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

Deliverable D6.1
Integration, pilot set-up, human centric applications and validation plan

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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
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
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
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
gNB	Next Generation NodeB
GNSS	Global Navigation Satellite System
GPP	General Purpose Processor
GPS	Global Positioning System
GUI	Graphical User Interface
HLS	HTTP Live Streaming
HTTP	Hypertext Transfer Protocol
HW	Hardware
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
M	Milestone
MA	Mobile Asset
MAP	Mobile Access Point
MC	Mission Critical
MC-PTT	Mission Critical – Push to Talk
MCS	Mission Critical Services
MEC	Multi-Access Edge Computing
MIMD	Multiple Instruction Multiple Data
MPEG-DASH	Dynamic Adaptive Streaming over HTTP
MQTT	Message Queuing Telemetry Transport
NFV	Network Functions Virtualization
NO	Network Operation
NODM	Network Operation Decision Making
NW	Network
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
RAT	Radio Access Technology
REST	Representational State Transfer
ROS	Robot Operating System
RSSI	Received Signal Strength Indicator
RSU	Road Side Unit
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 document provides a DEDICAT 6G platform integration overview including logical perspective based on inputs from WP2 and components perspective based on inputs from WP3, WP4 and WP5. The logical overview presents briefly a common DEDICAT 6G architecture which was described in D2.2 [1] and D2.3 [2]. Regarding the components overview, it summarizes the different mechanisms for supporting dynamic distribution of intelligence shown in D3.1 [3], the different mechanisms for dynamic coverage and connectivity presented in D4.1 [4] and the different mechanisms for security, privacy and trust depicted in D5.1 [5].

Four use cases are proposed in DEDICAT 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 360º, *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 initial integration of the mechanisms developed in WP3, WP4 and WP5 into an overall working system presenting the different scenarios and detailed stories. Each use case presents different stories where the main actors are described, and the new technologies are presented in order to fulfil the DEDICAT 6G requirements. Furthermore, the human centric applications/services offered to the end users are described.

For each scenario, the pilot setup is presented describing the different hardware & software elements which will be integrated in the use case setup plan. Regarding the use case architecture, the DEDICAT 6G components are identified and the specific use case components are also described, including the key interfaces for each use case.

Concerning the validation activities, for each use case the list of metrics/KPIs are presented including the target values and the evaluation method.

Finally, a common preliminary planning for all use cases is presented with the first objectives of setup, showcasing and evaluation, which will be updated in D6.2.

1 Introduction

WP6 has the strategic objective of implementation of the project pilots and validation. It leverages from the WP2, WP3, WP4 and WP5 contributions and puts into practice the respective technology in different use cases. DEDICAT 6G focuses on four use cases:

1. **Smart warehousing** encompasses real-time automated tracking, monitoring and optimized operation of a warehouse using *Automated Guided Vehicles (AGV)* in a trusted way to improve operations such as picking sequence and product quality assessment. It places particular emphasis on real-time human-machine interaction, intelligence offloading and security;
2. **Enhanced experience** brings live streaming applications that use enhanced data overlay in 360° and augmented reality applications, as well as more complex data sets in virtual reality, with the necessary hard requirements in terms of bandwidth and compute capabilities for massive video processing and distribution. This use case is centered on distributed intelligence, compute offloading and caching, and dynamic coverage extension;
3. **Public safety** (*Public Protection and Disaster Relief (PPDR)*) shows how the resilience of critical communications can be strengthened through DEDICAT 6G solutions and how human safety can be protected in extreme situations, such as natural or man-made disasters, through the use of various assets (*Unmanned Aerial Vehicles (UAV)*, *AGVs,* etc.). This use case focuses on intelligence distribution, dynamic coverage extension, security assurance and human presence in the loop;
4. **Smart highway** demonstrates the benefits that connected and autonomous mobility can obtain from connectivity *Beyond 5G (B5G)* and 6G, especially in the area of efficiently delivering the lowest possible delay and ultra-reliability. It is related to distributed intelligence, computation and cache offload, dynamic coverage extension, security and human-in-the-loop.

The key objectives of the WP6 are:

- Plan and implement the use cases pilots' setup and simulations, showcasing the project solutions in the areas of smart warehousing, enhanced experience, public safety and smart highway. This includes the integration of the outcomes of WP3, WP4 and WP5 and the development, integration and deployment of use case specific software components (e.g., front-end for security staff in public safety use case);
- Develop human-centric applications in the scope of the project use cases and showcase novel interaction between humans and digital systems. Innovative interfaces and devices such as smart glasses, connected cars, robots and drones will be integrated with the mechanisms developed in WP3, WP4 and WP5 to develop human-centric applications in the *Proof of Concept (PoC)* pilots for the four use cases;
- Perform technical validation as well as non-technical validation;
- Establish best practices and guidelines from the experiments and provide corresponding feedback to the B5G/6G community, through activities in WP7.

1.1 Scope

Task 6.1 focuses on the integration of the mechanisms developed in WP3, WP4 and WP5 based on the architecture defined in WP2. The task also addresses the planning and operational requirements of the experiments. A common approach is prepared for the different use cases to maintain standards and the potential to establish best practice irrespective of the application domain. This task also elaborates, based on input from WP2, on the scenarios that apply for experimentation and validation taking into account the target *Key Performance Indicators (KPI)* both in terms of technical performance (e.g., response time, scalability, etc.) but also in terms of stakeholder acceptance and non-technical validation with respect to each use case. This task also includes development, integration and deployment of use case specific software components and implementation of relevant simulations. Finally, a key outcome of this task is the development of human-centric applications by integrating innovative interfaces and devices such as smart glasses, connected cars and robots in the PoC pilots for the four project use cases.

This document outlines the integration of the mechanisms developed into an overall working system, the pilot set-up (including deployment of hardware and development and integration of use case specific components and simulations implemented), the development of human-centric applications in the scope of the pilots. Furthermore, it specifies the corresponding 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.

1.2 Structure

Section 2 provides a DEDICAT 6G platform integration overview including logical perspective based on inputs from WP2 and components perspective based on inputs from WP3, WP4 and WP5. The logical overview presents briefly a common DEDICAT 6G architecture which was described in D2.2 [1] and D2.3 [2]. Regarding the components overview, it summarizes the different mechanisms for supporting dynamic distribution of intelligence shown in D3.1 [3], the different mechanisms for dynamic coverage and connectivity presented in D4.1 [4] and the different mechanisms for security, privacy and trust depicted in D5.1 [5].

Section 3, Section 4, Section 5 and Section 6 present an overall description, respectively UC1 – Smart warehousing, UC2 – Enhanced experience, UC3 – Public safety and UC4 – Smart highway, of scenario 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. For each scenario setup, the demonstration details are presented identifying the DEDICAT 6G architecture components and the use case specific components. Regarding the validation plan, the lists of metrics/KPIs are presented including the target values and the evaluation method.

Section 7 describes a common preliminary planning for all use cases with the first objectives of setup, showcasing and evaluation.

Finally, Section 8 concludes the deliverable.

2 Platform integration overview

2.1 Logical overview

In D2.2 [1], a first functional model and functional decomposition have been elucidated and proposed. While the former one 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 so-called *Functional Components (FC)* that populated those layers (a.k.a. *Functional Groups (FG)*). This functional decomposition offers a logical view of which functionalities are needed in the DEDICAT 6G in order to fulfil our various project technical objectives.

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. 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 the D2.2 [1] (and forthcoming D2.4) *System Use Cases (SUC)*. The interface they implement must also be compliant with the logical interface described in the architecture document (which remains language independent).

The purpose 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 to the well-known Sense-Awareness-Analyze & Decide-Act loop where:

- **"Sensing":** is undertaken mostly by agents scattered at the Edge 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, Edge Node, *Micro-services (µS)*/FC-related contexts which are in turn used by the various DM components depending on their

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

roles and inner goals. Designing 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;

- **"Analyzing & 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 (intents) actions 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.

Figure 1 focuses on the DM components, elucidating most of the interactions existing between the "Analyzing & 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.

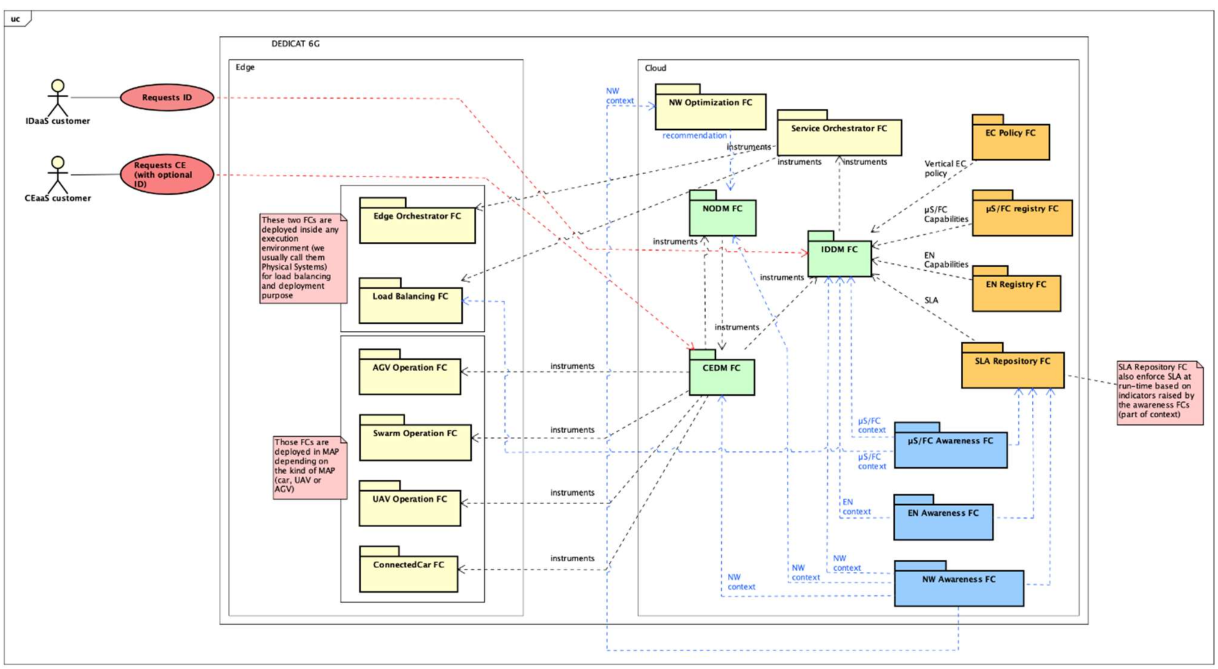

Figure 1: Decision Making and its interactions

In Figure 1 above, we can see that the three DMs 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)* only matters 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 would rely on the CEDM FC to cover that aspect. Finally, if a CEaaS request involves network slicing aspects, the NODM ought to be the component dealing with it, by interacting with the Legacy 5G system.

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 User Equipment-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 contexts 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 relies on various kinds of MAPs such as AGVs (Robots), UAVs (drones) and Connected Cars; it 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);
  - CE related: a collection of FCs is used to implement the CEDM FC decisions:
    - 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 platform. This component is also responsible for enforcing the SLA, 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 Nodes and its execution environments;
- NW Status Agent FC: they are -likewise- responsible for collecting information about networking, focusing on performance and operation.

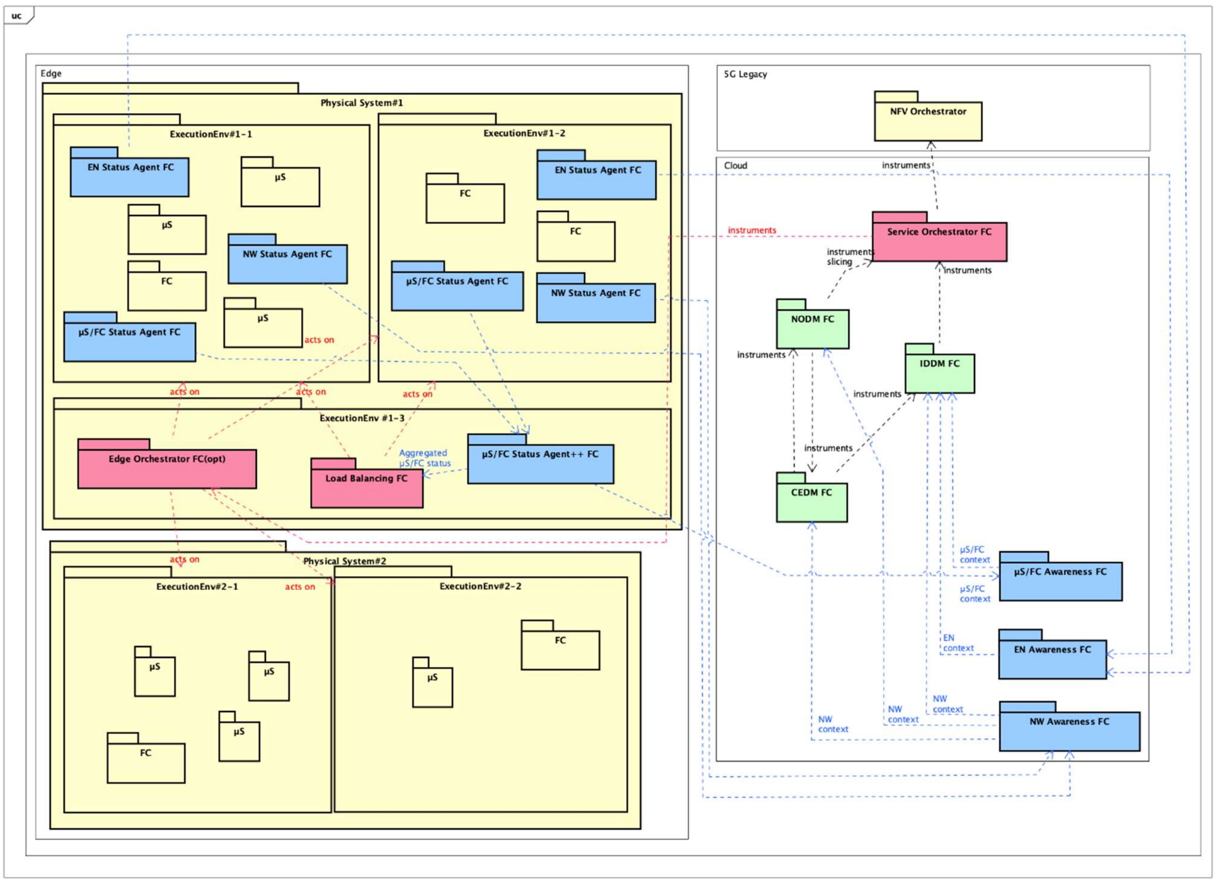

Figure 2: Hierarchies of agents as used for Edge Computing purpose

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 ++. That one in turn provides a bigger view (still at the information level) to the LoadBalancing 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 LoadBalancing 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. The Orchestrator residing in the cloud -say the master orchestrator- is instrumenting Edge Orchestrators (only one in that figure) and also the *Network Functions Virtualization (NFV)* Orchestrator residing at the 5G legacy system (for various purposes including network slicing).

As a final remark, it has probably been noticed that we have not explicitly shown Security Privacy and Trust components. 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.

2.2 Mechanisms overview

This section summarizes the different mechanisms for supporting dynamic distribution of intelligence shown in D3.1 [3], the different mechanisms for dynamic coverage and connectivity presented in D4.1 [4] and the different mechanisms for security, privacy and trust depicted in D5.1 [5]. 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 fulfill 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 migrate 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 it will be. A metric related to this is called usability or *programmability*. Finally, the *means/algorithms for placing the intelligence* efficiently contribute a big deal to how efficient distribution is.

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

Context switching - Traditional 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 [6] and *Thick Control Flow (TCF)* execution [7].

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 [8], broadcasting/multicasting, flexible mapping.

Load balancing - Load imbalance is one of the most important reasons for poor utilization of the computational hardware. In a networked computing system, such 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 an *S* server region would be *S* 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 [9][10].

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 [11] 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)* [11] and TCF execution [7].

Synchronization - Synchronization is the key mechanism to ensure the correct behavior 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 [12][13].

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 [13][14].

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. Additional 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 bandwidth. The main software techniques to reduce the performance penalties are matching the software parallelism with the hardware one and the blocking technique [14].

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 be reporting these techniques in more details in Deliverable D3.2.

2.2.2 Mechanisms for dynamic coverage and connectivity

WP4 addresses the design and development of mechanisms for the dynamic coverage and connectivity extension through the exploitation of innovative devices (e.g., drones, robots, connected cars, other mobile assets like forklifts in a warehouse, etc.). The overall aim is to enable the dynamic, opportunistic setup of dynamic coverage and connectivity extensions for covering areas that cannot be easily reached, where infrastructure is required only for a finite, short amount of time, or where regular network infrastructure has been damaged e.g., due to terrorist actions or natural disasters.

DEDICAT 6G investigates complex optimization problems aiming to decide the optimal number of MAP entities to deploy, the optimal positions of MAPs in continuous space, the configuration of the radio network of the MAP, the dynamic association of multiple users to multiple access points and the finding of the nearest docking station for charging to provide the required coverage and connectivity extension and to ensure the QoS expected by the mobile nodes. Several strategies for dynamic coverage and connectivity extension and their preliminary implementation are presented in D4.1[4]:

- The first strategy is to provide context awareness in support of coverage extension by using sensing node devices to detect a possible overload of communication networks. This system will provide knowledge about the environment (i.e., devices discovery) and create heat maps with real-time information about the occupation of a given space, which can be used to prevent congestion problems in communications networks;
- The second strategy concerns the UAVs deployment for coverage extension i.e., to find the optimal number and positions of MAPs, the radio configuration of the MAP and the dynamic association of multiple users to multiple MAPs. The objective is to maximize the throughput and ratio of well-served users while minimizing the number of drones deployed and the execution time;
- The third strategy is to manage MAPs, i.e., to monitor the location of all MAPs and calculate the total communication costs as well as the finding of the nearest docking station for charging;

- The fourth strategy is to associate users to MAPs, i.e., 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;
- The fifth strategy is to offer *multi–Radio Access Technologies (RAT)* capabilities. The efficient RAT selection and configuration schemes estimate the characteristics of the wireless environment and optimize the selection and management of the available wireless resources in order to provide harmless coexistence and increase the overall performance of the MAP.

These strategies can be defined and 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).

2.2.3 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 will discuss 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 trying 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 a 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, framework is using 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 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 (DMP)* 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 a smart contract 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 of 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.

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 [15]. 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 very 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.

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 perspective of 1) a warehouse manager and 2) a typical warehouse worker is described in the two stories.

Story 1: This story puts focus on a warehouse administrator or 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 are performing 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 foremostly. 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 3), 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;
- environmental parameters for storing different goods;
- daily 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;
- 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.

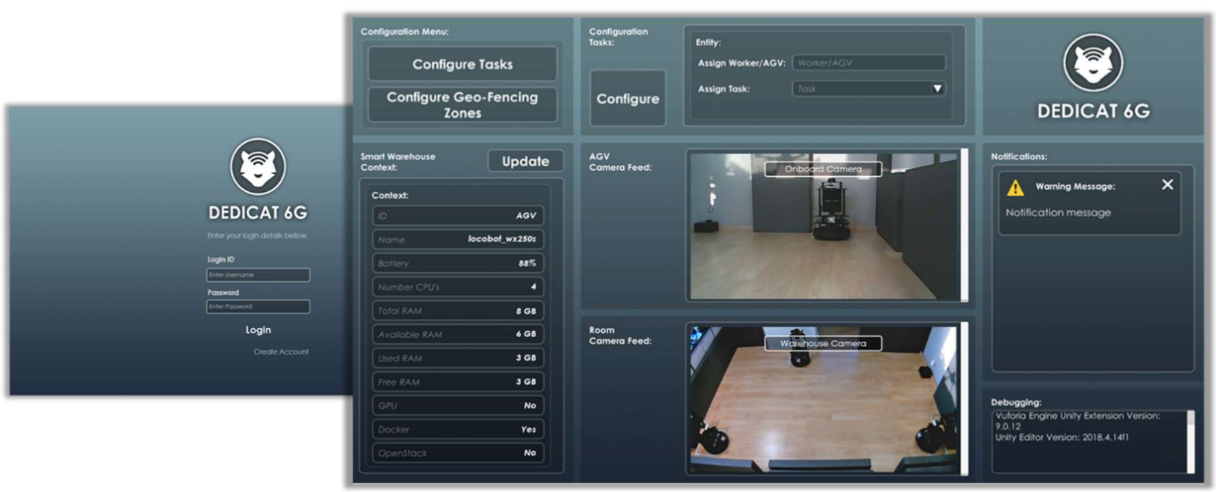

Figure 3: View of warehouse manager dashboard

Through the **warehouse worker mobile app** (Figure 4), the worker receives a list of daily tasks as specified by the warehouse manager. A worker can also inspect status reports of AGVs, for example on the result of quality processing. A worker can also direct AGVs towards a product or an area of interest if he/she is authorized to do so. Finally, in the scope of training other workers, one worker can provide another with instructions on how to utilize the AR interface of the mobile App to navigate the warehouse, how to use robots, etc.

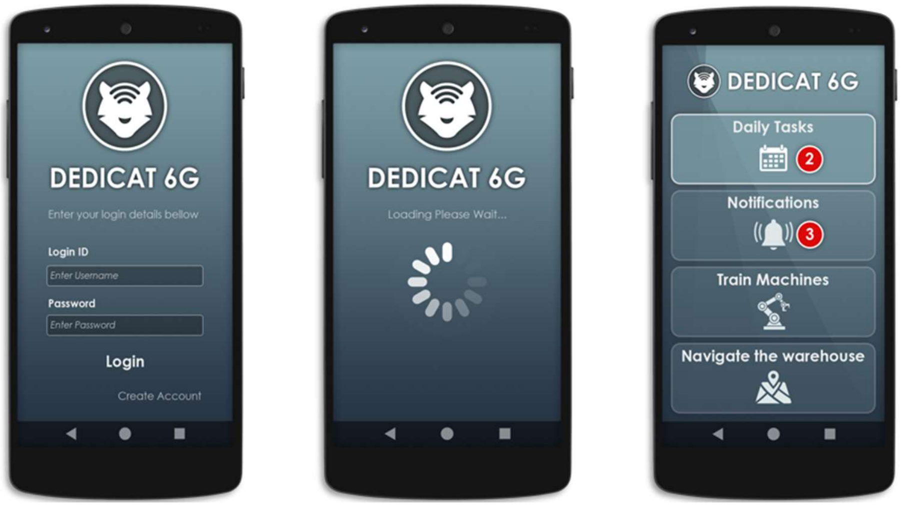

Figure 4: Warehouse worker mobile application

The workers training Augmented Reality application will combine real world objects with digital information. For example, a specific model of a robot has on its 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 have access to the robot's statistics in real time, download the user's manual, interact with the 3D model or even watch video and animations explaining how the robotic arm works.

Figure 5: Warehouse worker Augmented Reality application for training

In the context of UC1 (Smart Warehousing) and aligned with both Story 1 and Story 2, outlined in the previous, the rest of this section presents an indicative scenario focusing on automated quality control. The quality check task is configured and monitored from the dedicated dashboard that is utilized by the warehouse manager (Figure 3), while the warehouse worker can interact with the warehouse manager, the AGVS and the other warehouse facilities through his/her mobile app. The scenario starts with an AGV (Robot) being configured to an initial position. The task of the AGV is to perform quality checks on the products of the production line of the warehouse. If the product is damaged the outcome of the quality check will be negative. That means that the product should be moved to the repair area of the warehouse in order to be picked up from the workers. If the product is in a satisfactory condition, the outcome of the quality check will be positive. Thus, the product will be delivered to the shipping area. In order to simulate a warehouse product and its good or bad condition a blue box represents a good product and a red box a bad product respectively.

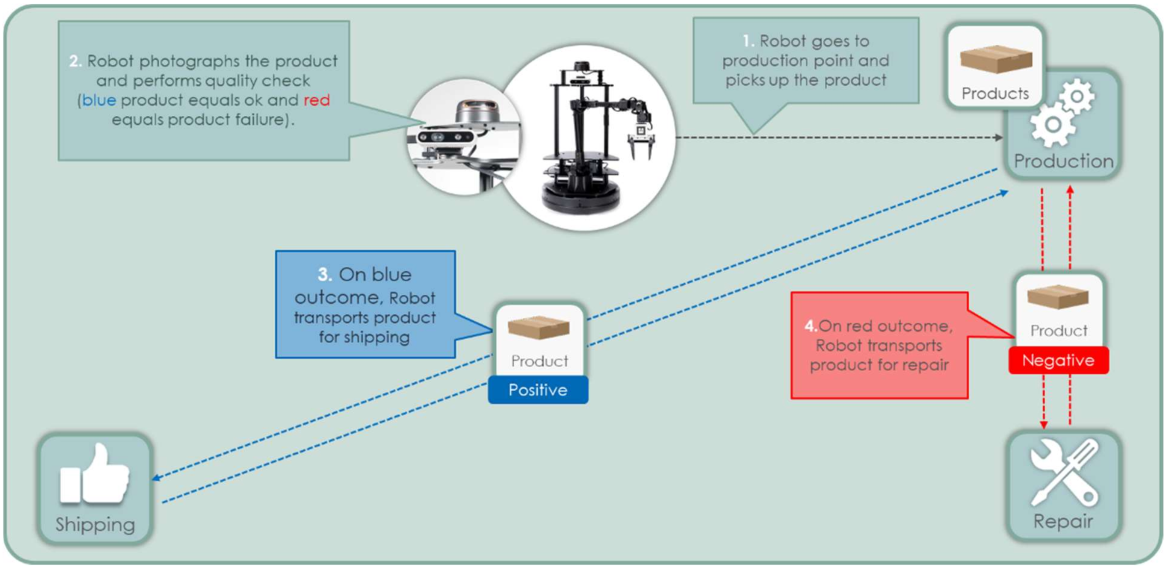

Figure 6: Indicative quality check scenario in the scope of Smart Warehousing

3.2 Scenario Setup

3.2.1 Pilot setup

Figure 7 depicts the full setup considered at this time for realization of the Smart Warehousing use case. This setup considers the following:

- AGVs are deployed and configured to perform smart warehousing tasks;
- IoT system deployed and configured to perform smart warehousing tasks;
- BLE (Bluetooth Low Energy) beacons are provided for *Mobile Assets (MA*);
- IoT system for access control is connected to electric locks;
- Environmental sensors are connected to the IoT system;
- Personnel are authorized and registered;
- Smart warehousing layout/plan is digitalized;
- DEDICAT 6G mobile app is installed on personnel mobile devices;
- DEDICAT 6G web dashboard is provided to the warehouse manager;
- DEDICAT 6G solutions for distributed computing, opportunistic networking and trust and security management are deployed and configured.

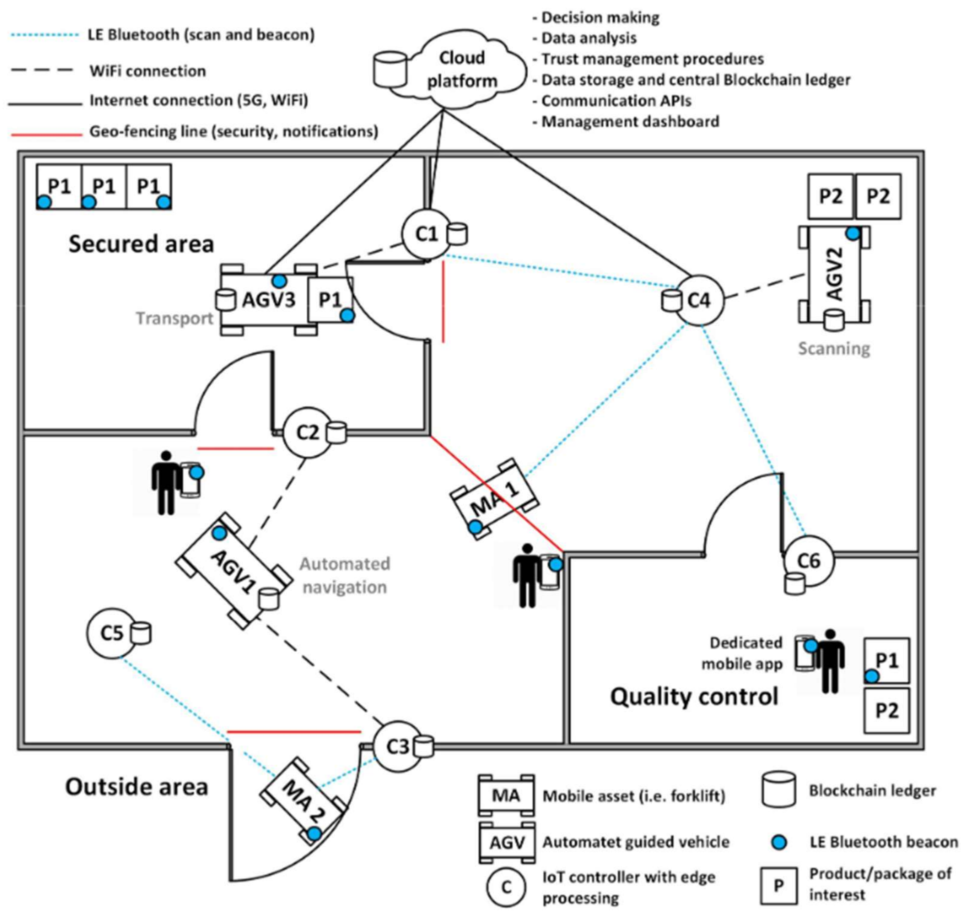

Figure 7: Smart warehousing use case setup plan

AGVs

<u>*LoCoBot WX250 6 DOF:*</u> The LoCoBot 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 open-source Python API.

Figure 8: 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.

The WidowX 250 is a 6-degree 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 9: AGV hardware components

3.2.2 Architecture instantiation

3.2.2.1 DEDICAT 6G architecture components

The detailed functional decomposition of the DEDICAT 6G architecture instantiation in this use case is described in D2.3 [2]. Section 2 highlights the essential architectural components as well. This sub-section provides an overview of the key architecture components that will be implemented in the scope of this use case pilot.

Table 1: DEDICAT 6G architecture components in UC1

Component	Description
AuthN FC	Responsible for the granting access of the DEDICAT 6G platform, relying on AuthZ for the “access rights” aspect
EN Registry FC	Provides information on the Edge Nodes (including AGVs) that can be exploited for intelligence distribution
µS/FC Registry FC	Stores the meta-data related to the microservices uploaded in the µS/FC Repository FC
µS/FC Repository FC	Stores the uploaded microservices images related to the Smart Warehousing such as the Product Quality Check
EC Policy Repository FC	Stores the Edge Computing policies related to Smart Warehousing
EN Status Agent FC	Provides monitored information about the current status of the edge nodes registered to the platform

Component	Description
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
NW Status Agent FC	Monitors the network of the Smart Warehousing infrastructure
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
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
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).
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
NW Awareness FC	Provides information on the status of the network of the Smart Warehousing infrastructure
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).

3.2.2.2 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 10 presents a very high level, abstract, view of the smart warehousing implementation thus far. The DEDICAT 6G platform is presented in this figure, for the sake of simplicity, as a "box" without going into the details of the involved FCs. The arrows indicate the direction of the information among the particular UC entities/components, while the numbers on the arrows indicate the sequence of actions or events. In the current implementation, a Flask HTTP Web server is exploited for communication between the specific UC components. A Streaming service and a QualityCheck service are deployed on the AGV packaged as Docker containers. The Streaming service allows to stream video from the AGV camera to the Warehouse Manager dashboard, while the QualityCheck service comprises all the functionality required to perform the quality check of a product by a robot and accordingly transfer it to the shipping area or the repair area. The AGV runs bare metal a Robotic Agent code which is essentially a Python script that utilizes the Robot Operating System of the AGV. The Robotic Agent sends the desired information (robot status, etc.) to the DEDICAT 6G Platform. Similarly, the mobile application of the warehouse worker also sends relevant information. Both the AGV and the warehouse worker information can then be retrieved by the Warehouse Manager Dashboard, while, as also described in the previous, via the Warehouse Manager Dashboard tasks of worker or AGVs can be configured. In the depicted example the Streaming service and QualityCheck service are activated. It should be noted that the video streaming itself is realized over UDP.

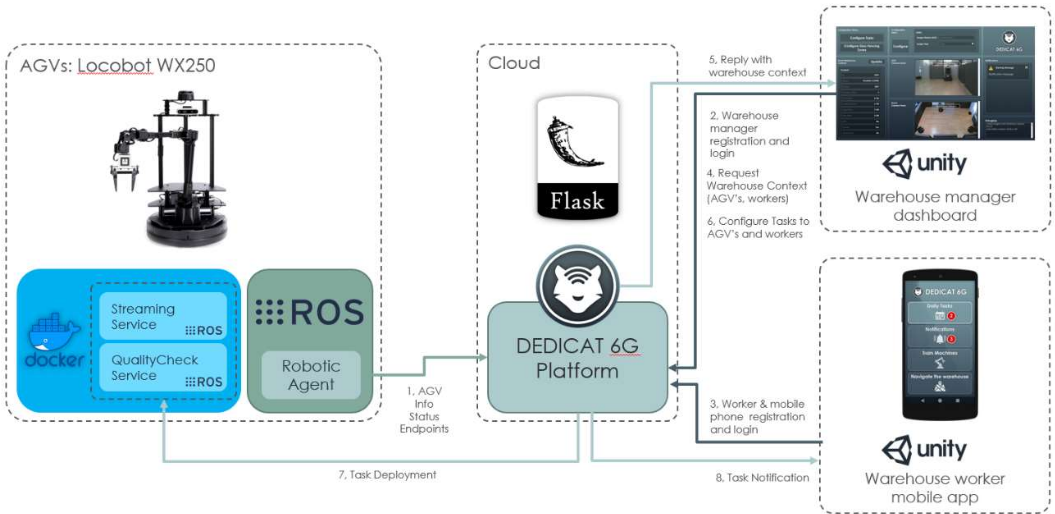

Figure 10: View of the smart warehousing implementation

3.2.2.3 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 will be implemented in the scope of this use case pilot are listed:

- 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.

3.3 Validation plan

3.3.1 List of KPIs and target values

Table 2 presents the list of KPIs related to the Smart Warehousing use case, describing the evaluation methods and defining the target values:

Table 2: UC1 – Smart warehousing KPIs list

KPI ID	Description	Evaluation method	Target value
UC1_ KPI1	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 to improve quality of experience.	Measurements will be collected at the application layer by adding timestamps to requests between functional entities/service components of an overall service. Then the 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). Jitter measurements will also be collected e.g., with the use of iPerf.	End-to-end: 200ms *Uplink (UL)/ Downlink (DL)* network delay: 10ms
UC1_ KPI2	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.	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.	<10 Mbit/J
UC1_ KPI3	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 quality assurance:	Time will be measured for completing product quality check and order picking with and without DEDICAT 6G solutions and in particular AGVs.	15% reduction
UC1_ KPI4	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 level of automation is de-	Estimation of workers entering areas they are not meant to before DEDICAT 6G and comparison with workers being automatically kept out of sensitive warehouse areas with the use of smart gates and geo-fencing as part of DEDICAT 6G Smart Warehousing implementations. Estimation	>=10%

KPI ID	Description	Evaluation method	Target value
	ployed.	of collisions between workers or workers and light machinery, before DEDICAT 6G and comparison with avoided collisions due to DEDICAT 6G solution.	

The preliminary validation plan in terms of schedule is presented in Section 7.

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 [16] as well as accessing the similar services. As a consequence, a large audience is vying for the same network resources within a small area [17], 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 [18], [19]. 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 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 perform 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 because online users can obtain higher quality to be streamed to end users via novel proactive adaptation against fluctuating network conditions. Mobile multicast can provide not only network savings and even resources such as energy savings, but also improved quality of experience for the end users. Dynamic coverage extension according to the crowd movement will also ensure improved quality, especially on the UL side. Naturally, improved service quality can increase the financial value of the service(s). Virtual participation, especially during COVID-19 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 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.

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 of the artist you are also interested in. 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. A so-called Connected Car has been deployed at the beginning of the concert in order to increase radio capacity as the event is expected to be the first massive Facebook Live event over 6G.

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. 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. The dedicated remote users will have the ability to access these services in a secure way. 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 can increase the *End-to-End (E2E)* latency compared to more traditional solutions. Finally, the Smart Glasses that will also be utilized are depicted next.

Optinvent will provide Smart Glasses in the event site illustrated in Figure 11, which will produce content for the end users. Optinvent will provide several ORA-2 smart glasses for each of the events. These devices are running on Android device platform and should be connected each to a local smartphone through 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 *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 hotspot). This point should be assessed in the incoming month to select the best way to stream video from the glasses with minimal latency. 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 (APP)* 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 11.

Figure 11: The components for the Smart Glasses to be used in the Enhanced Experience

VTT will provide the 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 13) 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 12 represents the sample tests using *Long Term Evolution (LTE)* (5G) multicast streaming to three end user devices with pre-encoded content.

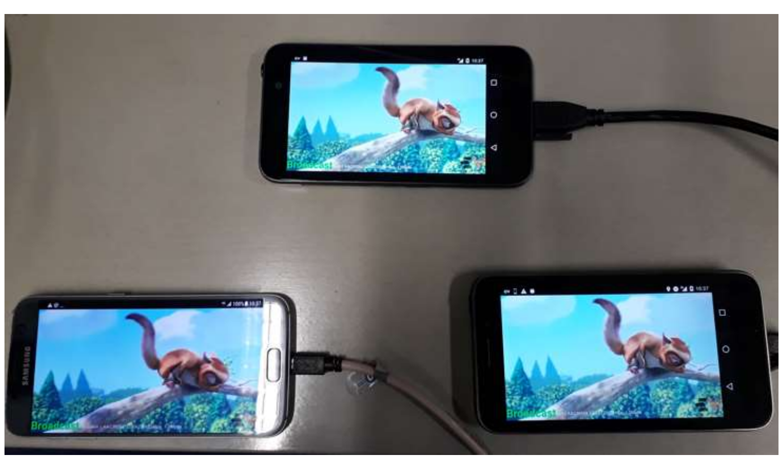

Figure 12: A sample set of end user devices supporting mobile multicast.

Figure 13: A sample photo of Facebook Live session (Photo by Nicolas LB on Unsplash)

4.2 Scenario Setup

4.2.1 Pilot setup

The site setup 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 computation processing. In addition, Mobile Access Points, namely as Connected Car as introduced in [2], are included to provide dynamic coverage of which the first prototype is depicted in Figure 15. During the evolution of the project this mobile prototype will be taken smaller to enable easier portability and mobility in different setups. Figure 14 illustrates the overall setup of the Enhanced Experience.

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.

In overall according to Figure 14, the setup 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.

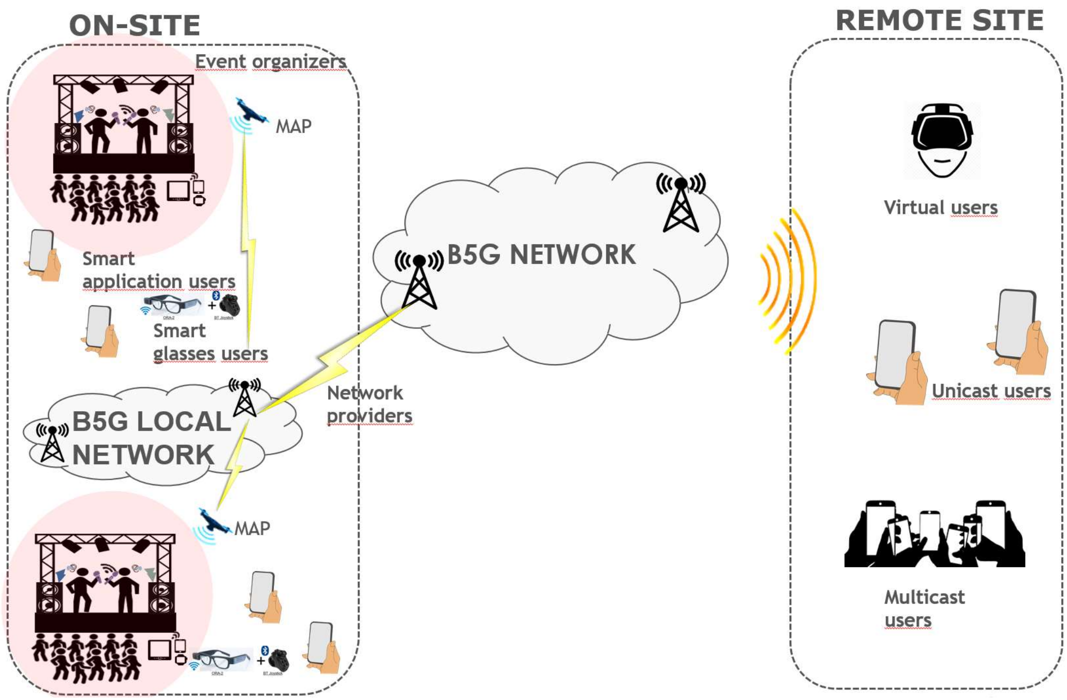

Figure 14: The set-up plan for the Enhanced Experience (UC2)

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.

In this scenario, to provide a flexible coverage, MAPs will be deployed dynamically. That is, after they are located at certain positions, the location of their placement can be adjusted depending on crowded users' movement. While the terrestrial base station can also provide coverage, users capable of multi-connectivity could have multiple choices in RAT selections. Considering uneven traffic load distributions, the efficient user association and resource allocation mechanisms is required to provide the expected network performance. User association and resource allocation mechanisms would be demonstrated via SW program.

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 MEC 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 15: First prototype of 5G MAP

4.2.2 Architecture instantiation

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 [2]. Section 2 highlights the essential architectural components as well. The functional components in question for UC2 include in brief:

Table 3: DEDICAT 6G architecture components in UC2

Component	Description
Dashboard FC	Used for interaction with the *Event Organizer* in order to manage the deployment and management of the DEDICAT 6G components in the Enhanced Experience architecture
AuthN FC	Responsible for the granting access of the DEDICAT 6G platform (relying on AuthZ for the "access rights" aspects).
CEDM FC	Communicates with the IDDM FC to check µS deployment feasibility (Connected car) with possibility to provide counter proposals, and instructs physical deployment of MAP
IDDM FC	Receives information about the ENs and the microservices and, as output, provides task/Physical System allocation to the Service Orchestrator FC which is responsible for the actual deployment of the tasks (µS or FC).

Component	Description
µS/FC Repository FC	Stores the uploaded microservices such as video streaming platform
µS/FC Registry FC	Stores the meta-data related to the microservices and FCs uploaded in the µS Repository FC
EN Policy Repository FC	Stores the Edge Computing (MEC) policies
EN Status Agent FC	Provides monitored information about the current status of the edge nodes registered to the DEDICAT 6G platform
NW Status Agent FC	Monitors the network of the Enhanced Experience infrastructure
µS/FC Status Agent FC	Provides monitored information about the current status of the microservices being executed in the use case infrastructure
Service Orchestrator FC	Receives recommendations from the IDDM FC and acts over the ENs in order to orchestrate the microservices and FCs deployed over the Enhanced Experience
NW Awareness FC	Provides information on the status of the network of the Enhanced Experience infrastructure
NW Optimization FC	Optimizes the network for the coverage extension component based on the current status of the Connected Car
Network Performance Analytics FC	Receives network performance metrics from the µServices and provides the information to Dashboard FC for visualization and analytics
Logging FC	Logs and collects, and stores several types of data of the system and platform behavior
Load Balancing FC	Receives monitored information about the edge nodes and the microservices and acts over the Enhanced Experience infrastructure in order to balance the network and processing load
EN Awareness FC	Receives information from a group of EN 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.
µS/FC Awareness FC	Receives information from a group of µS Status Agent FC and publish it to the rest of the FCs available on the DEDICAT 6G platform after enriching it to the DM expectations.
ConnectedCar Operation FC	Provides a basic management of Connected Car.

4.2.2.2 UC 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:

- Number of connected users (needed for switch for multicast to unicast and vice versa);
- Throughput (The increased throughput by the use of MAPs will be also considered as the effect of traffic offloading);
- Network delay;
- 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 16. This SW based tool performs passive network performance evaluation and gathers the wanted and essential network parameters in focus. Qosium holds two parts, namely as 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 first phase as an ongoing phase, it is investigated whether Qosium can be installed directly into the Smart Glasses or is the first node point the Smartphone providing the mobile network connection to the Smart Glasses. Alongside the Probes, Qosium Scope is used for visualizing and/or gathering the results.

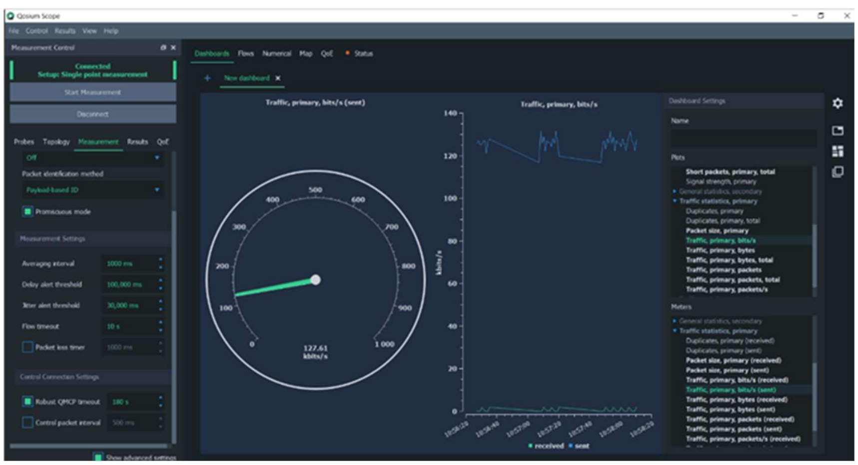

Figure 16: Qosium SW network tool for measuring and visualizing the KPIs

In addition to Qosium, Grafana visualization tool will be used as well for gathering long-term statistics of the system behavior to be shown in a secured Internet web page. This will be illustrated better in the next deliverable D6.2.

4.2.2.3 Interfaces

As stated earlier, the functional architecture with main components in UC2 is illustrated in detail in deliverable D2.3 [2] where also the overall interaction between components is shown. Here we highlight the high-level interfaces according to data flows between different components and illustrate the physical interfaces. The more detailed application-based interfaces will be represented in the revised deliverable, D6.2.

Table 4: Interfaces for components on the Enhanced Experience

Component	Interfaces
Smart glasses	HW: • Wi-Fi 802.11b/g/n network interface @ 2.4 GHz • 5M pixel camera interface for recording SW: • Android GUI as user interface • Video streaming application o Description: Capture and live stream video data to network o Input: camera feed o Output: video data stream towards network URL (edge server address) / video conferencing setup (i.e., host IP address)
Smartphone / mobile devices	HW: • Wi-Fi 802.11b/g/n mobile hotspot @ 2.4 GHz / (5 GHz) • B5G modem support as network interface (currently @ 3.5 GHz) • Multicast middleware interface for enabling mobile multicast (currently @ 2.4/2.7 GHz) SW: • Video streaming application (paired with Smart Glasses) o Description: Control/stream/cast features paired with Smart Glasses through Wi-Fi o Input: Video/control stream from Smart Glasses o Output: similarly, as with Smart Glasses or cast the video to larger screen using i.e., ChromeCast feature • Video streaming application (legacy) o Description: Enhanced streaming using ▪ a) legacy cameras and applications (i.e., FaceBook Live) ▪ b) enhanced cameras and applications with e.g., XR compatible cameras (i.e., 360° degree) o Input: camera feed o Output: * similarly as with Smart Glasses • Video playback application o Description: Receive the live video stream ▪ a) directly from the source cameras (i.e., Smart Glasses) ▪ b) from dedicated MEC/edge (video streaming platform)

Component	Interfaces
	○ Input: Live video stream ○ Output: Display playback, network performance analytics, logging • Multicast-unicast application ○ Description: Smart switching between multicast and unicast streaming in mobile network ○ Input: Live video stream from multicast-broadcast service (see [2]) ○ Output: Display playback, network performance analytics, logging
(MEC) Edge servers	HW: • Network interface to core network (usually wired) SW: • Mobile multicast streaming server ○ Description: Receive live video content, process it, and multicast-broadcast it to users ○ Input: MPEG-DASH video stream from video streaming platform ○ Output: UDP multicast stream towards eNB/gNB, network performance analytics, logging • Mobile multicast controller ○ Description: Control the mobile streaming channel (unicast vs multicast) by the number of users and/or channel usage ○ Input: Network performance analytics ○ Output: True or false parameter to be passed to mobile multicast streaming server • Video streaming platform ○ Description: Serving and transcoding the video content suitable for network adaptation and variety of user devices ○ Input: Video stream from content providers aka streaming applications ○ Output: Video stream to user's playback applications, network performance analytics, logging

4.3 Validation plan

Figure 17 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 will set internal milestones during the phases in order to have certain checkpoints during the project. Dissemination aka participation to 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 trialing event(s) during the last project year will be refined during this year.

As can be seen in Figure 17, we have initially differentiated the work for the video service part and communication. These parts will first progress individually to be integrated and evaluated together in the later phases. The video streaming part focuses on setting the content production and delivery setup as a unity, which combines basically the Smart Glasses, multicast features, playback applications with the video service architecture.

The current phase as M15 is approaching contains the early design and individual integration of the partner's assets and components. Some of the relevant components are already integrated and ready for evaluation in the next phase. Thus, some require dedicated planning for determining the required interfaces between the components. Naturally, this phase also involves the identification of requirements needed for system-wide integration as well as communication between the DEDICAT 6G platform.

During the next phase, we intend to integrate more components together and maybe to revise the required setup if we encounter integration issues. Also, the evolutionary development of the individual components will continue during the later phases as well.

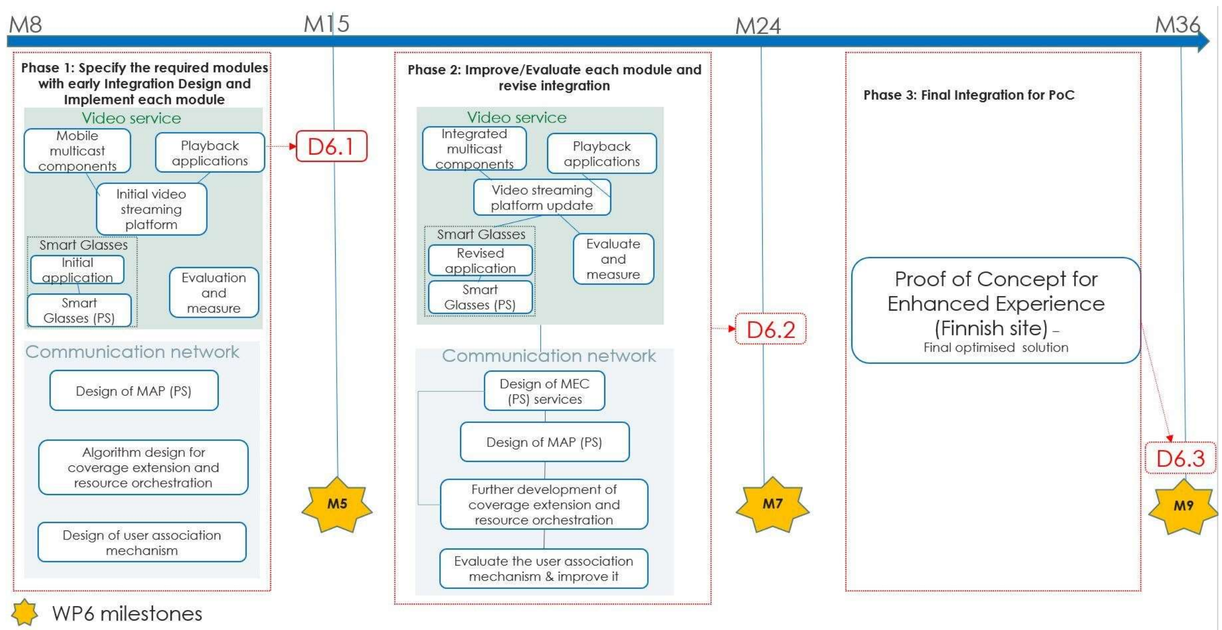

Figure 17: Validation and schedule plan for UC2

Lastly, in Phase 3, we strive to integrate all components together and showcase demos including multiple components. In addition, we will prepare for proof of concept for this UC at the Finnish site to be completed before M36. This plan is also outlined in Section 7.

4.3.1 List of 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 extension and impacts on real-time video streaming.

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

- Service availability: When the area of *Point of Interests (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 capacity is not sufficient enough for all users. Since MAPs are 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;
- Decreased energy consumption: The developed solutions should contribute to decreased energy consumption in the network devices 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 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 5: UC2 – Enhanced experience KPIs list

KPI ID	Description	Evaluation method	Target value
UC2_ KPI1	Service (video) Latency	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.	Network delay < 10 ms E2E latency < 200ms

KPI ID	Description	Evaluation method	Target value
UC2_ KPI2	Throughput for each user	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.	Bitrate > 5 Mbit/s
UC2_ KPI3	Service reliability	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.	PLR < 10^{-3}
UC2_ KPI4	Service availability	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.	99%
UC2_ KPI5	Edge offloading performance	Edge offloading performance will be measured with S/W simulation based patterns, where traffic over MAPs is divided by the total network traffic.	> 50% (but depending on the number of MAPs)
UC2_ KPI6	Decreased energy consumption (servers / UEs)	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.	<10 Mbit/J

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.

Those 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.

Public Safety use case aims to demonstrate Dynamic Coverage Extension and Intelligent resource reallocation through two contexts of crisis management.

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.

The Context #1: non-urban or natural disaster

The first context demonstrates loss of connectivity after a natural disaster through 3 stories. The DEDICAT 6G platform deploys coverage on the area where the most count for PPDR users in order to connect them for collaboration and crisis management.

This context has defined three stories related to three phases which could be encountered during the crisis management.

At the early stage, the DEDICAT 6G platform will reconnect First Responders immediately after a disaster in a non-urban environment by deploying a coverage using AGVs or UAVs (Story #1). The DEDICAT 6G equipment for coverage is defined at the Command-and-Control Center by the operator who has integrated the disaster area coordinates into the system.

In order to get early situation awareness from a disaster area, drones or robots are deployed on the scene in order to get video collection sent to the disaster scene.

Before arriving, PPDR users are able to get early information on the situation from the scene and prepare first mission to go.

Images from the scene are streamed through the DEDICAT 6G platform to users' smartphones or to operator and field officers Smart Glasses. The DEDICAT 6G platform has already deployed Mission Critical Services for Voice (MC-PTT), Video (MC-Video) and data (MC-Data).

DEDICAT 6G platform supports all communications on the field between users, data collection from users and connected objects (location, video, third data…).

First Responders are able to use their smart devices to collect, share and visualize information.

DEDICAT 6G platform is maintained until the response to the crisis ended or operated infrastructure becomes available but can continue to support any failure (this part is described in the second context).

In the meantime, the DEDICAT 6G platform allows PPDR and Public Safety organizations to inform population on the situation (Story #2). Those mechanisms are similar to the UC2 - "Enhanced Experience". This part describes how the PPDR users are able to share some information with the population which is difficult without DEDICAT 6G capabilities.

First Responders are able to receive collection of data (including video) from the scene before arriving and during the crisis management (Story #3). Based on mechanisms for intelligent distribution and coverage extension, resources of DEDICAT 6G platform can be reallocated depending on missions' evolution (new area to be covered for data collection or First Responders engagement…). First Responders can leverage information by the use of Smart Sensors, Smart Glasses, new applications on Smartphones or connected to intelligent systems (Weather conditions estimation, databases request based on pictures or voice…).

The First Responders will be able to support victims and leverage their mission management experience.

This first context will also demonstrate how DEDICAT 6G platform can integrate innovative tools for efficient End-to-End Disaster Response.

The Context #2: non-sufficient working communication services during large event and large crowd

This context describes three stories during a large event with a risk of network failure. The DEDICAT 6G platform will support the available operated infrastructure with mechanisms of dynamic coverage extension to deliver resilient and efficient connectivity for the mission of First Responders. The large event supposed an early organization, involving the DEDICAT 6G preparation and its pre-deployment to event premises. The stories in context #2 start when an incident happened, causing a sudden crowd movement (Story #4). The DEDICAT 6G platform, when has identified the movement, sends a notification to "Site Manager" and "Security" team. Due to the large crowd, the public connectivity comes to its limitation. The Control operator triggers the DEDICAT 6G connectivity support in order to maintain sustainable communication for attendees using the festival mobile application in order to receive evacuation instruction.

DEDICAT 6G platform has deployed a resilient, efficient extended capacity for Security team and First Responders allowing the crisis management (Story #5). With the preparation of the event, First Responders are able to identify position of initial incident in the indoor area of the festival, get feedback from video streaming and take the first decision of response to support victims and starting to secure the area.

The mission accomplishment is successfully achieved with DEDICAT 6G.

Because of the existence of a public infrastructure and the dynamic coverage extension, DEDICAT 6G allows an interaction between attendees to the event and First Responders (Story #6) in order to involve public in the crisis management value chain by sharing right information for evacuation, be able to collect data to raise situational awareness. DEDICAT

6G is participating to reduce the stress of public impacted by the incident which impact positively the decrease of numbers of victims.

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.

To benefit from mission critical services provided by the 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 18: MCX Client application

The MCX Client application shall provide *Press To Talk (PTT)* (voice) group call, video call, video streaming and mapping (as shown on Figure 18).

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 spot 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 version and are compatible with any existing application 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 19.

Figure 19: The components for the Smart Glasses to be used in the Public Safety use case

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

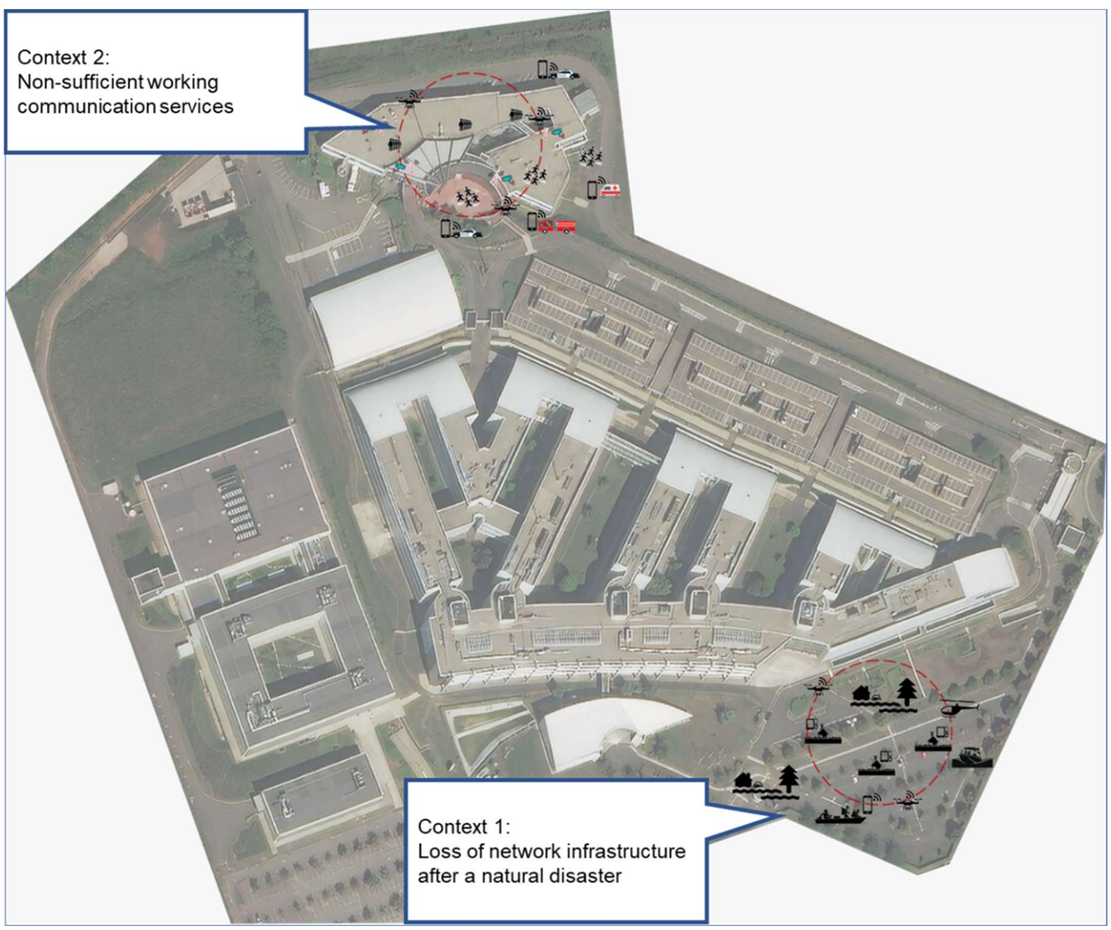

Figure 20: Location of Pilot Setup for Public Safety UC3

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 the containers by launching a configuration file.

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

AGV and Drone

Figure 21: Clearpath Robotics Jackal Unmanned Ground Vehicle

In the scope of this use case pilot, a Clearpath Robotics Jackal Unmanned Ground Vehicle/AGV (Figure 21) 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 23).

Figure 22: 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 22). 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.

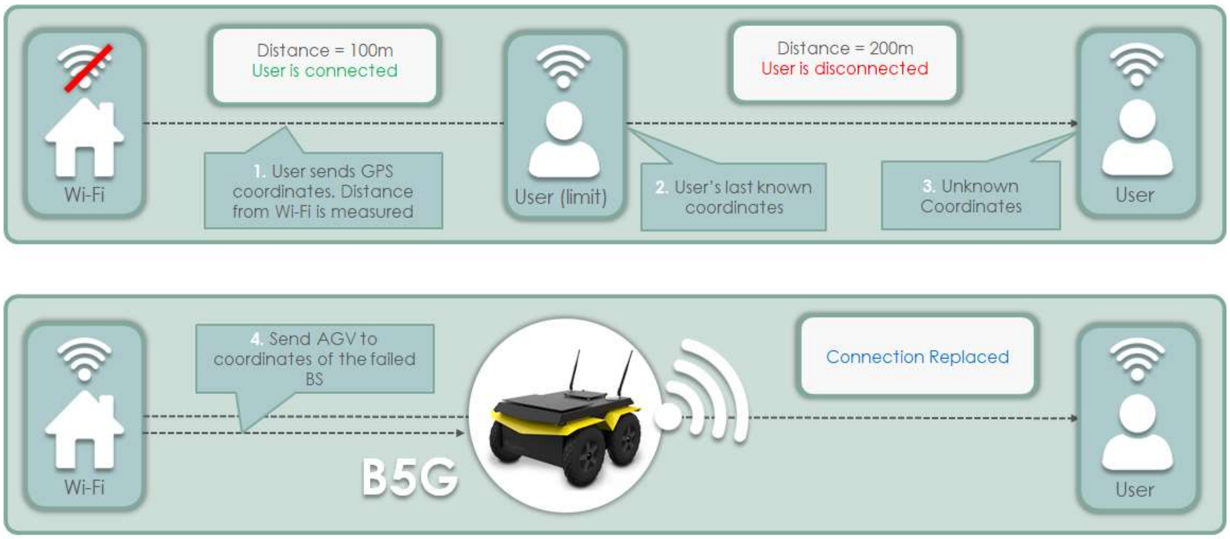

Figure 23: High-level view of Jackal being used as a MAP

5.2.2 Architecture instantiation

5.2.2.1 DEDICAT 6G architecture components

The following section describes in brief the DEDICAT 6G architectural components which apply for UC3. The detailed functional decomposition of the interconnection of this use case is described in D2.3 [2].

Table 6: DEDICAT 6G architecture components in UC3

Component	Description
Dashboard FC	Dashboard providing access to the DEDICAT 6G platform through its GUI for the service setup
AuthN FC Logging FC	Authentication functionalities for granting the user's access into platform and logging functionalities for recording and collecting the system behavior;
μS/FC Repository FC	Stores the uploaded microservices such as video streaming platform
EN Status Agent FC	Provides monitored information about the current status of the edge nodes registered to the DEDICAT 6G platform

Component	Description
µS/FC Status Agent FC	Provides monitored information about the current status of the microservices being executed in the use case infrastructure
Service Orchestrator FC	Orchestrate the microservices and FCs deployed over the Public Safety depending on information collected with Status Agent FC.
Load Balancing FC	Load balancing and service orchestration functionalities for deploying and balancing Mission Critical services in the suitable edge
EN Awareness FC	Status agents for reporting periodically the state of the services in edge nodes and network
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.
CEDM FC	Communicates with the IDDM FC to check µS deployment feasibility (Connected car) with possibility to provide counter proposals, and instructs physical deployment of MAPs
IDDM FC	Receives information about the ENs and the microservices and, as output, provides task/Physical System allocation to the Service Orchestrator FC which is responsible for the actual deployment of the tasks (µS or FC).
NW Awareness FC	Provides information on the status of the network of the Public Safety infrastructure
LoadBalancing FC	Balances the execution load inside EEs and provides an optimized and fair distribution of tasks between EEs.
UAV Operation FC	Provides the basic management of UAV.
Swarm Operation FC	Provides autonomous management of a set of drones.
AGV Operation FC	Provides the basic management of robots and provides a palette of so-called atomic actions it can perform. Those atomic actions are then played with, in order to build more complex capabilities.
Connected Car Operation FC	Provides a basic management of Connected Car.

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 setup 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 setup.

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.

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 will be implemented in the scope of this use case pilot are listed:

- 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 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 Service Orchestrator FC has an interface with Load Balancing 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.

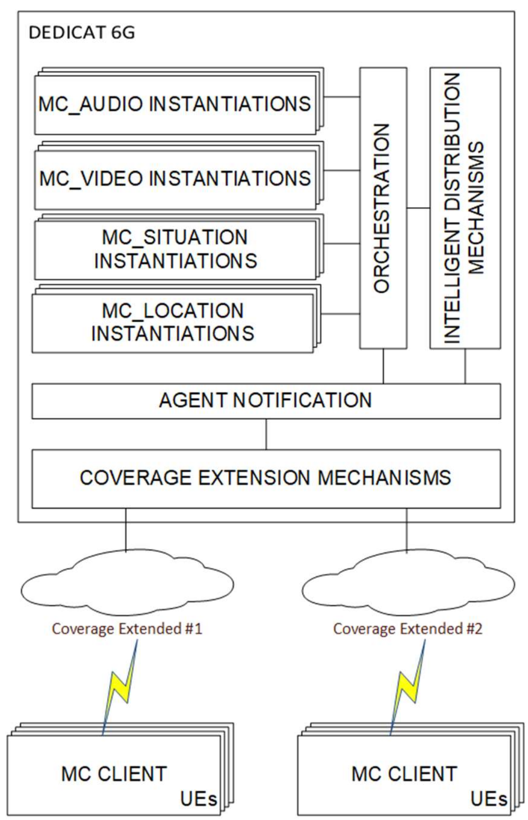

Figure 24: Connectivity Client applications with MCX services

5.3 Validation plan

5.3.1 List of KPIs and target values (UC leader)

Table 7 presents the list of KPIs related to the Public Safety use case, describing the evaluation method and defining the target values:

Table 7: UC3 – Public Safety KPIs list

KPI ID	Description	Evaluation method	Target value
UC3_KPI1	MC-PTT (voice) to MCX Audio service access time	Measure will be done at UE level. Results will be compared with an MCX deployed on a 5G network.	Access time < 300 ms 95% of request
UC3_KPI2	End-to-End MC-PTT (voice) access time for all MCX client under the same network coverage	Measure will be done at UE level. Results will be compared with an MCX deployed on a 5G network.	Access time < 1000 ms
UC3_KPI3	Mouse-to-Ear (voice) latency	Measure will be done at UE level. Results will be compared with an MCX deployed on a 5G network.	Access time < 300 ms 95% of voice burst
UC3_KPI4	Maximum late call entry time	Measure will be done at UE level. Results will be compared with an MCX deployed on a 5G network.	Late entry time < 150 ms 95% of late call request
UC3_KPI5	End-to-End MC-DATA (IP Data) and MC-VIDEO (video) request time for IP packets transmission	Measure will be done at UE level. Results will be compared with an MCX deployed on a 5G network.	Transmission request time < 10 ms
UC3_KPI6	User Data Rate	Measure will be done at UE level. Results will be compared with an MCX deployed on a 5G network.	DL user data rate shall be 100 Mbps UL user data rate shall be 50 Mbps
UC3_KPI7	Successful packet transmission (Reliability)	Measure will be done at UE level. Results will be compared with an MCX deployed on a 5G network.	Reliability indicator at least 99,999% of success for a 32 bytes IP Packet within 1ms

The preliminary validation plan in terms of schedule is presented in Section 7.

6 UC4: SMART HIGHWAY

6.1 Scenario and stories

Smart Highway use case is executed in the context of smart mobility. The goal is to make use of 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 user end as well as to load-balance the resources. Furthermore, this use case will also demonstrate 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 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.

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 analyzing 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 Scenario 1

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 25, 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.

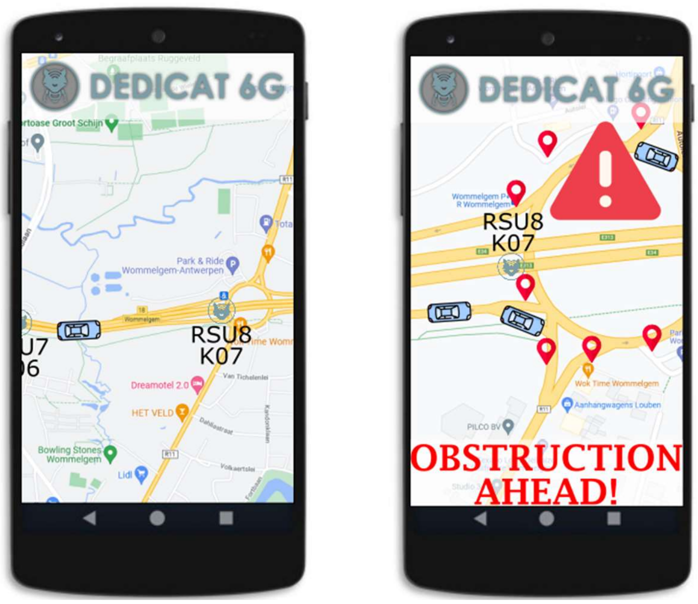

Figure 25: LDM App mock-up

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 Scenario 2

In scenario 2 that is linked to story 2, the human-centric application basically aims to increase road safety by recognizing VRUs on the road-side and predicting dangerous situations. For this purpose, RSU's application, which serves as an edge computing, and mobile application for pedestrians are being developed.

The RSU application (Figure 26) has 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.

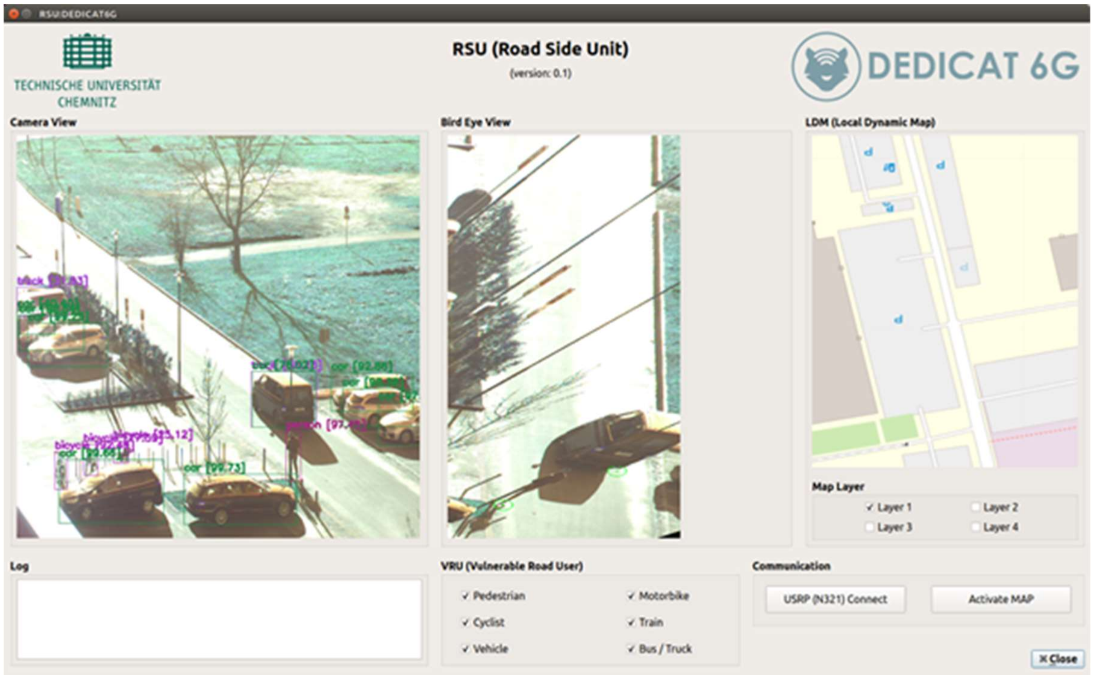

Figure 26: The RSU application

The VRU mobile application (version 0.1) based on Android OS (Figure 27) has the following features:

- Pedestrian location information is obtained using the Android smartphone's onboard GPS transceiver;
- Send location information to RSU;
- We have received an important notice from RSU;
- A warning message is displayed on the screen.

Figure 27: VRU mobile application

6.2 Scenario 1 Setup

6.2.1 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 29. The highway on top of the intersection is equipped with an RSU, as seen in Figure 29, capable of transmitting signals through short range communication towards road users. The roundabout connects to the exits of the highway.

Figure 28: Location of the UC on map (Belgium site)

Figure 29: 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 Cloud

The Cloud is a remote processing data center located outside of the Smart Highway (Figure 30). This location 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 set-up 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 30: Remote processing data center (Belgium site)

6.2.1.2 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.

6.2.1.2.1. RSU

Figure 31 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 31: RSU on E313 highway

6.2.1.2.2. 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 32: IMEC's experiment car with On-board Unit

6.2.2 Architecture instantiation

6.2.2.1 DEDICAT 6G architecture components

The components described in this section were detailed in UML diagrams on D2.3 [2]. Based on the UMLs, we could identify the DEDICAT 6G architectural components and build the table below. In Table 8, we provide the name of the component that was defined in the DEDICAT 6G platform and a short description of what situation this component is used on UC4 related to Scenario 1.

Table 8: DEDICAT 6G architecture components in UC4 – Scenario 1

Component	Description
Dashboard FC	Used for interaction with the *Operation Manager* in order to manage the deployment and management of the DEDICAT 6G components in the Smart Highway infrastructure.
AuthN FC	Responsible for the grating access of the DEDICAT 6G platform
CEDM FC	Communicates with the NODM FC to collect information about the network status and can act over the NODM FC to activate the coverage extension on the smart cars
IDDM FC	Receives information about the ENs and the microservices and, as output, provides recommendations to the Service Orchestrator FC
µS/FC Repository FC	Stores the uploaded microservices related to the Smart Highway such as the V2X Application µS and the Sensing Node µS
EC Policy Repository FC	Stores the Edge Computing policies related to the Smart Highway
µS/FC Registry FC	Stores the meta-data related to the microservices uploaded in the µS/FC Repository FC
EN Registry FC	Stores the metadata related to the registered edge nodes
Service Orchestrator FC	Receives recommendations from the IDDM FC and act over the ENs in order to orchestrate the microservices and FCs deployed over the Smart Highway
EN Status Agent FC	Provides monitored information about the current status of the edge nodes registered to the platform
µS/FC Status Agent FC	Provides monitored information about the current status of the microservices being executed in the use case infrastructure
NW Status Agent FC	Monitors the network of the Smart Highway infrastructure
NW Awareness FC	Provides information on the network status in the Smart Highway infrastructure.
NW Optimization FC	Optimizes the network for the coverage extension component based on the current status of the Smart car
Load Balancing FC	Receives monitored information about the edge nodes and

Component	Description
	the microservices and acts over the Smart Highway infrastructure in order to balance the network and processing load over the multiple hosts available
NODM FC	Receives recommendations from NW Optimization FCs in order to reconfigure the network and meet the desired objectives for V2X communication
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
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

6.2.2.2 UC 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 9: 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

6.2.2.3 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 10.

Table 10: 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)

6.3 Scenario 2 Setup

6.3.1 Pilot setup

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

6.3.1.1 RSU platform

Hardware

The RSU prototype hardware configuration is shown in Figure 33. 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 6.3.2.2.

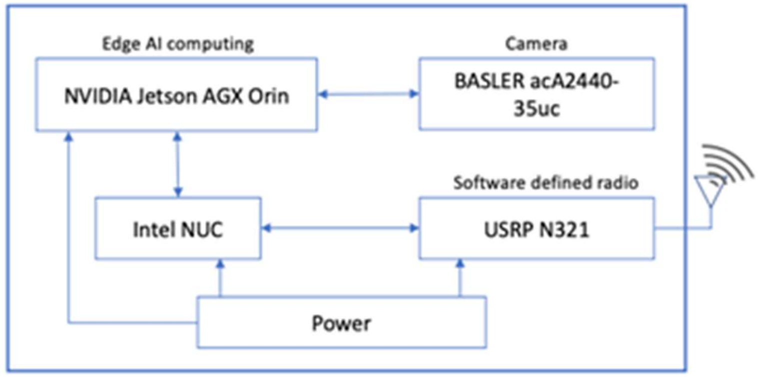

Figure 33: RSU prototype hardware configuration

Software

Figure 34 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 analyzes 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.

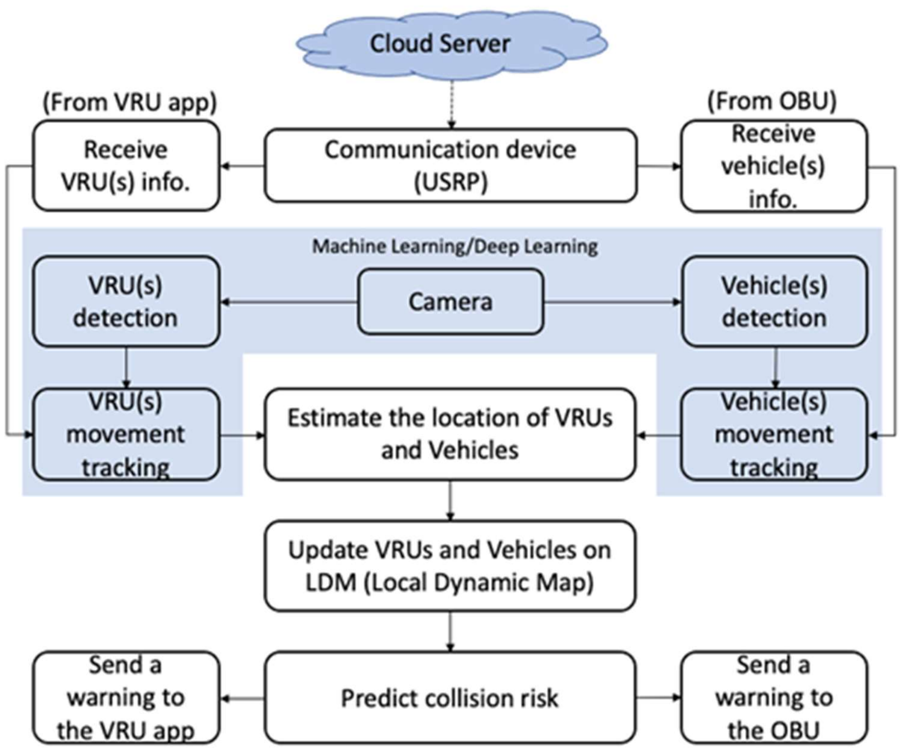

Figure 34: The overall software structure of the proposed RSU

The *Graphical User Interface (GUI)* of the software running on RSU (version: 0.1), which is edge computing, is shown in Figure 26. The GUI is implemented based on Qt5. The screen consists of 6 UIs and the role of each is 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 [20] 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 [21], and Layer 4 is generated from the GPS coordinate information of the VRU calculated from bird eye view;
- VRU: it selects the VRU type displayed on the screen;
- 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;
- Log: it displays error log records.

6.3.1.2 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 [22]. 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 [23]. Additionally, most road accidents involving VRUs occur because road users fail to detect the presence of VRUs in a timely manner and respond appropriately [24]. 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 27, 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.

6.3.1.3 Vehicle platform

As shown in Figure 35, TUC's research vehicles are Volkswagen Tourans, BMW i3 and Volkswagen ID4[2]. The vehicle is equipped with an OBU and sensors such as RADAR, LiDAR, FIR, NIR, MobileEye, and GNSS for autonomous vehicle implementation.

[2] Delivery is expected in the second quarter of 2022.

Figure 35: TUC vehicle platform

Figure 36 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 36: SDR-based V2X communication device on TUC vehicle platform: (a) installation setup (b) UE (c) CN+eNB

6.3.1.4 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.

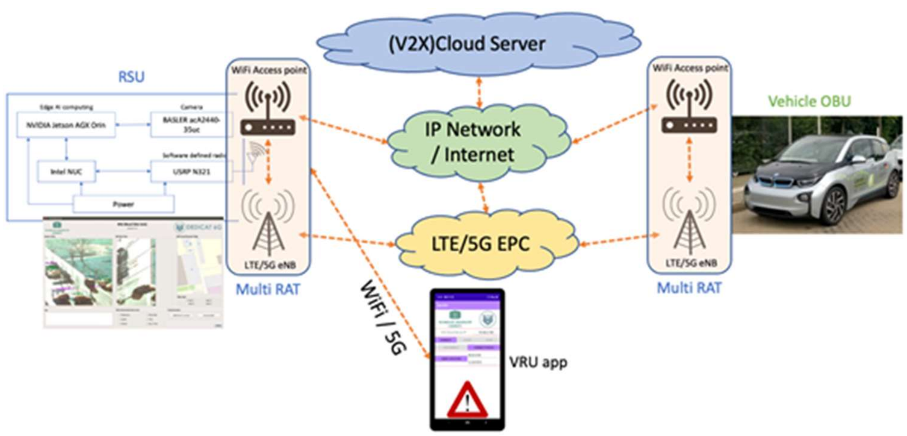

Figure 37: End-to-End Network for UC4

As shown in Figure 37, 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 is related to D3.2 and D4.2, and the practical application to UC4 will be done in D6.2.

6.3.1.5 Sensing node platform

This subsection describes the sensing node platform.

Hardware

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 connectivity device, whose connectivity resources are centrally controlled through the Sensing Node µS dashboard. Sensing node prototype hardware configuration is shown in Figure 38.

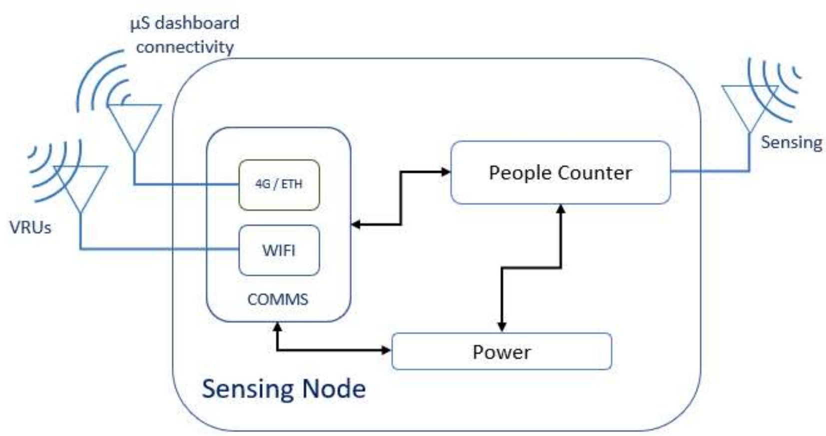

Figure 38: Sensing node prototype

Software

The sensing node is a prototype running on a Raspberry Pi, supported by the buildroot operating system based on Debian OS. Its 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 the Table 11.

Table 11: 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 below.

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 *Data Base (DB)* used by the Sensing Node µS dashboard to generate heat maps with estimates of the coverage area occupancy and to generate statistics and trends.

```
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@59072@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@58534@1@0@@@~
```

Figure 39: Screenshot of the log that records the messages received from the sensing nodes

The information collected by the nodes is processed in the cloud and sent by the software 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.

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.

6.3.2 Architecture instantiation

6.3.2.1 DEDICAT 6G architecture components

Figure 40 shows the mapping of the DEDICAT 6G Functional architecture components for PoC on the Smart Highway use case at Germany Site.

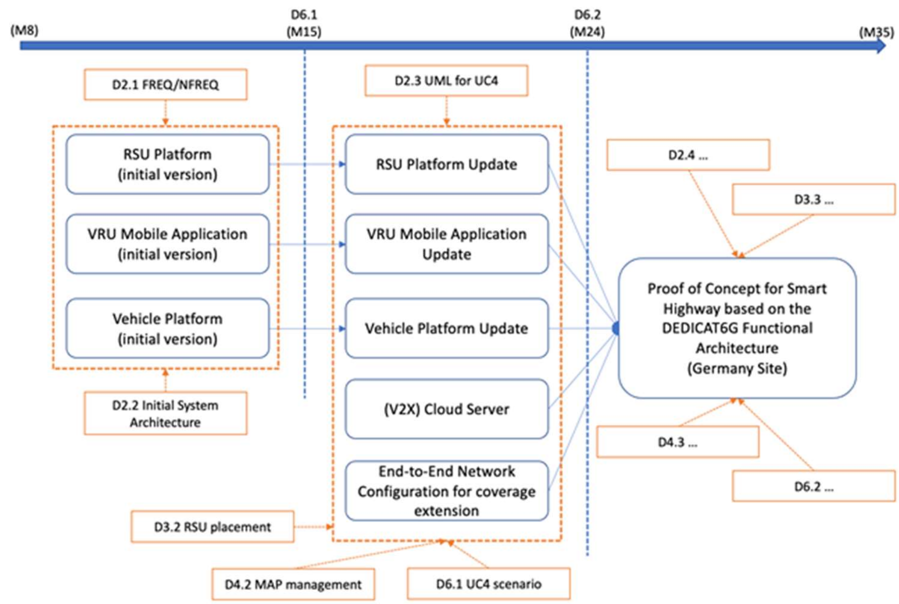

Figure 40: The mapping of the DEDICAT 6G Functional architecture components on Smart Highway at Germany Site

Table 12: DEDICAT 6G architecture components in UC4 – Scenario 2

Component	Description
Dashboard FC	Used to interact with Operation Manager to manage the deployment and management of DEDICAT 6G components.
AuthN FC	Responsible for granting the RSU, OBU, VRU apps access to the DEDICAT 6G platform.
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.
IDDM FC	Receives information about ENs and µS and then provides results to Service Orchestrator FC and Dashboard FC.
µS/FC Repository FC	Stores the uploaded µS related to the Smart Highway such as the V2X Application µS and the Sensing Node µS
EC Policy Repository FC	Stores the Edge Computing policies related to the Smart Highway.
µS/FC Registry FC	Provide information on the V2X Application µS and the Sensing Node µS
EN Registry FC	Provides information on the Edge Nodes such as RSU, OBU that can be exploited for intelligence distribution.
Service Orchestrator FC	Receives recommendations from the IDDM FC and acts over

Component	Description
	the ENs in order to orchestrate the µS and FCs deployed over the Smart Highway.
EN Status Agent FC	Provides monitored information about the current status of the edge nodes registered to the platform.
µS/FC Status Agent FC	Provides monitored information about the current status of the µS being executed in the use case infrastructure.
NW Awareness FC	Provides information on the network status in the Smart Highway infrastructure.
NW Status Agent FC	Provides monitored information about the current status of the network in the Smart Highway infrastructure.
NW Optimization FC	Optimizes the network for the coverage extension component based on the current status of RSU and OBU.
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
NODM FC	Receives recommendations from NW Optimization FCs in order to reconfigure the network and meet the desired objectives for V2X communication
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
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

6.3.2.2 UC 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 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.

Component	Description
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 33 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 Core
    - 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 (Pout)

Table 14: 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 15: 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 16: 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 17: 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 18: 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 in Figure 38 are as follows:

- People Counter
  - 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

Figure 41: People Counter IoT device appearance

- Industrial Router
    - CPU: Industrial 32 bits CPU
    - SDRAM 128MB
    - FLASH 16MB
    - Interfaces: RS232, RS485
    - Wi-Fi support 802.11b/g/n. support AP
    - LAN: 2x 10/100Mbps Ethernet ports
    - WAN access methods, including static IP, DHCP, PPPOE, 3G /4G (possible 5G), ETH 10/100Mbps Ethernet port
    - Power range: DC 5~35V

6.3.2.3 Interfaces

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

Table 19: 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

Component	Interfaces
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

6.4 Validation plan

6.4.1 List of KPIs and target values

Table 20 presents the list of KPIs related to the Smart Highway use case, describing the evaluation method and defining the target values:

Table 20: UC4 – Smart highway KPIs list

KPI ID	Description	Evaluation method	Target value
UC4_ KPI1	5G Vehicular-Based MAP Downlink/Uplink Throughput	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	>= 16 Mbps

KPI ID	Description	Evaluation method	Target value
		second)	
UC4_ KPI2	5G Vehicular-Based MAP Latency	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	<= 20 ms
UC4_ KPI3	LDM Response time from identifying dangerous situation until emitting warming message	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	<= 100 ms
UC4_ KPI4	LDM network throughput downlink/uplink usage	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	>= 16 Mbps

The preliminary validation plan in terms of schedule is presented in Section 7.

7 Preliminary Planning

The following section describes the preliminary planning and first objectives of setup, show-casing and evaluation from M8, when WP6 started, to M24 related to the end of second year of the DEDICAT 6G project.

Figure 42: DEDICAT 6G milestones (from M8 to M24)

The preliminary planning for each use case is 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 valida-tion 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 in-volved 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.

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 test-ing.

M21: Minimum viable proof of concept.

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

8 Conclusions

This deliverable reports the activity conducted in the work package 6 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). Firstly, it presented a DEDICAT 6G platform integration overview including logical perspective based on inputs from WP2 (D2.2 [1] and D2.3 [2]), and components perspective based on inputs from WP3, WP4 and WP5 (D3.1 [3], D4.1 [4] and D5.1 [5]).

Secondly, there are specific sections for each use case to describe the scenarios and detailed stories associated to them. For UC1, there is one scenario with two detailed stories; for UC2, there is one scenario with three detailed stories; for UC3, there is one scenario with six detailed stories and for UC4, there are two scenarios with one detailed story in each one. Furthermore, the human centric applications/services offered to the end users are described like the warehouse manager dashboard and the warehouse worker mobile app as example for the UC1. Next the scenario setup is illustrated showing the main actors, the involved technologies and the HW & SW components which will be integrated in each use case setup plan. In the instantiation architecture subsection, it identifies the DEDICAT 6G architecture components described in detailed in D2.3 [2] together with the specific UC components, including the key interfaces for each use case. Moreover, there is a validation plan subsection to define the list of metrics/KPIs with their evaluation methods and as well as the target values. The identified KPIs will evaluate the performance improvement with the DEDICAT 6G platform in terms of latency, energy consumption, service reliability, service availability or throughput.

Finally, D6.1 presents the preliminary planning for all use cases showing the first objectives of setup, showcasing and evaluation from M8, when WP6 started, to M24 related to the end of second year of DEDICAT 6G project. In a second iteration, the WP6 planning will be updated and reported in D6.2.

References

[1] DEDICAT-6G, "Deliverable D2.2 – Initial system architecture". September 2021.

[2] DEDICAT-6G, "Deliverable D2.3 - Revised scenario description and requirements". February 2022.

[3] DEDICAT-6G, "Deliverable D3.1 - Mechanisms for dynamic distribution of Intelligence". December 2021.

[4] DEDICAT-6G, "Deliverable D4.1 – First release of mechanisms for dynamic coverage and connectivity extension". December 2021.

[5] DEDICAT-6G, "Deliverable D5.1 - Specification of security framework and trust management platform". December 2021.

[6] J. Kowalik (editor), Parallel MIMD computation: the HEP supercomputer and its applications, MIT Press, Cambridge, 1985.

[7] V. Leppänen, M. Forsell and J-M. Mäkelä, Thick Control Flows: Introduction and Prospects, In the Proceedings of the 2011 International Conference on Parallel and Distributed Processing Techniques and Applications (PDPTA'11), July 18-21, 2011, Las Vegas, USA, 540-546.

[8] M. Forsell, J. Roivainen, V. Leppänen, J. L. Träff, Implementation of multioperations in thick control flow processors, in: IEEE International Parallel and Distributed Processing Symposium (IPDPS) Workshops, 2018, pp. 744–752.

[9] M. Forsell and V. Leppänen, Moving Threads: A Non-Conventional Approach for Mapping Computation to MP-SOC, PDPTA'07, June 25-28, 2007, Las Vegas, USA, 232-238.

[10] M. Forsell and V. Leppänen, A moving threads processor architecture MTPA, Journal of Supercomputing)57, 1 (2011), 5-19.

[11] M. Flynn, Some Computer Organizations and their Effectiviness, IEEE Transactions on Computers 21, 9 (1972), 948-960.

[12] A. Ranade, How to Emulate Shared Memory, Journal of Computer and System Sciences 42, (1991), 307-326.

[13] M. Forsell, A scalable high-performance computing solution for networks on chips, IEEE Micro 22 (5) (2002) 46–55.

[14] J. Keller, C. W. Keßler, J. L. Träff, Practical PRAM Programming, John Wiley & Sons, 2001.

[15] "Warehousing and Storage Market: Global Industry Trends, Share, Size, Growth, Opportunity and Forecast 2022-2027." https://www.imarcgroup.com/warehousing-and-storage-market

[16] M. Keltsch, S. Prokesch, O. P. Gordo, J. Serrano, T. K. Phan and I. Fritzsch, "Remote Production and Mobile Contribution Over 5G Networks: Scenarios, Requirements and Approaches for Broadcast Quality Media Streaming," 2018 IEEE International Symposium on Broadband Multimedia Systems and Broadcasting (BMSB), Valencia, Spain, 2018, pp. 1-7, doi: 10.1109/BMSB.2018.8436772.

[17] H. Dujuan, "Mobile communication technology of sports events in 5G era," Microprocessors and Microsystems, Vol. 80, Feb. 2021, https://doi.org/10.1016/j.micpro.2020.103331

[18] Y. Mao et al., "A Survey on Mobile Edge Computing: The Communication Perspective," IEEE Commun. Surveys & Tutorials, Vol. 19, Issue 4, 2017.

[19] R. Borralho et al., "A survey on coverage enhancement in cellular networks: Challenges and solutions for future deployments," IEEE Commun. Surveys & Tutorials, 2021, DOI: 10.1109/COMST.2021.3053464

[20] SAFESPOT SP 7 SCORE - SAFESPOT Core Architecture, D7.3.1 Annex2 - LDM API and Usage Reference (2010).

[21] https://www.openstreetmap.org

[22] "Number of pedestrian deaths caused by road accidents in the European Union (EU-28) between 2010 and 2018", https://www.statista.com/statistics/1197292/pedestrian-traffic-fatalities-in-the-eu/
[23] "Distracted Walking: A Major Working Safety Concern", https://www.omag.org/news/2018/1/2/distracted-walking-a-major-working-safety-concern
[24] J.J. Anaya, P. Merdrignac, O. Shagdar, F. Nashashibi, J. E. Nara, "Vehicle to pedestrian communications for protection of vulnerable road users", 2014 IEEE Intelligent Vehicles Symposium Proceedings, June 8-11, 2014, Dearborn, Michigan, USA, pp 1037-1042.