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CODECO

Cognitive Decentralised Edge Cloud Orchestration

D8: Fine-grained Use-case Design and Business Impact

v2.0

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Project Partners

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Executive Summary

Deliverable D8 of the CODECO project relates to the work that was developed under task 2.1 and outlines the outputs of this action during the first six months of the project. The task is focused on detailing use cases through the identification of business KPIs, actors, equipment required, operational settings, data requirements, among other topics that are covered in this document.

Each Use-case leader with all the consortium partners have been engaged in mapping the details of the use cases and based on the common understanding of the functionality of the CODECO framework, their functionalities were documented.

Keywords: Use-cases. Templates, user journeys, actors.

Document Revision History

Version	Date	Description of change	List of contributors
v0.1	26.01.2023	Initial Proposal for Use Cases Template	INTRA
v0.2	27.01.2023	Updates based on internal review & discussions	INTRA
v0.3	30.01.2023	Updates on needed UC info	INO
v0.4	10.02.2023	Updates on info required for workload placement and migration	SIEMENS
v0.5	23.02.2023	New attribute – Metadata Requirements	INO
v0.6	23.02.2023	Updates on UC #2, #5 & #6	INO
v0.7	28/02/2023	Updates on UC #4	INO
v1.0	08/03/2023	Updates on document structure	INO
v1.1	09/03/2023	Updates on UC#1	UGOE
v1.2	04/04/2023	New attributes: CODECO single cluster and multi-cluster functionality. Comments on provided inputs from UCs	INTRA
v1.3	17/04/2023	Updates on ToC	INO
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v1.5	15/05/2023	Updates on UC5	FOR, Rute C. Sofia
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v1.6	02/6/2023	First version of Conclusions; Various edits and improvements in the document	INTRA
v1.7	26/06/2023	Updates on UC3 and Section 3	INO
v1.8	28.06.2023	Global review; UC5 revision; section 3 completion	FOR, Rute C. Sofia
v1.9	29/06/2023	Global review	INO
v2.0	30/09/2023	Minor changes after INTRA revision	INO

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List of Acronyms and Definitions

Acronym	Meaning
ACM	Automated Configuration Manager
AGV	Automated Guided Vehicles
AI	Artificial Intelligence
AoI	Age of Information
AMR	Automated Mobile Robots
API	Application Programming Interface
AR	Academia and Research
BGP	Border Gateway Protocol
CENOS	Cognitive Energy Network Optimization System
CPU	Central Processing Unit
CV	Computer Vision
DEV	Software developers and early adopters
DMP	Data Management Plan
DoA	Description of Action
ETSI	European Telecommunications Standards Institute
GDPR	General Data Protection Regulation
GOV	Municipalities, public authorities, policy makers
ICT	Industrial and SME players
IIoT	Industrial Internet of Things
IoT	Internet of Things
JSON	JavaScript Object Notation
KPIs	Key Performance Indicators
LDM	Local Dynamic Map
LIDAR	Light Detection and Ranging
LTE	Long Term Evolution
MAC	Media Access Control
MaaS	Manufacturing as a Service
MDS	Media Delivery System
ML	Machine Learning
MQTT	Message Queue Telemetry Transport
NetMA	Network Management and Adaptation
OBU	On Board Unit
OdbL	Open Database License
QoE	Quality of Experience
QoS	Quality of Service
pAoI	Penalty Age of Information
PDLC	Privacy-preserving Decentralized Learning and Context-awareness
RAM	Random Access Memory
RAT	Radio Access Technologies
REST	Representational State Transfer
ROCOF	Rate of Occurrence Of Failure
RRL	Recurse Requisites List
RSU	Roadside Unit
SDK	Software Development Kit
SME	Small Medium Enterprise
SUMO	Simulation of Urban Mobility
SWM	Scheduling and Workload Migration

TEE	Trusted Execution Environment
UC	Use Case
UI	User Interface
UML	Unified Modelling Language
VRU	Vulnerable Road User
V2X	Vehicle to Everything
VP	Value Proposition
YOLO	You Only Look Once

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Acknowledgements

Acknowledgements to all the partners who have contributed to the successful delivery of this document. Special thanks to the use case leaders who have played a crucial role in driving this specification forward.

1 Introduction

1.1 Scope and Purpose

The main goal of CODECO is to research, implement and validate a novel cognitive, cross-layer and highly adaptive Edge-Cloud management framework, which will enable flexible and effective orchestration of decentralized data workflows, dynamic offloading of computation and adaptive networking services across the Cloud/Edge computing continuum. CODECO will be validated in the scope of six innovative use cases that are destined to showcase the value-added Cloud/Edge functionalities of the CODECO framework, including functionalities like latency and power efficiency optimization, real-time computation adjustments, as well as flexible and adaptive networking infrastructures from the far Edge to the Cloud. The use cases are aimed at demonstrating the whole range of CODECO functionalities and features in a wide array of deployment configurations serving the needs of different stakeholders like infrastructure providers and Cloud/Edge application developers.

This deliverable provides a detailed description of the CODECO use cases based on the work that was carried out in the scope of task T2.1 of the project's workplan. The detailed description of the use cases includes a comprehensive presentation of their functionalities, the stakeholders and beneficiaries involved in them, the main user journeys served by each use case, the experimentation environment of each use case, as well as their market relevance and potential business impact. A detailed description of the use cases will be used to drive the technical development of the project, including the specification of the CODECO architecture and technical components that are carried out in other tasks of WP2. The presented use cases will provide a set of reference scenarios that will be used to design CODECO components and functionalities across the entire development lifecycle of the project. Furthermore, they will serve as a basis for the actual implementation of the use cases based on the CODECO technologies. As part of the implementation and evaluation of the use cases, the project partners will drive the technical specification of the use cases down to implementation detail, using the CODECO framework components and architecture.

1.2 Methodology

The starting point for the detailed description of the CODECO use cases was the information about the use cases that is contained in the Grant Agreement Annex II (i.e., Description of Action (DoA)). These initial descriptions were further detailed, refined, fine-tuned, and aligned to the functionalities of the CODECO framework based on a series of meetings and workshops of the CODECO WP2 partners, including the owners/leaders of the use cases. This process leveraged the following methodological instruments:

- **Use-case Template**: A template for a detailed description of the use case was developed. The goal of the template was twofold: First to ensure that each use case description comprises a set of minimal information, and second to ensure some level of uniformity in the description of the six use cases. The collected information for each use-cases was defined based on the inputs of WP2 partners and aims to standardize the different approaches to easily understand the needed requirements of CODECO Platform.
- **Use-cases Workshops**: Following an initial description of the use cases, each use case was discussed and fine-tuned in the context of a workshop that brought together all use cases stakeholders per use case, including the use case owner (end-user) and technical partners involved in the development and integration of the use case. Although, no rigorous co-creation and co-design process was followed, these workshops comprised

co-creation and co-design elements, as CODECO partners collaborated in the detailed specification of each use case (rf. To Table).

- **Business and Market Analysis**: A short business and market analysis in the domain of the use cases took place to establish the market relevance and to describe the potential business impact of each use case.

Table 1: CODECO use-case workshops on definitions and requirements.

# UC Workshop	Date & Time	UCs presented	Notes
1st UC Workshop	15/03/2023, 16-18h	P1 P2 P3	3 UCs were presented by the UC leaders and QA followed aiming to a better understanding of the UCs
2nd UC Workshop (during CODECO plenary)	05/04/2023, 15-18h	All	All UCs were presented by the UC leaders followed by detailed discussions on UCs definitions and relation to CODECO technology

These methodological instruments were used in the scope of a three-phase approach that is illustrated in Figure 1:

- **Phase 1 – Initial Analysis and Specifications (M1-M2)**: This phase spanned the first two months of the project. It conducted an initial analysis of the use cases starting from the information on the DoA and the early specifications of the CODECO functionalities in other tasks of WP. Its main outcome was the initial description of the use cases in the provided template and their refinement in line with envisaged CODECO functionalities.
- **Phase 2 – Functional and Non-Functional Specifications (M2-M5)**: This phase shed light in the functional and non-functional specifications of the use cases based on a series of co-design/co-creation workshops where the various functionalities were discussed and specified in detail.
- **Phase 3 – Business Specifications and Fine-Tuning (M5-M6)**: This was the last phase of the use cases specification tasks. It focused on an initial business and market analysis of the domain of each use case towards documenting the potential business impact of each one.

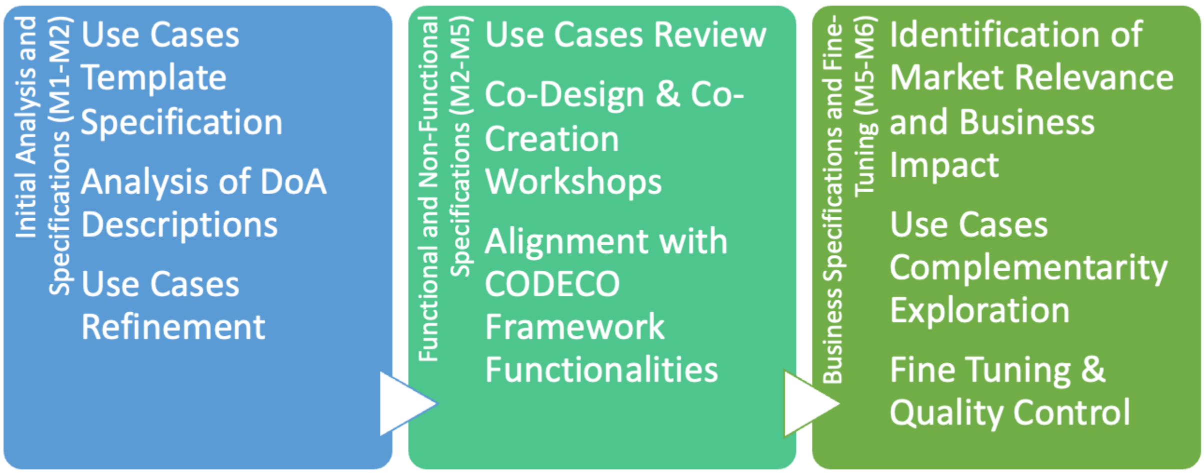

Figure 1: Main phases of the use-cases definition methodology.

Note that in the context of this document and in-line with the theory of use cases based engineering, a use case is finer-grained and more detailed than a business case. A business case describes some purpose for which a user might use your system and all the features of the software that they would require to achieve that purpose. Business cases describes the system at a high level and give a rationale for each feature of the existing system, while use cases give a detailed account of what each feature does. This deliverable provides the description of fine-grained use cases, beyond high level functionalities contained typical in business cases.

1.3 Document Structure

This introductory section is dedicated to introducing the scope and methodology of the deliverable, while at the same time presenting the structure of the document. The remainder of the document is structured as follows:

- **Section 2** is focused on use case description, including business analysis, and is divided into six sub-sections (one per use case).
- **Section 3** aims to analyse use cases from the technological point of view in an integrated way.
- **Section 4** concludes the document and presents an outlook for the use of the presented descriptions as input to other tasks and activities of the project.

1.4 Dependencies

A deeper understanding on the CODECO components and how they operate is described in Deliverable D9 (*CODECO Technological Guidelines, Reference Architecture, and Initial Open-source Ecosystem Design intermediate version*). D9 provides additional input into the operation of CODECO, and the high-level specification of its components, thus providing benefits to the understanding of the use-cases.

We strongly advise a careful reading of D9. To assist the reader, section 1.5 provides a brief description of the CODECO framework and its components.

1.5 Summary, CODECO Framework and its Components

CODECO is a containerized application orchestration framework composes of modular micro-services illustrated in Figure 2, to support the following aspects:

- **Automated configuration**, related with application setup and application runtime across Edge-Cloud, by taking into consideration compute, network, and data aspects. Automated configuration is handled by the CODECO *Advanced Configuration and Management (ACM)* component.
- **Data as a resource**. CODECO addresses, via its *Metadata Manager (MDM)* component data as a resource in the sense that available snapshots from the overall Edge-Cloud infrastructure, integrating different perspectives (application, user, system, data, network) at different instants of the CODECO operational workflow can be provided to different CODECO components, to assist in detecting relevant changes.
- **Dynamic scheduling and workload migration** is supported by the CODECO component *Scheduling and Workload Migration (SWM)*. SWM integrates a novel concept by Siemens, seamless computing, including a novel scheduler for Kubernetes (K8s) that considers data-network-computation requirements to provide a best match between application requirements and available infrastructure (nodes, their computational and data properties, as well as network nodes and links), and to schedule and re-schedule application workloads across single cluster and federated cluster environments, considering application and user requirements.

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- **Context-awareness and privacy preserving decentralised learning**, supported in the component *Privacy-preserving Decentralised Learning (PDLC)*. CODECO relies on context-awareness to be able to achieve a joint data-network-compute orchestration, and on privacy-preserving decentralised learning and inference to best support readjustment of aspects such as the processing capability, computational resources, networking resources and interconnections in real-time.
- **Infrastructure adaptation based on a cross-layer data-compute-network approach**. Via the CODECO *Network Management and Adaptation component (NetMA)*, CODECO assists in adapting not just computational (node resources) but also the networking infrastructure interconnecting such nodes.

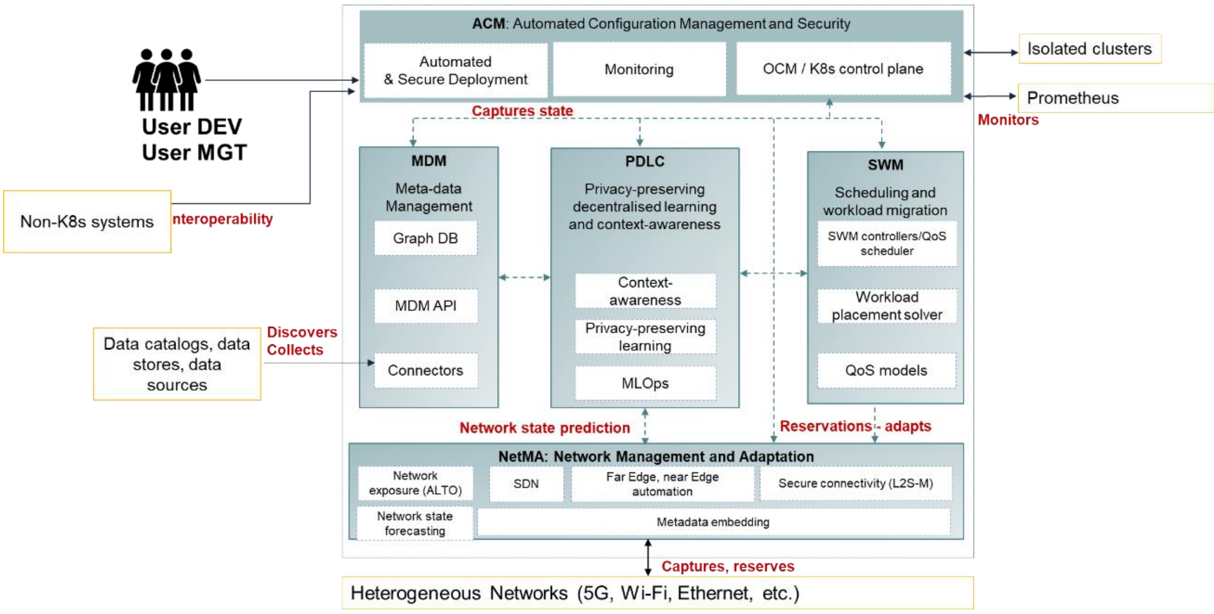

Figure 2: The CODECO K8s framework and its components.

CODECO as a framework shall support the setup of applications across clusters (the so-called K8s application deployment) and the cluster runtime management operations for single and multi-cluster environments. Users relying on CODECO during an application deployment are named as **user DEV** in CODECO (rf. To Deliverable D9). Users relying on CODECO during the cluster runtime management are referred to as **user MGT**-

Components that are expected, at the current initial stage of development (M6) to be co-located with the K8s control plane are ACM and SWM.

All the other components are expected to reside in both worker nodes and if required, they may also operate on the K8s control plane.

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2 Use-cases

In the next sections, the six use-cases of CODECO, numbered from P1 to P6, shall be described based on the following format (rf. to 1.2, Methodology):

- **Scope**. Provides the reader with a high-level description of the use-case.
- **Description**. Provides, via a tabular format the fine-grained description of the use-case. The metadata for the attributes of the use-cases is provided in Annex I.
- **Business impact**. Explains the key drivers and impact for each of the proposed user journeys in each use-case.
- **System architecture**. Provides a visualization and additional details for the setup of the use-cases (WP5).
- **UML use-case diagram** provides a visualization for the triggering of the user journeys in each use-case.

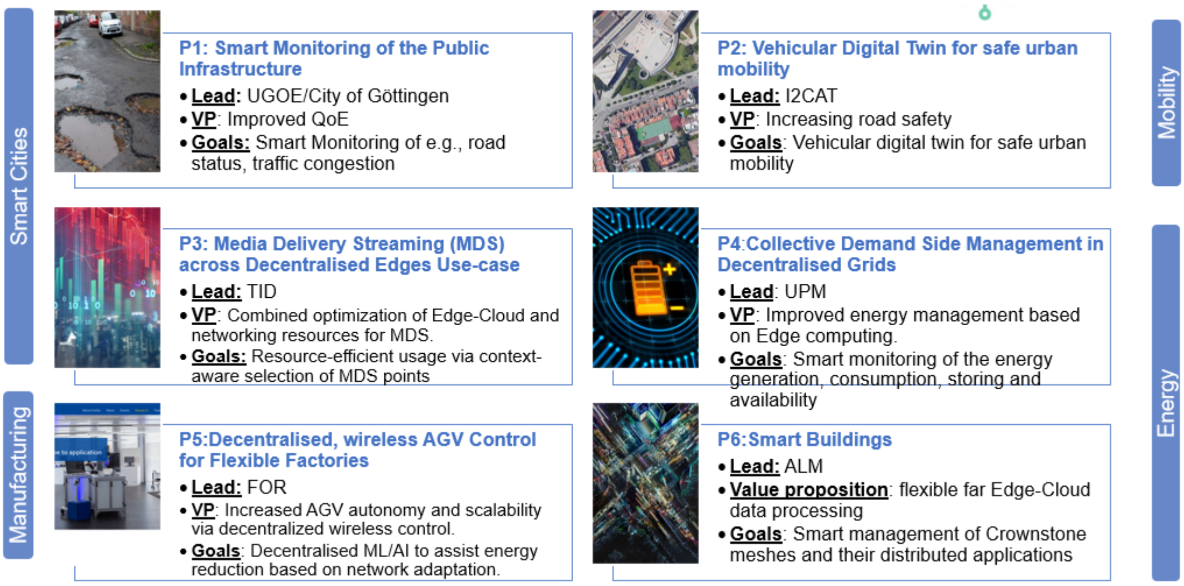

Figure 3: The CODECO use-cases.

2.1 P1: Smart Monitoring of the Public Infrastructure

2.1.1 Scope

In recent years, there has been a remarkable increase in the use of Smart City solutions aimed at benefiting both residents and visitors. Those usually are achieved by leveraging advanced technology and data analytics to monitor traffic/ detect pedestrians, etc. The data collected from various sensors and devices is transmitted and analysed to optimize traffic patterns/ city planning and improve the quality of life for everyone. Now, with CODECO we can achieve a more connected, efficient, and sustainable solution. CODECO addresses the demand for handling large amounts of data in smart cities, including those with low latency demands. It is capable of orchestrating data flow across diverse features, both in terms of computation and networking. Besides, CODECO ensures a smooth and secure integration of data across Edge-Cloud environments. This ensures that data flows seamlessly and securely from Edge devices to the Cloud and vice versa, enabling end-to-end integration of smart city services. CODECO's decentralized approach to orchestration, along with its ability to deploy services in isolated, self-sufficient containers, offers great flexibility and adaptability. This means that smart city services can be deployed and executed in any environment, and the networking infrastructure can adapt to the needs of the services and the surrounding environment. This helps in creating a more resilient and adaptable smart city infrastructure.

The global purpose of P1 is to improve traffic flow and pedestrian safety in the city of Göttingen and assist in strengthening the existing Smart City concept through the implementation of a road monitoring and analytics system at the far Edge. This system comprises two parts: traffic monitoring at the city periphery, and pedestrian distribution monitoring in the city centre. By collecting and analysing at the Edge valuable data on traffic and pedestrian behaviour, this use case aims to optimize management, reduce congestion, and enhance overall pedestrian safety and comfort, while also providing valuable insights for city planning.

In the initial phase of the pilot, P1 will focus on two specific zones in Göttingen: the city periphery, which experiences high volumes of vehicular traffic, and the city centre, where pedestrian activity is most concentrated. On a first phase of operation, these two areas shall be considered to integrate a single cluster (together with the Cloud server(s) operated by the city and UGOE). On a second phase, the two areas shall be configured as two distinct clusters.

The periphery of the city will be equipped with a combination of thermal cameras, computing units, and communication units. This will enable the real-time collection and analysis of traffic data, tracking vehicle counts and congestion levels. These insights will be used to optimize traffic flow, reduce bottlenecks, and improve overall traffic efficiency. In parallel, the city centre will see a combination of LiDARs, computing units, communication units, and using data analytic techniques to track pedestrian movement patterns and density. The data collected will be crucial for improving pedestrian safety, managing crowd flow, and informing city planning initiatives. The back-end data centre can obtain real-time processing results at the Edge and visualize them to the public. As the pilot progresses, the data gathered will be evaluated and used to adjust traffic patterns, modify transport routes, and potentially redesign city layouts to better accommodate pedestrian and vehicular flow.

This pilot scenario, combining technological advancement and data-driven decision-making, is the first step towards transforming Göttingen into a truly smart city, enhancing the quality of life for its residents and visitors alike.

Edge nodes co-located with the cameras represent Kubernetes (K8s) worker nodes; the control plane is expected to reside in the Cloud. Hence, in the context of this use-case, CODECO shall be used to orchestrate (reallocate) resources across Edge-based environments, to assist in the degree of control decentralisation.

2.1.2 Description

The description of P1 in accordance with the metadata provided in Annex I is provided via Table 2

Table 2: P1 fine-grained tabular description.

UC Attribute	Description
Code	Smartcity-P1
Lead	UGOE
Actors	• GOV and municipalities can monitor traffic and get analytics on patterns (e.g., traffic, volumes of cars, bikes, etc.). • Network Infrastructure provider offers network connection. • Cloud/Edge infrastructure provider offers computation and storing resource for analytics. • User DEV, Subscriber (e.g., Citizen) can get information about traffic.
Equipment	• Customized Edge Devices

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UC Attribute	Description
	• Cameras LiDAR, e.g., Livox AVIA1, LSLIDAR CS322 • Thermal cameras such as FLIR Thermicam 23, InfiRay AT614 • Cloud servers: S3 data storage service is provided by GWDG5 • Roadside Units (RSUs) • LoRa/LoRaWAN/5G/Fiber infrastructure
Operational Settings	The use case will be implemented in Göttingen, a city with a vibrant city center and main streets that offer a diverse mix of infrastructure, including designated car lanes, bike lanes, and pedestrian areas, making it an ideal location for testing and validating our solution.
Datasets	• Video/image from thermal cameras – without personally identifiable information (20G/day/camera) • Point Cloud data from LiDARs (20G/day/camera) • Analytics results, e.g., location/density of cars/ pedestrian (500M/day/camera) • Citizen feedbacks
Services to be Integrated	For video processing, including transmission and storage, we require a reliable video compression standard such as H.264. To enable video analytics, we require advanced computer vision tools such as YOLO[6].
Services to be Developed	Deliver highly accurate and timely traffic/pedestrian distribution indicators with the help of CODECO's 's abilities to orchestrate data flows across diverse features (both in terms of computation and networking), integration of data across Edge-Cloud environments, and the decentralized approach to orchestration, along with its ability to deploy the services in isolated, self-sufficient containers.
User Journey #1	**Transportation planning and management** The government and municipalities will have access to real-time traffic analytics, including abnormal alarms, as well as long-term traffic pattern analytics. By automatically collecting and analysing data on traffic behaviour, they can gain insights that can inform decision-making and improve city planning, enhancing traffic safety and efficiency.
User Journey #2	**Property development and investment**: The infrastructure provider and deployer need to carefully consider the selection, deployment, and maintenance of the system, considering the feasibility and costs associated with each step. Once the system is deployed, the infrastructure provider conducts testing and validation to ensure that it is working effectively and providing the desired results.
User Journey #3	**Advertising and marketing** The citizen will have access to real-time traffic information through downloadable apps or public boards, enabling them to plan their travel and make informed decisions about their routes.
Non-Functional Requirements	Privacy protection in video collection and transmission; GDPR Compliance.
KPIs	• The number of installed CODECO toolkits in the city (>30). • The number of CODECO smart app downloads (>30). • Accuracy (>80%) and latency of analytics (<40ms).
CODECO Single-Cluster Functionality	Our chief objective within a single cluster is the establishment and integration of both worker nodes and the master node into the K8s system. Therefore, key aspects supported by CODECO in this use-case are i) zeroconfig and privacy preservation aspects (ACM, PDLC); ii) energy reduction (via PDLC analysis and NetMA monitored network). SWM is used for assisting the selected applications; re-scheduling may be required if the traffic load increases heavily.

[1] https://www.livoxtech.com/de/avia
2 https://www.lslidar.com/product/c32-mechanical-lidar/
3 https://flir.netx.net/file/asset/17428/original/attachment
4 https://www.infiray.com/products/at61-remote-temperature-monitoring-system.html
[5] https://gwdg.de/
[6] https://www.ai4europe.eu/research/ai-catalog/yolo-v5-object-detection

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UC Attribute	Description
	This process ensures a streamlined and efficient structure for our operations. CODECO, with its advanced features, plays an integral role in this setup. Its capabilities, including context-awareness and the facility to reallocate resources across various environments, significantly augment the degree of control decentralisation. Each location equipped with an Edge device with sensors acts as a K8s worker node. This structure reinforces the system's scalability and resilience, ensuring that each Edge device can perform computations and data processing independently while still being part of the larger network. To further enhance the capabilities of these K8s worker nodes, we implement a set of functionalities. These are bifurcated into two key categories: one aimed at traffic monitoring, and another focused-on pedestrian distribution monitoring. This modular approach allows us to deploy, update, and scale each service independently, providing a resilient system that can quickly adapt to changing requirements.
CODECO Multi-Cluster Functionality	During the first phase of deployment, P1 shall focus on a single deployment, one cluster. For a latter phase (M18-M36), we shall consider a federated-cluster scenario, where the clusters are deployed across the city (identification to be done until M18).
CODECO Components and Technologies	• **ACM**: Adapt to the needs of the applications being run in a secure way. • **MDM**: collects metadata describing new local datasets and the lineage of data as it is replicated across the Edge/Cloud, enabling fast, accurate orchestration of data processing. • **PDLC**: Integration of user behaviour (context awareness) and support for local data analytics. • **SWM**: Support dynamic offloading where content on-demand is based on user-centric behaviour (e.g., people's interests). • **NetMA**: Network adaptation based on traffic volumes.
CODECO Objective	O4: To support multi-domain Edge Cloud operations integrating openness and greenness
Risks	• R1: Privacy issues, e.g., in video collection. • Countermeasure1: Introducing Lidar and thermal cameras eliminates the need for RGB data collection by capturing depth information with laser technology. It safeguards privacy by avoiding capturing sensitive information, such as faces or messages
Milestones	**P1.1** – design of the use-case (functional design, topology, equipment, etc.); definition of phases of deployment – M3, D8 **P1.2** – inception event, use-cases (M12, WP6) **P1.3** – integration in the lab, full setup, initial experiments (M18, D27) **P1.4** – single cluster demos, experimentation, and validation; community engagement (M24; CODECO workshop) **P1.5** – final demos, showcase (D18, D20; M36)
Implementation Timeline	**M1-M3**: WP2, T2.1, the initial design of the SmartCity-UC1 interactions with city Göttingen. **M3-M6**: WP2, WP5, integration of CODECO components (WP5); input in the first CODECO event. **M8-M20**: integration, deployment, collection data, model building, and experiments; community engagement. **M20-M30**: refinements and emo preparation; analyse possibility to deploy demos in operational environments; prepare work to the CODECO workshop; eventually to a democamp (WP7). **M31-M36**: refinements, experiments, tutorials, and demos; D18, D20; show-case events and demos.
Planned HW Infrastructure	• Compute nodes: 5-10 Edge nodes, each with 8 CPU cores and 8/16GB of RAM

UC Attribute	Description
(Compute Nodes/ Network)	• The infrastructure can be scaled up to 50 compute nodes without significant performance degradation. Beyond a threshold, additional network upgrades may be necessary to maintain acceptable latency and bandwidth.
Application (types)	• Application server component that manages user requests and provides access to the database. • Database server component that stores and retrieves data. • The application server needs to be stateful, so migrating it to another server can be complex and requires careful planning. • The application and database servers need to run on-premises due to security and compliance requirements.
Deployment criteria/KPI	• Minimize bandwidth costs: we want to consider the bandwidth usage of each compute node and factor that into our decision-making process when deciding where to place workloads. We may also want to consider the bandwidth costs associated with network connections, such as those incurred when data is transferred between nodes. Overall, our goal would be to choose a deployment strategy that minimizes our bandwidth costs while still meeting our performance and reliability requirements. • Bandwidth cost: < 10G/month/camera • Overall detection and counting accuracy: >= 80% • System latency: <= 40ms • Rate of occurrence of failure (ROCOF): <= 5%
Deployment flexibility	The data storage components have a constraint of being restricted to a single node with adequate memory. Additionally, certain components will require deployment within the premises of buildings connected to public/private networks. MDM shall be used to assist in detecting potential compliance issues.
Metadata Requirements	• Resource utilization data (e.g., CPU, memory, network usage) of each compute node and application component. • Latency and bandwidth measurements between different components of the application. • Information on data sources and sinks used by the application, including their format, schema, and location. • Application-specific parameters and configurations, such as model hyperparameters or algorithm settings. • Application-level metrics, such as accuracy or throughput. • Security-related metadata, such as user access control and encryption settings. **More info about this topic is available on the P1 metadata description in Annex II.**

2.1.3 Business Impact

A smart city application focused on traffic has the potential to revolutionize the field of traffic planning and management. Through the provision of real-time information on various traffic elements, including vehicles, pedestrians, cyclists, and motorcyclists, this technology can significantly contribute to urban traffic optimization, accident prevention, and various other aspects of transportation efficiency and safety.

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A summary of the business impact for the different proposed user journeys is as follows:

- **User Journey #1 Transportation planning and management:** The real-time traffic data collected by the road usage monitoring system can be used to optimize transportation planning and management in the city. This can benefit businesses that rely on efficient transportation and logistics, such as delivery services, public transportation companies, and trucking companies.
- **User Journey #2 Property development and investment**: The pedestrian distribution monitoring part of the system can provide valuable insights into foot traffic patterns in different areas of the city. This information can be used to make data-driven decisions about property development and investment. Real estate companies and property developers can use this data to identify high-traffic areas and make informed decisions about where to invest in new properties or develop existing ones.
- **User journey #3 Advertising and marketing**: The data collected by the system can also be used for advertising and marketing purposes. For example, businesses can use the data to identify high-traffic areas and strategically place their ads in these locations. This can help businesses reach their target audience more effectively and potentially increase sales.

2.1.4 System Architecture

Figure 4 provides a high-level perspective on the proposed system architecture considering one cluster deployment, detailing both non-CODECO and CODECO components. The K8s control plane with the respective CODECO nodes is represented to run in the Cloud but may also be deployed at the near Edge. The worker nodes are deployed in Edge nodes co-located with cameras across the city.

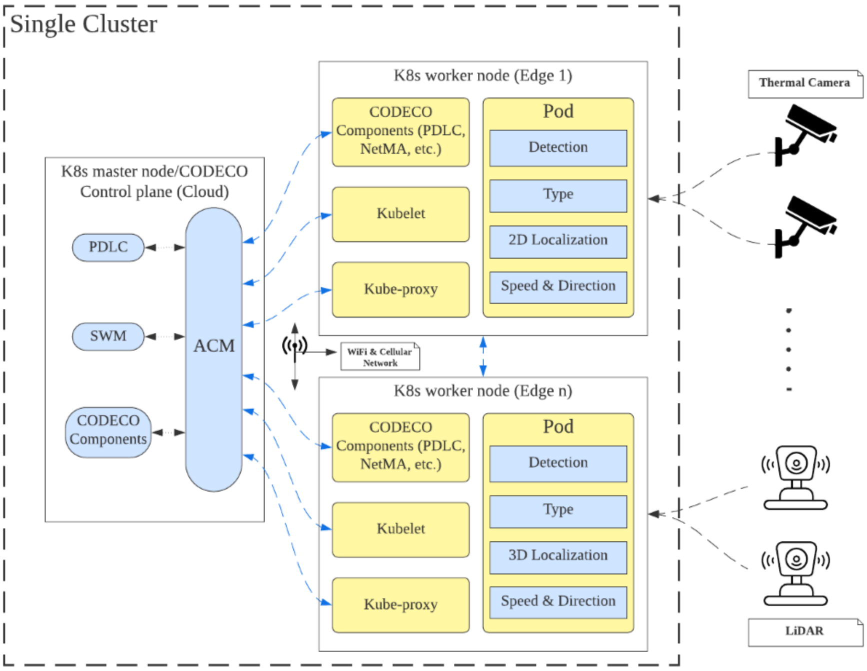

Figure 4: P1 system architecture.

As illustrated, there are CODECO components and non-codeco components.

Non-CODECO components deliver highly accurate and timely traffic indicators such as vehicle counting, traffic density, and traffic flow by using thermal camera sensors. With this data, cities can have an overview of the number of vehicles entering/leaving Göttingen, monitor traffic patterns, and use the information to reduce congestion. This information can also be used to identify potential bottlenecks or problem areas in the transportation system, allowing officials to proactively address issues before they become major problems. In addition, this information could be used to optimize existing infrastructure to better meet the needs of residents and visitors. These components will also deliver highly accurate and timely pedestrian distribution indicators such as pedestrian counting, pedestrian density, and pedestrian distribution heat map by using the LiDAR sensor. It can be a valuable tool for city planning. On the one hand, it can help the city to have an overview of the number of pedestrians in some key areas in Göttingen city centre. On the other hand, it can help to understand pedestrian traffic patterns: Heat maps can provide the city with a visual representation of where pedestrians tend to congregate, move, and dwell in public spaces. By analysing these patterns, the city can identify high-traffic areas and prioritize them for improvements, such as new crosswalks, street furniture, or public amenities.

CODECO Components shall be placed both at the Cloud (K8s master node) and Edges (K8s worker nodes). For each location chosen for implementation, we will outfit it with an Edge device equipped with an array of sensors such as thermal cameras or LiDAR systems (rf. To section 2.1.2). In this use-case. An Edge node will be the same as a K8s worker node. This arrangement ensures the autonomous computational and data processing capabilities of each Edge device, all while remaining interconnected within the larger network. The data collected by these devices, including video and point Cloud data, must be pre-processed, and stored locally. This local storage of data is a crucial step that allows for future reference, audits, and given the sensitivity of the data to outflows from the specified area.

As briefly explained in section 2.1.2, CODECO is useful in the context of this use-case to support a smooth deployment and management of Edge nodes (e.g., managing nodes going down; new nodes entering the system). CODECO is also instrumental in the creation of a privacy-preserving environment for data analytics.

2.1.5 UML Use-case Diagram

The initial proposed workflow for P1 is illustrated in Figure 5, for a single cluster deployment, considering the two categories of users in CODECO (user DEV) and normal K8s users. User DEV shall rely on CODECO to assist in a lower effort deployment of the P1 Edge nodes across the city. Regular users shall rely on the developed applications, thus relying on CODECO to ensure privacy preservation, compliance, and energy-awareness.

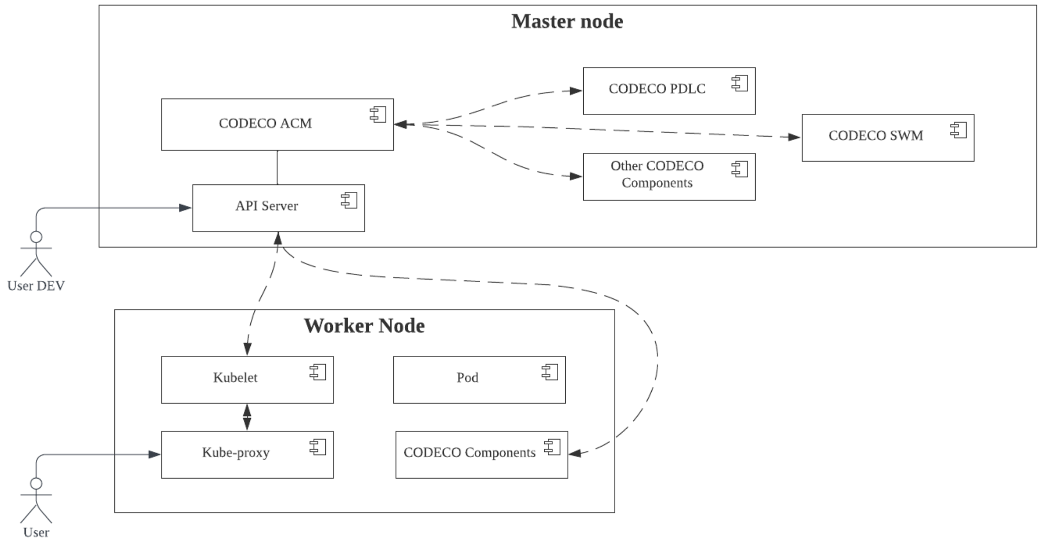

Figure 5: P1 UML diagram.

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2.2 P2: Vehicular Digital Twin for Safe Urban Mobility

2.2.1 Scope

P2 makes use of the CODECO framework to support a Vehicular Digital Twin aimed to improve the safety of *Vulnerable Road Users (VRU)* in Urban Environments. Any mobility oriented Digital Twin requires the extensive deployment of ultra reliable low latency services around the area it supports. Starting from the V2X communication capabilities to Computer Vision (CV) detectors capable of tracking all the moving parts within the mobility environment. For this reason, the current use case relies on *V2X Roadside Units (RSUs)* and cameras to gather all the necessary information to track vehicles and pedestrians and then feed it to the vehicular Digital Twin, which will detect dangerous situations or behaviours and alert them.
The deployment and scalability of this service has challenges around the infrastructure side, where the information should be processed as close as possible to the V2X nodes and ensure low latency communications. This, in turn, translates to always having a fresh track of all the moving parts.
The pilot scenario focuses on the mobility environment of the interior and adjacent street of a UPC campus known as “Campus Nord” in Barcelona, which is located next to the I2CATs offices. This environment offers an interesting balance with walkable pedestrian zones that include bike lanes, as well as car lanes on the adjacent street. It encompasses a mix of various transportation modes, with *Vulnerable Road Users (VRUs*) playing a central role. However, VRUs can find themselves in dangerous situations when sharing spaces with cars. Which addresses the UC being presented.
This scenario presents an ideal testing ground due to its size, allowing for the examination of multiple areas and their respective control measures. Additionally, it provides a diverse representation of all transportation modes commonly found in urban environments. Consequently, this scenario offers the perfect setting to assess and address the challenges associated with different modes of transportation, ensuring the safety and efficiency of urban transportation networks.

2.2.2 Description

The description of P2 in accordance with the metadata provided in Annex I is provided via Table 2

Table 3: P2 fine-grained tabular description.

UC Attribute	Description
Code	Mobility-P2
Lead	I2CAT
Actors	• **VRUs**. A VRU, refers to vehicles or transport users who lack physical protection while navigating roadways, making them more susceptible to harm. They require heightened caution from both them and drivers to ensure their safety on the streets. Their role is to move around and expect to be advised when engaged in dangerous situations. Their goal is to prove that they can be safer thanks to the infrastructure services and the notification through V2X. • **Pedestrians**: They will be equipped with a smartphone and tracked by the camera. Are the most vulnerable ones. • **Light Mobility Vehicles (bike or electric scooter**): Equipped with an OBU or smartphone and tracked by a camera. They tend to get in riskier situations due to its speed and fragility. • **Cars**: Equipped with an OBU. Can find themselves in dangerous situations when sharing mobility spaces with lighter, more vulnerable, modes of transportation. Their role is to move around the car lanes and engage in risky behaviours with VRUs and to proof that the dangerous situations are avoided when detected by the system and notified.

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UC Attribute	Description
	• **Cameras:** The cameras, which will be connected to the corresponding service. Will spot VRUs that are not connected. And notify them of their position and track to the infrastructure. Their role is to detect the position and trajectory of all the moving entities that are not connected. To then pass this information to the infrastructure. Their goal is to make sure the use case works even when there are some vehicles or pedestrians not connected. • **V2X RSUs.** They will be the point of contact from the vehicles and UC users and the infrastructure. There will be some of them to ensure full coverage of the use case scenario. They will need to ensure minimum latency to the infrastructure. Their role is to serve as point of contact between the infrastructure and the V2X environment. Their goal is to make sure the messages emitted by the OBUs, or the infrastructure are mutually received.
Equipment	• On Board Units (OBUs) developed by I2CAT with LTE-V2X and 802.11p compatibility based on Gateworks hardware.[7] • Smartphone • RSUs developed by I2CAT with LTE-V2X and 802.11p compatibility, based on Gateworks hardware. • - Cameras • - Cloud servers • - Edge nodes • - Smart 5G CPEs
Operational Settings	The use case will be set up next to the I2CAT's offices, where there is a university campus and one of the biggest highways in Barcelona. Such an environment provides the perfect mix of car lanes, bike/electric scooter lanes and pedestrian areas.
Datasets	**Datasets previously obtained:** • Real-time synthetic data from cameras and V2X RSUs, produced with the simulators CARLA[8] and OMNet++[9]. • Synthetic data from SUMO[10] dangerous trajectories datasets. • Trajectory predictions generated by AI/ML components (Predictions already done produced with the information simulated). **Data collected (Datasets that will be produced):** • Positions and trajectories of all vehicles and pedestrians moving around the environment.
Services to be Integrated	On the vehicular communications side there will be the need to integrate the ETSI C-ITS protocol stack developed by I2CAT, with the following services integrated: • VRU basic service • DEN basic service • CA basic service On the sensor side, there is a need to integrate the open *Computer Vision (CV)* component that can parametrize the position of non-connected VRU. So, from this side: • Road Users detection and positioning through CV. • This requires advanced CV tools as YOLO.
Services to be Developed	• *Local Dynamic Map (LDM)* as a Digital Twin that can work on the Cloud-Edge continuum. • UI capable of handling the information gathered by the LDM
User Journey GOV	The GOV stakeholder will have the availability to see a real time low-latency digital twin of the moving entities around the designated urban public space. Check

7https://www.gateworks.com/products/?gclid=CjwKCAjw-vmkBhBMEiwAlrMeF5wRJQ1uLVZLZTfemQvizG7b8115O3MSqVh7n2EbdPrc-Do8pUV-bxoC9LwQAvD_BwE

[8] https://carla.org/
[9] https://omnetpp.org/
[10] https://sumo.dlr.de/docs/FAQ.html

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UC Attribute	Description
	dangerous behaviour and immediate notifications when any incident happens (along with the place where the incident happened and how it happened).
User Journey ICT	The ICT (both mobile communications and Cloud providers) will use the CODECO framework to achieve reliability and low latency. Which is crucial for the present UC.
User Journey AR	The AR stakeholders will be capable of ensuring through the proper research the viability of a system of Vulnerable Road User Awareness. And provide solid information that reduces/eliminates incidents with that kind of users.
User Journey DEV	The DEVs and especially the early adopters will run around the campus as VRU. And will receive an audio-visual notification. On the other side other early adopters will be using conventional cars that will also notify collisions.
Non-Functional Requirements	Privacy protection and robustness against attacks when emitting V2X messages.
KPIs	KPIs are further debated in section 2.2.3. A summary is as follows: • **Latency**: Average latency (V2V, V2P or V2I) < 50ms. • **Age of Information (AoI):** Average AoI < 70ms; Average Peak AoI < 200ms • **Penalty Age of Information**: The penalty function is the L2-Norm between the estimated trajectory and the real one. • **Average Penalty Age of Information:** < 20. • **Average Peak Penalty Age of Information**: < 50. • **Processing time**: < 5 ms. • **Neighbourhood Awareness Ratio:** must be 100% for distances < 100 meters. There is a tolerance of missing a neighbour for distances from 100 to 300 meters. (Nar above 80%).
CODECO Single-Cluster Functionality	The single cluster functionality involves deploying all infrastructure nodes in the Cloud and orchestrating their replication to different Edge servers based on precise tracking of KPIs. This process may even include artificially introducing potential malfunctions, such as added delays, to ensure that the established requirements set by all KPIs are consistently met. The single cluster functionality is further described in section 2.2.4.
CODECO Multi-Cluster Functionality	To be defined on a later stage of the project (until M18).
CODECO Components and Technologies	• **NetMA**: Ensures the security of communications between the different nodes and set up the different clusters in a transparent way putting focus on the reduction of latencies between nodes. • **MDM**: monitors the compliance aspects and may also collect sensed data, e.g., location, which may assist a better distribution of the application workload. • **PDLC**: PDLC shall provide (via the use of context-awareness) estimations for the "best" Edge (V2X) node (Edge node selection) based on specific constrains (e.g., application constrains) The Context-awareness Agent monitors the compliance of requirements such as low latencies and relies on multiple metrics to select the best position to store the information regarding a V2X node. The PDLC-DL sub-component processes the collected parameters data and provides predictions and suggestions that allow other CODECO components to take more intelligent decisions. • **SWM**: Handles the scheduling/re-scheduling of the application workload, based on the processing (by PDLC) of vehicle or pedestrian characteristics, which may assist on a better placement taking into consideration context-awareness beyond the usual compute parameters considered in K8s.
CODECO Objectives	• O1: To reduce the Edge-Cloud setup and management time via an automated, cognitive approach. • O2: To optimize Edge-Cloud operations via a privacy preserving data-compute-network orchestration.
Risks	• **R1**: Not get the approval of the town halls/municipalities.

UC Attribute	Description
	• Countermeasure 1: As a countermeasure, we plan to deploy the RSUs on the rooftop of I2CAT's and UPC campus offices which are not directly dependent on the municipalities. • **R2**: Poor 5G coverage on some urban areas (despite the system will be resilient to that due to the nature of vehicular communications). • Countermeasure 2: Either usage of LTE without Edge servers (direct to Cloud) for the connections that are not capable of connecting directly to the RSU or deploy private 5G network. • **R3**: Vandalism against the infrastructure deployed. • Countermeasure 3: The idea is to deploy all the infrastructure on inaccessible rooftops.
Milestones	**M2.1**: Development and deployment of a VRU Awareness Service **M2.2.:** Development and deployment of the Vehicular Digital Twin as an LDM; and integration with the Cloud Edge continuum. Also, with the capability of aggregating data coming from multiple sources (like cameras or V2X) **M2.3:** Development and testing of a collision avoidance app that runs over the Digital Twin, and triggers alerts to all the users in the system. [3] **M2.4.:** Orchestration of the different services within the Edge-Cloud continuum Barcelona.
Implementation Timeline	**P5.1**: design of the use-case (functional design, topology, equipment, etc.). definition of phases of deployment – M3, D8. **P5.2**: inception event, use-cases (M12, WP6). **P5.3:** integration in the lab, full setup, initial experiments (M18, D27). **P5.4**: decision, concept for multi-cluster demos (M20). **P5.5:** single cluster demos, experimentation, and validation; community engagement (M24; CODECO workshop). **P5.6:** final demos, showcase (D18, D20; M36).
Planned HW Infrastructure (Compute Nodes/ Network)	The planned HW infrastructure is described in section 2.2.4 (System architecture)
Application (types)	Rf. to section 2.2.4 (System architecture)
Deployment criteria/KPI	The deployment criteria outlined in section 2.2. prioritizes the optimization of performance across all the described metrics. However, to summarize, the primary objective is to achieve superior network performance, particularly in terms of reducing latencies, rather than focusing solely on computational costs or energy consumption.
Deployment flexibility	There are no restrictions on deploying different nodes, allowing each component to be instantiated in parallel across multiple nodes. In certain scenarios, the monitoring of specified metadata may necessitate the instantiation of a new V2XCOM before any other content, primarily to handle the processing of packet headers.
Metadata Requirements	The metadata considered in the current use case is thoroughly explained in the subsequent sections. However, to provide an overview, the list includes the following: • Latency • Age of Information • Penalty Age of Information • Peak Penalty Age of Information • Processing time • Neighbourhood Awareness Ratio

UC Attribute	Description
	• Each of these metrics will be elaborated on in the upcoming sections to provide a comprehensive understanding of their significance and impact in the context of the use case. **More info about this topic is available on metadata description in Annex II**.

2.2.3 Business Impact

A V2X Vulnerable Road User awareness application has the potential to revolutionize the way we think about road safety. By providing real-time information about the location and movements of vulnerable road users such as pedestrians, cyclists, and motorcyclists, this technology can help prevent accidents and save lives. A summary of the business impact expected is as follows:

- One potential business case for this technology is in the public sector. Municipalities and other government agencies responsible for mobility could use this technology to monitor and reduce the number of incidents involving vulnerable road users and other vehicles. By providing real-time data on the movements of these users, the application could help city planners design safer roads and intersections.
- Another potential business case is in the insurance industry. Insurance companies could use the data collected by the application to improve their revenue by accurately assessing risk and reducing the number of claims. The positional and camera data provided by the application could also help insurance companies more accurately determine fault in the event of an accident.
- The automotive industry is also a potential market for this technology. Car manufacturers are always looking for new features to include in their vehicles, and a V2X Vulnerable Road User awareness application could provide an extra layer of safety for drivers. This technology could be particularly useful for vulnerable vehicles such as bikes, electric scooters, and motorcycles.

2.2.4 System Architecture

The Vehicular Digital Twin for Urban Mobility use case follows the System architecture depicted in Figure 6.
Before delving into the intricate details of the interaction between the modules depicted in Figure 6, it is crucial to provide a comprehensive description of the functionalities encompassed by each module:

- **V2XCOM** (or V2XreferenceKit): This module serves as the backbone for handling the ETSI C-ITS protocol stack across various layers, including Network and Transport, Facilities, Security, Management, and certain application layers. It efficiently manages the communication framework required for V2X interactions.
- **Digital Twin** (Local Dynamic Map (LDM) in the ETSI C-ITS standard): Although the LDM resides within the Facilities Layer, it assumes the role of a distinct module owing to its significance as a Digital Twin. This module acts as a repository, meticulously storing and managing all positional and relevant data obtained from V2X communications and computer vision (CV) processing. The LDM holds crucial information that enables a comprehensive understanding of the environment.
- **V2X Forwarder**: Functioning as a V2X application, the V2X Forwarder plays a pivotal role in forwarding V2X packets or, more generally, information through various Radio Access Technologies (RATs). It possesses the capability to aggregate multiple packets into a single coherent unit, when necessary. Additionally, the V2X Forwarder creates V2X

Awareness packets in situations where users without connections are detected through CV techniques.

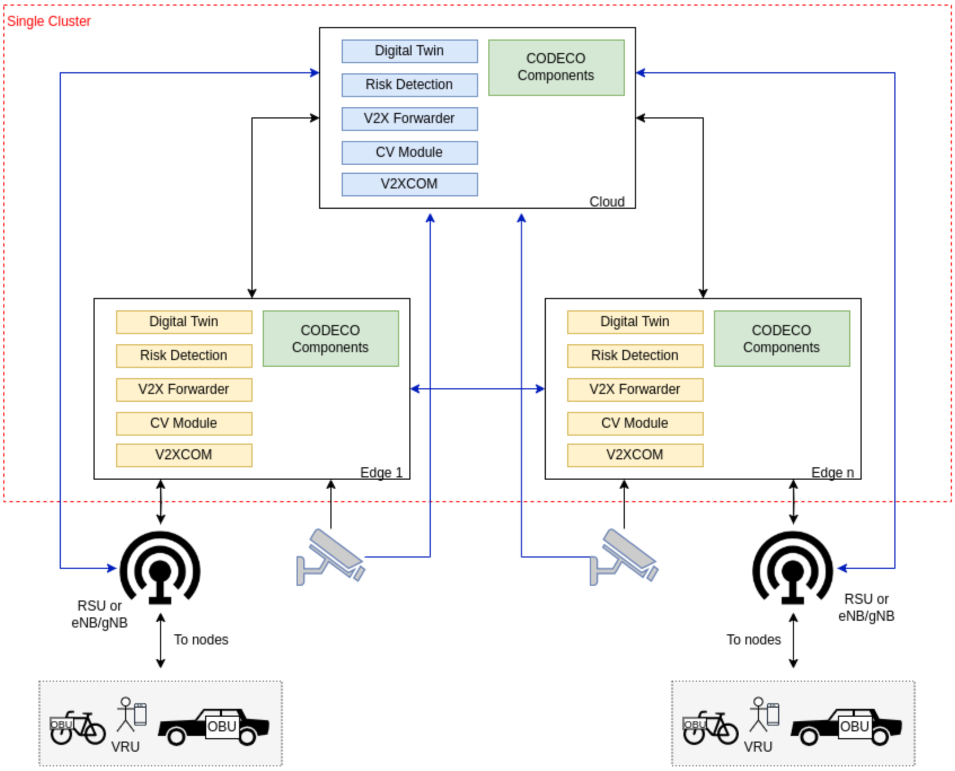

Figure 6: P2 system architecture.

- **CV module**: This module undertakes the task of processing frames captured by one or multiple cameras using the YoloV5 computer vision model. By analysing the visual data, it accurately detects the positions and trajectories of all nodes or entities within the scene. The CV module seamlessly communicates the positions of all detected modules to the Digital Twin, allowing the latter to merge this information with the data obtained from V2X communications.
- **Risk detection module**: As the name suggests, this module focuses on implementing the detection of potential hazardous situations. It constantly assesses the positions, trajectories, and behaviours of all users, utilizing the information stored in the LDM. By leveraging this data, the risk detection module effectively identifies risky scenarios and takes appropriate measures to mitigate any potential dangers.

The deployment strategy for all the modules in the present use case is designed to be flexible, allowing for a versatile topology. Initially, the modules are deployed in a Cloud environment, after which they are orchestrated and scheduled across multiple Edge servers to optimize performance.
Instances of the Digital Twin and V2X Forwarder modules will be instantiated on different Edge servers based on the evolving metrics. The aim is to ensure that all metrics fall within acceptable ranges, prioritizing safety. For example, the CV module may initially run on the Cloud server. However, if the delay between the Cloud and the Edge at a specific location adversely affects message generation for unconnected users, a decision might be made to move most of the computing resources to the Edge while still retaining some in the Cloud.
Another scenario involves packet forwarding. If one Edge server becomes overloaded with processing a substantial number of devices, assistance may be required from the Cloud server or other nearby Edge computing nodes.

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Several key metrics are considered for the use case, including:

- Latency between different modules of the UC application.
- Age of Information, which measures the time it takes for information from vehicles or Vulnerable Road Users (VRUs) to reach the Digital Twin.
- Penalty Age of Information (pAoI), which quantifies the deviation from optimal service or standard constraints through a mathematical function.
- Peak Penalty Age of Information (peak pAoI), which identifies local maxima in the continuous function of pAoI, indicating potential problematic performance.
- Processing time, especially for the CV module, which involves computationally intensive tasks.
- Neighbourhood Awareness Ratio, which is calculated with a delay.

The Digital Twin, also known as the Local Dynamic Map (LDM), is designed to handle only the necessary information for its position. In the case of a new LDM instantiated on an Edge node, it independently manages and coordinates the information related to the area covered by the closest Roadside Unit (RSU).
This approach allows for testing against multiple topologies, such as one where Edge servers can connect with each other, and another where they can only connect to the Cloud. Additionally, artificial delays or breaks can be introduced in the modules to assess the resilience of the CODECO framework in each scenario.

2.2.5 UML Use-case Diagram

The heterogenous sensor-V2X related modules of the present use case interact with each other following the structure shown on Figure 7.

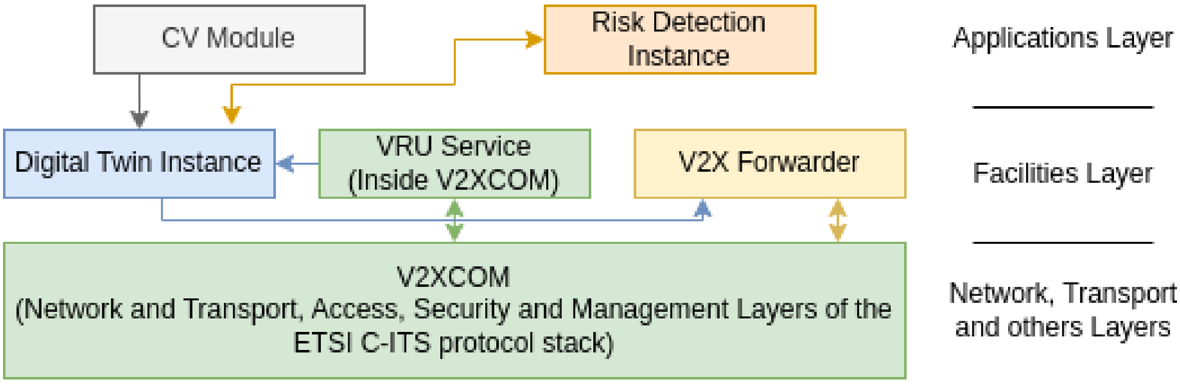

Figure 7: P2 UML diagram.

In addition to the functionalities described in the previous section, it is essential to outline the various information flows between the modules:

1. **V2XCOM to V2X Forwarder**: All packets, regardless of the Facilities standard they belong to, are transmitted to the V2X Forwarder. Each packet is accompanied by information specifying the Radio Access Technology (RAT) it originates from or the unicast IP in the case of conventional mobile communications. The V2X Forwarder then determines whether to forward the message to other RATs and unicast Ips (using the V2XCOM module) or ignore it altogether.
2. **Digital Twin to V2X Forwarder**: Certain packets received from the V2XCOM module may be ignored by the V2X Forwarder. This occurs because the V2X Forwarder awaits queries from the Digital Twin to aggregate multiple messages and achieve the same effect as directly forwarding the packets.

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3. **VRU Service (V2XCOM) to Digital Twin**: Whenever a new Vulnerable Road User (VRU) Awareness Message (VAM) is received, it undergoes processing, and its information is directly stored in the Digital Twin. Digital Twin serves as a repository for VRU-related data.
4. **Digital Twin to Risk Detection Instance**: The Risk Detection Instance continually receives updates on the positions and trajectories of all moving entities from the Digital Twin. With each update, the Risk Detection Instance assesses the potential for dangerous situations. If a hazardous situation is identified, the Risk Detection Instance notifies relevant parties.
5. **CV Module to Digital Twin**: The CV Module continuously processes images captured by associated cameras and extracts positional information from the detected nodes. This positional information is promptly stored in the Digital Twin, allowing for comprehensive data integration.

These information flows ensure efficient communication and coordination between the modules, enabling the exchange of crucial data for the proper functioning of the system.

2.3 P3: MDS across Decentralized Edge-Cloud

2.3.1 Scope

P3 focuses on the smart and efficient distribution of media content (e.g., video streaming, gaming, Augmented Reality/Extended reality (AR&ER) across a multi-domain, multi-cluster Edge-Cloud. The use-case therefore leverages on a combined optimization of both connectivity (from the underlying transport network) and computational resources (supporting the MDS streamers and distribution logic).
P3 promotes a tighter computational/networking integration and optimizes the overall resource usage while reaching a good level of *Quality of Experience (QoE).* To reach this, the use-case focuses on an interaction between a *Media Delivery System (MDS),* via CODECO, and the CODECO component NetMA which shall rely on a decentralized concept of the IETF ALTO protocol[11] to expose capabilities (e.g., topological information together with associated metrics, available resources, or functions) that promote joint adaptation.

The key aspects to be demonstrated concern:

- demonstrating the CODECO informed orchestration of virtualized delivery points with the purpose of selecting the most appropriate Edge facility- according to specific constraints in both the Edge-compute (CPU, RAM, or storage) and the network sides (i.e., latency, bandwidth),
- obtaining a real-time, updated view of the network status, for instance due to optimizing the delivery, for triggering on-demand instantiation of Edge delivery points.

2.3.2 Description

The description of P3 in accordance with the metadata provided in Annex I is provided via Table 4.

Table 4: P3 fine-grained tabular description.

Attribute	Description
Code	Smartcity-P3
Lead	TID
Actors	• MDS platform owner. • Network Infrastructure owner. • Cloud/Edge infrastructure owner. • MDS content owner. • MDS subscriber.
Equipment	• Servers for hosting MDS. • Network equipment for distributing MDS content. • VMs/containers for emulating content caches and consumers. • VMs/containers for implementing probe systems.
Operational Settings	**Virtualization / containerization of MDS delivery endpoints.** This can be done using a virtual environment with Kubernetes or similar. **Virtualization / containerization of probes**. This can be done both with a virtual environment with Kubernetes (or similar, e.g., OpenStack). Interfaces for orchestrating the placement of all of them. The data exchanged and the type of interfaces should be studied deeply during the definition of the architecture, but mainly for this UC, what is required is the following: (1) between

[11] https://datatracker.ietf.org/wg/alto/about/

Attribute	Description
	the network and the client (i.e., the application-service provider) an interface (API REST for example) to expose/access the network characteristics; (2) another interface to trigger the required connectivity; and (3) for each domain (either network or compute) the enablement of advertising network information and characteristics. **Exposure of network metrics and topology**. There is a need of obtain network resource information. For that purpose, it is required to have a protocol to extract topology information, such as BGP or LLDP. Furthermore, collection of metrics should be performed for complementing the topological view. **AI/ML processing capabilities.** Using AI/ML algorithms instead of a traditional algorithm can help improve results. The environment should be able to support this type of tool (data processing, storage, definition of algorithms, etc).
Datasets	**Potential datasets:** • **User demand/preferences** with respect to the MDS contents. This information may be a JSON file with a list of requirements and preferences as well as traffic information as expected BW required, points of exchange or time slots. This information can be pre-existing data, not being too important the variance in time. • **Network, computer and MDS metrics and state**. These datasets provide information about the characteristics of the environment. It could be information retrieved from a network protocol such as BGP or LLDP. The better is having realistic datasets with periodical variances.
Services to be Integrated	Virtualized MDS, network infrastructure and probes for service assurance and decision problems
Services to be Developed	Media
User Journey #1	There are three actors in this use case. The primary actor is the application-service provider (and network capability client). There are also two secondary actors: the application-service client, and the network operator. To be able to provide the information to the main user, the network operator obtains a *Pid_file* and *cost_map* generated with the inter-AS routing protocol BGP and BGP-LS and it updates them showing information from the network. *PIDs (Prefix Identification)* associated to customer's IP prefixes represent consumers of video streaming. PIDs associated to the connection of MDS streamers represent the potential sources of MDS traffic. As a main actor, the App-server provider wants that each time a client requests it a service, he could obtain an updated network view to complement its internal view. The MDS logic request ALTO to obtain network information before selecting the source to provide the data required: checking network and cost map info from both kinds of PIDs it is easy to match MDS streamers with customers. To select the more convenient streamer in each case, the UC User con complement the RRL (Recurse Requisites List) with the view of the lowest cost between PIDs of MDS streamers and PIDs of customers. For example, for a given PID of customers, e.g., *pid0:0a0a0a01*, the more convenient streamer can be determined from the lowest cost of *pid0:0a0a0a05* and *pid0:0a0a0a06* (assuming the rest of considerations in RRL is similar). If the assignation is possible, it indicates to the App client the IP of the server with the resource.
Non-Functional Requirements	• **Endpoint Authentication**: Even the information is not critical, it is needed an endpoint authentication to avoid data poisoning. • **Interoperability**: System should be multi-vendor and do not have dependencies with the hardware/software used to deploy the UC. • **Maintenance**: System should be easy to maintain and update, having clear documentation about its parts, how it works and how to update it.

Attribute	Description
	• **Reliability**: System should be able to detect a fall and recover from it. Also, should have a failure-resistant deployment.
KPIs	• Efficiency level achieved in the usage of both computer and network resources. • Reaction time reduction in terms of adaptation execution.
CODECO Single-Cluster Functionality	The following is a preliminary design to be refined along the project lifetime. The single-cluster case is centred on the optimal delivery of content to end-users (i.e., subscribers to the MDS system). The functionality can be described as: 1. ALTO module connects to a BGP speaker to obtain network information and integrates it as network and cost maps. 2. Periodically, ALTO updates this information with the information received from the network controller and the BGP speaker. 3. When a network information client (i.e., the MDS system in this case) wants to obtain this network information, it requests the maps via the API REST. 4. The steps 2 and 3 continue periodically. 5. When an application-client (i.e., the end-user as subscriber of the MDS) asks for a resource (i.e., a content), the application-service provider needs to decide the best MDS delivery point to provide the resource. To select the best one, they need to obtain updated network information (for a combined network/compute decision). 6. To obtain this network information, it requests the maps via the API REST. 7. Based on the retrieved information, the MDS performs a combined decision in regards the best delivery point to serve the end-user request. 8. Steps 2, 3 and 4 continue periodically.
CODECO Multi-Cluster Functionality	The following is a preliminary design to be refined along the project lifetime. The multi-cluster case is centred around the optimal instantiation of new delivery points for complementing the footprint of the MDS, and the interconnection of that new instance with the origin MDS delivery point so that the contents are provided to such new instance in an efficient manner (i.e., subject to some quality constraints). 1. ALTO module connects to a BGP speaker to obtain network information and integrates it as network and cost maps. 2. Periodically, ALTO updates this information with the information received from the network controller and the BGP speaker. 3. Based either on received end-user requests, or in some planning decision, the MDS decides the need of instantiating a new delivery point so that the delivery of contents to a set of end-users becomes optimized. To do so, the MDS evaluates the different options (i.e., clusters available) combining both compute and network information, so optimizing the overall decision in terms of resources and performance metrics. 4. Once identified the target cluster, a new delivery point is instantiated and interconnected with the MDS footprint for content injection. 5. The end—users requests for the base of customers that benefit from the new delivery point will be served from such new instance following the single-cluster functionality.
CODECO Components and Technologies	• **ACM**: Leveraging on-specific components to expose information assisting optimal decision to improve resource usage. • **MDM**: MDM supports orchestration by providing real-time event streams with metadata describing the state of relevant data and systems. • **NetMA**: Promotes joint articulation of data, computation, network adaptation via a cognitive approach which exposes function as a service to assisting optimal decision to improve resource usage. • **SWM**: Workload migration can be one of the triggers of instantiation of new MDS delivery points in the Edge-Cloud continuum.

Attribute	Description
	• **PDLC:** provides network estimations requested by NetMA, to assist detection of abnormal patterns and an eventual need for adaptation.
CODECO Objective	O2: To optimize Edge-Cloud operations via privacy preserving data-compute-network orchestration. O3: To provide automated, privacy preserving and secure management of multi-cluster, multi-domain environments
Risks	• **R1**: Inefficient usage of compute and network resources. • Countermeasure1: The inefficient usage of compute and network resources could be due to either not having a proper decision mechanism for selectin the proper delivery point (in single-cluster case) or computing node (in the multi-cluster-one), or either because the information is not fresh enough at the time of taken the decision. To overcome these issues, the objective is first to define and validate algorithms for proper resource allocation, and second to guarantee up-to-date exposure of resource information. • **R2**: Impact on customer QoE • Countermeasure2: At the time of selecting either the delivery point or the computing facilities to deploy a new delivery endpoint, the parameters for decision are expected to be QoS-based apart from availability of resources. An expectation of QoE is not considered. This can be considered as a future line of work in the framework of the project, analysing methods that could permit an estimation of the QoE to be used as an axis for decision.
Milestones	**M3.1:** Creation of network and cost maps from the transport network, including performance metrics associated to them via ALTO protocol. **M3.2:** Integration MDS and ALTO so that the MDS can consume the network and cost maps, taking delivery decisions in consequence. Visibility in ALTO network and cost maps of compute resources available in different nodes of the Edge-Cloud continuum **M3.3:** Consumption of such information by CODECO components for an optimal placement of new MDS delivery points **M3.4.:** Interconnection of new delivery points with the existing MDS footprint, and allocation of new end-user requests to such new delivery points.

Implementation Timeline	Regarding the implementation timeline, different phases are considered:
	• **Phase 1:**
	  ○ single-cluster functionality. Deployment of ALTO in NetMA and creation of network and cost maps, including performance metrics.
	  ○ Interaction with other CODECO components for single-cluster scenarios.
	  ○ Integration of ALTO in MDS logic.
	  ○ Validation of single-cluster functionality
	• Phase 2: multi-cluster functionality.
	  ○ Inclusion of available compute resources in ALTO.
	  ○ Consumption by other CODECO components of network and cost maps with performance metrics and compute resources for placement decisions.
	  ○ Validation of multi-cluster functionality.

Planned HW Infrastructure (Compute Nodes/ Network)	Compute nodes with resources (e.g., CPU, RAM). Network topology between compute nodes with capabilities (network components like switches or routers, network technology, bandwidth, latency).
Application (types)	Media contents with different resolution. To be defined the kind of contents to consider in the use case (most probably streaming)
Deployment criteria/KPI	• For customers: QoE. • For MDS system: in case of requiring instantiation of new delivery points, compute, and network metrics (e.g., CPUs, memory, latency, throughput) to

Attribute	Description
	ensure proper service delivery. The network metrics measurables are latency and hops, the compute metrics measurables are capacity and band weight.
Deployment flexibility	The deployment flexibility will be determined by service and network constraints: QoE, performance metrics (e.g., latency, jitter, bandwidth), location of customer content demands.
Metadata Requirements	At the time of writing, it is not yet clear what kind of metadata can be of interest for the use case. Aspects such as restrictions related to content (I.e., distribution rights) or to location (I.e., geofencing) could be representative of the type of information to influence the delivery of the traffic in the network, or even the selection of the delivery endpoint (or the compute node where to instantiate it). This is left for further study during the refinement of the use case and its implementation.

2.3.3 Business Impact

To fulfil the ever-changing demands of their clients, companies in the telecommunications sector are continually working to improve their services. Customer turnover is one of the most important issues that service companies must deal with. The revenue and profitability of a firm can be significantly impacted by high customer turnover rates. Service providers are making investments in technology that can raise the quality of the customer experience (QoE) to deal with this problem.

One way to reduce costs without a great investment is optimizing the use of the resources available. To archive this, this use case uses exposure capabilities to allow the network client to select the best path according to the nodes and path characteristics and the internal client information. By this, the telecom operator increases service satisfaction improving QoE. This solution allows better resource use, reducing delivery expenses and optimizing the capabilities available in both network and Edge-Cloud.

2.3.4 System Architecture

For the MDS use case, an initial system architecture is defined, which is subject of refinement along the implementation of the use case and the development of the different CODECO components.
For each of the service situations, i.e., single-cluster and multi-cluster, two different system behaviours are exercised.
In the single cluster, understood as baseline case, the MDS will interact with the CODECO components with the objective of optimizing the content delivery considering network metrics in addition to the MDS view of the delivery resources. Such interaction between MDS and CODECO will imply the interaction with the different components (NetMA, SWM, MDM, etc) for multiple purposes. In the following figures, only the NetMA component is highlighted for the only purpose of remarking the interaction with this component for retrieving network information (by leveraging on ALTO).
The operation of P3 in a single cluster is represented in Figure 8. In the single-cluster case, once the end-users request a service to the MDS (step 1), the MDS logic interacts with the CODECO components for retrieving information about the network metrics applicable to the different existing delivery points (step 2). Once this information is retrieved, the MDS analyses the combined compute and network information, including the availability of contents, and takes a decision on what is the more convenient delivery point to serve the end-users (step 3). With that, the end-users access the selected delivery point.
On the other hand, the multi-cluster case is exercise for the optimal instantiation of delivery points across the Edge-Cloud continuum motivated by the presence of end-users in each area.

As before, the interaction between MDS and CODECO components implies the interplay with different components, even though only NetMA is highlighted for simplicity.

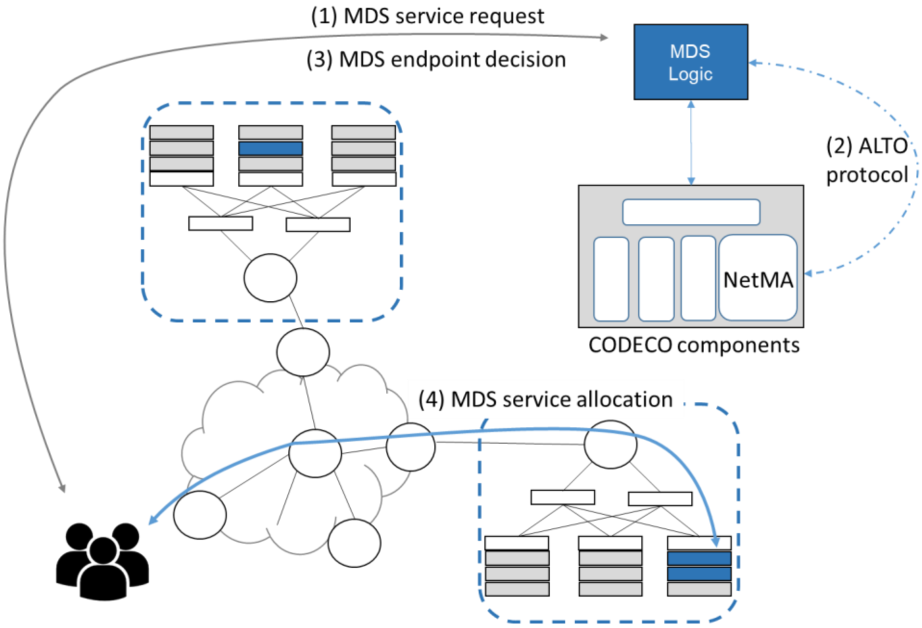

Figure 8: P3 single cluster representation.

In the multi-cluster case , the MDS identifies a (potential) end-user base that can drive an optimization of the delivery system (step 1). To identify the more convenient node where deploy a new delivery endpoint in the Edge-Cloud continuum, the MDS logic interacts with the CODECO components to retrieve potential sites where deploy the endpoint collecting both network and compute metrics (step 2). After processing all that data, the MDS logic will decide where to instantiate the new delivery point, optimized from that perspective. The new endpoint will be interconnected with the Origin MDS node as well with the rest of the MDS footprint by means of L2S-M overlay for feeding contents, etc (step 3). Once the new endpoint is available, the requests coming from the end-users will be served as described in the single-cluster case.

Note that the motivations for the placement of new delivery endpoints can be triggered by other processes and situations, e.g., as for a workload migration triggered by SWM.
As said, the use case will be refined along the progress of the project, so different situations could be documented as part of the single- and multi-cluster cases.

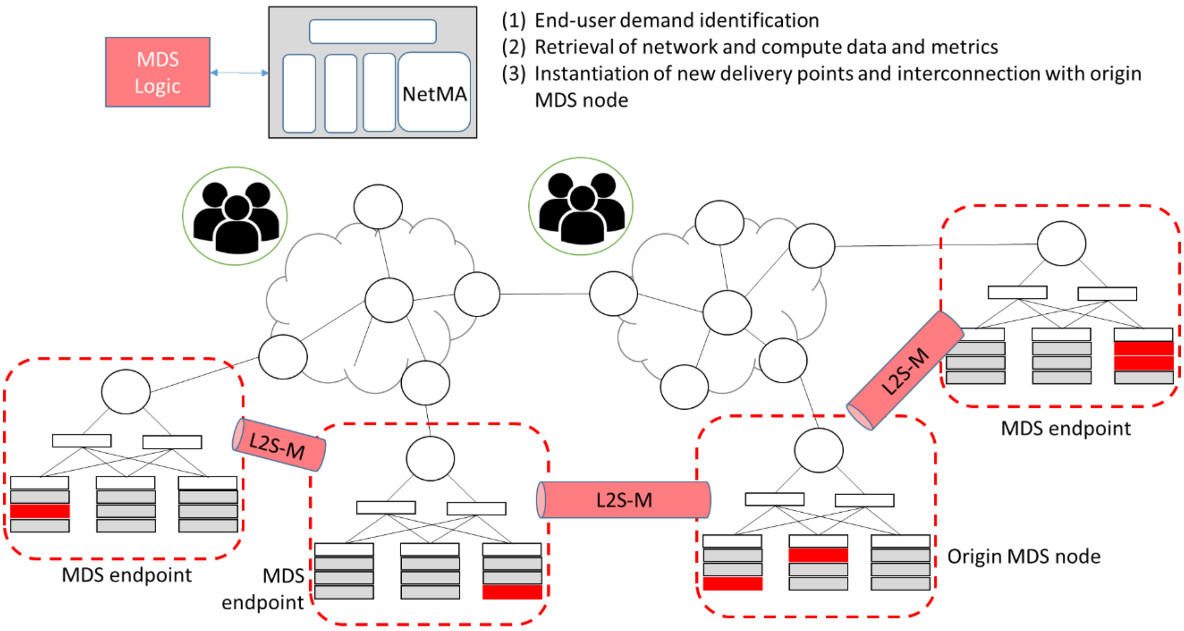

Figure 9: P3 multi-cluster architecture representation.

2.3.5 UML Use-case Diagram

Both single and multi-cluster scenarios can be represented by a UML use case diagram, illustrated in Figure 10. The single-cluster scenario motivates the optimal assignment of MDS delivery point, while the multi-cluster scenario motivates the optimal instantiation of a new MDS delivery point.

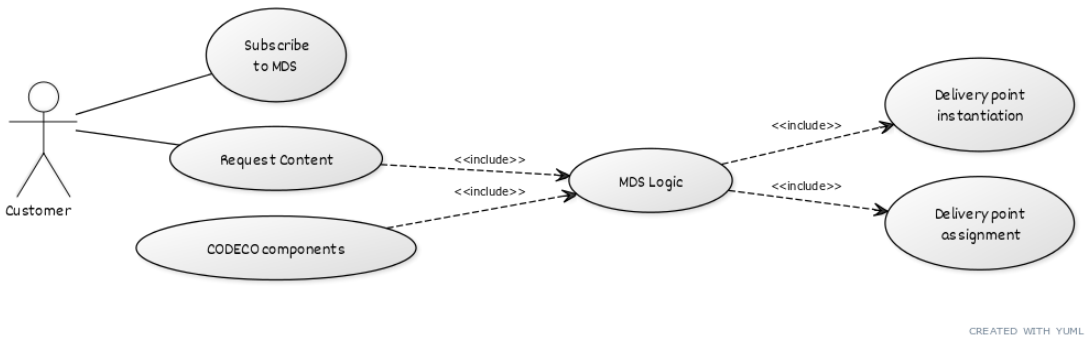

Figure 10: P3 use-case UML diagram.

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2.4 P4: Demand-side Management in Decentralized Grids

2.4.1 Scope

The proposed use case for the distributed energy management system focuses on implementing an active demand response decentralized management system for building decarbonization. It aims to optimize energy usage, improve sustainability, and enhance the resilience of buildings by integrating renewable energy sources and enabling intelligent demand response actions.

The use case also emphasizes the joint orchestration of computational and networking resources to ensure efficient coordination and management of energy-consuming devices and the networking infrastructure within buildings. It focuses on achieving a holistic view of data in the IoT-Edge-Cloud continuum, enabling comprehensive monitoring, analysis, and replication of energy-related data.

CODECO framework leverages the power of K8s to build a decentralized energy management system. By integrating worker nodes (which in this use-case have a correspondence with Edge nodes) and employing the CODECO's developed tools like ACM, PDLC, and modular functionalities, P4 aims at achieving efficient resource utilization, scalability, resilience, and adaptability in energy management operations integrating the energy-related IoT systems and the computing needs.

2.4.2 Description

The description of P4 in accordance with the metadata provided in Annex I is provided via Table 6.

Table 5: P4 fine-grained tabular description.

Attribute	Description
Code	Energy-P4.
Lead	UPM
Actors	Prosumers, Energy Communities, Aggregators, DSO, Cloud/infrastructure providers
Equipment	• Physical Energy Related Equipment • PV Panels • Smart Meters (Generation and Consumption) • Electric Loads • Shift Demand Manager • Electric Vehicle • EV Charger • Computing Equipment (Distributed)
Operational Settings	The use case will be implemented in three University Campus and singular buildings.
Datasets	Energy related data (real generation, consumption, forecasted models, energy price) may be provided
Services to be Integrated	Energy Dashboard
Services to be Developed	• (Energy) Scheduling services • $CO2$ Optimisation models (for decarbonisation) • Energy Cluster configuration • Cognitive Energy Network Optimization System (CENOS)
User Journey #1	UPM aims to be climate neutral by 2030. To this end, it seeks synergies between generation and energy consumption between its different campuses and its buildings. It leverages Edge computing capacity to make its associated

Attribute	Description
	generation and consumption forecasts, and scheduling and optimization models. From them, it decides how to group the different energy assets to achieve the best performance in terms of decarbonisation. This calculation is executed in the Cloud and associated to the physical environment (cluster) defined, where IoT data collected on the real-time operation to take the necessary corrective measures on planning.
User Journey #2	UPM acting as an energy community wants to offer energy aggregation (offering network flexibility and balance services to the system operator and distributors) and charging services for electric vehicles.
Non-Functional Requirements	Trusted Execution Environments (TEE)
KPIs	• Number of buildings involved. (>3) • Energy assets integrated. (>100) • Amount of kilowatt and kilowatt hours of the energy community. (30% UPM consumption) • Amount of energy saved (not bought from the grid). 10-20% • Number of energy clusters created and modified per day. (20) • CO_2 emissions reduction. (>10%)
CODECO Single-Cluster Functionality	P4 can be implemented as a single cluster or a multi-cluster setup. This decision depends on factors such as the scale of the operations and the geographical distribution of the energy assets (linked to Edge devices). In the K8s system, the worker nodes, which for this use-case shall correspond to Edge nodes equipped with sensing capabilities (sensors and actuators), are integrated into the cluster alongside the master node. This integration ensures a streamlined and efficient structure for energy management, allowing the required for distributed computation and data processing. This deployment will take advantage of CODECO context-awareness and resource allocation and optimisation tools, such as the PDLC component. All this information is processed on worker nodes by using federated techniques. In addition to the network management features this UC incorporates specific functionalities focused on energy management. These functionalities are designed to optimize energy generation, consumption, and distribution within the decentralized system. By leveraging the capabilities of the K8s worker nodes, these energy management functionalities enable efficient monitoring, control, and optimization of energy resources. The modular approach allows for independent deployment, updates, and scalability, ensuring that the system can adapt to changing energy requirements and improve overall energy efficiency.
CODECO Multi-Cluster Functionality	The main advantage of a multi-cluster deployment for active demand response decentralized management is increased scalability and resilience. Active demand response systems often deal with a large volume of data and require significant computational resources for real-time decision-making. By deploying multiple clusters, you can distribute the workload across multiple computing resources, allowing for higher scalability. Each cluster can handle a portion of the workload, ensuring that the system can handle increased demand and accommodate growing energy management needs. Multi-cluster deployment enables geographic distribution of computing resources. This can be advantageous for active demand response applications, especially in scenarios where buildings or energy systems are spread across different locations. With multiple clusters, the UC can distribute the workload and balance the computational resources more efficiently. Load balancing algorithms can be employed to optimize resource utilization across clusters, ensuring that each cluster operates within its capacity and workload is evenly distributed. This improves the overall efficiency and performance of the active demand response system.

Attribute	Description
CODECO Components and Technologies	• **ACM**: P4 shall consider ACM to collect and be able to inject to the system energy requirements from the user, e.g., on demand response requirements, such as real-time energy data, grid conditions, and consumer preferences. • **MDM**: P4 expects to rely on MDM to efficiently collect, analyse, and process energy consumption data, as well as relevant contextual information related with buildings. • **PDLC**: P4 relies on PDLC to can apply these techniques to leverage distributed data sources for collective intelligence, enabling insights and decision-making while preserving privacy. • **SWM**: P4 shall rely on SWM to optimize the selection of the infrastructure elements (e.g., node placement) taking into consideration the required allocation of computing resources for real-time demand response decisions, ensuring effective load management and energy optimization. • **NetMA**. NetMA may be used to assist in the exposure of energy data across the whole infrastructure, and to provide an optimal adaptation to the requirements of the system.
CODECO Objective	O4: To support multi-domain Edge Cloud operations integrating openness and greenness
Risks	• **R1:** The regulatory framework for energy communities and energy trading is limited. • Countermeasure1: In a controlled environment, this kind of trading's may be simulated and the advantages of using CODECO analysed. There are several energy services and business models that may be built upon CODECO so a potential energy BM will be carried out.
Milestones	• UC Requirements aligned with CODECO. • Data Collection and Integration. • Demand Response Algorithms and Optimization Models. • Integration with Building Systems. • Pilot Deployment. • Scale-up and Deployment.
Implementation Timeline	• Definition: M1 – M6 • Experimentation: M7 – M36 • Development and Demonstration: M20 – M36
Partners Involved	UPM
Planned HW Infrastructure (Compute Nodes/ Network)	There could be up to two or three computing nodes for each building. The most standard deployment would be one for each one. We can provide servers up to 64 GB RAM and 4 CPUs to virtualize functions. The interconnections between Pods are supported, in CODECO, by NetMA. In the context of P4, we shall rely on a network infrastructure being developed in the Telecommunication School. The interconnection of this infrastructure shall also serve the purpose of testing the capabilities of NetMA to adapt to different network technologies.
Application (types)	• Energy IoT systems use several of the most common interfaces of this kind of solutions (RESTful API, Modbus or WebSocket) • The IoT systems do not need high resources but the models processing data (forecasting, scheduling,) are indeed computationally demanding. • The key element for its optimal functioning is latency. • The data used is simple and does not require excessive bandwidth. • Network restrictions – Some of the actuators on physical equipment may not be manageable in the Cloud.
Deployment criteria/KPI	The most critical criterion in the system, as it is decisive for active demand management, is latency. In any case, as this is a use case for improving energy

Attribute	Description
	management, minimizing the energy impact of nodes and connections is of undoubted value for the pilot.
Deployment flexibility	• There are no restrictions on deploying different nodes, allowing each component to be instantiated in parallel across multiple nodes. • Edge allows to improve the computing of local data, but data may be processed in another site.
Metadata Requirements	Initially, main metadata will regard with information on local datasets to support data sharing and the potential use of distributed learning models.

2.4.3 Business Impact

The business case for a distributed energy management system lies in its ability to optimize energy usage, enhance grid resilience, and enable the integration of renewable energy sources. By decentralizing energy management, such a system allows for efficient utilization of distributed energy resources, including solar panels, wind turbines, and energy storage devices.

With increasing concerns about climate change and the need to transition to a low-carbon economy, the market demand for distributed energy management systems is growing. This demand is driven by factors such as government regulations promoting renewable energy adoption, rising energy costs, and the desire for energy independence and resilience.

The market analysis reveals a significant potential for growth in the distributed energy management system market. The system caters to various sectors including residential, commercial, and industrial, where energy consumers seek ways to reduce costs, improve sustainability, and contribute to environmental goals. Additionally, the integration of advanced technologies, such as IoT, AI, and blockchain, into these systems further enhances their capabilities and market attractiveness.

Key market players in the distributed energy management sector include energy service companies, technology providers, utilities, and energy aggregators. These players offer a range of solutions, including energy monitoring and control platforms, demand response management systems, and virtual power plant solutions.

The impact of distributed energy management systems is multifaceted. They enable consumers to reduce their energy bills through optimized energy usage and by leveraging locally generated renewable energy. Additionally, these systems contribute to grid stability and resilience by balancing energy supply and demand in real-time, reducing the strain on centralized power infrastructure. Moreover, distributed energy management systems foster the integration of renewable energy sources, accelerating the decarbonization of the energy sector. They facilitate the transition from a traditional centralized energy model to a decentralized and democratized energy system.

Overall, the high-level market analysis reveals a growing demand for distributed energy management systems driven by energy cost savings, sustainability goals, and the need for resilient energy infrastructure. The market presents opportunities for innovative solutions and collaboration among stakeholders to transform the energy landscape towards a more sustainable and efficient future.

2.4.4 System Architecture

The system architecture represented in Figure 11 is still in a very initial stage of development. Nonetheless, it shall, for energy management utilizes a decentralized approach, leveraging a combination of Edge computing, Cloud computing, and Kubernetes (K8s) for efficient resource allocation, data processing, and decision-making. The architecture consists of the following components:

- **Edge Devices:** These are devices located at various energy generation and consumption points, equipped with sensors, and connected to the local energy infrastructure. Examples include smart meters, renewable energy sources (e.g., solar panels, wind turbines), and energy storage systems. Each Edge device acts as a worker node within the K8s system, capable of performing computations and data processing independently.
- **Master Node:** The master node serves as the central control plane within the K8s system. It manages and orchestrates the distributed resources and tasks across the Edge devices. The master node is responsible for coordinating energy generation, consumption, and optimization algorithms, as well as collecting and analysing data from the Edge devices.
- **Energy UC Cluster:** The Energy UC cluster consists of the master node and multiple worker nodes (Edge devices). It provides a scalable and resilient infrastructure for managing the decentralized energy system. The K8s cluster handles workload scheduling, resource allocation, and load balancing to optimize energy management tasks.

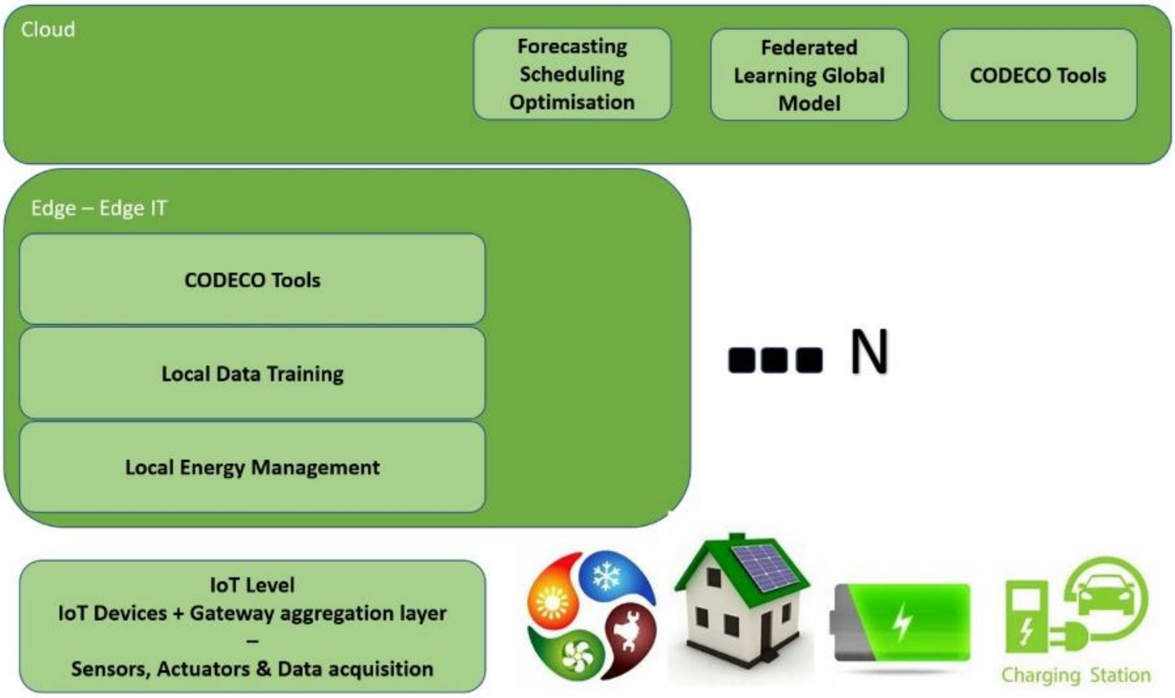

Figure 11: P4 system architecture.

2.4.5 UML Use-case Diagram

The initial proposed workflow for P4 is illustrated in Figure 12, for a single cluster deployment.

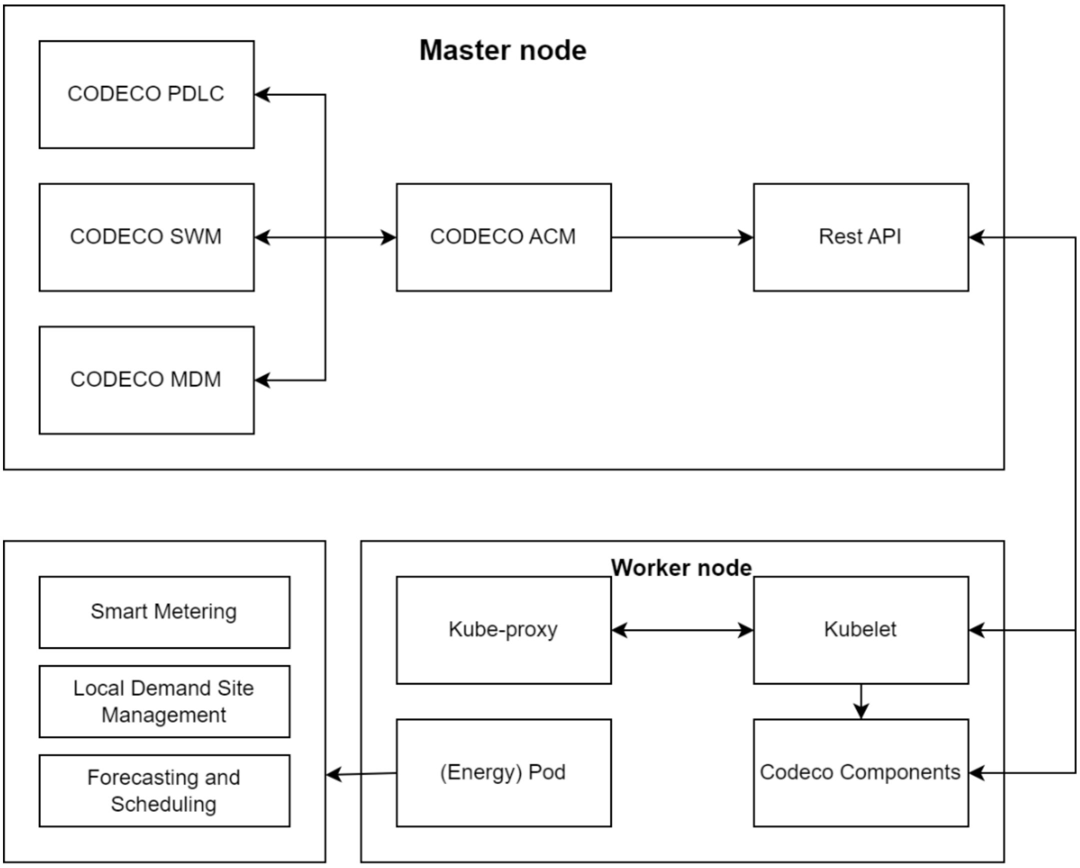

Figure 12: P4 UML use-case diagram.

This UML diagram illustrates the flow of data and control in a decentralized energy demand side management system. The sensors collect energy-related data, which is transmitted to the Edge device for local management execution. The local manager handles real-time decision-making and control tasks. For more complex optimization functions, some computing is offloaded to the Cloud, where advanced algorithms or machine learning models can be applied to optimize energy consumption, load balancing, or other energy-related tasks. Internally in each of the pods, there are three specific use-case components:

- Smart Metering.
- Local Demand Site Management.
- Forecasting and Scheduling.

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2.5 P5: Wireless AGV Control via CODECO for Flexible Factories

2.5.1 Scope

There is today an increasing need to consider *Automated Mobile Robots (AMRs)*, of which one example are *Automated Guided Vehicles (AGVs)* in manufacturing environments, to support the heterogeneous and growing demand of material handling and logistics in flexible factory environments.

While current AGV fleets are based on pre-defined task assignment and pre-defined paths, there is an urgent need to provide a more flexible control to support fleets with a larger number of AGVs, and to support an increasing number of tasks/goods to be transported. By reaching a higher level of autonomy, it is possible to increase overall efficiency while reducing operational costs. The integration of wireless technologies to support the control of AGVs, e.g., 5G, Wi-Fi 6/7, becomes highly relevant and shall be explored by CODECO. However, relying on wireless implies also that the control of AGV systems is prone to interference and intermittent connectivity, thus requiring a higher degree of adaptation which CODECO is expected to provide. Hence, in addition to the wireless connectivity aspects concerning interference mitigation, synchronization, this use-case shall also demonstrate the CODECO capability to proactively adapt the overall network energy consumption and to mitigate interference and failures.

In this context, the use-case shall explore AGVs handling goods within a warehouse, being subject to remote control and requiring real-time support. The use-case expects to be developed in three phases:

- Phase 1, single cluster, static control plane.
- Phase 2, single cluster (multi-master), mobile control plane.
- Phase 3, federated clusters.

AGVs shall therefore expected to carry different micro-services (dockerized), as illustrated in Figure 13 for a single cluster. In this case AGVs shall correspond to Kubernetes worker nodes, while the control plane shall reside on a static node. The AGV micro-services shall be managed via CODECO, being the CODECO components placed across the control and data plane of K8s.

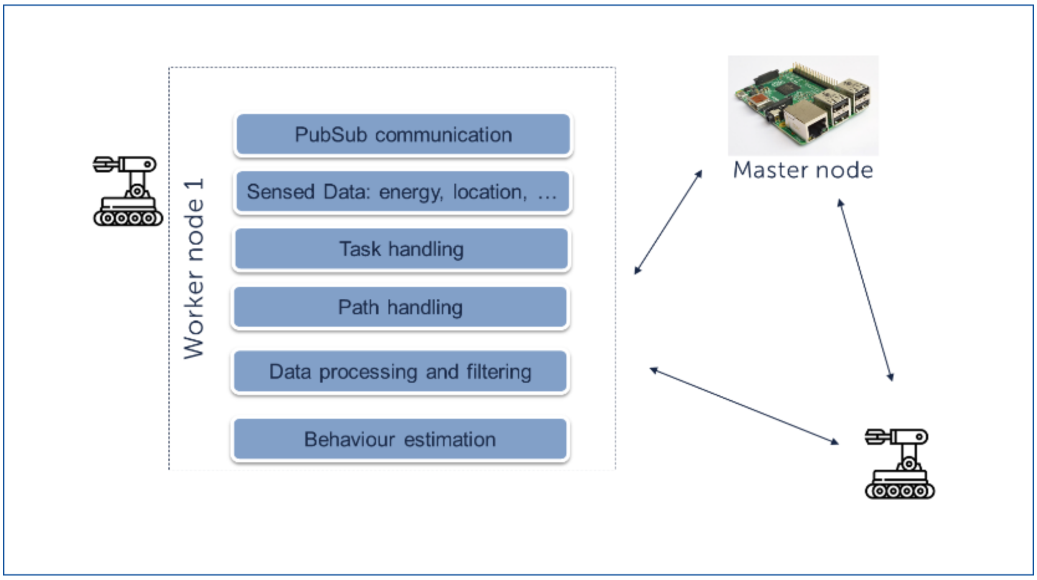

Figure 13: P5, example of micro-services to be deployed in the UC.

On a second phase, the control plane shall also be deployed on a mobile node.
CODECO shall explore distributed ML approaches considering computation as close as possible to data sources; networking features (e.g., available bandwidth); energy awareness, to assist in a higher degree of autonomy. The CODECO framework will be installed across the fortiss IIoT Lab (expected to reach 10 nodes, mobile and embedded).
The experimental environment will be developed based on realistic scenarios, derived from consultation with manufacturing partners. A final demonstration involving multi-cluster domains will be provided together with an external manufacturing partner of FOR.

2.5.2 Description

The description of P5 in accordance with the metadata provided in Annex I is provided via Table 6.

Table 6: P5 fine-grained tabular description.

Attribute	Description
Code	Manufacturing-P5
Lead	FOR
Actors	• **AGVs** (far Edge nodes) – mobile robots with different sensors (e.g., cameras, environmental sensors) • **User**: user DEV, developer willing to deploy the CODECO AGV App; user Operator, human operators, and respective terminals, remotely assisting AGVs. • **AGV fleet Controller** node.
Equipment	• - ~10 nodes (static and mobile): • - Static nodes, max 5: embedded devices, such as RPI 4 • - Mobile nodes, 5-6, Turtlebots • - Industrial AGVs, 2 • - 1 control node (serving station), laptop or embedded device (local or remote)
Operational Settings	The use-case is expected to be deployed in the fortiss IIoT Labs[12]. This is an open, experimental and demo facility. The CODECO testbed shall be interconnected to EdgeNet and to a CODECO Cloud shared space. We shall consider three scenarios (SCx): • **SC1**, a single cluster with at least 3 nodes (minimum configuration, 2 worker nodes, 1 master node) • **SC2**, single cluster, 3 master nodes, multiple subnets (up to 10 nodes) • **SC3** (M25-M36), federated environment with at least 2 clusters, remotely (different floors, or different rooms). It is feasible to discuss with partners and integrate other remote clusters. We are proposing to, on the last year, look for a potential manufacturing entity and propose a joint demonstration.
Datasets	**Potential datasets:** • AGV Tasks (synthetic or real datasets) • Routes (video frames; video metadata) • Other sensed data, e.g., node consumption, CPU, memory, energy; external data, such as obstacles.
Services to be Integrated	• Sensing capability, including local image processing (routes, obstacles). • Task handler (emulator possibly) via a controller dashboard. • Pub/Sub communication (communication between AGVs via MQTT Sparkplug but also possibly via other PubSub approaches, e.g., Named Data Networking[13], coaty.io).

[12] https://www.fortiss.org/forschung/fortiss-labs)
[13] https://named-data.net/

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Attribute	Description
Services to be Developed	• -**Orchestration**, Edge-Cloud (AGV to controller) and Edge-Edge (AGV to AGV). • **Setup and Data analytics.** AGV controller dashboard based on the CODECO orchestration (Web App). • **Performance evaluation dashboard component (Web)** to show differences between a decentralised and centralized approach. • **AGV fleet App**, to allow the user to play with the use-case.
User Journey #1 DEV, ICT, AR	**Deployment of micro-services in an AGV fleet** Rf. To the system architecture in section 2.5.4, where, steps represented in green squares, 1-9, and to the UML schemes in section 2.5.5. The user wants to deploy a new CODECO offered application in UC5 across an AGV fleet and wants also to manage its application workload with K8s/CODECO. For this purpose, the user starts by accessing the CODECO ACM UI (1) via the available dashboard (AGV controller). The dashboard shall interact with the ACM UI, via a specific customization for the use-case. Hence, via the dashboard the user DEV shall be able to select a pre-defined set of micro-services deployed for the use-case (2). For the initial CODECO AGV App, the UC shall provide a basic set of micro-services available, such as the ones illustrated in Figure 2. For instance, PubSub approach such as MQTT Sparkplug or NDN; micro-service for task handling; micro-service for object detection). Some of these services will be mandatory; some will be optional. Then, the user is also requested to enter a set of requirements (3), e.g., key requirements such as latency; size of the fleet (how many AGVs to consider); type of communication (e.g., 5G, Wi-Fi); channel aspects, etc. These parameters serve the purpose of creating the so-called CODECO Application model (YAML file(s)), which is key to adequately schedule resources to be used. Once completed, ACM stores this information (ApplicationModel, CRD format, (4)), making it accessible via the usual K8s methods to other components of CODECO, in alignment with the CODECO CRs/CRDs. SWM starts the initial placement (5). The deployment of the AGV services (ApplicationGroup) is started, being all deployment developed in a single cluster (1 Pod per worker node; 1 AGV corresponding to a worker node) set up by default with all involved nodes that are within range at an instant in time, and that may appear later in the radio range of the controller (6). For the case of an AGV fleet based on multiple remote locations (phase 2), then ACM shall activate the procedures for federated clusters, instead of deployment on a single cluster. Further development aspects shall be considered during the development of CODECO features for federated clusters (M18-M36). CODECO shall handle in addition the required network path handling, by taking into consideration aspects such as interference mitigation, channel properties, etc. This shall be handled via the information collected via NetMA for the wireless interconnections across AGVs (7). If required, routes shall be set to optimize the overall communication (8). The user (DEV) shall be able to observe the existing cluster via a CODECO dashboard (9), and be able to make initial adjustments, if required (9).
User Journey #2 ICT, AR	**AGV Fleet control – Resilient infrastructure** Rf. To the system architecture, Figure 4,steps represented in dark brown squares, 1-9, and to the UML scheme in section 2.5.6. This user journey relates with the runtime management of the CODECO AGV Apps. The aim is to assist AGVs in autonomous navigation on indoor, blocked spaces. Key challenges concern energy optimization and support of intermittent

Attribute	Description
	connectivity. ICT stakeholders relevant for this use-case are mobile communications, Edge-Cloud providers. For this deployment we will investigate existing proposals for AGV communication, e.g., derived from VDMA guidelines and shall consider both a single cluster and a multi-cluster deployment. On a first phase, we shall consider a centralized approach where the central controller has a global perspective on the overall K8s infrastructure (data, compute, network, (1)) which is regularly updated based on data collected via different CODECO components and managed via the CODECO CRs/operators (2, 3). The CODECO PDLC performs, for this specific scenario, an analysis of robustness of the overall graph, and of the existing links in terms of energy consumption across a pair of nodes, as well as in terms of channel conditions, RTT, between two nodes (4). It can propose an adaptation of the overall communication infrastructure derived from functional and non-functional network requirements to the SWM scheduler (5) which shall then decide on whether to adapt the overall infrastructure (6). Additional re-scheduling supported by CODECO shall take into consideration aspects such as energy consumption. If an AGV is expected to run out of battery in x seconds, then its micro-services shall be passed (replicated or offloaded) to another suitable AGV, automatically selected by CODECO based on the Application model requirements provided by the user. On a second phase, we shall consider a decentralized approach, where each AGV shall be responsible to transmit its own perspective of the K8s infrastructure at an instant in time to other AGVs. The infrastructure data (data observability, computation, network) is regularly updated by different CODECO operators (2) to the CODECO control plane, which now shall consist of a multi-master cluster. The selection of 3 master nodes per cluster, to ensure resilience, shall be done based on NetMA input (1) to ensure a stronger resilience to failures.
Non-Functional Requirements	• **Scalability**, capability of CODECO to cope with an increasing number of application deployments across variable fleet sizes (large, heterogeneous) and towards mobile devices. • **Privacy**, capability of CODECO to manage a varying infrastructure across a single or different locations (multi-domain environments). • **Resilience and availability**, capability of CODECO to support five nines system availability in the verge of network interference and intermittent connectivity.
KPIs	• **Operational**: number of nodes supported (at least 5); reduction in failures (resilience). • **Strategic**: better and sustainable performance, reducing the required energy consumption and increasing resilience in mobile environments • **Societal**: reduction of stress (reduced human intervention).
CODECO Single-Cluster Functionality	The key aspect we want to test within one cluster deployment is the elasticity added to the K8s system both during application setup and runtime. Context-awareness, behaviour estimation and capability to reschedule resources in heterogeneous, mobile environments are the key aspects supported by CODECO in terms of a higher degree of control decentralisation. In Phase I , each AGV is a K8s worker node and a CODECO node. Sensed data locally stored; may be pre-processed; PDLC-CA is therefore a service active in each AGV. In terms of application workload, a set of micro-services has been described and shall consist of tasks to be handled; sensed data that may assist the navigation and the overall application replication or offloading; routes. These correspond to 3 categories with different features (scarce datasets, dense dataset; different requirements in terms of real-time exchange across AGVs). On this first phase, sensed data collected on each AGV (CODECO node/k8s worker node) still needs to be passed to the CODECO control plane, which is co-located

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Attribute	Description
	with the K8s Master node. Here, data is expected to be analysed, eventually aggregated, and sent back. Updates to the CODECO CRDs are also expected. Moreover, AGVs are mobile, so connectivity between Pods is intermittent. CODECO will help in both the deployment of Pods and in increasing robustness across the Pod overlay, via behaviour prediction. On a second phase, we shall consider as explained a decentralized control approach, where each AGV can directly communicate and pass their graph to other AGVs. In this context, this implies that there are 3 master nodes per cluster and hence, a distribution of the CODECO control plane as well. The key aspect being addressed is redundancy. In this context, CODECO shall also assist in selecting the master nodes, considering aspects such as channel state, or interference, or node aspects, such as energy.
CODECO Multi-Cluster Functionality	During phase 3 (M18-M36) the use-case shall consider a deployment involving an AGV fleet across two locations. In this context, during Application setup and in addition to scalability the key aspects to address concern privacy preservation across remote environments (federated clusters). A second relevant aspect related with the application runtime is the capability of CODECO to further assist the network adaptation across multi-domain environments, in a way that can still serve requirements such as expected latency, or a reduction in the overall energy consumption of the system across different locations.
CODECO Components and Technologies	• **ACM**, setup of a single and federated clusters (e.g., per geo-location, due to other context aspects) – higher degree of flexibility, eventually better coordination (reduced signalling overhead, lower latency). • **MDM**: provides real-time metadata to support ML-based orchestration. • **PDLC**: context modelling (based on data from MDM, NetMA) to best select Edges (AGV as an Edge). • **SWM**: support scheduling and workload migration with intermittent connectivity. • **NetMA**: support for mobile nodes direct communication (exposure of network features and requirements), based on requirements of available and reliable wireless/cellular environments.
CODECO Objective	P5 expects to demonstrate the CODECO capability to proactively increase the K8s infrastructure resilience and adapt the overall network energy consumption of an AGV fleet (and at an individual level), thus contributing to mitigate interference and failures in mobile environments.
Risks	• **R1**: Definition of adequate application workloads, based on realistic deployments. • <u>Countermeasure R1</u>: perform a survey to different manufacturing stakeholders, collecting information to design a realistic environment. • **R2**: Scalability testing, difficulty in deploying a relevant number of nodes in a local testbed. • <u>Countermeasure R2</u>: emulate a large-scale scenario based on realistic information collected and derived from values obtained on the local testbed(s). • **R3**: Federated cluster usage will need to be better defined. • <u>Countermeasure R3</u>: revise the use-case during the second phase of the project, when the federated cluster scenarios shall be better understood.
Milestones	• **P5.1** – design of the use-case (functional design, topology, equipment, etc); definition of phases of deployment – M3, D8. • **P5.2** – inception event, use-cases (M12, WP6) P5.3 – integration in the lab, full setup, initial experiments (M18, D27). • **P5.3** – single cluster demos, experimentation, and validation; community engagement (M24; CODECO workshop) • **P5.4** – multi-cluster integration completion experiments (M31) • **P5.5** – final demos, show-case (D18, D20; M36)

Attribute	Description
Implementation Timeline	**M1-M3**: WP2, T2.1, initial design of the use-case **M4-M6:** WP2, WP5, scenario design in the fortiss IIoT Labs; definition of equipment, etc; interconnection with EdgeNet set; input in D8. **M7-M12:** setup in the fortiss IIoT lab; integration of CODECO components (WP5); input in the first CODECO event. **M13-M18**: integration, deployment, and experiments; community engagement. **M18-M24**: refinements and single-cluster demo preparation; start defining the integration across federated clusters; analyse (WP7) possibility to deploy demos in operational environments; prepare work to the CODECO workshop; eventually to a democamp (WP7) **M25-M31:** WP5, multi-cluster deployment and assessment; WP7, interactions with the community and stakeholders. **M31-M36**: refinements, experiments, tutorials; D18, D20; show-case events and demos.
Planned HW Infrastructure (Compute Nodes/ Network)	Rf to section system architecture. FOR shall rely on the nodes and equipment provided in rubric "equipment". The deployment starts with 1 cluster and can locally (fortiss IIoT Lab) consider 3 clusters. The FOR clusters will be interconnected with other clusters, via the CODECO shared space and/or EdgeNet (FOR is already interconnected with EdgeNet).
Application (types)	At the current stage, not all applications are defined. Services to deploy in AGVs and in the controller node, offered to the user as illustrated in Fig.1 and Figure 4 (Use-case architecture), all to be dockerized: • PubSub: MQTT Sparkplug (RabbitMQ or Mosquitto); eventually Named Data Networking (NDN) • Python-based App(s) for task-handling modelling (AGV controller) • Open-source apps to support environmental sensing; object sensing, etc). • Database (if required), graphDB (Neo4j).
Deployment criteria/KPI	• Time to completion of a task (latency): reduction in 20% due to decentralized control. • 10% of reduction in the number of collisions. • 10% improvement of energy efficiency of the network (overall involved nodes) and eventual network lifetime.
Deployment flexibility	• Micro-services are expected to be replicated or offloaded based on specific requirements provided by the user during setup and derived from the network state during runtime. • Constraints may arise due to aspects such as network congestion, battery status, etc. These are expected to be supported via a higher understanding of the surrounding context.
Metadata Requirements	• Rf. To the metadata descriptions in Annex II.

2.5.3 Business Impact

The P5 value proposition (VP) canvas is provided in Figure 14. The application of CODECO to the context of AGV fleet decentralized control has as customer segments the CODECO target groups DEV (developers), ICT (large industry and SMEs) and AR (Academia and Research). The targeted vertical domains are Manufacturing and Logistics, which correspond to domains where there is an increasing growth in the need of automation and cognitive processes to improve the overall operations in critical environments. With the integration of Industrial IoT and ML, these sectors are experiencing a major change towards decentralisation, as observable in the concept of *Manufacturing as a Service (MaaS).*

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Target customer	VP 1	VP2
Customer perspective	DEV: segment wants zeroconf deployment, low skill investment	ICT, AR, SMEs: zeroconf, scalability, and low cost fleet management, with energy efficiency
Competing alternative	Proprietary solution providing 99.999% reliability High investment in training	Proprietary, customized solution often tailoring 1 cluster. Federated clusters (e.g., remote locations) requires high investment (CapEx and OpEx)
Differentiators		
Performance	**Scalability**, capability of CODECO to cope with an increasing number of application deployments across variable fleet sizes (large, heterogeneous) and towards mobile devices. **Resilience and availability**, capability of CODECO to support five nines system availability in the verge of network interference and intermittent connectivity.	**Privacy,** capability of CODECO to manage a varying infrastructure across a single or different locations (multi-domain environments). **Resilience and availability**, capability of CODECO to support five nines system availability in the verge of network interference and intermittent connectivity.
KPIs	• Time to completion of a task (latency): reduction in 20% due to decentralized control. • 10% of reduction in the number of collisions. • 10% improvement of energy efficiency of the network (overall involved nodes) and eventual network lifetime.	10% improvement of energy efficiency of the network (overall involved nodes) and eventual network lifetime. 10% improvement of total setup times

Figure 14: P5 value-proposition canvas.

The proposed solution in this use-case consists of CODECO and of a set of AGV fleet Apps to assist the deployment of the use-case, and to play with CODECO components. The key innovation aspects in UC5 relate with the use of context-awareness and behaviour estimation to provide a higher degree of flexibility to the overall system, thus allowing control of AGVs to be handled in a decentralized way, expected to bring benefits in large-scale environments.
In terms of performance, the application of CODECO in UC5 is expected to improve scalability, resilience, and availability in comparison to K8s, adding also novel support in mobile environments.

2.5.4 System Architecture

The three scenarios currently considered that shall guide the use-cases deployment in WP5 are provided in Table 7. For the first user journey (user DEV, application deployment setup), the key aspect is to test the capability of CODECO to assist in zeroconfig, considering that nodes are mobile and may fail during deployment; and to test the scalability capability of CODECO (number of deployed nodes vs. deployment time).

For the second user journey (operator), the main goal is to test the elasticity of CODECO, and its support for infrastructure resilience in mobile environments. KPIs have been provided in section *2.5.2 (P5 Description)*.

Table 7: P5 topological components for the three phases of deployment.

Scenario	Nr clusters	Nr master nodes per cluster	Nr worker nodes per cluster	Network technology	IP subnet
SC1	1	1	3-10	Wi-Fi 6, 1 WLAN	Single
SC2	1	3	3-10	Wi-Fi 6	2-3
SC3	2	1	3-5	Wi-Fi/5G	2-3

SC1 shall be deployed in the first phase (rf. To the use-case timeline) and is illustrated in illustrated in Figure 15.

SC1 represents a single cluster with one master and where each AGV is a K8s worker node and a CODECO node. Moreover, the AGV controller is co-located with the CODECO control plane (K8s master node). In the controller, we shall user services, namely, a task handler to simulate tasks (different rates, different volumes, different types of carried data) to AGVs. AGVs are CODECO nodes as well, and K8s worker nodes. For phase I, we shall consider 2 worker nodes and scale to 10 worker nodes, some mobile.
In terms of application workload, a set of micro-services has been described and shall consist of tasks to be handled; sensed data that may assist the navigation and the overall application replication or offloading; routes.
We shall first test the deployment based on 1 cluster, single subnet; then change to 1 cluster, 2 subnets. Moreover, the network technology considered in this case will be Wi-Fi (5 or 6).

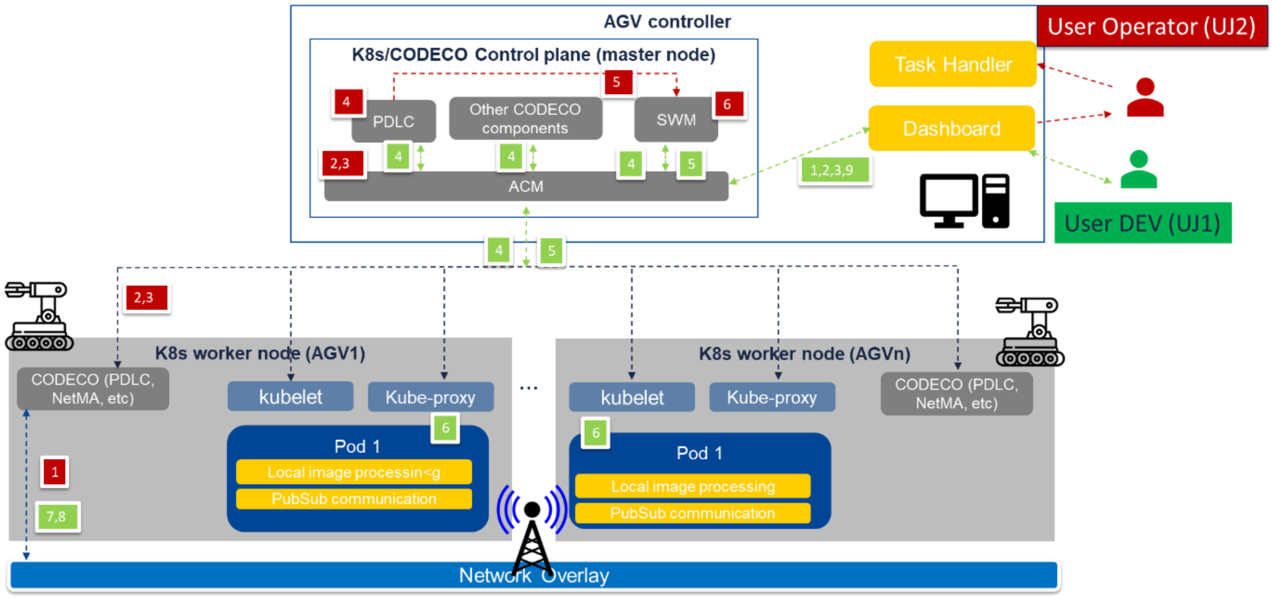

Figure 15: P5 system architecture, one cluster.

On a <u>second phase</u>, still with 1 cluster (SC2) we shall consider as explained a decentralized control approach, where each AGV can directly communicate and pass their graph to other AGVs. In this context, this implies that there are 3 master nodes per cluster and hence, a distribution of the CODECO control plane as well. The key aspect being addressed is redundancy. In this context, CODECO shall also assist in selecting the master nodes, considering aspects such as channel state, or interference, or node aspects, such as energy.

During **phase 3** (M25-M36) the use-case shall consider a deployment involving an AGV fleet across two locations. In this context, during Application setup and in addition to scalability the key aspects to address concern privacy preservation across remote environments (federated clusters). A second relevant aspect related with the application runtime is the capability of CODECO to further assist the network adaptation across multi-domain environments, in a way that can still serve requirements such as expected latency, or a reduction in the overall energy consumption of the system across different locations.

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2.5.5 UML Use-case Diagram

The UML use-case diagrams for a single cluster and a multi cluster deployment are illustrated respectively in Figure 16 and Figure 17, considering the two categories of users in CODECO (user DEV) and user MGT. The operational workflow has been described in section 2.5.4.

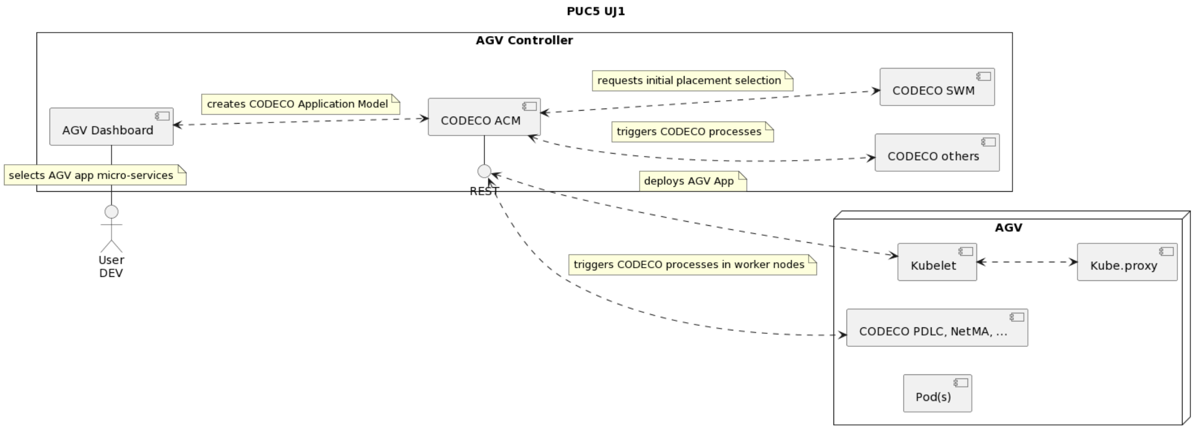

Figure 16: P5 use-case UML Diagram, single cluster.

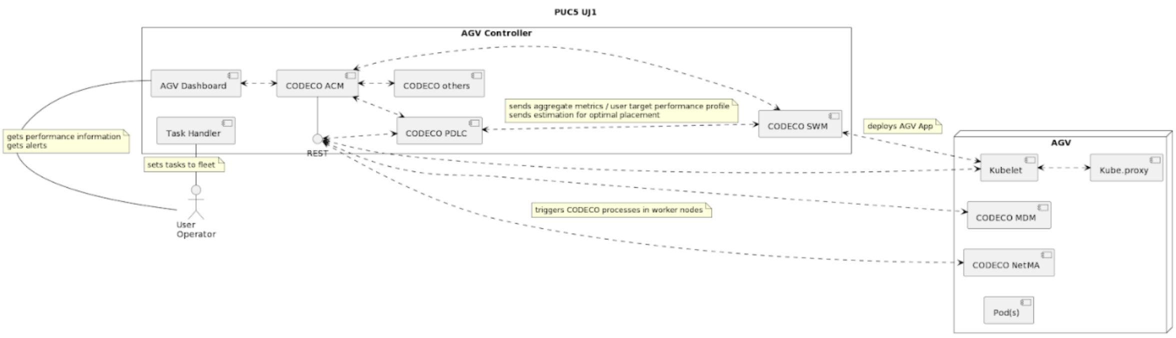

Figure 17: UML use-case diagram, federated clusters.

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2.6 P6: Automated Crownstone Application Deployment for Smart Buildings

2.6.1Scope

In CODECO P6, we will focus on novel mechanisms for automated deployments of smart office / smart building applications on the Crownstone Platform. In this context, an application is defined as a collection of related functionalities realized by means of a set of interconnected application components which can run either in the Cloud, on the Crownstone Hub, or inside a Crownstone Node. The key issue we will address is how the CODECO technologies can help with automated deployment of multiple applications on the Crownstone platform, both in single cluster situations (where multiple Crownstone Hubs form a single manageable entity with a single user base), and in multi-cluster situations (where multiple Crownstone Hubs form multiple manageable entities with different (but potentially overlapping!) user bases).
The Crownstone platform technology has been developed within the Almende group during the past years. The five main constituents of the technology are:

1. Smart lustre terminals called **Crownstone nodes**, which can be mounted inside power outlets. Each Crownstone node has five capabilities: switching on and off (or dimming) the devices attached to the power outlet, measuring the power consumption of the device attached to the power outlet, maintaining BLE connections with wireless sensors and/or actuators, communicating with other Crownstone nodes via Bluetooth mesh, and running small apps called Microapps on the processor inside the Crownstone node.
2. USB-sticks called **Crownstone Bridges**, which are Crownstone nodes with their UART connected to USB male socket, but without the technology to switch on/off devices and measuring power consumption. Bridges are used to connect a Bluetooth Mesh network to a Crownstone Hub.
3. Raspberry Pis with a specific software stack installed called **Crownstone Hubs**. These are used to collect data from larger collections (at most 256) of Crownstone nodes, to process data, to deploy Microapps to Crownstone nodes, and to connect to the Cloud.
4. A Cloud Service called the **Crownstone Cloud,** which serves to administer and exchange information about spheres (i.e., buildings / environments with Crownstone nodes that are connected to each other), rooms, Crownstone nodes, smartphones, and their relationships.
5. A React Native based app called the **Crownstone App**, which lets your smartphone act as a beacon which can be detected by Crownstone nodes and provide a management dashboard for managing all details of the Crownstone platform within a single sphere.

The Crownstone platform was originally developed as a universal domotics solution for the consumer market. However, recently, Almende has decided to make a shift from B2C to the B2B market, offering the Crownstone platform as a universal smart building technology for office environments, industrial environments, etc. This poses completely new challenges on the technology, which are partially addressed in this use case.

2.6.2 Description

The description of P6 in accordance with the metadata provided in Annex I is provided via Table 6.

Table 8: P6 fine-grained tabular description.

Attribute	Description
Code	SmartBuildings-P6
Responsible Partner	ALM
Actors	Crownstone application developers Building managers
Equipment	• Crownstone nodes • Crownstone hubs • Crownstone USB bridges • Smart building sensors and/or actuators
Operational Settings	Medium-to-large-scale buildings with a multitude of rooms equipped with sensors and/or actuators. There will be two types of lab environments: 1) The Almende office playground environment, consisting of ~1-2 hubs, ~20 Crownstone, ~5 rooms. This setting is used to represent single-office or home environments. The main user is the application developer wishing to test and deploy applications. 2) The larger-scale 'multi-office' environment, where the main user is considered a building manager wishing to deploy applications in production.
Datasets	Crownstones are sharing observation on a continuous basis and this data can be easily gathered and stored in a database by a Raspberry Pi with a Crownstone Bridge. This has already been done at our Almende offices, to build a database with measured signal strengths from other Crownstone and beacons to aid in the analysis of people moving through a built environment, as well as with measured power consumption levels of devices connected to Crownstone Node-equipped power outlets. More data of this type can be collected during the CODECO project.
Services to be Integrated	• Crownstone Python libs and SDK • Bluenet (Crownstone firmware) • Crownstone-microapp (microapp library and example apps) • Crownstone-tools (pipelining for data streams to/from crownstones) • InfluxDB (databases) • Grafana (visualization) • K8s (as basis of ACM components) • ACM components already in use.
Services to be Developed	• Flexible application (microcontainer, hub+crownstone) deployment+orchestration manager + client (on hub) (FADO manager / FADO client for referring in this document). • Microapp deployment manager for the Crownstone hub
User Journey #1	A microapp developer develops a microapp to be run on subset of Crownstone in the network, and wants to deploy apps quickly without moving within Bluetooth range to Crownstone, copy-pasting MAC addresses, etc. They set relevant parameters in config file and the microapp deployment manager will make sure the microapps are correctly uploaded to the designated Crownstone.
User Journey #2	A building manager wants to deploy applications without worrying about the network topology of Crownstone. They can push a single configuration file and FADO manager will orchestrate the deployment of the applications among the hubs. Any issues around deployment (e.g., resource problems) are fed back to building manager, if possible, with directions for fixing the issues.
User Journey #3	As a set of applications is running within a multi-hub building, the topology of the network changes (e.g., a sensor is moved to another room). Without human

Attribute	Description
	intervention, the FADO manager recognizes the topology change and adapts the application orchestration, optimizing the distribution of applications over the nodes.
User Journey #4	During a certain period, an application requires more resources (e.g., due to a local event). The FADO component monitors the resource need of the application and can re-orchestrate applications according to their needs.
User Journey #5	Assume the requirement that service personnel anywhere in a large set of buildings carry a special device just containing a single button. This button activates a small BTLE device to send a message for help including identification of the person requesting help. This message is then received by the nearest Crownstone , tagged with the id of the Crownstone (to identify the location through the associated room in the db) and relayed through a hub to the entity responsible for the follow up. This scenario requires Crownstone to always recognise and decrypt/encrypt for that given user in any building to guarantee proper operation.
Non-Functional Requirements	• Non-invasiveness (e.g., Crownstone basic functionality always remains). • Privacy-preserving with respect to data captured by sensors related to people in the building and their behaviour.
KPIs	Average time between changing deployment file and updated deployment in sphere (depends on network)
CODECO Single-Cluster Functionality	Crownstones are organised in sets that share a set of authorisation keys. The intention is that privacy sensitive decisions require specific keys to be executed on (sets of) Crownstone. This information is kept private through continuous encryption with rotating keys seeded by the keys belonging to the different user levels and users. The single cluster level can therefore request admin level clearance to access certain acquired data.
CODECO Multi-Cluster Functionality	Some cases require larger data sets to be gathered to enable analysis. If this data is aggregated over a large area or population, privacy sensitivity requires anonymisation of this data to a level where it can no longer be traced back to the individual location or person. Encryption must be organised in such a way that the data set can be used by the audience intended. This is a scenario that we consider more a multi-cluster scenario.
CODECO Components and Technologies	• **ACM**: Leveraging on-specific CODECO components to expose information assisting optimal decision to improve resource usage. • **MDM**: MDM supports orchestration by providing real-time event streams with metadata describing the state of relevant data and systems.
CODECO Objective	O1: To reduce the Edge-Cloud setup and management time via an automated, cognitive approach
Risks	**R1**: Shared resource problems introduce classical problems which are known to be hard to tackle fully automatically. Countermeasure1: third party application developers need to step out of the standard approach to introduce their own hardware and be convinced to make use of a common smart building infrastructure.
Milestones	• Microcontainer framework for hub microapp applications specification and development • Management and monitoring tools for deployed application portfolio in place • Integration with ACM components • If needed: integration with MDM component
Implementation Timeline	• **Single-Cluster set-up**, experimentation with CODECO components, first demonstrator: M7 – M18 • **Further development and Multi-cluster set-up,** final demonstrators: M19 – M36
Planned HW Infrastructure (Compute Nodes/ Network)	Shown in the diagram in section 2.6.4, system architecture. Vertically from the top, we have Linux-based crownstone hubs / computational nodes (e.g., Raspberry Pis, but can also include devices with more resources), Crownstones (nrf52-based) and far-Edge sensor/actuator nodes. The hubs are assumed to be on a single shared network.

Attribute	Description
Application (types)	Specific applications and thus their components are not clearly defined. Examples of components could include: • MQTT brokers • Databases and visualizers (InfluxDB, Grafana) • Application-specific logic Required resources depend heavily on the application. As for statefulness, naturally database servers store heavy datasets and as components are thus costly to migrate. Applications may contain a separate data storage component that ideally stays on the same node, where the rest of the application components are stateless. However, exceptions may occur. With regards to privacy, for a lot of applications running on premise is preferred or even required.
Deployment criteria/KPI	Costs are mostly related to physical vicinity of crownstone hubs to crownstones and the sensors/actuators (for hubs connected to the crownstones mesh). The reason for this is that one of the main limitations of the network is the Bluetooth mesh bandwidth. With fewer hops required for communication between crownstone and hub, the network will be more reliable and mesh traffic will be less strained. Hence, good KPIs would be the load on the Bluetooth mesh and the average number of hops for mesh messages. For some applications, latency is also relevant.
Deployment flexibility	Data storage components are limited to a single node with sufficient memory. Some components will have to run on crownstone hubs which are connected to the crownstone mesh.
Metadata Requirements	• Bluetooth mesh topology between crownstones and hubs • Physical location of nodes (hubs, crownstones, sensors/actuators) • Ability of an Edge node to connect with crownstones (equipped with crownstone USB dongle) • Crownstone microapp status information • Sensor/actuator link status **More info about this topic is available on metadata description in Annex II.**

2.6.3 Business Impact

The management and deployment of crownstones is currently highly centered around the use by consumers. This entails the use of the Crownstone app to manage crownstones, locations and schedules including constraints.

A business oriented management scenario should enable managing organisations to organise sets of crownstones into spaces, users and (micro)applications. A typical scenario might require the sharing of all users over all buildings, while a set of crownstones cannot currently exceed 256 elements. The option to have multiple sets of crownstones recognising and tracking most if not all users(/assets) is a much requested feature that will increase the target market.

Our crownstone platform enables the deployment of multiple different applications, developed by multiple third parties, on a single infrastructure inside a smart building, thereby avoiding that every new end user application installed in the building always introduces new hardware components to run the application on. The difficulty, however, is that we need to have better tools to manage and monitor the portfolio of installed applications in a single building or even over multiple buildings, as they share the same infrastructure. Our new tooling will build these tools to overcome this new management problem.

2.6.4 System Architecture

The Microapp deployment architecture illustrated in *Figure 18* can be divided in a Cloud level, a local (per building/apartment) level and AIoT level.

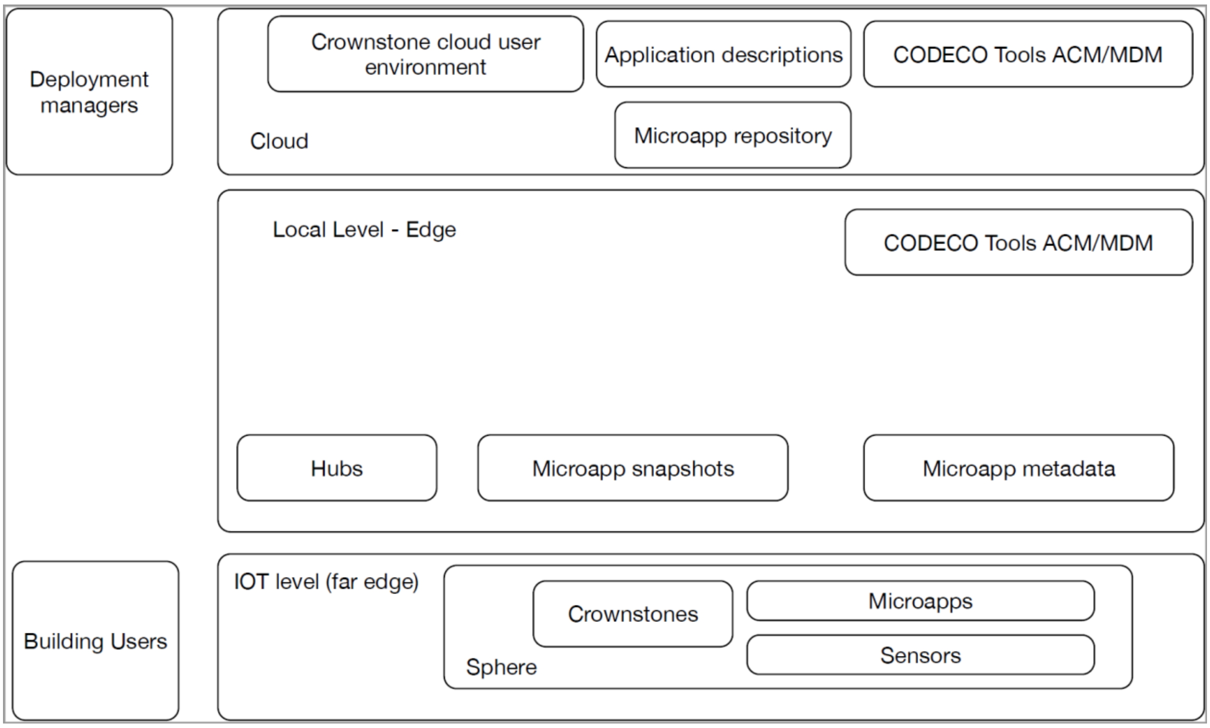

Figure 18: P6 system architecture.

Crownstone are already administered in spheres. A sphere is a collection of crownstones with associated locations (e.g., rooms) and users. A digital twin of this representation is present in the crownstone Cloud.

Microapps can communicate with the crownstones and the local hub, that serves as a relay for the Cloud-based environment. Collections of microapps can be configured (together with optional added sensors) in the Cloud and adapt to the locally available resources.
The Cloud environment will be combined with the CODECO ACM/MDM functionalities to allow for this adaptive distribution and deployment of microapps. The crownstone firmware is already able to receive the microapps. The CODECO MDM functionality will be made available on the hub level to execute the configurations defined at the Cloud level.

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2.6.5 UML Use-case Diagram

The initial UML use-case diagram is provided in Figure 19.

Figure 19: P6 UML Use-case Diagram.

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3 Use-case Technological Analysis

In this section, we embark on an analysis of use cases from a technological perspective, taking an integrated approach to examining the impact of CODECO components. By analysing multiple use cases together, we can uncover common patterns, identify synergies, and gain a deeper understanding of the benefits of using CODECO framework. Table 9 provides an overview on the CODECO components across use-cases. **It should be highlighted that any use-case relies on the CODECO framework and is therefore expected to consider all the CODECO components.** Therefore, in Table 7 the "x" aims at providing a perspective of the components that **contribute the most** to the orchestration aspects in the use-case. Then, the last column provides the main CODECO aspect being addressed in the use-case.

To provide an example, rf. To P6, where two components are highlighted, ACM, MDM. The reason is that the core focus of P6 is on the **zeroconfig support** provided by CODECO, which is supported by ACM. Nonetheless, the other components are expected to be used as well (at a lesser degree). The specific benefits introduced in the UCs by the components that are most relevant for each use-case are detailed next.

Table 9: CODECO components in the different CODECO UCs.

Use Case	Sector	ACM	MDM	PDLC	SWM	NetMA	Key CODECO target
P1: Smart Monitoring of the Public Infrastructure (UGOE)	Smart Cities	X	X	X	X	X	Edge-Edge workload migration
P2: Vehicular Digital Twin for Safe Urban Mobility (I2Cat)		X	X	X	X		Edge-Edge mobile workload migration
P3: MDS across decentralized Edge-Cloud (TID)	MDS	X	X	x	X	X	Network exposure, federated environments
P4: Demand Side Management in Decentralised Grids (UPM)	Energy	X	X	X	X	X	Energy-aware and context-aware orchestration
P5: Wireless AGV control via CODECO for flexible factories (FOR)	Manufacturing	X	X	X	X	X	ML-based orchestration, mobile environments
P6: Automated Crownstone Application Deployment for Smart Buildings (ALM)	Smart Buildings	X	X	x			Zeroconfig, large-scale environments

3.1 P1: Smart Monitoring of the Public Infrastructure

The aim of this use case is to improve traffic flow and pedestrian safety in Göttingen and build a smart city through the implementation of a road monitoring and analytics system, and the main advantages of using CODECO framework are:

- Scalability and Resilience: With CODECO, the system can achieve scalability and resilience. Each location equipped with an Edge device and sensors acts as a worker node in the K8s system. This distributed architecture allows independent computations and data processing while maintaining connectivity with the larger network. It ensures that the system can handle increasing data volumes, traffic demands, and scale effectively.

- Efficient Data Pre-processing and Storage: The CODECO framework provides orchestration that can support a local data aggregation and more efficient data processing and storage, as it can support a context-aware placement of application workloads across the different Edge nodes deployed in P1.
- Automated Network Management and Adaptation: With NetMA, the process of setting up interconnections for Edge-Cloud operations becomes automated. This reduces manual effort and time spent in network setup and maintenance, making the implementation of a traffic/ pedestrian monitoring and analytics system more efficient. The integration of diverse network environments (in our use case: wireless and cellular) is streamlined, simplifying operations, and reducing complexity.
- Optimization and Valuable Insights: By collecting and analysing valuable data on traffic and pedestrian behaviour, the use case aims to optimize traffic management, reduce congestion, and enhance pedestrian safety and comfort. The CODECO adopts a data-compute-network orchestration of the resources across Edge-Cloud, which is expected to improve user QoE.

3.2 P2: Vehicular Digital Twin for Safe Urban Mobility

The aim of this use case is to improve the safety of VRUs in Urban Environments by providing real-time monitoring and analysis of the mobility environment, enabling enhanced safety measures and proactive decision-making. The main advantages of using CODECO framework are:

- Ultra-Reliable Low-Latency Services: The deployment of ultra-reliable low-latency services is essential for this use case, considering the need for real-time tracking and communication between V2X nodes and CV detectors. CODECO addresses the challenges associated with infrastructure deployment and ensures that information is processed as close as possible to the V2X nodes, minimizing latency, and enabling efficient and responsive communication.
- Security and Transparent Cluster Setup: The NetMA component of CODECO ensures the security of communications between different nodes in the system. Moreover, the ACM component supports the transparent and privacy preserving setup of clusters, , focusing on resource efficient from a data-compute-network perspective, increasing the system resilience and the integrity and confidentiality of data transmitted within the system.
- Optimal workload placement via context-aware Edge selection: PDLC shall provide (via the use of context-awareness) estimations for the “best” Edge (V2X) node (Edge node selection) based on specific constrains (e.g., application constrains) The Context-awareness Agent monitors the compliance of requirements such as low latencies and relies on multiple metrics to select the best position to store the information regarding a V2X node. The PDLC-DL sub-component processes the collected parameters data and provides predictions and suggestions that allow other CODECO components to take more intelligent decisions.
- Scheduling and Workload Migration: The SWM component of CODECO handles the scheduling and workload migration of application modules based on vehicle or pedestrian characteristics. This ensures that information is processed within the appropriate constraints, optimizing the system’s performance and efficiency.

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3.3 P3: MDS across decentralized Edge-Cloud

The aim of this use case is to enable a smart and efficient distribution of media content across a multi-domain and multi-cluster Edge-Cloud environment to ensure a high level of QoE for users. The main advantages of using CODECO framework are:

- Orchestration: The CODECO framework enables the selection of the most appropriate Edge facility based on specific constraints in both the Edge-compute (CPU, RAM, storage) and network sides (latency, bandwidth). By leveraging CODECO's capabilities, the system can make optimal decisions for resource allocation, ensuring efficient delivery of media content.
- Cognitive Approach and Resource Optimization: The CODECO component NetMA promotes a cognitive approach that facilitates the joint articulation of data, computation, and network adaptation. It exposes functions as a service to assist in optimal decision-making for resource usage which improves the performance and enhance the overall efficiency of media content distribution.

3.4 P4: Demand Side Management in Decentralised Grids

This distributed energy management system use case is focused on implementing an active demand response decentralized management system for building decarbonization, and the main advantages of using CODECO framework are:

- Automated Configuration and Cognitive Edge-Cloud Management: The CODECO framework enables automated configuration and cognitive management of Edge and Cloud resources. In the context of the use case, this means that the framework can dynamically allocate and optimize resources based on demand response requirements, real-time energy data, grid conditions, and consumer preferences. This automation and cognitive approach ensure efficient and intelligent management of resources, leading to optimized energy usage and improved sustainability.
- Efficient Data Collection and Analysis: The MDM component of CODECO provides tools for efficient collection, analysis, and processing of energy consumption data, as well as relevant contextual information. By leveraging MDM capabilities, the use case can effectively monitor and analyse energy-related data in the IoT-Edge-Cloud continuum. This comprehensive view of data allows for informed decision-making and enables proactive management of energy-consuming devices.
- Resource Optimization for Real-Time Demand Response: The SWM component of CODECO offers capabilities to optimize the allocation of computing resources. In the use case, SWM can be utilized to allocate resources for real-time demand response decisions. This ensures effective load management and energy optimization, as resources are allocated in a way that maximizes the efficiency of demand response actions.
- Holistic View and Comprehensive Monitoring: The CODECO framework facilitates a holistic view of data in the IoT-Edge-Cloud continuum. By integrating data from various sources and devices, the use case can monitor energy consumption, grid conditions, and other relevant factors comprehensively. This comprehensive monitoring enables a better understanding of energy patterns, facilitates data-driven decision-making, and supports the replication and analysis of energy-related data for further optimization.

3.5 P5: Wireless AGV control via CODECO for Flexible Factories

The advantages of using the CODECO framework in this use case AGVs and AMRs in flexible factory environments are as follows:

- Flexible Control and Task Assignment: The CODECO framework enables a more flexible control system for AGV fleets, allowing for dynamic task assignment and adaptation to changing demands. By reaching a higher level of autonomy, the use case can increase overall efficiency and reduce operational costs. CODECO facilitates the coordination and management of AGVs, supporting a larger number of vehicles and tasks/goods to be transported.
- Integration of Wireless Technologies: The use case highlights the relevance of integrating wireless technologies, such as 5G, Wi-Fi 6/7, for the control of AGVs. CODECO can explore and leverage these wireless technologies to enable efficient and reliable communication and control of AGV systems. This integration requires the framework to address challenges related to interference mitigation, synchronization, and intermittent connectivity. CODECO provides the necessary adaptation capabilities to ensure reliable communication despite potential interference and failures.
- Federated Clusters and Flexibility: The ACM component of CODECO supports the setup of single and federated clusters, allowing for better coordination and reduced signalling overhead. This flexibility in cluster configuration enables efficient management of AGVs across different geo-locations and context aspects. The use case can leverage CODECO's ACM capabilities to optimize resource allocation, reduce latency, and improve coordination among AGVs.
- Real-time Metadata and ML-based Orchestration: The MDM (Metadata Management) component of CODECO provides real-time metadata to support ML-based orchestration. This capability allows for efficient and intelligent decision-making based on the current state of AGVs and the factory environment.
- Context Modelling and Edge Selection: The PDLC component of CODECO supports context modelling based on data from MDM and NetMA. In the use case, PDLC can utilize this context information to select the best edges (including AGVs) for specific tasks. This enables efficient utilization of AGVs as edges and enhances the overall performance and adaptability of the system.
- Scheduling and Workload Migration with Intermittent Connectivity: The SWM of CODECO supports scheduling and workload migration in the presence of intermittent connectivity. AGVs in a wireless environment may face intermittent connectivity, and SWM provides mechanisms to handle such situations, ensuring the smooth operation of AGV systems.

3.6 P6: Automated Crownstone Application Deployment for Smart Buildings

This use case is focused on novel mechanisms for automated deployments of smart office / smart building applications on the Crownstone Platform, and the main advantages of using CODECO framework are:

- Efficient Management of Single and Multi-Cluster Situations: The use case addresses both single cluster situations, where multiple Crownstone Hubs form a single manageable entity with a single user base, and multi-cluster situations, where multiple Crownstone Hubs form multiple manageable entities with different user bases. ACM facilitates the efficient management of these situations. It enables the management and coordination of resources, applications, and user bases in a scalable and flexible manner. This allows for effective management of deployments across different clusters, ensuring optimized performance and user experience.

- Real-time Metadata Management: The MDM component of CODECO plays a crucial role in this use case. It provides real-time metadata that supports the deployment and management of smart office/smart building applications. MDM collects, analyses, and processes relevant metadata, including application-related information and contextual data. This enables intelligent decision-making and optimization during the deployment process, ensuring efficient utilization of resources and enhanced application performance.
- Streamlined Application Management: With CODECO, the management of interconnected application components becomes more streamlined. The framework provides a unified approach to managing applications across different environments, simplifying the deployment, monitoring, and maintenance processes. This streamlining of application management improves efficiency, reduces complexity, and enhances the overall user experience.

4 Summary

The CODECO Deliverable D8 provides a detailed description of the CODECO use cases, based on information about their rationale, their main functionalities, their technical characteristics, and their market relevance. The starting point to produce this deliverable has been the high-level descriptions of the use cases that are included in the CODECO DoA document. These high-level descriptions have been refined and detailed based on the collaboration of the CODECO partners that are involved in each of the use cases. In this direction, the project has implemented various use cases definition and specification activities, including dedicated workshops for each one of the use cases.

The CODECO use cases cover a rich set of topical themes, spanning sectors like manufacturing, energy, smart buildings, as well as smart management of public infrastructures (I.e., smart cities). They are appropriate for driving the development and validation of the CODEO container orchestration framework, as they use all the CODECO modules and functionalities. Moreover, they will result in different deployment configurations for the CODEO modules, which is likely to allow for a complete and multi-facet validation of the project's platform and functionalities.
Detailed descriptions of the use cases of the present deliverable will be provided as inputs to the technical work packages, where the technical components of the CODECO system are developed. Hence, they will drive the scientific and technical developments of CODECO in these work packages. In this direction, the UCs have already been considered in the scope of the development of the first version of the CODECO architecture as part of deliverable D9. Furthermore, the various UCs will be further refined and detailed as part of the UCs integration and deployment of the project. As part of this process, they will be also confronted to the actual capabilities of the CODECO platform, including its supported functional and non-functional requirements.

Overall, the present deliverable completes a first, yet important step in the CODECO platform development and validation journey, which is to be continued and completed in other technical work packages of the project and in particular WP5.

References

[1] ETSI (2023-02). Intelligent Transport Systems (ITS); Vehicular Communications; Basic Set of Applications; Local Dynamic Map (LDM); Release 2. (ETSI TS 103 938 V2.0.0)

[2] ETSI (2023-02). Intelligent Transport Systems (ITS); Vulnerable Road Users (VRU) awareness; Part 3: Specification of VRU awareness basic service; Release 2. (ETSI TS 103 300-3 V2.2.1)

[3] ETSI (2019-09). Intelligent Transport System (ITS); Vulnerable Road Users (VRU) awareness; Part 1: Use Cases definition; Release 2. (ETSI TR 103 300-1 V2.1.1)

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Annex I – Use-case Template and Metadata

Attribute	Description
Code	A unique code for the UC, destined to facilitate requirements traceability. Some naming convention can be followed like: SmartCity-UC1-V1, Energy-UC3-V1 etc.
Lead	CODECO Partner that coordinates the use-case.
Actors	The main actors (e.g., humans, IT systems) involved in the Use Case; Make sure you prioritize and focus on CODECO actors (e.g., telcos, Cloud/infrastructure providers, developers)
Equipment	List of equipment (e.g., sensors, devices, Edge/fog nodes etc.) involved in the use case implementation
Operational Settings	Short description of the use case setting e.g., lab/field environment, city, energy plant, pilot plant etc.
Datasets	List any datasets (existing or to be produced) to be used in the use case – This should be consistent with the inputs to the DMP of the project
Services to be Integrated	Describe any readily available services (e.g., analytics functions, data collection/generation) to be used in the Use Case
Services to be Developed	Describe any readily services (e.g., analytics functions, data collection/generation) that will be developed to enable the use case
User Journey #1	Describe a User Journey of the use case from the CODECO stakeholders' perspective e.g., A Developer wants to do YYZ, An Infrastructure Provider wants to do XYZ
User Journey #2	As above, repeat for more User Journeys as necessary
…..	
User Journey #N	As above, repeat for more User Journeys as necessary
Non-Functional Requirements	List any non-functional requirements linked to the above user journeys like security, privacy etc.
KPIs	Provide KPIs for the above-listed functional & non-functional requirements
CODECO Single-Cluster Functionality	Describe your vision of the CODECO system functionality in terms of single cluster operation from the use case point of view
CODECO Multi-Cluster Functionality	Describe your vision of the CODECO system functionality in terms of multi-cluster operation from the use case point of view
CODECO Components and Technologies	Provide a preliminary list of CODECO technologies/components used in the Use Case based on the DoA; There is no need to provide any technical specification at this stage, but rather add some preliminary technology context
CODECO Objective	Please tag the use case by the CODECO objectives that it addresses/ demonstrates
Risks	What are the risks of failure? Regulatory, technological, commercial?
Milestones	What will be the main and critical milestones?
Implementation Timeline	Please provide an indicative implementation timeline (including key milestones where applicable) for the use case
Partners Involved	Provide the list of partners involved in the use case and very briefly their roles (e.g., infrastructure provider, end-user, solution integration, component X provider etc.)

Attribute	Description
Diagrams (optional)	If applicable, please provide some diagrams illustrating the use case or specific user journeys of it (e.g., UML diagrams)
Planned HW Infrastructure (Compute Nodes/ Network)	Compute nodes with resources (e.g., CPU, memory ram). Network topology between compute nodes with capabilities (network components like switches or routers, network technology, bandwidth, latency). Scalability (quantity structure) beyond demonstrator: Which sizing of the infrastructure (compute, network) is expected?
Application (types)	Components of application with interfaces/connections Requirements/restrictions of each component (e.g., average/peak CPU, ram usage, data) Requirements on connections between the components of an application (e.g., minimum bandwidth, maximum latency) “Statefulness” of components, constraints (or difficulty or costs) to migrate the components. Network restrictions (e.g., application/component must run on premise not in Cloud)
Deployment criteria/KPI	What are the relevant criteria or objectives that should influence the placement (and migration) of workloads? E.g., “Costs”, like: • Node costs (e.g., operating costs, energy costs) • Connection costs (e.g., operating costs, energy costs) • Overall latency
Deployment flexibility	What is the degree of freedom for the placement of the application components? Are certain components bound to specific compute nodes?
Metadata Requirements	The CODECO Metadata Manager (MDM) collects metadata from CODECO components and the environment, making it available to the CODECO Framework and Use Cases to support their operation. Provide a preliminary list of metadata that could be collected to support this use case: For example: •Local system status information to support orchestration •Information on local datasets to support data sharing •Other information to support the distributed operation of the use case.

Annex II – Initial Dataset Information

P1 Datasets

Dataset name	**Infrared traffic scenario dataset & High-density urban scenario point Cloud dataset**
Dataset unique ID	HEU-101092696-CODECO-infratraff & HEU-101092696-CODECO-highpoint
Dataset description	Infrared traffic scenario dataset: This dataset will contain infrared images/videos of some traffic areas in different periods (day and night, different seasons). The data will be collected by thermal cameras in real traffic scenarios at the city periphery. Thermal cameras will be installed at 3-5 meters height at a depression angle. We may also add some labels to the data to better train our vehicle detection and counting function (number of vehicles). High-density urban scenario point Cloud dataset: This dataset will contain point clouds of some urban scenarios in different periods (day and night, different seasons). The data will be collected by LiDARs in real urban scenarios (crowded streets, city center). We may also add some labels to the data to better train our pedestrian detection and counting function (number of pedestrians).
Related WP/Task	WP2
Data origin	UGOE and municipalities
Will you re-use any existing data? If YES, how?	No
Methodologies for data collection / generation	Infrared traffic scenario dataset: Infrared images/videos are captured using thermal cameras placed at a height of 3-5 meters at a depression angle. The cameras are installed in traffic scenarios at the city periphery. Data is collected during different periods of the entire day and throughout the different seasons to capture a variety of traffic conditions. The images are processed, identifying, and counting the number of vehicles present in each image. The final dataset includes the raw infrared images/videos and their corresponding labels. High-density urban scenario point Cloud dataset: Point clouds are captured using LiDAR scanners situated in urban scenarios. (Crowded streets, city center) Data is collected during different periods of the entire day and throughout the different seasons to capture a variety of pedestrian behaviours and densities. The raw LiDAR data is processed to generate 3D point clouds of the scanned areas. The point clouds are then processed, identifying, and counting the number of pedestrians present in each frame. The final dataset includes the raw point Cloud data and their corresponding labels.
Data format	Infrared traffic scenario dataset: MPEG4/JPEG, XML

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Dataset name	**Infrared traffic scenario dataset & High-density urban scenario point Cloud dataset**
	High-density urban scenario point Cloud dataset: LAS, XML
Data storage	The raw data will be uploaded to S3 data storage service provided by GWDG. The data will be utilized and processed based on this Cloud-based storage platform. Then the final datasets could be uploaded to Zenodo.
Expected size of the data	Hundreds of GB – dozens of TB
Metadata and standards	Author – UGOE Keywords: infrared traffic scenario; high-density urban scenario
For whom might the dataset be useful?	UGOE
Data access, sharing and licensing	The dataset is hosted on a Cloud-based platform. Users can access the data through a web interface or by using our RESTful API for more advanced queries. Users are permitted to download and share the data for non-commercial purposes. Any publications or presentations based on these data should credit the source. The datasets will be licensed under a Creative Commons Attribution-Non-commercial 4.0 International License (CC BY-NC 4.0). The data may not be used for commercial purposes without explicit permission.

P2 Datasets

Dataset name	**Private Vehicle Trajectory on an urban environment with collisions**
Dataset unique ID	HEU-101092696-CODECO-Trajectories
Dataset description	Datasets generated with SUMO simulator to recreate a reckless driving experience. The objective of this scenario is to increase the possibility of both lateral and frontal collisions between vehicles. There are two different scenarios situated in the center of Barcelona, so the real coordinates of the vehicles in these scenarios can be considered.
Related WP/Task	WP2
Data origin	The data has been produced with SUMO Traffic simulator
Will you re-use any existing data? If YES, how?	It is not based on any other existing datasets.
Methodologies for data collection / generation	To generate these datasets there are made several modifications on the SUMO simulator (done with the TraCI interface) which adds more reckless vehicles that will ignore the traffic lights and sometimes circulate at higher velocities than permitted. Then the same TraCI interface is used to extract the data from the simulation (both the recording of the collisions, and the positions of all the vehicles).
Data format	The record of the collisions is stored in a XML file with the same format extracted from TraCI, and the positions are stored as a CSV file.
Data storage	The dataset is published and shared in a public GitHub repository: https://github.com/Fundacio-i2CAT/Collisions_Datasets
Expected size of the data	There are several types of datasets, the shorter ones cover between 5 and 10 hours and are about 500-1000 MB. And the longer ones (like

	barcelona_v2.tar.xz), have a higher density of vehicles, and cover around 50 hours with 20 GB.
Metadata and standards	To be decided in the future
For whom might the dataset be useful?	The dataset is created to train ML algorithms which can predict and avoid collisions between vehicles in a realistic urban scenario. So, a stakeholder would be any research groups related to autonomous or connected vehicles or generating ML algorithms.
Data access, sharing and licensing	ODC Open Database License (OdbL)

Dataset name	**Cyclist Dataset for Object Detection in YOLO Format**
Dataset unique ID	HEU-101092696-CODECO-Cyclist
Dataset description	This dataset contains 13.7k labeled images, one thousand of which do not contain cyclists. The size of each image is 2048x1024 and the bounding box follows YOLO's format: [id, center_x, center_y, width, height]. The dataset has a size of 2 GB. X. Li have created the dataset, F. Flohr, Y. Yang, H. Xiong, M. Braun, S. Pan, K. Li, and D. M. Gavrila and has been titled "Tsinghua-Daimler Cyclist Detection Benchmark Dataset in Yolo format for Object Detection." The dataset is freely available for non-commercial purposes such as academic research, teaching, scientific publications, or personal experimentation. License: Attribution-Non-commercial-ShareAlike 3.0 IGO (CC BY-NC-SA 3.0 IGO) The dataset is posted on Kaggle: Cyclist Dataset for Object Detection | Kaggle.
Related WP/Task	WP2
Data origin	The data comes from a paper titled: A New Benchmark for Vision-Based Cyclist Detection and is posted on the Kaggle website (Cyclist Dataset for Object Detection | Kaggle). X. Li, F. Flohr, Y. Yang, H. Xiong, M. Braun, S. Pan, K. Li, and D. M. Gavrila. A New Benchmark for Vision-Based Cyclist Detection. In Proc. Of the IEEE Intelligent Vehicles Symposium (IV), Gothenburg, Sweden, pp.1028-1033, 2016. The dataset also has an affiliation with Daimler.
Will you re-use any existing data? If YES, how?	N/A. The dataset will be used as is.
Methodologies for data collection / generation	N/A. The dataset will be used as is, no modification or addition will be done.
Data format	The dataset consists of two folders, the first one has images in jpeg format and the second folder has the labels for each image, in txt files in the YOLO format.

Data storage	The dataset is only 2GB and will not have be stored statically only to train the computer vision model (YOLO).
Expected size of the data	2 GB
Metadata and standards	Tsinghua-Daimler Cyclist Detection Benchmark Dataset in yolo format for Object detection. The creators of the dataset are X. Li, F. Flohr, Y. Yang, H. Xiong, M. Braun, S. Pan, K. Li, and D. M. Gavrila. Also, all rights not expressly granted are reserved by Daimler. The dataset follows the YOLO format.
For whom might the dataset be useful?	For computer vision experts that want to train a YOLO model to detect cyclists as a single entity. Unit now cyclists were detected as a combination of bicycle+person.
Data access, sharing and licensing	Attribution-NonCommercial-ShareAlike 3.0 IGO (CC BY-NC-SA 3.0 IGO)

Dataset name	**Urban environment mobility patterns with VRUs**
Dataset unique ID	HEU-101092696-CODECO-VRUMobility
Dataset description	In the UC2 scenario, comprehensive data regarding the trajectories and positions of various road users (such as pedestrians, bikes, and electric scooters) as well as cars will be meticulously collected over a specific time. Each user's data will be tagged anonymously, ensuring privacy and security. The collected data will encompass essential trajectory fields typically transmitted through a V2X VAM or CAM message, including latitude, longitude, heading, speed, acceleration, and margins of certainty. Additionally, several other relevant data points will be recorded. This valuable dataset will serve a twofold purpose. Firstly, it will be utilized to enhance the accuracy and effectiveness of the risk detector by leveraging real-world data from the specific scenario in which the detector is being assessed. Secondly, the stored data can be harnessed for other purposes, particularly to enhance various aspects related to the CODECO framework. For instance, it can aid in refining orchestration processes by improving the estimation of users present in a particular area. Furthermore, the data can contribute to optimizing service metrics by facilitating better anticipation of user behaviour in situations that necessitate service improvement.
Related WP/Task	WP5
Data origin	Data collected through camera sensors and V2X communications
Will you re-use any existing data? If YES, how?	No
Methodologies for data collection / generation	During a few days, the data of the VRUs and cars in the UC2 scenario will be collected.
Data format	The data will be stored firstly in a database and then dumped into CSV
Data storage	It must be decided
Expected size of the data	~10GB

Metadata and standards	VRUs, cars, urban mobility, UPC campus, I2CAT offices,
For whom might the dataset be useful?	There will be the option to spot and improve the risky detection algorithms in real situations.
Data access, sharing and licensing	The license has yet to be decided and the anonymized and RGPD-compliant way of storing this data as well.

P5 Datasets

Dataset name	**UC5 AGV fleet tasks**
Dataset unique ID	HEU-101092696-CODECO-UC5-AGVTasks
Dataset description	The dataset comprises different lists of tasks to be conducted by an AGV. A task is a tupple with at least the following fields: <id, source, destination, size (Mb), target location, action >. Different datasets shall be generated (synthetic data) for the purpose of validation.
Related WP/Task	WP5, T5.1-T5.3
Data origin	Task handler component in UC5, AGV controller. This will be a python-based service, which will generate synthetic data sets based on specific requirements.
Will you re-use any existing data? If YES, how?	The dataset shall be used within CODECO, and re-used by FOR in the context of its fortiss IIoT Lab.
Methodologies for data collection / generation	Python based service, capable of generating realistic tasks. Volume of tasks to be varied. Configuration of tasks to be varied. Reference: VDMA AGV communication standards and guidelines.
Data format	txt
Data storage	The dataset will be made available via the CODECO Cloud repository (Partners); via the Eclipse CODECO GitLab and via the Zenodo CODECO community.
Expected size of the data	Orders of MB.
Metadata and standards	The task datasets shall include at least: Header: title, author affiliation, other relevant sources, creation date and purpose; license; expected update frequency Body: one task (tupple) per line, where tupple fields are separated via a regular separator such as ““or “,”
For whom might the dataset be useful?	ICT, AR, SMEs
Data access, sharing and licensing	The dataset will become freely / openly accessible based on an open license (e.g., Creative Commons).

Dataset name	**UC5 AGV Sensed data**
Dataset unique ID	HEU-101092696-CODECO-UC5-AGVSensing

Dataset description	Datasets in this category shall collect sensed information that may assist AGVs in an understanding of their surroundings, and in collision avoidance.
Related WP/Task	WP5, T5.1-T5.3
Data origin	Sensors and camera integrated into each AGV in UC5
Will you re-use any existing data? If YES, how?	The dataset shall be used within CODECO, and re-used by FOR in the context of its fortiss IIoT Lab.
Methodologies for data collection / generation	Reference: VDMA AGV communication standards and guidelines. Data to be collected over the course of several days (at least 2), different times of the day to reach a reasonable volume (e.g., 1-5 GB per AGV) and considering different signal conditions, as well as nLoS and LoS scenarios. Data will be collected in each AGV, and first locally stored (FOR server). Data will be pre-processed to manage identifier and field obfuscation (e.g., IP, MAC) for the identified fields. Similar larger datasets will also be searched (e.g., Kaggle).
Data format	Text, image, xls
Data storage	The dataset will be made available via the CODECO Cloud repository (Partners); via the Eclipse CODECO GitLab and via the Zenodo CODECO community.
Expected size of the data	Orders of GB.
Metadata and standards	Datasets in this category shall be developed per type of sensed data, e.g., routes, obstacles (video); environmental data (telemetry); etc. The task datasets shall include at least: Header: title, author&affiliation, other relevant sources, creation date and purpose; license; expected update frequency Body: id, timestamp, source id, storage id
For whom might the dataset be useful?	ICT AR SMEs
Data access, sharing and licensing	The dataset will become freely / openly accessible based on an open license (e.g., Creative Commons).

P6 Datasets

Dataset name	**Almende Crownstone Presence data**
Dataset unique ID	HEU-101092696-CODECO-UC6-CROWN
Dataset description	A test setup comprising 15 Crownstone are combined in a sphere (collection) and the RX/TX data recorded by each participating radio together with the timestamp is registered on average every second. It is possible to tag this data with additional measured values through added sensors using the microapp infrastructure such as humidity
Related WP/Task	The WP(s)/task(s) of the CODEO workplan that include the work, which will produce/generate the dataset.
Data origin	The data is collected using a special USB Crownstone running the BTLE Mesh protocol to participate in the sphere's communication. The USB serial connection is then used to communicate the

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	information to a local hub. The information is subsequently uploaded to a local influx database server.
Will you re-use any existing data? If YES, how?	No
Methodologies for data collection / generation	See above
Data format	CSV and JSON
Data storage	The data is GPR sensitive and stored in an influx database
Expected size of the data	To volition. We use time periods as an indication, e.g., a week, a month.
Metadata and standards	No standards are applicable yet.
For whom might the dataset be useful?	Any future microapp developer, but as indicated, the data is GPR sensitive.
Data access, sharing and licensing	Non-public, potentially public in a (yet unknown) aggregated and/or anonymized form.