by a factor 5. Note, however, that both NSGA-II and Random Search depend on the number of iterations to determine timing, whereas the proposed MORL algorithms have static timing and resource usage in nature. More interesting results are found on Figure 108, which shows the average reward over 50 runs. The x- axis shows the weight for the network objective, where a 0 is the corner weight focusing on device objectives and 1 is the opposite corner weight focusing on network objectives. Note that the cloud solution does not satisfy the latency solution and is invalid, being purely shown as reference.

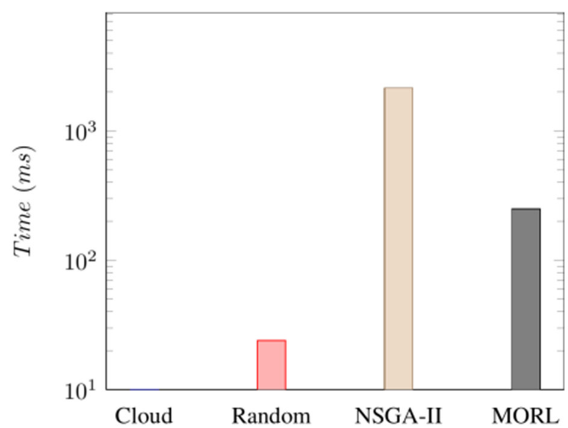


Figure 106: Execution time

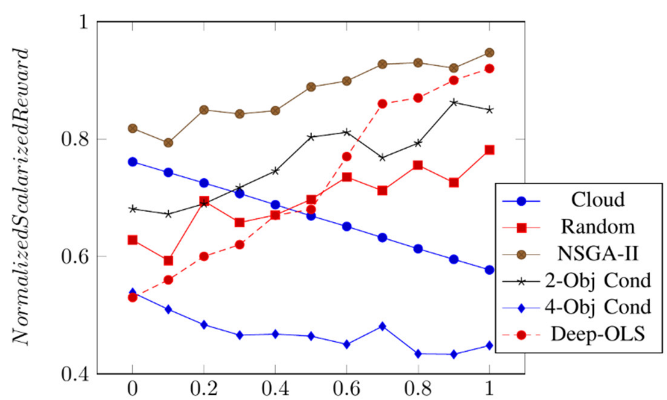


Figure 107: Average Scalarized Reward

It is clear that the NSGA-II algorithm finds the optimal solution. This is at the tradeoff of consuming considerably more time and resources. The bi-objective Conditioned Network approach comes quite close to the NSGA-II algorithm, which showcases that a trained network is a valid approach in resource-constrained service placement. Interestingly, the neural network generally also finds better solutions in 50 timesteps than the random algorithm does in 1000. This is partially accredited to a light skew in the normalization, making network objectives slightly more valuable. In addition, if a corner weight of the Deep-OLS fails to converge, the subsequent search becomes infeasible. We notice that the conditioned network trained on four objectives succeeds at finding useful solutions, but is outperformed by nearly all other approaches. This is likely due to the large jump in complexity between solving for two and four objectives.

The results showcase the brittleness of applying Deep-OLS in practical scenarios. The approach depends on finding the policies for the weight extrema first, but if these values are far apart, the algorithm stops working as expected. In addition, the approach suffers from search space complexity differences. In our scenario, it is considerably easier to optimize for network objectives, by putting all services on the same device, than it is to optimize for device objectives. This mismatch makes it difficult to build an automated Deep-OLS search methodology, as the network objective policy converges considerably faster. We recommend to instead train individual policies with individual hyperparameters per weight and apply OLS on top.

6.3.2 Next steps for the third period

For TUC: the third phase is to integrate components and services from WP2, WP3, and WP4 into UC4, as shown in Figure 102. We will complete the implementation of the V2X communication module based on the USRP N321 and apply it to UC4. It also contains evaluation and measurements of the developed component's performance and KPIs using the implemented V2X communication module. In addition, we will prepare for proof-of-concept demonstration video of UC4 at the German site to be completed before M36.

For IMEC and related with coverage extension, the focus will be on the configuration and coexistence of different RATs based on the technology recognition. Moreover, for the topic of distributed intelligence, using the MORL techniques described, further objectives, such as privacy and security, and constraints, such as software requirements, can easily be added. The impact of these added objectives and constraints should be evaluated, and the scalability of the proposed techniques validated. The trained models could be further improved to reduce resource consumption and inference time, using network pruning. In addition, our proposed technique can be extended to larger and varying computer networks or application chains such the LDM for the Smart Highway. This can be tackled by using the strengths of Graph Neural Networks (GNNs), which allow neural networks to process graphs of any size.

7 Final planning

The following section describes the achievement done at month M24 and the final planning with objectives of setup, showcasing and evaluation to M36 related to the end of the DEDICAT 6G project.

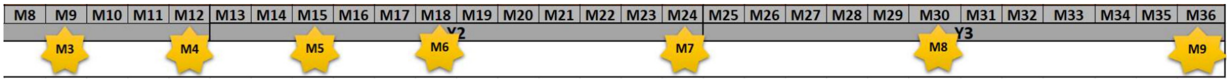


Figure 108: DEDICAT 6G milestones (from M8 to M36)

The achievements at month 24 and the final planning to month 36 for each use case are as follows:

UC1 Planning:

M8 – M15: First specification of components instantiation and integration in the scope of the Smart Warehousing use case. Specification of pilot setup and definition of human centric applications. Specification of validation plan for the Smart Warehousing pilot in terms of KPIs to be assessed and the corresponding evaluation methods (M5, D6.1).

M15 – M18: Enhancement of integration and overall use case implementation, in terms of components implemented and human centric applications.

M18 – M24: Enhancement of integration and overall use case implementation. First validation results (M7, D6.2).

M24 – M30: Continuation of integration and overall use case implementation.

M30 – M36: Finalisation of use case implementation, testing and validation (M9, D6.3).

UC2 Planning:

M8 – M15: Design of the architecture and different components, addressed especially in D2.1, D2.2, and D2.3 also introducing the relation to DEDICAT 6G platform and different involved actors. Early integration of individual components (M5, D6.1).

M15 – M24: Beginning of larger integration and implementation, revised plans if necessary. Evaluating the current performance against the identified KPIs (M7, D6.2).

M24 – M36: Further integration, experiments in trials, and evaluation in a real environment (M9, D6.3).

UC3 Planning:

M13 – M18: First implementation of the Mission Critical services for audio, video, location, registration, implementation of MCX Client application.

M17: Preparation of the pilot site and contingent plan.

M18: Deployment of the components on the cloud, MCX interfaces definition.

M18-M22: First evaluation of UC3 and results estimation.

M25-M32: Further integration, showcasing during pilot and evaluation.

M33-M36: Results analysis and report in D6.3.

UC4 Planning:

M13 – M17: Development of the application, purchasing physical components, preparation of the pilot site.

M18 – M21: Installation and deployment of the components, on-site experiments and testing.

M21: Minimum viable proof of concept.

M24: More refinements (M7, D6.2).

M24 – M30: Continuation of integration and overall use case implementation.

M30 – M36: Finalisation of use case implementation, testing and validation in D6.3.

8 Conclusion

This deliverable reports the activity conducted in WP6 on the integration and pilot's setup of the four use cases: Smart Warehousing (UC1), Enhanced Experience (UC2), Public Safety (UC3) and Smart Highway (UC4) from the start of WP6 in month M8 to the end of the second year of the project, M24.

Firstly, it presented an updated DEDICAT 6G platform integration overview including logical perspective based on inputs from WP2 (D2.4 [1] [2]), and components perspective based on inputs from WP3, WP4 and WP5 (D3.2 [3], D4.2 [4] and D5.2 [5]).

Secondly, four specific sections related to each use case described and updated the scenarios and detailed stories associated to them. Each section related to a use case described the human centric applications/services offered to the end-users, such as the Warehouse Manager dashboard and the Warehouse Worker mobile app as example for the UC1. Furthermore, each use case described, when relevant, assets (either from partner's premises or other EC Innovative project) which are reused. Has a table taking into account the KPIs described in WP2 to WP5 and defined the baseline value which will be compared to after the evaluation in order to comment the gain. The measurement and evaluation took only into account the KPIs measured.

Moreover, there is a validation plan subsection describing the list of metrics/KPIs with their evaluation methods and as well as the target values each UC aims to reach. In order to evaluate the performance improvement with the DEDICAT 6G platform in terms of latency, energy consumption, service reliability, service availability or throughput, baseline values have been identified for each KPI.

Finally, D6.2 presented the final planning for all use cases, showing the final objectives of setup, showcasing and evaluation from M8, when WP6 started, to M36 related to the end of the DEDICAT 6G project. In a last iteration, the WP6 evaluation and results will be reported in D6.3 at M36.

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