D2.3

Development and deployment final report

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LIST OF ABBREVIATIONS AND ACRONYMS

Abbreviation	Meaning
3GPP	3rd Generation Partnership Project
4G	Fourth generation of broadband cellular network technology
4K	Video resolution (3840 × 2160)
5G	Fifth generation of broadband cellular network technology
ADAS	Advanced driver-assistance systems
AI	Artificial Intelligence
AMF	Access and Mobility Management Function
API	Application Programming Interface
ATP	Automated Truck Platooning
CAM	Connected and Automated Mobility
CO_2	Carbon dioxide
CN	Core Network
CNF	Containerized Network Function
COTS	Commercial off-the-shelf
C-ITS	Cooperative Intelligent Transportation System
DCET	Dynamic Control Loop for Environment Sensitive Traffic Management Actions
E2E	End to end
EAMS	Enterprise Asset Management System
ECS	Elastic Search
eMBB	Enhanced Mobile Broadband
eNB	Evolved Node B
FAIR	Findability, Accessibility, Interoperability, Reuse
GW	Gateway
HW	Hardware
EPC	Evolved Packet Core
ETSI	European Telecommunications Standards Institute
FDD	Frequency Division Duplex
FTED	Floating Truck Emission Data
GLOSA	Green Light Optimal Speed Advisory

gNB	Next generation NodeB
GNSS	Global Navigation Satellite System
HMI	Human-Machine Interfaces
IaaS	Infrastructure as a Service
IoT	Internet of Things
ITS	Intelligent Transportation System
KNF	Kubernetes network function
KPI	Key performance indicator
LCMM	Low Carbon Mobility Management
LL	Living Lab
LTE	Long Term Evolution (4^{th} generation mobile network technology)
M2M	Machine to machine
MANO	Management and Network Orchestration
MIMO	Multiple Input, Multiple Output
MEC	Multi-access Edge Computing
MME	Mobility Management Entity
mMTC	massive Machine Type Communications
ML	Machine Learning
mMTC	Massive Machine-Type Communications
MNO	Mobile Network Operator
Nb-IoT	Narrow-band Internet of Things
NFV	Network Function Virtualization
NFVI	Network Function Virtual Infrastructure
NR	New Radio
NSA	Non-Stand Alone
NSD	Network service descriptor
OBU	Onboard Unit
OSM	Open Source MANO (Management and Network Orchestration)
OTA	Over the air
PCT	Piraeus container terminal
PER	Packet error rate
PGW	Packet Data Network Gateway

QC	Quay side crane
RAN	Radio Access Network
SA	Stand Alone
SAE	Society of Automotive Engineers
SGW	Serving Gateway
SMF	Session Management Function
SME	Small-medium enterprise
SW	Software
TAVF	Testfeld autonomes- und vernetztes Fahren
TDD	Time Division Duplex
TLF	Traffic Light Forecast
TMS	Traffic Management System
TRL	Technology readiness level
UC	Use Case
UDM	Unified Data Management
UE	User Equipment
UI	User interface
UHD	Ultra-High Definition (video)
UMTS	Universal Mobile Telecommunications Service
UPF	User Plane Function
uRLLC	Ultra-reliable low latency communications
VNF	Virtual Network Function
vTMC	Virtual Traffic Management Center
WiFi	Wireless networks technology based on IEEE 802.11 family standards

Table 1: List of Abbreviations

EXECUTIVE SUMMARY

This deliverable aims to provide the final overview of the 5G deployments in all Living Labs, and the implementation of the data collection tools and systems. The development and deployment followed the deployment plans as defined in D2.1. To verify the development and deployment is fitting for the execution of the trials, the link is made with D3.1.

First a generic overview of the 5G services and applications related to the use cases is given, providing a base to fall back on when reading the document. With this basis, data management is elaborated focussing on the central part and the KPIs available for evaluation. The tools use a combination of a central aggregator with site-specific deployments. The KPIs cover 5G specific and use case-specific items.

Following these generic parts are the details of the development and deployment of each of the Living Labs:

- The Site Overview provides a brief picture of the location, equipment, use-cases and 5G sites. This overview sets the context for the remainder of the Living Lab description.
- The Deployed Components per site describes the equipment deployed and available for the use cases. The section continues with the details of these items together with the description of the available 5G network(s) (including spectrum, antenna's modems, etc.), and with the description of the software components used.
- The Use Cases continue the description with how these components have been tied together to provide the functionality for each of the use cases, providing the reader with a complete overview of what is available for the end-users, and how this has been created using the components.
- The description of Data Collection finalizes the Living Lab descriptions by offering the view how the KPIs mentioned in section 2.3 are collected.

The document concludes with a description of the deviations and open points (if any), and how these will be (are) addressed.

The document finalizes with the overview of referenced documents. This is to ensure the context of the document is complete and duplicate information is prevented as much as possible.

1. INTRODUCTION

1.1. Project intro

5G-LOGINNOV will focus on seven 5G-PPP Thematics and support to the emergence of a European offer for new 5G core technologies in 11 families of use cases.

5G-LOGINNOV's main aim is to design an innovative framework addressing integration and validation of Connected Automated Driving/Mobility (CAD/CAM) technologies related to the industry 4.0 and ports domains by creating new opportunities for LOGistics value chain INNOVation.

5G-LOGINNOV is supported by 5G technological blocks, including new generation of 5G terminals notably for future Connected and Automated Mobility, new types of Industrial Internet of Things 5G devices, data analytics, next generation traffic management and emerging 5G network architectures, for city ports to handle upcoming and future capacity, traffic, efficiency and environmental challenges.

5G-LOGINNOV will deploy and trail 11 families of Use cases targeting beyond TRL7 including a GREEN TRUCK INITIATIVE using CAD/CAM & automatic trucks platooning based on 5G technological blocks.

Thanks to the new advanced capabilities of 5G relating to wireless connectivity and Core Network agility, 5G-LOGINNOV ports will not only significantly optimize their operations but also minimize their environmental footprint to the city and the disturbance to the local population.

5G-LOGINNOV will be a catalyst for market opportunities build on 5G Core Technologies in the Logistics and Port operations domains, thus being a pillar of economic development and business innovation and promoting local innovative high-tech SMEs and Start-Ups. 5G-LOGINNOV will open SMEs' and Start-Ups' door to these new markets using its three Living Labs as facilitators and ambassadors for innovation in future European ports.

5G-LOGINNOV's promising innovations are key for the major deep-sea European ports in view of the mega-vessel era (Hamburg, Athens), and are also relevant for medium sized ports with limited investment funds (Koper) for 5G.

1.2. Purpose of the deliverable

The purpose of this public document is to record the results of WP2 being the developed & deployed systems and uses-cases, deviations, and the learnings. With this deliverable the audience can gain overview and insights in what has been realized to produce use-cases and services like 5G-LOGINNOV. The deliverable further offers WP3 the overview of what is available for the execution of the trials.

This purpose is served by:

- Presenting a brief overview of the Living Labs and use-cases;
- Presenting the data (KPIs) and how they are collected;
- An overview of each Living Lab containing:
  - The site overview;
  - Deployed components;
  - Use-cases and storyboards;
  - The implementation of the data collection tools.

Attainment of the objectives and explanation of deviations

The objectives related to this deliverable have been achieved partially as scheduled. Due to delivery delays caused by chip supply shortages, some equipment will be received later than the deadline of this deliverable. Consequently, an update on this deliverable will be provided when the equipment has been received and installed. Details are presented at the individual Living Labs.

1.3. Intended audience

This deliverable is PUBLIC and intended for the following audiences:

- 5G-LOGINNOV partners can use the document for reference during the execution of follow-up work, and for the acquisition of cross-site knowledge.
- The European Commission, the Agency, and the related reviewers can use this deliverable to gain insight in the deployed systems, use cases and services to validate that the work performed fits and completes this part of the work plan.
- Any reader can use the deliverable to gain insight in how these kinds of innovations can be realized, deployed, and used.

1.4. Structure of the deliverable and relationship with other work packages/deliverables

This deliverable is structured in the following manner:

- **Chapter 1:** Introduction, provides a brief overview of the project and the purpose and audience the deliverable is intended for.
- **Chapter 2**: Development and Deployment Overview, provides a generic view of the developments from a high level and describes the implementation of the central data collection tools and mechanisms.
- **Chapter 3**: Development and Deployment in Living Lab Athens, describes in detail the site, deployed components, network, operational use cases, and data collection in the port of Athens.
- **Chapter 4:** Development and Deployment in Living Lab Hamburg, describes in detail the site, deployed components, network, operational use cases, and data collection in the port of Hamburg.
- **Chapter 5:** Development and Deployment in Living Lab Koper**,** describes in detail the site, deployed components, network, operational use cases, and data collection in the port of Koper.
- **Chapter 6:** Conclusion, concludes the overall development and deployment report.
  Chapter 7: References, provides an overview of the content and information used to realize this deliverable.

2. DEVELOPMENT AND DEPLOYMENT OVERVIEW

2.1. Generic View of the Innovations in 5G-LOGINNOV Ports with Focus on 5G Aspects

Table 2 summarizes the usage of the 5G services and applications within the context of the use cases that will be demonstrated in 5G-LOGINNOV Living Labs, as also detailed in D1.1.

5G Service/Application	UC 1	UC 2	UC 3	UC 4	UC 5	UC 6	UC 7	UC 8	UC 9	UC 10	UC 11
Network Slicing	X										
MEC	X		X	X	X	X		X	X	X	X
NFV-MANO	X		X	X	X	X					
Precise Positioning								X	X	X	X
Traffic Management Applications								X	X	X	X
High-performance CCTV Surveillance Applications (including VSaaS)			X	X	X	X					
Real-Time Tracking & Enhanced Visibility		X	X					X	X	X	X
Maintenance Support					X		X				

Table 2: 5G LOGINNOV Use Cases and 5G

2.2. Data Management

2.2.1. Overview

The evaluation activities of the project rely on the collection of the data produced at each Living Lab during the trials [1]. Thanks to a central data collection tool, the evaluation data are aggregated and the evaluation team is able to access indexed data and perform data analysis such as the calculation of the relevant KPIs (see Section 2.2.3.2).

The evaluation data management consists in ensuring that the collected data is FAIR (Findability, Accessibility, Interoperability, and Reuse) according to the project's Data Management Plan [2]. It requires a coordination between the intra-Living Labs partners as well as the coherence of the collected data across the Living Labs. To this aim, a description of the data collection process from the data acquisition through the local processing towards the ingestion into the central data collection was described in D2.2 [3]; such process is illustrated on Figure 1. Each Living Lab partner is free to implement the data acquisition and processing procedure of its choice. Then to prepare for the ingestion into the central data collection tool, the Living Lab data are documented with a set of metadata as detailed in D2.2 [3].

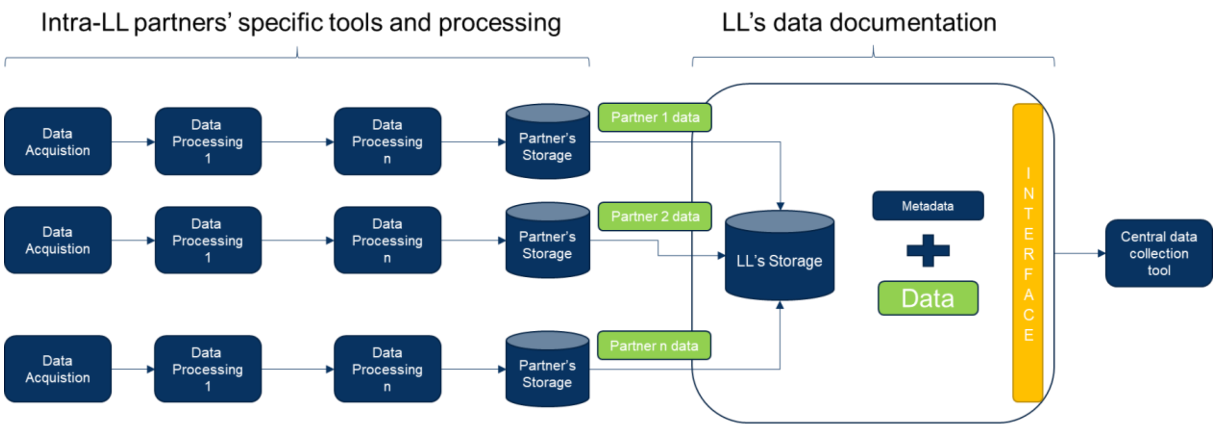


Figure 1: Evaluation data acquisition, processing, storage and ingestion into the central data collection tool

The production version of the central data collection tool including the interface to receive Living Labs data is described in the next subsection.

2.2.2. Centralized Data Collection Server

2.2.2.1. Architecture

The architecture of the central data collection tool is depicted on Figure 2. It is composed of 4 modules:

- Data ingestion
- Data indexing
- User interface
- Authentication & authorisation

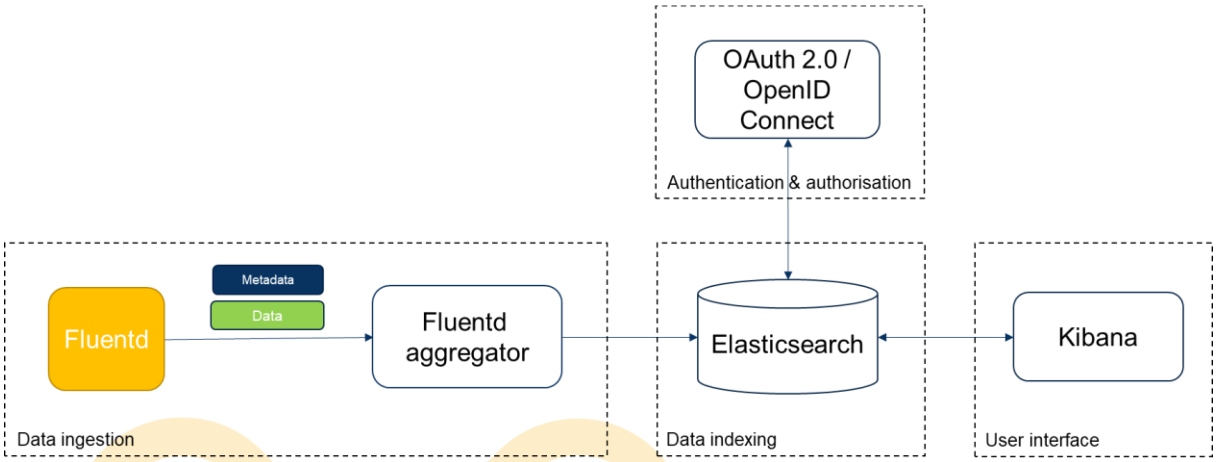


Figure 2: Central data collection tool modules

The data ingestion module is responsible for the ingestion of the data from the Living Labs. It acts as an interface between the Living Labs and the central data collection tool. A submodule controlled by a Living Lab is interfaced with an aggregator on the central tool side. The retained technical solution is Fluentd, an open-source data collector.

The data indexing module is responsible for the indexing and the storage of the data from the Living Labs to allow search and analysis on-premise or using any specialised tool including data visualisation solutions. Elasticsearch has been chosen for the technical implementation.

The user interface module relies on the data indexing module to provide the user a dashboard to perform data analysis and visualisation. The evaluation team will interact with the tool through this module. Elasticsearch can be interfaced with numerous UI solutions, but Kibana has been chosen as it is part of the Elasticsearch ecosystem.

The authentication & authorisation module is responsible for the authentication of the users of the tool. It can be configured to provide specific authorisations according to the user profile and the applicable policies. The technical solution relies on OAuth 2.0 and OpenID connect.

More details on these modules with the requirements they fulfil are provided in the dedicated deliverable D2.2 [3]. The deployment of the exploitation version of the tool is addressed in the next subsection.

2.2.2.2. Deployment

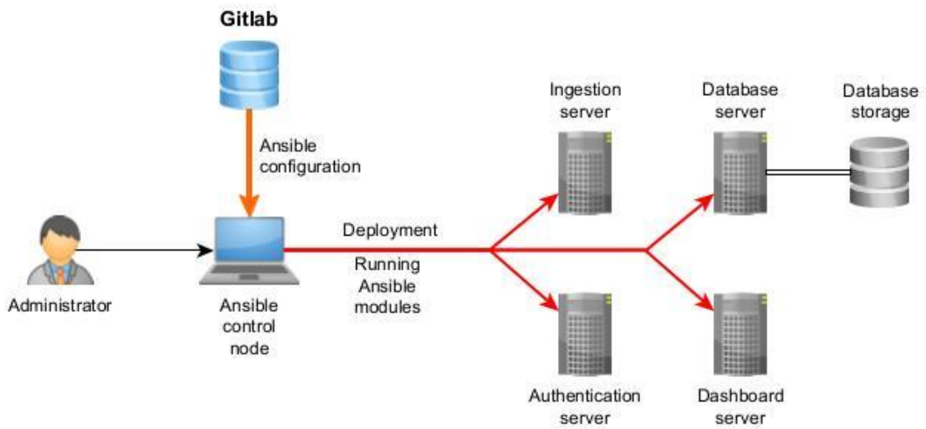
The deployment has been designed to be automated and as straightforward as possible. A set of Ansible[1] roles and playbooks[2] have been developed allowing to build the required environment and install each component of the central data collection tool, along with its dependencies.

Thanks to a central configuration file, these playbooks are adaptable to various deployment environments. They were developed mainly using various virtualization solutions such as Docker and VirtualBox, to host the central data collection tool components. The exploitation version is deployed in Azure virtual machines.

Ansible playbooks and environment files are stored and versioned in a git repository hosted on Gitlab, allowing an easy deployment of any version of the tool.

Deploying the central data collection tool is done in two main steps (Figure 3):

- First the chosen Ansible configuration (playbooks and settings) is pulled from Gitlab towards the control node (server running Ansible).
- Then the Ansible playbooks are run to launch the tasks on the managed nodes (VMs running the data collection tool services).



[1] Ansible is an open-source software provisioning, configuration management, and application-deployment tool enabling infrastructure as code. It is primarily intended for IT professionals, who use it for application deployment, updates on workstations and servers, cloud provisioning, configuration management, intra-service orchestration, and nearly anything a systems administrator does on a weekly or daily basis.

[2] A playbook is a configuration file written in YAML that provides instructions for what needs to be done in order to bring a managed node into the desired state.

Figure 3: Ansible tools deployment

The main components of the data collection tool are deployed on VMs with the specifications shown in on Table 3. These VMs are scalable to handle any increase of the amount of ingested data.

Table 3: Central data collection tool VMs characteristics

Role	Designation	vCore	RAM
Ingestion	B2ms	2	8 Gb
Authentication	B2s	2	4 Gb
Database	B4ms	4	16 Gb
Dashboard	B4ms	4	16 Gb

DNS records have been created to access these VM, along with certificates provided by AKKA:

https://ingest.5g-loginnov.akka.eu
https://auth.5g-loginnov.akka.eu
https://db.5g-loginnov.akka.eu
https://dahsboard.5g-loginnov.akka.eu

2.2.3. Living Lab Data

2.2.3.1. Data ingestion

This component is implemented using Fluentd[3] which aims to:

- Unify the logging with a common JSON data structure
- Offer a pluggable architecture based on data sources, data filters and data outputs
- Use as minimum resources as possible
- Offer a built-in reliability

Fluentd provides a set of pluggable modules which ensure that different data sources can be used, filtered, and sent to different outputs. Fluent instances are used as illustrated on Figure 4 to allow:

- The LL the possibility to manage complex data sources
- The central data collection tools to apply certain pre-processing among which data quality tests.

[3] https://www.fluentd.org/

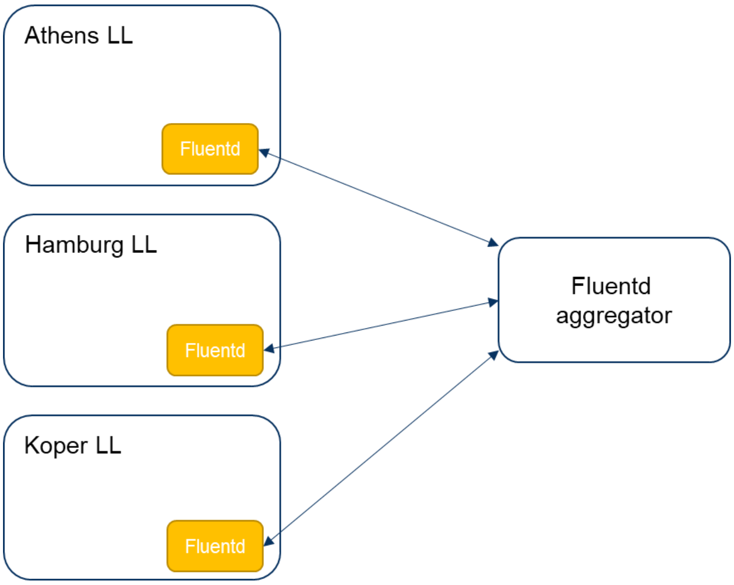


Figure 4: Communications between several instances of FluentD

The current release of the central data collection tools uses Fluentd v1.14.3.

2.2.3.2. Data indexing

The implementation of the 5G-LOGINNOV's data models is based on an adaption of the Elastic Commons Schema as illustrated on Figure 5.

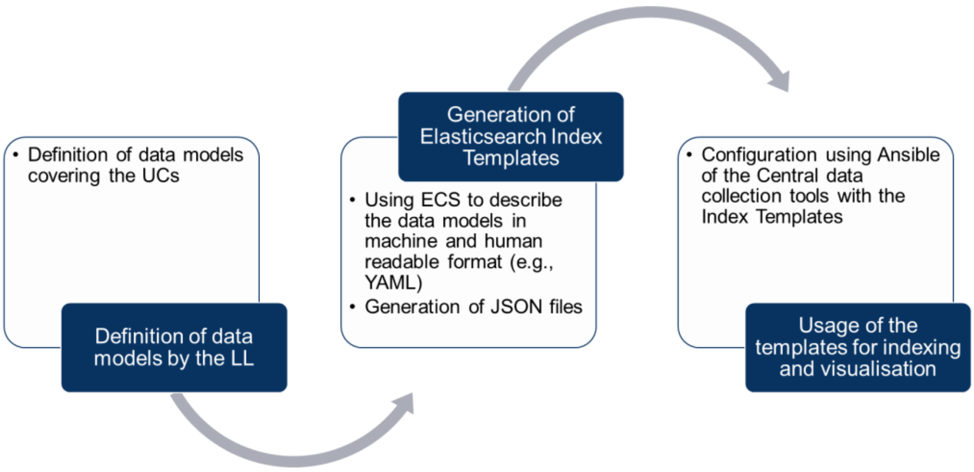


Figure 5: Common Evaluation data generation procedure

Based on the identification of evaluation data fields provided in D2.2 [3], each LL defines a consistent data model to be used for evaluation purposes. From these data models, the ECS approach is exploited to describe the data fields in YAML as illustrated on Figure 6.

```yaml
- name: athens-v1.0
  title: Athens
  group: 2
  short: Fields about the Athens Living lab.
  description: >
    According to the storyboards, the Athens LL will hand over the following data to the central tool.

  type: group
  fields:

    - name: inference_time
      level: extended
      type: float
      required: false
      short: The time required to process the input of video stream(s) and infer the presence/absence
      description: >
        The time required to process the input of video stream(s) and infer the presence/absence of people (UC4) OR

    - name: number_of_detections
      level: extended
      type: integer
      short: Number of people detected (UC4) or number of seals detected (UC5)
      description: >
        Number of people detected (UC4) or number of seals detected (UC5)

    - name: type
      level: extended
      type: text
      short: Seal or Person
      description: >
        Seal or Person
```

Figure 6: Data description using YAML

After describing the data models in YAML, As illustrated on Figure 7, Python scripts are used to generate documentation and JSON files which corresponds to the Elasticsearch index templates.

```
python3 scripts/generator.py   --subset  usage-example/fields/ll-athens/ll-athens.yml \
                               --out  usage-example/ll-athens  \
                               --template-settings usage-example/fields/ll-athens/template-settings.json \
                               --mapping-settings  usage-example/fields/ll-athens/mapping-settings.json
```

Figure 7: Index template generation for the Athens LL

Finally, the index template is used to configure Elasticsearch and Kibana for visualisation of the data, their storage and indexing.

2.3. KPIs Specifications

2.3.1. Athens Living Lab KPIs

This section refers to D1.4 (Initial specification of evaluation and KPIs) [4] where the specifications and details for the KPIs have been detailed as depicted in Table 4. A broad range of KPIs will be illustrated with respect to 5G KPIs (data rate, latency, etc.), AI/ML based KPIs (e.g., inference time and accuracy), as well as logistics and operational KPIs (fuel consumption, travel distance and CO_2 emissions, etc.).

UC	Measurable Objectives and Indicators	Validation/Measurable Outcomes	KPI(s)
2,3,4	5G-based cellular communications system	Deployment and validation of the 5G network and services	• End-to-end Latency • One-way Latency.
3,4,5,7	5G-based cellular communications system	Deployment and validation of the 5G network and services	• Connection Density • Reliability
4,5	5G-based cellular communications system	Deployment and validation of the 5G network and services	• Area Traffic Capacity • Bandwidth • User Experienced Data Rate
4,5	Novel surveillance technologies and mechanisms (pioneering portable 5G-IoT device, AI/ML based video analytics) with MANO orchestration Support	Development and deployment of novel 5G-IoT devices to support UC4 and UC5 in Athens LL.	• Model Accuracy/ Reliability • Model Inference Time • Deployment Time
7	Improve utilization of the port warehouses and storage spaces by at least 15%	Development and deployment of predictive maintenance service of UC7.	• Parts in Stock

7	Reduce total cost of spare parts and tyres annually by at least 10%	Development and deployment of predictive maintenance service of UC7.	• Parts in Stock • Vehicle Breakdowns • Vehicles Under Maintenance • Vehicles Unexpected Breakdown • Maintenance Costs of Vehicles
2	Reduce percentage of empty container runs by 15%	Development and deployment of device management platform ecosystem service of UC2 at Athens LL.	• Percent of Empty Containers Runs
5	Reduce vessel operation completion times by at least 5%	Development and deployment of UC5 automation for ports: port control, logistics and remote automation.	• Vessel Operation Completion Time
2	Traffic redistribution in port operations based on real-time truck localization data	Development and deployment of device management platform ecosystem of UC2 at Athens LL.	• Mean time of container job
2	Reduced time for a device to connect to the network in comparison to existing 3G / 4G based devices	Development and deployment of device management platform ecosystem service of UC2 at Athens LL.	• Time needed the device to open network connection
2,3	• Extrapolation of the potential CO_2/NO_X savings based on the real traffic volume to the port terminals. • Reduce emissions produced by trucks delivering/picking up containers at least 15%	Development and deployment of optimal selection of yard trucks services of UC3 and device management platform ecosystem service of UC2 at Athens LL.	• CO_2 Emissions • Fuel Consumption • Truck Travel Distance
3,7	Minimize percentage of yard equipment assets idling for more than one shift	Development and deployment of optimal yard truck selection service of UC3, and predictive maintenance service of UC7 at Athens LL.	• Assets Idling
4,5	Optimise the use of human resources in yard equipment port operations	Development and deployment of UC4 surveillance cameras and video analytics, and UC5 automation for ports: port control, logistics and remote Automation.	• Human resource optimization (person hours)

Table 4: LL Athens KPIs (reference D1.4)

The main point of difference with D1.4 considers use case 3, with the amendment of 5G localization technology. The augmentation of the use case along with more details regarding the relevant software and hardware components are detailed in Section 3.3.3. Table 5 presents details on the KPIs for the augmented version of the use case 3.

KPI	Description
Inference Time	The time required for the machine learning model to process the input of video stream(s) and infer the presence/absence of people in the selected area(s)
Inference Accuracy	The accuracy (ratio of success) of the machine learning model for detecting the presence/absence in close proximity to trucks Based on the resulting confusion matrix and the derived true/false positive/negatives relevant ratios of the classifier, precision (fraction of correctly classified instances containing humans among the entirety of instances classified as such) and recall (fraction of correctly classified instances containing humans among the entirety of instances actually containing

	humans) for each of the two classes (i.e., human present or not) will be calculated.
Bandwidth	Maximum uplink and downlink bandwidth measured from the yard truck to the reference 5G Edge IoT node, i.e., Kubernetes worker node.
One Way Latency	The one-way latency is the total time that is required for a packet to be generated at the communication unit at the transmitter's side, until it is received at the communication unit at the receiver's side.
Deployment Time	Elapsed time from the moment the deployment is started via the orchestrator until the system is ready to use.

Table 5: LL Athens UC3 additional KPIs

2.3.2. Hamburg Living Lab KPIs

In order to comply with the clean air regulations, Hamburg wants to implement ITS solutions balancing the need for improving air quality with the economic interests of logistics service provider to deliver their goods in time and budget. Therefore, sustainable traffic management based on 5G and Connected and Automated Cooperative Mobility became a key pillar of Hamburg's 2030 ITS policy targets. The four use cases of 5G-LOGINNOV LL Hamburg are reflecting this need for clean air projects including innovative traffic management and GLOSA-based Automated Truck Platooning in 5G cellular operational environment as Deutsche Telekom is providing in the area of Hamburg especially in the city and port areas.

Real-time emission data from truck sensors will be transferred to traffic controllers calculating the optimum speed for the automated truck platoon in the logistics corridor, avoiding stop & go incident of the truck platoon, by 5G real-time truck trip & emission data collected by LCMM, Entruck and Continental IoT devices by using 5G Precise Positioning technology.

Facilitate the quantification of port decisions impact for mid-/long-term through Key Performance Indicators (KPIs): CO_2 emissions and air quality by measurement of fuel and emission reduction (CO_2/NO_X) of a truck platoon or trucks alone while driving with 5G GLOSA.

Support the 5G next generation network architecture and the use of 5G communication systems (dedicated bandwidths (per user) over 500MBit/s - depending on deployed network structure) the LL Hamburg will use the production network of T-Mobile with 5GNR (in 3.5 GHz spectrum) to get this high capacity.

The product solution of Deutsche Telekom with the partner Skylark will provide a precision level on 10 cm (comparable with 3 - 10 m for uncorrected GNSS signal. This solution will be integrated in the LL Hamburg use cases to increase the precision by factor 10 and to reduce the complexity of the solution.

Signal latency in the 5G environment will be reduced thru Mobile Edge Computing (MEC). The signal transfer time and the stability of the transmission will be improved. The signal transfer delay (latency) can come down near to 10 ms.

Based on the mentioned objectives and use cases (cf. Section 4.3), the LL Hamburg has specified its KPIs (for further details see D1.4 [4]):

- 5G-LOGINNOV 5G GLOSA & Automated Truck Platooning influencing urban road traffic by dynamic Increase average truck speed in single mode and platoon mode up to 5%
- Reduction of average acceleration activities in single mode and platoon mode up to 5%
- Reduction of stillstand time in single mode and platoon mode up to 5%

- Reduction of fuel consumption in single mode and platoon mode up to 10%
- Reduction of CO_2 emission in single mode and platoon mode up to 10%
- Increase value of 'EPI - cl per ton and km' up to 10% for vehicle trips
- Increase value of API 'KWh per ton and km' up to 10% for vehicle trips
- Extended cellular bandwidth on urban roads by 5G network
- Positioning quality on urban road networks with 5G by 10 cm
- Average signal latency in the 5G environment will be reduced thru Mobile Edge Computing (MEC) near to 10 ms during vehicle trips
- Reduction of the Packed Error Rate (PER) in 5G NSA production network by 10%

2.3.3. Koper Living Lab KPIs

In this deliverable we have again considered the KPIs, which were identified and specified in D1.4 (for further details see [4]). We will monitor KPIs in several areas. A summary of the KPIs to be monitored in KP LL are listed in the table below.

In order to assist all of the planned use cases, we will set up two 5G networks in the Port of Koper, namely the private 5G SA network and the 5G NSA commercial network. The Koper Living Lab targets the implementation of novel 5G technologies (MANO-based services and network orchestration, Industrial IoT, AI/ML-based video analytics, drone-based security monitoring, etc.) and cutting-edge prototypes tailored to be operated in the port environment. 5G network within Koper Living Lab will be designed to support the deployment of the innovative advanced use cases involving several cutting-edge 5G features and technologies and new devices (e.g. slicing, eMBB, uRLLC, mMTC, MEC, 5G-NR, etc.). To provide 5G KPIs we have already started collecting some data.

To support Port Control, Logistics and Remote Automation, SDK and annotated model will be developed and deployed. Some KPIs related with this use case will be measured through a qualitative assessment.

For several KPIs, telemetry data will be collected from some of the vehicles. This information will be collected from the vehicle CAN-Bus, using the Continental 5G IoT device and transmitted via the 5G network, to the port operation support system.

Also, private security operations management and support, featuring services to enable security operations, including personnel/team status monitoring, positioning and triage operations support with dedicated mobile applications will be evaluated.

Table 6: Koper Living Lab KPIs table (source: Deliverable D1.4)

UC	UC Name(s)	Measurable Objectives and Indicators	Validation/Measurable Outcomes	KPI(s)
1	Management and Network Orchestration platform (MANO)	Enhancing 5G IoT backend system elements with new NFV functionalities and MANO orchestration support - Remote network monitoring (OSM-CNF/rMON) IoT platform	Deployment and validation of the 5G IoT backend system components in LL Koper to support operation of the UC1	• Components Onboarding and Configuration (Backend) • Deployment Time (Backend) • Time to Scale (Backend) • Service Availability (Backend) • Components Onboarding and Configuration (Agent) • Deployment Time (Agent)

UC	UC Name(s)	Measurable Objectives and Indicators	Validation/Measurable Outcomes	KPI(s)
1,5	Management and Network Orchestration platform (MANO)	Dedicated private mobile system that will be built as standalone and self-operated 5G network and services platform infrastructure - VNF network (OSM-VNF) Private 5G network	Deployment and validation of the 5G network and services in LL Koper to support operation of the UC1, UC5 and UC6	• Components Onboarding and Configuration (Backend) • Deployment Time (Backend) • Time to Scale (Backend) • Service Availability (Backend) • Slice Reconfiguration (Backend)
1,5	Management and Network Orchestration platform (MANO)	Private 5G-based mobile services provided by the national MNO (Mobile Network Operator), tailored to the needs of port operation, will be provisioned and operated over the public MNO infrastructure	Deployment and validation of the 5G network and services in LL Koper to support operation of the UC1, UC5 and UC6	• Area Traffic Capacity • Availability • Bandwidth • Connection Density • Coverage Area Probability • End-to-End Latency • Reliability
5,6	Automation for Ports: Port Control, Logistics and Remote Automation	Enhancing functionalities of the 5G IoT GW to support 5G Non-Standalone and Standalone capabilities (NSA/SA), MANO orchestration and capturing of vertical and horizontal network and services KPIs, with support of E2E 5G monitoring capabilities	Deployment and validation of 5G IoT platform in the LL Koper to support operation of the UC5 and UC6	**Qualitative assessment**
5,6	Automation for Ports: Port Control, Logistics and Remote Automation	Proprietary computer vision SDK, multiplatform, to rapid prototyping in a large variety of sectors, including Advanced Driver Assistance System (ADAS), security, inspection and HMI	Development and deployment of the SDK in LL Koper to support operation of the UC5 and UC6	**Qualitative assessment**
5,6	Automation for Ports: Port Control, Logistics and Remote Automation	Annotation model to describe content of image sequences, in the form of: spatiotemporal entities, called Elements. Thus, VCD contains lists of Elements being: Objects, Events, Actions, Context or Relations, etc.	Development and deployment of the annotated model in LL Koper to support operation of the UC5 and UC6	• Model Accuracy/Reliability • Model Inference Time
5	Automation for Ports: Port Control, Logistics and Remote Automation	Enhancing equipment monitoring through the collection of telemetry data from vehicles involved in port operations	Development and deployment of IoT devices on vehicles in LL Koper, to support UC5	**Qualitative assessment**

UC	UC Name(s)	Measurable Objectives and Indicators	Validation/Measurable Outcomes	KPI(s)
5,6	Mission Critical Communications in Ports	Enhancing functionalities of the 5G IoT GW to support 5G Non-Standalone and Standalone capabilities (NSA/SA), MANO orchestration and capturing of vertical and horizontal network and services KPIs, with support of E2E 5G monitoring capabilities	Deployment and validation of 5G IoT platform in the LL Koper to support operation of the UC5 and UC6	**Qualitative assessment**
6	Mission Critical Communications in Ports	Novel surveillance technologies and mechanisms (drone-based, wearable cameras, AI/ML based video analytics)	Development and deployment of the mission critical and security related uses case (UC6) in LL Koper	• Model Accuracy/Reliability • Model Inference Time • Model Accuracy/Reliability • Model Inference Time

2.3.4. Open Call

5G-LOGINNOV organised an Open Call for the selection of five innovative start-ups and SMEs aiming to develop 5G-based solutions in the framework of activities carried out at the three Living Labs of the project. The Open Call was officially launched on 26-April-2021, to last until 15-Jul-2021; the event was advertised on the project website, on the ERTICO official site and through various communication channels (e.g. LinkedIn), as well as promoted by Living Lab leaders at local level. At the Open Call closing time (15-Jul-2021), 15 applications were received, addressing all the three Living Labs and covering a very broad range of application domains, including Intelligent Transport Systems (ITS), automated handling, safety and security, telecommunications, etc. All applications underwent a technical/business evaluation process, aiming to determine their ranking and to select the 5 winners granted with a service contract for each provider; the evaluation of eligible applications has been carried out by the 5G-LOGINNOV Project Management Team, including the Project Coordinator, the Innovation Manager, the Data Manager, the Communication Manager and all WP and LL Leaders. The evaluation process, carried out in respect of the principles of fairness and transparency, aimed to assess the applications under two distinct yet complementary perspectives:

- Technical aspects (relevance to selected Living Lab(s), degree of innovation, overall architecture, expected impacts and benefits, data sharing, project structure, etc.)
- Business and market aspects (ambitions, time-to-market, costs structure, business plan, etc.)

The 5 selected applications are listed in Table 7.

Acronym	Full Title	Applicant	Athens LL	Hamburg LL	Koper LL
TRITON	auTonomous dRones for marITime OperatioNs	Hellenic Drones			X
RESONATE	Real timE drowSiness detectiON, AlerTing and rEporting	Libra AI	X		

5G4A	5G-Loginnov-4-Amazon	eShuttle	X
TAADD	TAXi-AD Data	TAXi-AD GmbH	X
ITGS	Intelligent Traffic Guidance System	Roads.AI	X

Table 7: Applications winning the 5G-LOGINNOV Open Call

The selected applicants have been incorporated into the 5G-LOGINNOV consortium through a service contract granted by ICOOR and UNIMORE (University of Modena and Reggio Emilia) on behalf of the whole consortium, i.e. the services will be for the benefit of other beneficiaries of the project. All contracts have been signed and all the selected applicants started working actively on the project.

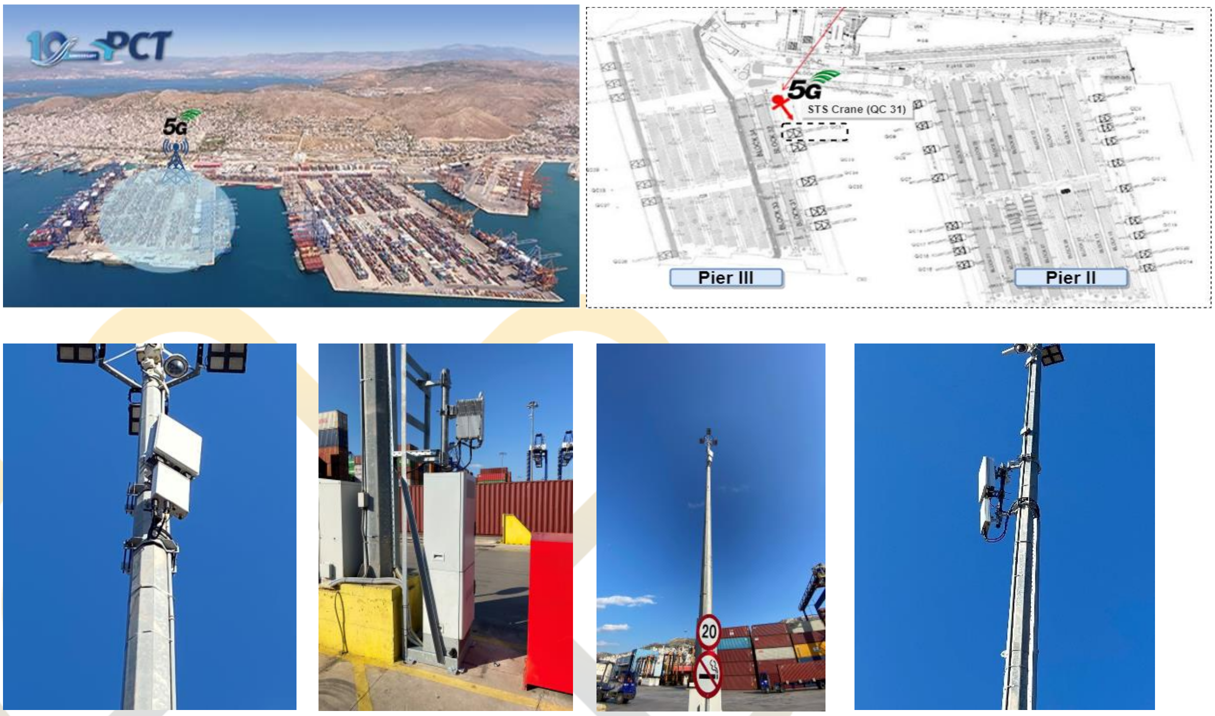
3. DEVELOPMENT AND DEPLOYMENT IN LIVING LAB ATHENS

3.1. Site Overview

As part of the 5G-LOGINNOV project, the Athens LL developed a set of use cases and platforms (explained in detail in the following sections), which communicate over the 5G NSA network with different types of end devices (5G-Trucks, 5G-Cranes, 5G-IoT, 5G UEs). 5G technology will enable the use case innovations exploiting the eMBB service and low latency transmissions of 5G, including NFV-MANO based applications and service orchestration, pioneering far edge computing solutions, computer vision and AI/ML-based video analytics. The portfolio of application innovations includes live tracking of 5G (yard and external) truck operations for efficient container job allocation, traffic management and predictive maintenance services by exploiting telemetry data (from various on-truck sensors) aggregated over the fleet of 5G connected trucks in (near-)real time; UHD transmissions of massive uplink video data from deployed 5G-IoT devices for port operations monitoring; remote, automated management and orchestration of end-to-end computer vision analytics services targeting safety/security and logistics applications, orchestrated as NFV-MANO services with 5G network support for lifecycle management of various service components (Figure 8).

Figure 8: LL Athens use cases and components.

The following Figures depict the deployed 5G radio access network (based on the RRU 5639w) at Piraeus Port and mapping in the port area. Vodafone's Core network operates outside the port premises, at Vodafone's datacentre. Currently PCT has an operational private 5G NSA network, operating in band n78 at 3.7GHz with 100 MHz bandwidth, providing 5G connectivity to a subset of the port Piers, whereas the remaining port areas are fully covered via 4G. The deployed base station (gNB) can support up to 64x64 MIMO communications providing up to 800 Mbps DL and 100 Mbps UL (average IP rates), whereas latency is between 10-20ms (c.f. Section 3.2).



Details on the hardware equipment are listed in Section 3.2.

3.2. Deployed Components

The following tables summarize the deployed components in Athens LL premises, with specifications. Table 8 depicts PCT assets (yard trucks, cranes, etc.) engaged in the 5G LOGINNOV project, whereas from Table 9 to Table 13 hardware and software specifications are illustrated (cameras, IoT nodes, 5G interface, OSM release, Kubernetes version, etc.).

Equipment Description	Addressed Use cases	Amount/Target	Available
5G modem (for IoT devices and yard trucks)	UC3, UC4, UC5, UC7	4	Expected date end of April
UHD cameras	UC4, UC5	4	4
Compute Node (edge processing node)	UC4, UC5	2	2
STS Cranes	UC5	1	1
Yard trucks	UC3, UC7	2	2
External trucks	UC2	5	5
5G UEs	UC2	5	5
gNB (RRU 5639w)	All	1	1

Table 8: LL Athens port Assets and hardware exploited in 5G LOGINNOV Project

Private 5G Network (NSA Mode)					
Radio Access Network	**CN**	**Frequency Bands**	**Channel BW**	**Max Throughput**	**Other**
5G NR (Release 15) NSA	5G Core (Release 15) NSA	n78, @3.7Ghz	100Mhz	800 Mbps DL and 100 Mbps UL (average IP rates)	Capable up to 64x64 MIMO

Table 9: LL Athens 5G NSA network specification

5G Modem/Iface (R5020 5G IoT Router)	
Frequency Bands	**5G NR NSA**: n1/n2/n3/n5/n7/n8/n12/n20/n25/n28/n38/ n40/n41/n48*/n66/n71/n77/n78/n79 **5G NR SA:** n1/n2/n3/n5/n7/n8/n12/n20/n25/n28/n38/ n40/n41/n48*/n66/n71/n77/n78/n79 **4G: LTE FDD:** B1/B2/B3/B4/B5/B7/B8/B12(B17)/B13/B14/B18/

	B19/B20/B25/B26/B28/B29/B30/B32/B66/B71 **4G LTE TDD:** B34/B38/B39/B40/B41/B42/B43/B48
Number of antennas	4 (ANT0 + ANT1 + ANT2 + ANT3)
Network protocols	PPP, PPPoE, TCP, UDP, DHCP, ICMP, NAT, HTTP, HTTPs, DNS, ARP, NTP, SMTP, Telnet, SSH2, DDNS, etc.
Ethernet Ports	4 x 10/100/1000 Mbps, 4 LAN by default, can be configured as 1 WAN + 3 LAN Support 802.3at PD feature on ETH0 (optional)

Table 10: LL Athens 5G interface specifications establishing interconnection of IoT and truck nodes with management platforms

IoT Node (NVIDIA Jetson AGX Xavier)	
Resource Type	**Specifications**
GPU	512-core Volta GPU with Tensor Cores
CPU	8-core ARM v8.2 64-bit CPU, 8MB L2 + 4MB L3
Memory	32GB 256-Bit LPDDR4x | 137GB/s
Storage	32GB eMMC 5.1
DL Accelerator	(2x) NVDLA Engines
Vision Accelerator	7-way VLIW Vision Processor
Encoder/Decoder	(2x) 4Kp60 | HEVC/(2x) 4Kp60 | 12-Bit Support
Size	105 mm x 105 mm x 65 mm

Table 11: LL Athens IoT node specifications for GPU enabled analytics at the (far-)edge

4K Camera (IPC-HFW3841T-ZAS)	
Resource Type	**Specifications**
Image Sensor	1/2.8”8Megapixel progressive CMOS
Resolution	8M (3840 × 2160); 6M (3072 × 2048); 5M (3072 × 1728/2592 × 1944); 4M (2688 × 1520); 3M (2048 × 1536/2304 × 1296); 1080p (1920 × 1080); 1.3M (1280 × 960); 720p (1280 × 720); D1(704 × 576/704 × 480); VGA (640 × 480); CIF (352 × 288/352 × 240)
Field of View	Horizontal: 113°–31° Vertical: 58°–17° Diagonal:138°–36°
Video Compression	H.265; H.264; H.264H; H.264B; MJPEG,
Video Frame Rate	Main stream: 3840 × 2160 @(1–20 fps by default) 3840 × 2160 @(1–25/30 fps when AI function disabled)

	sub stream: 704 × 576 @(1–25 fps)/704 × 480 @ (1–30 fps) third stream: 1920 × 1080 @(1–25/30 fps)
Bit Rate Control	CBR/VBR
Video Bit Rate	H.264: 3 kbps–8192 kbps H.265: 3 kbps–8192 kbps
Network	RJ-45 (10/100 Base-T)
Protocol	IPv4; IPv6; HTTP; TCP; UDP; ARP; RTP; RTSP; RTCP; RTMP; SMTP; FTP; SFTP; DHCP; DNS; DDNS; QoS; UPnP; NTP; Multicast; ICMP; IGMP; NFS; SAMBA; PPPoE; SNMP

Table 12: LL Athens UHD Camera specifications for AI-enabled video analytics services

Software Suite	
Software	**Specifications**
Open Source Mano (OSM)	Release 11
Microk8s	Version 1.22.8
Docker	Version 20.10.11
CUDA	Version 10.2
PyTorch	Version 1.8
OS of IoT Device	NVIDIA Linux Kernel: 4.9.253
OS of VMs (OSM, K8S)	Legacy Ubuntu Bionic: 18.04

Table 13: LL Athens software suite and software stack details

3.3. Use cases and Storyboards

3.3.1. NFV-MANO Platform and Kubernetes at PCT premises

A 5G-IoT system with NFV-MANO support (Figure 9) is deployed in Athens LL supporting a set of use cases that utilize 5G-IoT devices, 5G Quayside Cranes (QC) and data from 5G (yard) truck sensors. The platform is based on open-source solutions for service orchestration and life cycle management of applications at the (far-)edge. Particularly, OpenSource MANO (OSM) Release 11 is equipped with a Kubernetes cluster based on Microk8s tool (Version 1.22), to deploy container-based network functions (CNFs), tailored to video analytics services in various 5G-IoT nodes distributed at the Port's areas of interest. OSM and Microk8s are hosted at PCT's datacenter infrastructure, in two virtual machines (8CPU, 60GB storage, 8GB Ram), interconnected via gigabit ethernet link. The 5G IoT nodes (and relevant analytics services) will exploit the eMBB service and low latency transmissions of 5G, to deliver voluminous (inferenced) video streams for safety/security applications and monitoring, as well as port control, logistics and remote automation targeting the efficiency of port operations. The NFV-MANO platform supports UC3, UC4 and UC5 by orchestrating computer vision services, monitoring, data collection and lifecycle operations at the 5G IoT nodes.

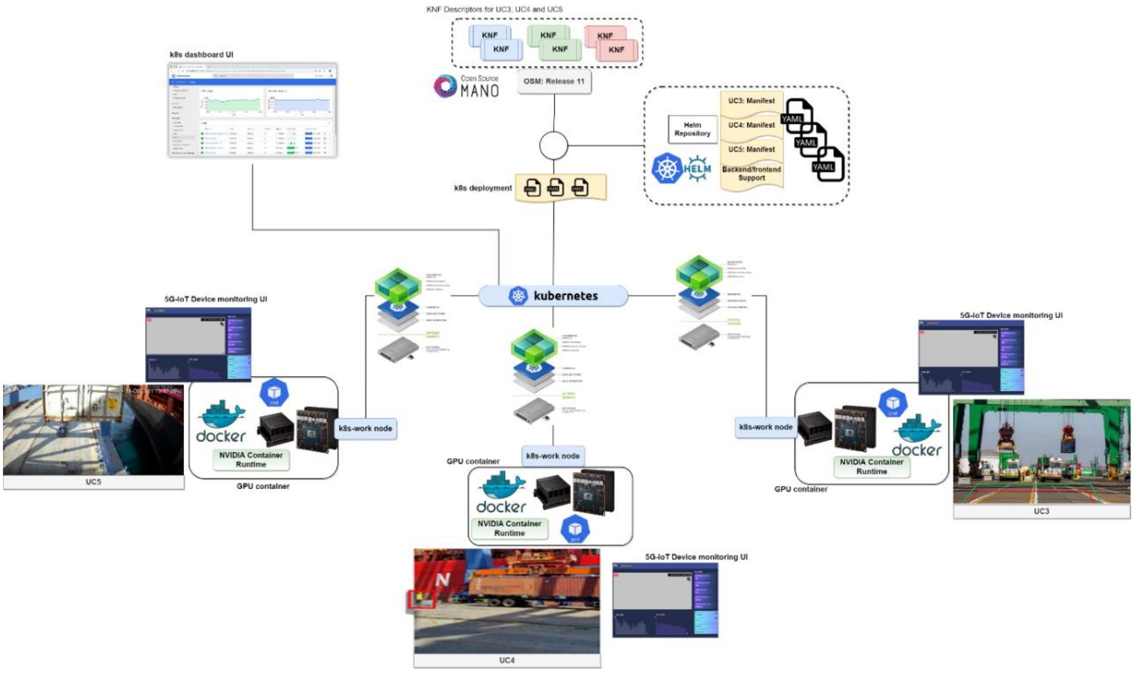


Figure 9: LL Athens NFV-MANO Platform at PCT

In Figure 10, the output of the kubernetes command line tool (kubectl) is shown depicting basic kubernetes services, i.e., CoreDNS (pod networking), storage service, metallb (loadbalancer), metrics and dashboard service for pod/services statistics as well as Helm3 for local kubernetes service management.

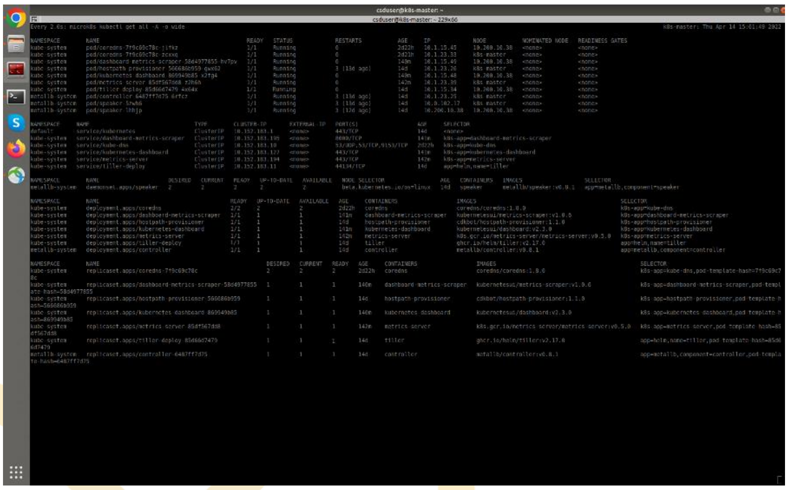


Figure 10: LL Athens Kubernetes orchestrator view at PCT

Figure 11 to Figure 14 depict the backend system, hosting a Django (version 4.0.2) database (located at the VM hosting the kubernetes orchestrator --master node) for storing KPI data related to AI-enabled use cases (e.g., inference time, inference accuracy, inferenced frames, etc.), as well as visual UIs for inspection and management used by PCT personnel.

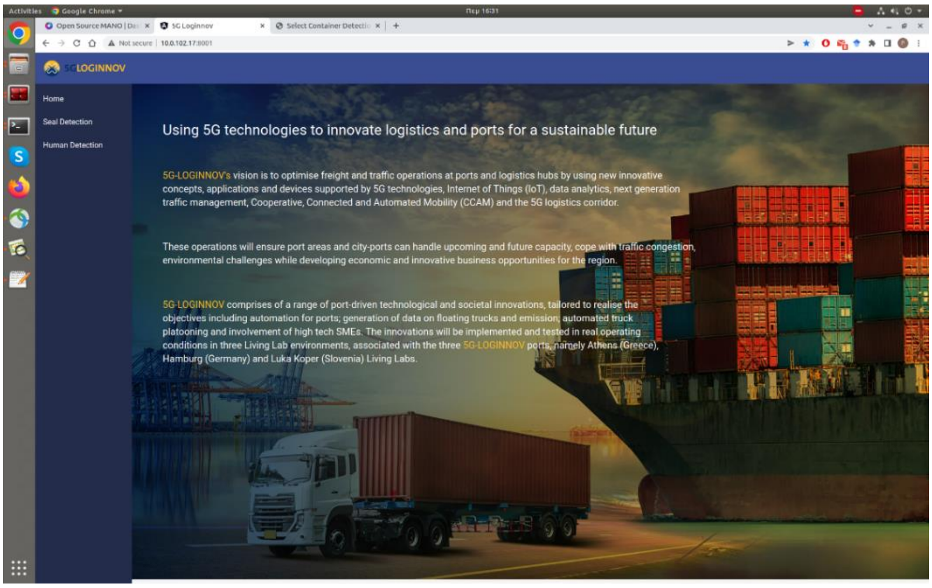


Figure 11: LL Athens backend UI Home Page

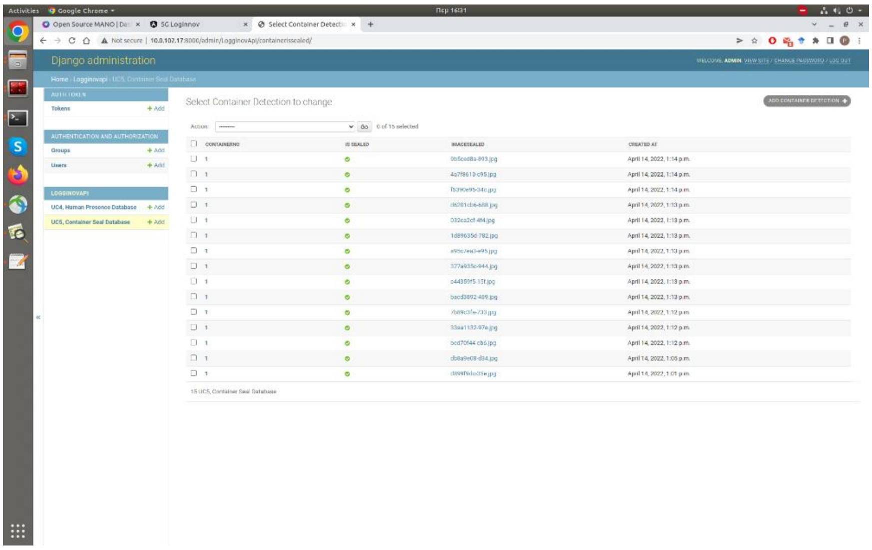


Figure 12: LL Athens django database UI

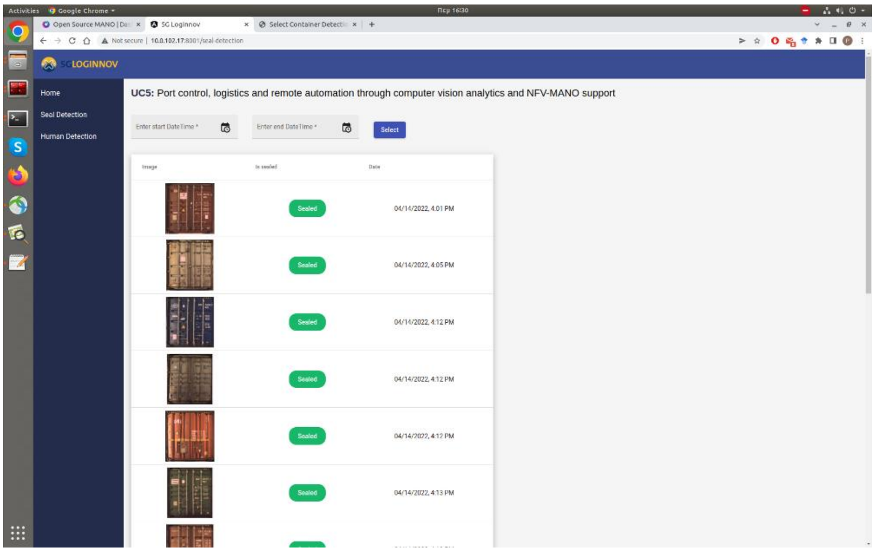


Figure 13: LL Athens container seal backend UI

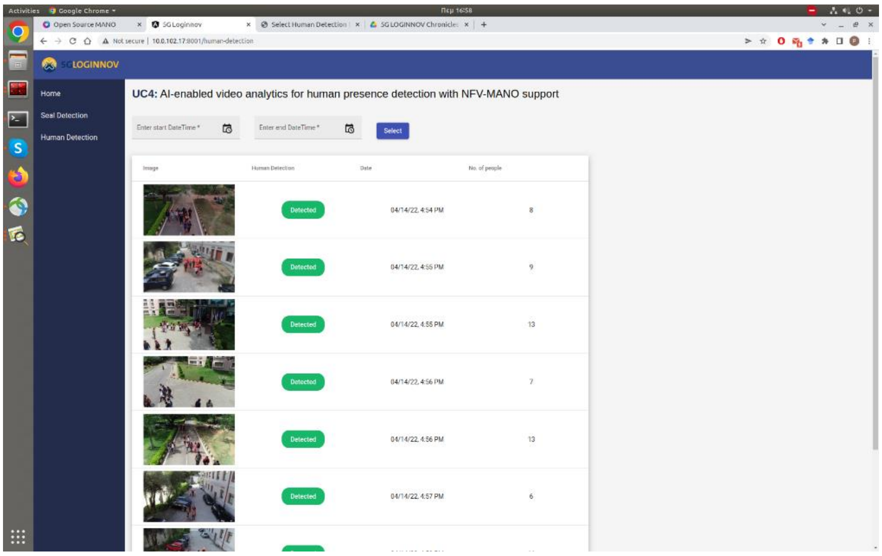


Figure 14: LL Athens human presence backend UI

3.3.2. UC2: Device Management Platform Ecosystem

This use case aims to aid port operations while leveraging the Vodafone Device Management Platform Ecosystem (IoT Platform). This use case is two-fold aimed: the first aim is an informative task, and the goal is to leverage the position of external trucks in order to estimate anticipated traffic towards the port; the second aim is informing (map based) all truck positions to other truck drivers in real time. This information is important for truck drivers when manoeuvring close to other trucks and during platooning.

The following figure depicts the connection between yard trucks. Each driver can see its truck location in conjunction with other trucks nearby. Each device communicates via a stream message-based server via web sockets. Its lightweight design with minimum CPU and RAM usage makes this implementation ideal candidate for near real time data exchange between devices. The data towards the VFI (IoT Platform) cloud is information regarding the 5G KPI measurements. Traffic information is also received from the platform.

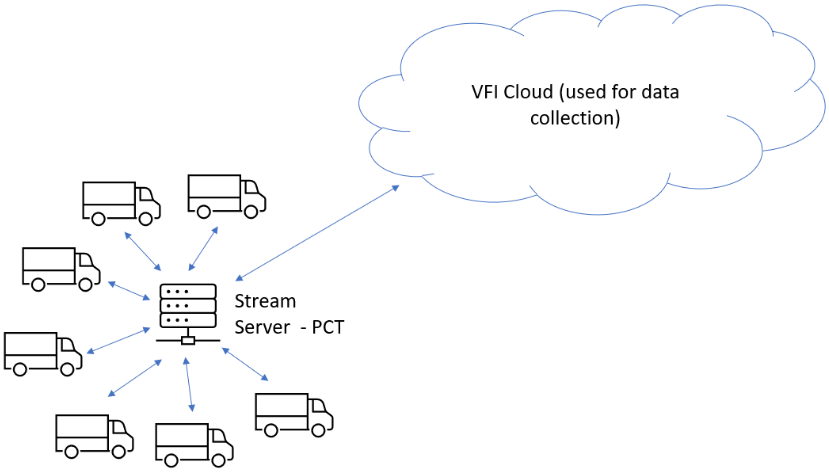


Figure 15: LL Athens Truck to stream server

Figure 16: LL Athens App in vehicle

Figure 17: LL Athens Truck driver app - UI

The stream server at PCT also generates a map of live vehicle position and gives a near-real time vehicle position.

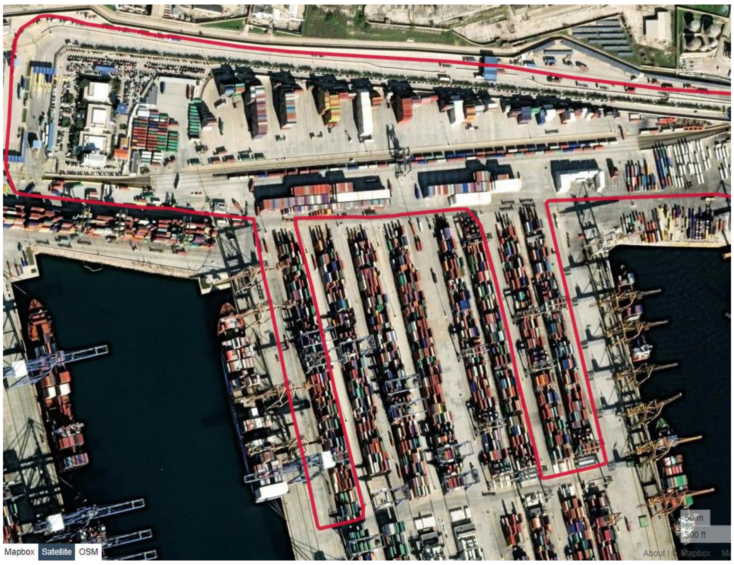


Figure 18: LL Athens Visualization of live track

3.3.3. UC3: Optimal selection of yard trucks

Use case 3 exploits the MANO Platform described in Section 3.3.1. The NSD and KNF descriptors are shown in Figure 19 and Figure 20, respectively. It is split into two main objectives: (a) to deliver a 5G enabled alert system for collision avoidance with human personnel in close proximity to yard trucks; (b) to collect live data from on-truck sensors and coordinate yard truck operations for the horizontal movement of containers within the port area.

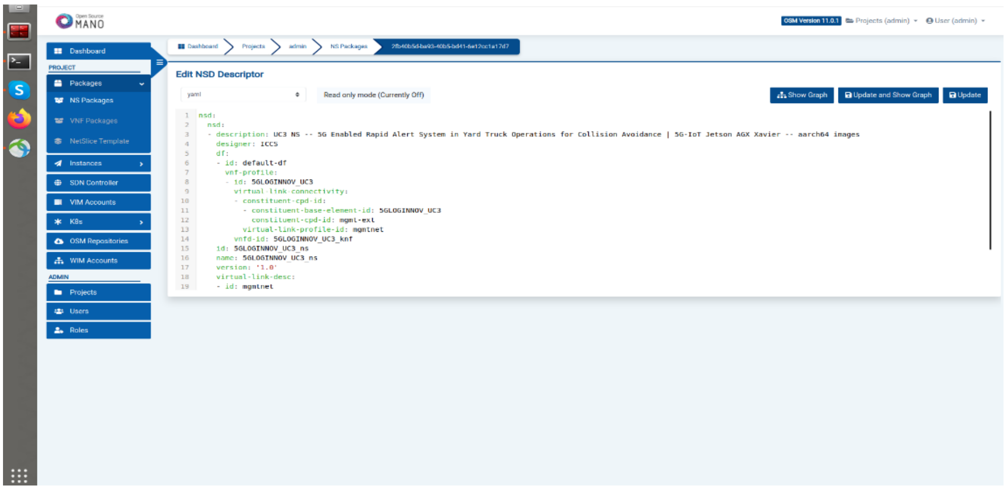


Figure 19: LL Athens UC3 NSD Descriptor

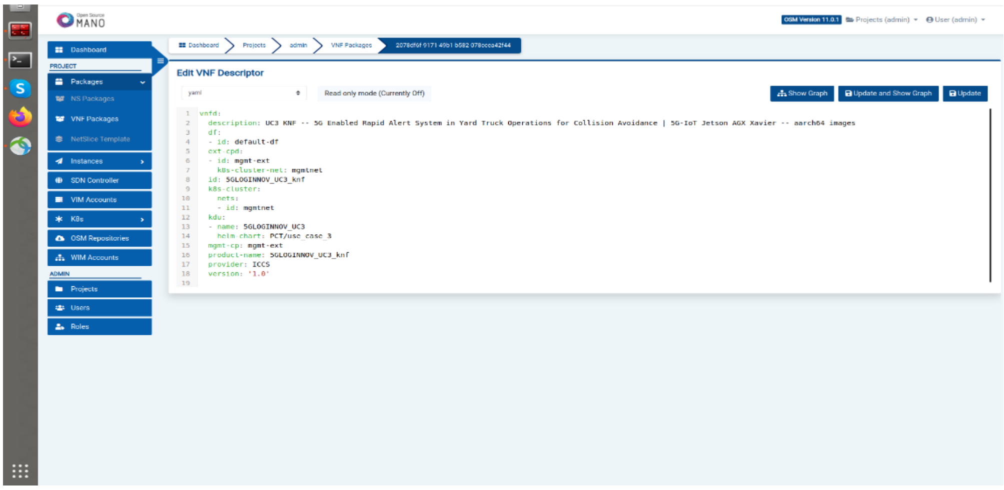


Figure 20: LL Athens UC3 KNF descriptor

OSM orchestrates the manifest files to be deployed at the 5G-IoT device that will host the AI-enabled algorithm for human presence detection at close proximity to 5G yard trucks, based on video input from UHD cameras equipped on yard trucks. Figure 21 depicts the camera installation and tablet at the cabin of the yard truck for showing the respective alerts.

Figure 21: LL Athens UHD Camera installation on PCT's Yard truck.

Orchestration of the service (management plane) happens over the 5G interface for service management and lifecycle operations. Data plane operations include UHD inferenced (annotated) video streaming at PCT's monitoring system, exploiting the eMBB service of the 5G network, whereas low latency communications are employed for delivering rapid alerts (video) to the yard truck driver for collision/accidents avoidance. The alert system operation is illustrated in Figure 22. On the left, a black screen is depicted at the tablet when no human presence is detected, whereas the inferenced video stream is triggered/delivered at the tablet when a person is detected (right most image).

Figure 22: LL Athens alert system view at the tablet installed on 5G connected yard truck

AI/ML-based 5G Enabled Rapid Alert System for Collision Avoidance

Port infrastructures contain heavy machinery equipment which handles large weights on and above ground, and yard trucks moving within the area for the horizontal movement of container, along with personnel. Despite the systematic measures and processes imposed to ensure safety for the working personnel, there are still margins where a trivial human oversight can result in an injury. Use Case 3 addresses this issue by exploiting state of the art object detection algorithms further customized to detect human presence in such areas of interest.

To this end, wide angle 4K camera was installed in PCT yard truck. Areas proximal to the truck were matched to corresponding pixel areas of the captured images. Due to the real time and local processing requirements and of the task the YOLO v4 deep neural network architecture was used as the human detection algorithm. Open-source datasets [5] [6] were sampled to create a dataset of ~110,000 images with ~400,000 annotated instances of humans. Training results from the public dataset of the AI-enabled human presence detection model are illustrated in Figure 23.

Figure 23: LL Athens testing results for human presence detection model

The resulting algorithm achieved a mAP of 0.52 and deployed on a Jetson AGX Xavier device could process images resized to a 640x480 size at a frame rate of ~30 fps, i.e., <25-30ms frame inference time. The resulting annotated 4K video was streamed over a 5G connection to the respective port authority and yard truck drivers, to deliver the 5G enabled rapid alert system for collision avoidance, as depicted in Figure 22.

5G Yard Truck Container Job Allocation

5G trucks are equipped with a telematics device, which is connected to the following sensors: CAN-Bus, GNSS localization, container presence sensors and a 5G interface to establish communications with PCT's traffic management system (TMS). Data from sensors are transmitted to the TMS depicting the digital footprint of yard truck operations (Figure 24), including the movement direction of yard trucks, velocity and current load carried (i.e., number of containers).

Figure 24: LL Athens traffic Monitoring System at PCT

At TMS a job allocation algorithm is running taking into consideration: (*i*) the pool of available open jobs i.e., containers movement within the port premises e.g., from a vessel to storage or rail/road transport network; (*ii*) the velocity/speed and moving direction of yard trucks; (*iii*) the number of containers already loaded (one or two) on each truck. To coordinate in real-time PCT's yard truck fleet operations (about 200-yard trucks are involved), the use case will exploit the low latency communications of 5G to rapidly deliver localization and other sensed data to TMS which will select the optimal, i.e., closet truck for a particular job.

3.3.4. UC4: Optimal surveillance cameras and video analytics

Use case 4 exploits the MANO Platform described in Section 3.3.1. The NSD and KNF descriptors are shown in Figure 25 and Figure 26, respectively.

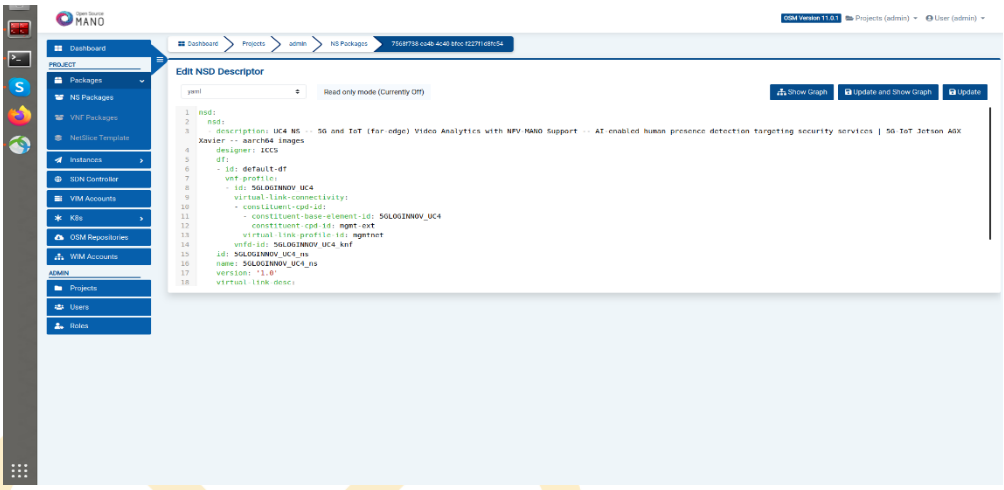


Figure 25: LL Athens UC4 NSD Descriptor

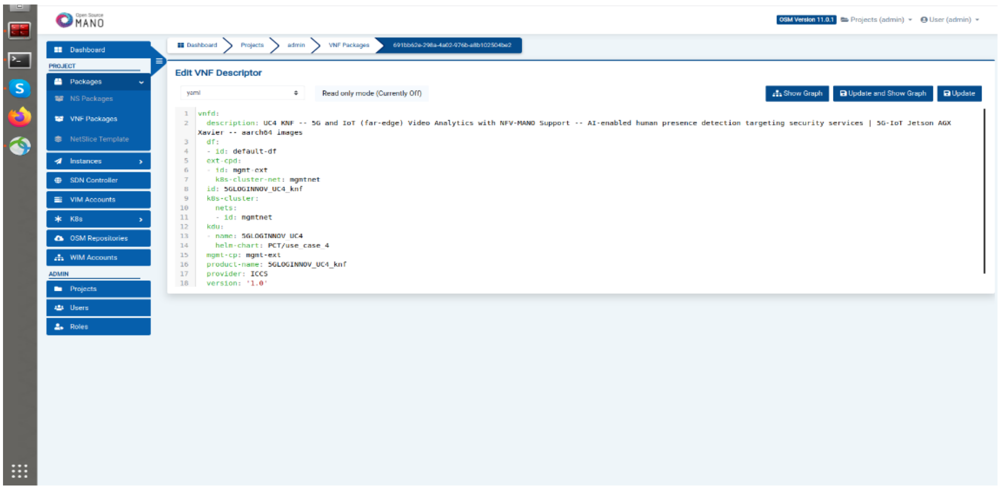


Figure 26: LL Athens UC4 KNF descriptor

OSM orchestrates the manifest files to be deployed at the 5G-IoT device that will host the AI-enabled algorithm for human presence detection, tailored to security/safety applications, based on video input from stationary UHD cameras. Orchestration of the service (management plane) happens over the 5G interface for service management and lifecycle operations. Data plane operations include UHD inferenced (annotated) video streaming at PCT's monitoring system, exploiting the eMBB service of the 5G network, whereas low latency communications are employed for delivering rapid alerts (video) to the monitoring platform.

The AI/ML-based human presence detection model is similar to the trained model used in Section 3.3.3, packaged as a KNF an distributed to the respective 5G IoT device for service provisioning and data collection.

3.3.5. UC5: Automation for ports: port control, logistics and remote automation

Use case 5 exploits the MANO Platform described in Section 3.3.1. The NSD and KNF descriptors are shown in Figure 27 and Figure 28, respectively.

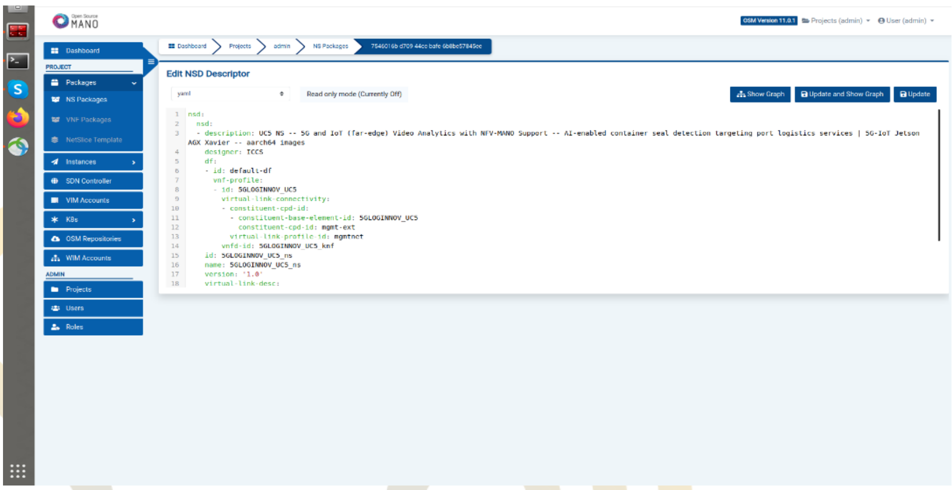


Figure 27: LL Athens UC5 NSD Descriptor

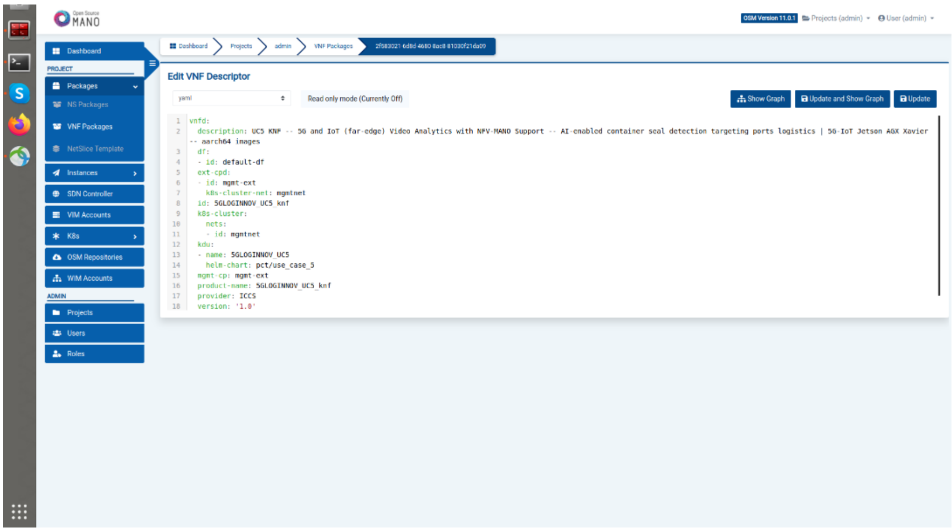


Figure 28: LL Athens UC5 KNF descriptor

OSM orchestrates the manifest files to be deployed at the 5G-IoT device that will host the AI-enabled algorithm for container seal detection, based on UHD video streams from cameras installed on PCT quayside crane (QC). Figure 29 depicts the architecture for device placement and camera at PCT's crane.

Figure 29: LL Athens 5G Crane for container seal detection service

Orchestration of the service (management plane) happens over the 5G interface for service management and lifecycle operations. Data plane operations include UHD inferenced (annotated) video streaming at PCT's monitoring system, exploiting the eMBB service of the 5G network.

AI-enabled container seal detection with NFV-MANO support

Use case 5 considers container seal detection performed in real time and unobtrusively, in the sense that the task is carried out by appropriately designed network and software services without slowing down port operations.

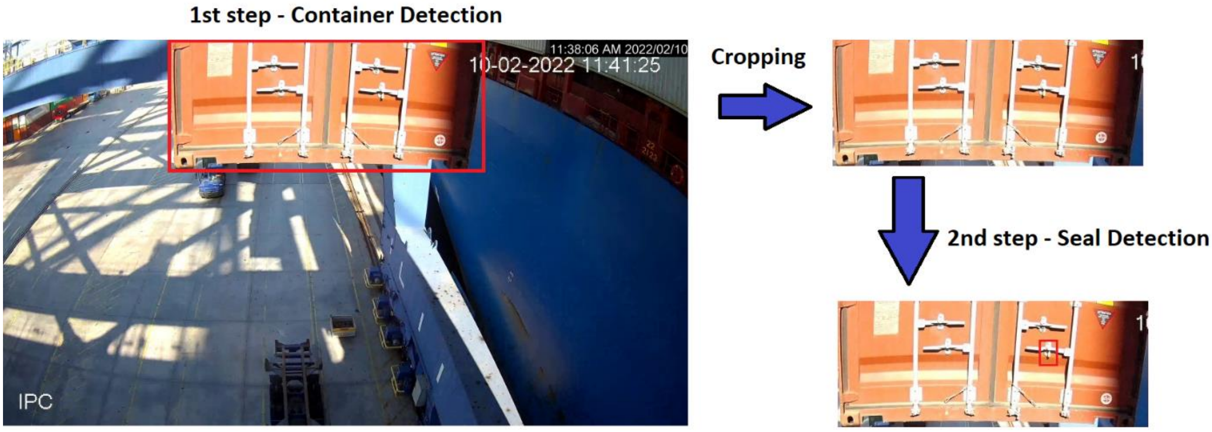
Containers are locked and sealed as shown in the following figures to ensure that the container remains closed while being transported, each container is expected to be delivered with its seals intact.

However, it is not rare for containers to arrive with broken seals and missing content especially when their transportation plan involves transhipments; in such cases, the involved ports should be able to prove that the container left the port with its seals unbroken or pay the claimed financial reimbursements.

It is therefore important for each port to design and maintain a process able to provide such proofs, yet not at the (time-wise) expense of the involved port operations. Use Case 5 addresses this issue by designing a 5G enabled computer vision service that detects (present or missing) seals on container images, and stores them properly annotated in a database, including the delivery of voluminous uplink transmissions of inferences video stream to PCT's monitoring system for live monitoring of loading/unloading operations. In this section, we describe the design and implementation of this service.

A wide-angle camera was installed at a port crane, continuously capturing 4K images of the ship loading/unloading process as shown in the following figures. Each frame is processed locally in a Jetson AGX Xavier device (where the NFV-MANO platform orchestrates all service components) and the resulting annotated video frames are streamed over a 5G connection, stored to a central database as well as the monitoring platform for live (inferenced-)service inspection.

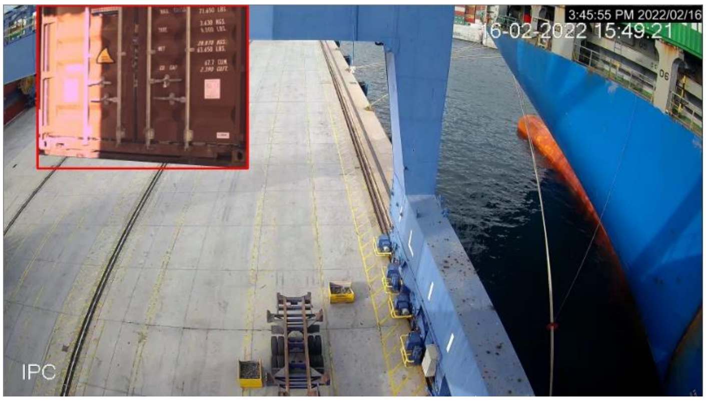
Frame processing consists in the application of a sequence of computer vision algorithms designed and/or parametrized to carry out the specific task at hand. This sequence consists of two steps. First, the captured frame is processed to detect the presence of a container being currently handled by the crane. If a container is detected, the first algorithm outputs the pixel coordinates of a bounding rectangle around it. The frame is cropped around that rectangle, and the cropped image is sent as input to the second algorithm which, detects the presence or absence of seals on the cropped container image. The entire process is depicted in the following figure.



We note that the application of two discrete detection algorithms, one for container and one for seal detection, is essential to meet the real time requirement; the container detection algorithm should work continuously processing the 4K video input. For the container detection algorithm, we downscale the image analysis by a factor of 0.25 to 0.1 at the CNF service, which ensures that the algorithm can process frames at a minimum rate of 25 fps, with adequate accuracy. On the contrary, the seal detection algorithm is executed only if a container has been detected. Furthermore, since the seal (if present) would be a very small fraction of the container surface, the seal detection algorithm requires an input image of high analysis; thus, the container is cropped from the original 4K image, and fed into the algorithm with a much smaller downscaling. This design ensures that the overall process can process images at high resolution fps, with direct effect in the algorithm's detection accuracy.

For both the container and the seal detection algorithms the YOLO v5 neural network architecture has been employed. Due to the absence of sufficient amounts of annotated data, we created synthetic data based on about 55,000 images of containers that were available from PCT's database. In what follows, we describe in detail the creation of these data and the training process of the two networks.

As previously mentioned, PCT provided ~55,000 container images, like the ones shown in the first figures. The images were not annotated; hence, a custom seal detection algorithm was developed. For details, we refer to [7]. The algorithm was used to annotate the images. Each image was then perturbed by random perspective transformations. The perturbed container images were then embedded in actual background sample scenes resulting in 2 synthetic datasets, one for container detection and one for seal detection, each one consisting of ~600.000 annotated synthetic images. Samples of the resulting datasets are given below



Experimental training sessions for each of the aforementioned neural networks have been conducted on a GeForce RTX 3090 GPUs, and are still ongoing. The container detection algorithm achieved a high mean average precision (mAP) of ~0.9 on synthetic images. The possibilities of further enhancing and/or balancing the corresponding training dataset with actual annotated images or applying further perturbations (i.e. other than perspective transforms) to produce more suitable synthetic images are currently under investigation. The seal detection network has achieved a mean average precision of ~0.5 on synthetic images, and remains to be further trained and evaluated on more actual captured video frames. The following figure shows intermediate evaluation results of the seal detection training process.

3.3.6. UC7: Predictive maintenance

In PCT the AI-based predictive maintenance tool has been implemented for the prediction of possible breakdowns of yard trucks, and to provide a data driven approach for purchasing spare-repair parts. The predictive maintenance tool is based on the innovations of the COREALIS project (768994/MG-7.3-

2017), and will be evaluated in 5G-LOGINNOV by using 5G technology, over the fleet of 5G connected yard trucks. Similar to UC3 presented in Section 3.3.3, UC7 employs data from on-truck sensors transmitted in real time over the 5G network. Particularly, the data exploited by the tool are obtained from the trucks CAN-Bus and sent by the telematics device (installed on yard trucks with access to CAN-Bus and other data) to the telemetry system of PCT. The proposed tool exploits historical and recent status/operational data for the assets in question, i.e., yard trucks, utilized by the ML algorithm and driving a per yard-vehicle data driven approach (schedule of purchases, storage of parts, proactive maintenance), by taking advantage of 5G technology that provides a flexible, reliable and predictable environment to remotely keep track of the connected assets on a real time basis.

Figure 30 depicts the web interface for the predictor tool. The user is able to select the time period of data that the prediction will be based on as well as the period and the specific spare parts for which the predictions need to be made. Its purpose is to train the developed algorithm based on historical maintenance and breakdown data in order to predict future breakdowns of yard trucks as well as the parts that will be affected and relative spare parts required for the maintenance. For more details please refer to D3.1 [1] storyboard.

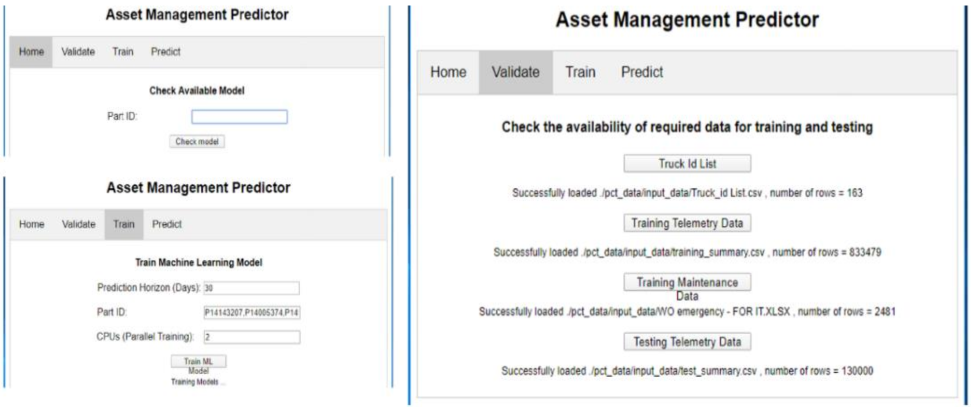


Figure 30: LL Athens predictive maintenance tool web interface

3.4. Data Collection

For the data collection in Athens LL a high-level architecture is depicted in Figure 31. A FluentD client will aggregate all data necessary for KPI (as defined in Deliverable 1.4) collection and evaluation, connected to the central data collection management tool explained in Section 2.2

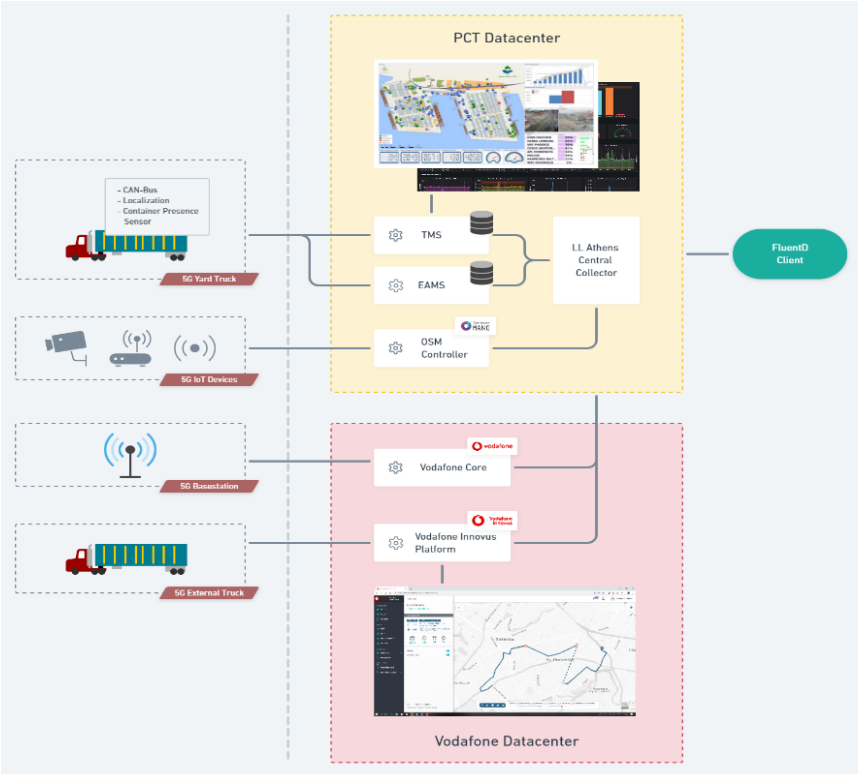


Figure 31: LL Athens data collection architecture in Athens LL

Data will be collected from various sources, e.g., 5G network (data rate, latency, etc.), 5G yard truck sensors (CAN-Bus, GNSS, container presence sensors, cameras), 5G external trucks sensors (CAN-Bus, GNSS, 5G UE data), 5G IoT nodes, and 5G Cranes, as well as operational/historical and logistics data gathered by PCT's management platforms: Traffic Management System (TMS), which gathers data for trucks daily operations (e.g., number of container movements, total travel distance, fuel consumption, live speed and movement direction within the port terminal); Enterprise Asset Management System (EAMS), including information regarding the operational condition of port assets (e.g., description of the yard truck breakdown, the part of the truck that was affected and the spare parts used for the repair).

All necessary data for the evaluation procedure of the KPIs will be collected (and pre-processed following the privacy/security regulations of the Piraeus port) at PCT and sent (at specific intervals) to the data collection tool explained in Section 2.2 (according to the developed data management models following the data collection tool specifications developed in Task 2.2).

4. DEVELOPMENT AND DEPLOYMENT IN LIVING LAB HAMBURG

4.1. Site Overview

With around 10 million containers, the Port of Hamburg is ranked No.3 in Europe. The disadvantage of the 70 km Elbe restricting access to the Northern Sea is compensated by the excellent rail network in the port and hinterland, of special importance for inter- and multimodal transport and logistics. Due to special situation as a city port, several terminals for container handling are spread across different parts of the city, which makes an efficient hand-over and automation within the intermodal transport chain (port internal transfers) of great importance for Hamburg's long-term competitiveness. Being part of the city's ITS Policy Strategy 2030 to optimize the transport chain, the inclusion of port transport logistics and hinterland connections was therefore crucial for the City of Hamburg policy makers.

(https://www.hamburg.com/business/its/11747566/strategy/)

Figure 32: Aerial view of Hamburg Port

For the ITS World Congress, which took place in October 2021, Hamburg launched in 2019 a test field for automated driving to optimize the access of trucks to the port terminals. The test field is available to all OEMs and mobility service providers for Car2X data exchange and other C-ITS functions. A total number of 50 traffic lights is currently available for Connected Automated Driving (CAD) test runs. The test field is located in the heart of the city close to the ferry boat terminals. In 5G-LOGINNOV, T-Systems, Continental, SWARCO and tec4u build their highly innovative 5G use cases directly on top of this test track and link the 5G features, in especially Mobile Edge Computing, low latency communication (uRLLC) and advanced IOT including massive Machine Type Communication (mMTC), to I.T.S. functions implemented by the Hamburg traffic authorities. The Hamburg Port Authority (HPA) already connected traffic lights operated in the ferry port and cruise terminal area to guarantee a seamless traffic flow within the heart of Hamburg's tourist zone near "Landungsbrücken".

What does TAVF offer?

With the test track, the Free and Hanseatic City of Hamburg has created an open platform on which research institutions and companies can test and trial applications of V2I/I2V communication and connected and automated driving. TAVF is equipped with the following features:

Transmission technology:

> ITS G5 (IEEE 802.11p)
> Hybrid communication (in preparation)

Technical equipment:

> More than 50 traffic lights and one bridge with Roadside-ITS-Stations (R-ITS-S)
> Thermographic cameras systems
> Intelligent street beacons
> Cooperative environmental sensors

Information provision:

> Open data platform (Hamburg Urban Data Platform)
> Highly accurate maps
> SPaT/MAP messages and forecast of the signal phase at all traffic lights
> Virtual signs (IVI)
> Sensor data for VRU protection (CPM)
> PKI V1.3.1 at all traffic signals

Special features of the routing:

> Various urban street topologies (including one-way streets, multi-lane streets, main and side streets)
> intersections with and without traffic lights
> Connection to the Motorway
> Demanding urban challenges such as a high proportion of mixed traffic or deep urban canyons with limited GPS

Gefördert durch:
Bundesministerium für Verkehr und digitale Infrastruktur
aufgrund eines Beschlusses des Deutschen Bundestages

Figure 33: Test track for automated and connected driving in Hamburg used by the 5G-Loginnov Living Lab

The interaction between the logistics corridors connecting warehouses, motorways and shipping terminals with the busy road network inside the densely populated city centre, that is the unique innovation highlight of the TAVF Hamburg test track. It is the missing link between the state-of-the-art digital intelligence implemented in the Port area by Hamburg Port Authority with a smooth and efficient operation in the nearby urban Hinterland.

In terms of 5G connectivity the network and computing infrastructure available at TAVF and the city-logistics use cases, Hamburg Living Lab demonstrates the potential of leveraging positive environmental impact by using 5G in data exchange for traffic management in particular outside the port and the hinterland. It develops and implements a methodology to capture the effect of the traffic infrastructure on regional emissions, making them comparable (standardized) by quantifying such influences under defined TMS congestion and other relevant factors (driver profile, vehicle profile, loading, etc.).
To this purpose, the following interactions with system elements of traffic management are currently under construction to demonstrate in Living Lab Hamburg:

- UC8/9 - Floating Truck & Emission Data (FTED):
  For use cases 8 and 9, emission data from floating vehicles/trucks will be made available in a cloud-based centre to enable situation monitoring on emissions.

- UC10 - 5G GLOSA & Automated Truck Platooning (ATP)- under 5G-LOGINNOV Green initiative:
  For this use case, the current and predicted traffic light signalling will be made available from traffic centres to vehicles, to allow an optimised trajectory planning for automated vehicle manoeuvering across intersections, saving energy and emissions.

- UC11 - Dynamic Control Loop for Environment Sensitive Traffic Management Actions (DCET):
  For use case 11, data received in UC8/9 and other data typically used in environmental traffic management will be used to trigger traffic management measures (strategies) in traffic control (e.g. changing traffic light framework programs, set speed limits, or provide instructions and directives to vehicles).

The living lab Hamburg demonstrates 5G innovations for logistics in the Hinterland of the harbour of Hamburg by using the public 5G network operated by the Deutsche Telekom. This public 5G network covers the designated test field for "connected and automated driving" (TAVF) of the city centre of Hamburg. Within this environment, the LL Hamburg illustrates on one hand how new functionalities of 5G as MEC, precise positioning as uRLLC can improve the efficiency of logistic operations, but on the other hand, also proves that improved 5G network functionalities as mMTC and eMBB are essential for stable service operation.

In this context, the LL Hamburg illustrates the use of network slicing, MEC, 5G enabled precise positioning, uRLLC, mMTC and eMBB in its use cases according to their functional abilities. While a 5G network connection for UC 8/9 and UC 11 is not time-critical, the provision of an information system to enable an optimized trajectory planning for automated vehicle maneuvering across intersections in UC 10 requires a connection with high reliability and low latency below 10ms. Having in mind an increasing population, several sensors, and connected devices in urban areas 5G connectivity will be essential for critical applications with strict connectivity requirements.

Hereby, network slicing is one of the key aspects of 5G that will allow network and service operators to satisfy specific connectivity demands of specific use-cases. By this, it can be ensured that each use case will always have the required resources.

The 5G-LOGINNOV Living Lab Hamburg will illustrate the use of two different virtualized and independent networks based on the available public 5G network.

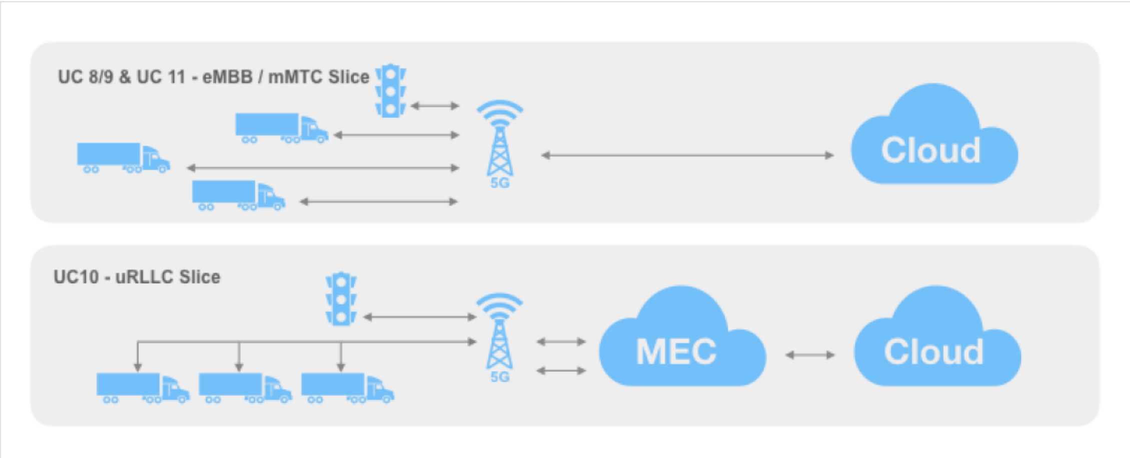


Figure 34: Network Slices LL - Hamburg

Each of the two slices will allow using the available network with the use-case specific required level of service quality, security, and reliability. As UC 8/9 and UC 11 mainly rely on bandwidth-related services, the eMBB / mMTC slice will provide to direct link to the cloud applications, while the mission-critical application in UC 10 will be served by the uRLLC slice and guaranteed a high level of security, reliability, and low latency. Figure 33 shows the existing set-up of TAVF and Telekom Mobile Edge Infrastructure implemented in Hamburg since 2021.

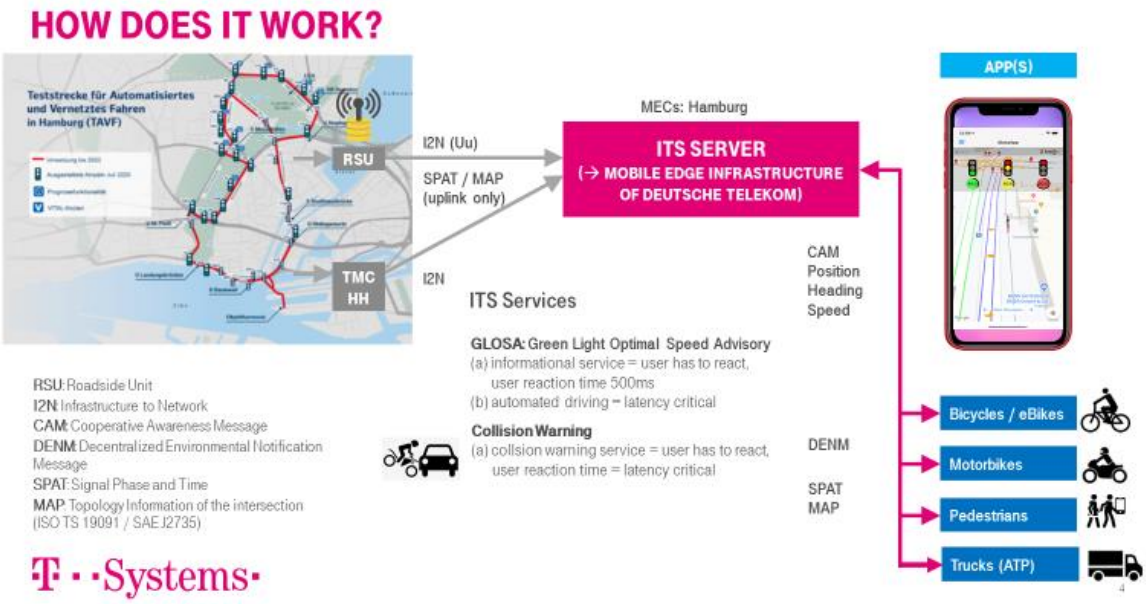


Figure 35: Technical Systems used in 5G-Loginnov - Hamburg

Related to the LL Hamburg use cases and the technical components needed (see chapter 4.2 Deployed Components) the initial timeline planning meanwhile have been updated and aligned (see table below).

Year/Month	2021												2022											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
MS/Month	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
Phase LL HH	S: Specification																							
					Dv: Development																			
									Dp: Deployment															
													V: Verification & Testing											
																			T: Trials					
UC-8/9	S				Dv							DP		V										
UC-10			S								Dv			Dp		V								
UC-11				S								Dv			Dp		V							

Table 14: Aligned timeline planning of use case development and deployment (April 2022), LL Hamburg

This aligned timeline planning feeds the overall objective to start the trials in month 23 of the project, as originally foreseen. Minor changes and the shift of detailed activities (e.g. ordering of technical equipment) still allows to start the trials in timer. Deviations per component are stated in the next chapter.

4.2. Deployed Components

4.2.1. Overview of components and architecture

In Figure 36 the different components deployed are listed showing the relationship to other deliverables and use cases of the project. It should be noted that network centric Precise Positioning Services do not necessarily require 5G and are already available in 4G/LTE. In D1.2 reference to the 5G mobile network is analysed, compared to this, D1.3 has a focus on the service components itself showing the business logic behind the 5G technology.

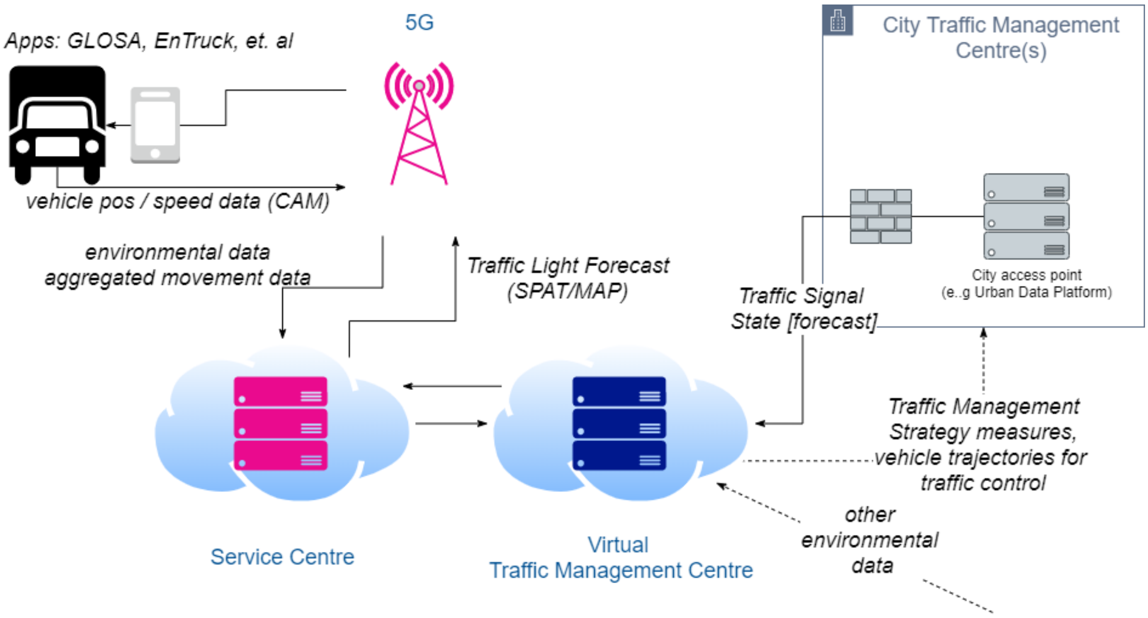


Figure 36: Service Architecture Living Lab Hamburg.

Within the following table the technical components (Services, infrastructure, hardware etc.) are listed in relation to the LL Hamburg use cases and their status concerning deployment beginning of April 2022. For further details see deliverable D2.1 Development and deployment plan in 2021 or see chapter 4.1 Site Overview above.

Equipment Description	Addressed Use cases	Status Deployment (Ready for technical verification in WP3)
Precise Positioning (Skylark)	UC8/9/10/11	Ready
5G Smartphones with LCMM/GLOSA	UC8/9/10	Ready
tec4u CarPC	UC8/9/10	Ready
Conti-IOT Box	UC8/9/10	Ready
Flowradar (HPA)	UC8/9/10	Ready, but Flowradar is not useable due service set on hold by Hamburg Port Authority
Mobileum 5G-KPI measurement tool	5G NSA coverage and network features (horizontal)	Ordered but not available in April 2022, therefore the deployment and testing are still only planned. The delay causes due the effect of pandemic and worldwide chipset lack. Planned integration for the LL Hamburg May/June 2022.
4K-Video	UC10	Use of videos and pictures not confirmed by legal authorities.
MEC	UC8/9/10/11	Ready and integrated
VTMC (SWARCO MyCity) Virtual Traffic Management Center	UC9/10/11	The ordered hardware is available but due pandemic

		influenced resource allocation the integration is delayed. Planned integration for LL Hamburg May/June 2022
5G NSA network of Deutsche Telekom	all	Due use of 5G NSA network already deployed in 2021 by Deutsche Telekom (see below).

Table 15: Technical components, LL Hamburg

4.2.2. 5G NSA network by Deutsche Telekom and services

In the 5G NSA approach by Deutsche Telekom, the existing 4G core (EPC) is working as an anchor network mainly for signalling purposes. This EPC is combined with new extended radio functions – focused on the provisioning of additional mobile bandwidth capabilities (5G New Radio – 5GNR). Deutsche Telekom is using additional frequencies from old UMTS solutions (2,1 GHz band) to offer more capacity for the clients. This function (dynamic frequency usage) is adapted from 3GPP R16.

5G Service/Application	Deployed
Radio Access Network	Production network 3,6 GHz / 2.1 GHz
Number of cell sites	3,6 GHz more than 20 sites / 2.1 GHz over 98% full coverage in Hamburg
Frequencies used	3.6 GHz / 2.1 GHz
Frequency Bandwidth	2,1 GHz – 20 MHz / 3,6 GHz 90 MHz
Mobile Core	3GPP R15 with DSS
Virtualised infrastructure	only partly
Orchestrator	DTAG internal
MEC	MEC: MobilEdgeX as product
Precise Positioning	Skylark as product
Network measurement	Mobileum as product

4.2.3. Mobile Edge Computing (MEC)

Edge computing is a key technology to meet end-to-end latency requirements introduced by new 5G services and to improve the efficiency of the whole network operation through the deployment of computing and storage resources at the edge of the network, closer to the mobile users. The exploitation of edge resources offers the possibility to execute computing tasks in a distributed manner directly at the edge of the network, reducing the traffic load on the core of the infrastructure and guaranteeing faster service responses. This approach allows high scaling in distributed MNO environments. Edge technologies are particularly suitable for all use cases with needs in direction of ultra-low latency and high availability of bandwidth in the mobile network.

The Multi-Access Edge Computing (MEC) framework, defined in the context of the ETSI MEC Industry Standardization Group (ISG), provides an open and standardized environment for the efficient and seamless integration of edge applications from different vendors and providers across distributed platforms located at the edge of the network [ETSI19-MEC003]. The MEC framework defined in identifies two main components in a typical MEC architecture, i.e. the “MEC Host” and the “MEC System”. It manages the virtualized resources available at the edge nodes through a Virtual Infrastructure Manager (VIM) and it embeds a MEC platform (MEP) to facilitate the interactions among MEC applications and the steering of the mobile traffic flows to/from the target applications. In this context, [ETSI19-MEC10-2] specifies the interfaces for onboarding and lifecycle management of MEC applications, as well as standard data models for descriptors and software packages to distribute multi-vendor MEC applications.

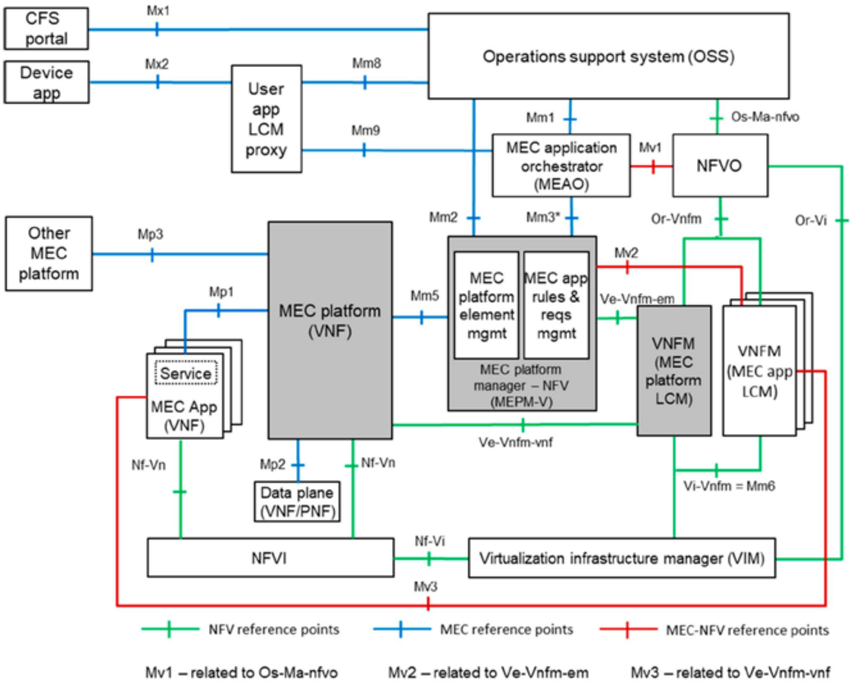


Figure 37: ETSI MEC reference architecture in an NFV environment (from ETSI GS MEC 003)

With respect to Edge Computing integration into 5G systems, 3GPP has defined a list of enabling functionalities that are briefly discussed in [TS 23.501], where a basic API for Application Function Influence on Traffic Routing is already specified.

4.2.4. Skylark

Precise Positioning

For nearly all use cases in Living Lab Hamburg, precise positioning is required. Navigation with accuracy of 3 – 15 meters, as found in typical GPS systems, does not meet the actual requirements. Precise Positioning delivers cloud-based corrections that deliver centimeter-level accuracy of up to ten centimeters. The solution is scalable for an unlimited number of applications and IoT devices. Precise Positioning is already available nationwide throughout the United States and Germany, with extended European coverage scheduled to come in 2020. The long-term target is to use the precise positioning solution from 5G standard components (3GPP Rel. 16).

The following Figure illustrates a Deutsche Telekom / Swift solution for precise positioning services.

The used solution contains the following components:

- Dual band GNSS antenna
- Multi Frequency GNSS receiver
- Mobile network access to the Skylark Corrections Service
- Embedded control unit running Swift Starling software to calculate the exact position from satellite signals and correction data from the Cloud

The GNSS correction signal will be provided 0,1 to 1 time per second, the local calculation of the exact position can be up to 10 times per second.

4.2.5. Mobileum

To measure 5G NSA KPIs in a live network environment under real live conditions of the Deutsche Telekom network, a vehicle will be equipped with measuring probes, to measure a variety of 5G KPIs on the move, e.g. the packet error rate in a 5G network, network bandwidths, latency end-to-end. For Deutsche Telekom, the preferred equipment provider for executing this type of measurements is the company Mobileum. Due delay of delivery this equipment will not be available before May 2022.

Figure 38: Logo 5G measurement equipment LL Hamburg

To measure and to evaluate the difference between standard GNSS quality of the LL Hamburg 5G devices and the precise positioning of 5G NSA 3GPP Release 15 network Skylark devices are deployed.

Skylark delivers are corrected signals by high precision to give insides to 5G precise positioning within 5G NR 3GPP Release 16.

4.3. Use Cases and Storyboards

Use cases LL Hamburg
UC8/9: Floating Truck & Emission Data (FTED)
UC10: 5G GLOSA & Automated Truck Platooning (ATP)-under 5G-LOGINNOV Green initiative
UC 11: Dynamic Control Loop for Environment Sensitive Traffic Management Actions (DCET)

Table 16: Use Case Overview, Hamburg Living Lab

To cover the UCs the LL Hamburg deployed the following setup also in preparation of the trials and the collecting of data concerning the evaluation.

For UC 8/9: Floating Truck & Emission Data (FTED) it is expected to increase average truck speed, to reduce acceleration and the standstill in single vehicle mode with equipped vehicles (vehicles for LL Hamburg will be equipped with devices of Entruck, Continental IoT and LCMM). For the platoon mode (UC 10: 5G GLOSA Automated Truck Platooning (ATP) under 5G-LOGINNOV Green Initiative) the smartphones will also run a GLOSA application as shown in the Figures of next subsections.

Rental cars have been equipped with LCMM and GLOSA on smartphones only using electric power supply and Entruck and Conti-IOT via CAN and electric power supply.

All equipment can easily be added to the given infrastructure of the vehicle via “plug ‘n’ play”. The three data collection bases will then be able to collect the data and the drivers will receive a schedule for data collection based on the evaluation scheme (baseline, operational, special events).

4.3.1. The Low Carbon Mobility Management (LCMM)

Vehicle drivers gain information on how to drive more efficiently and which effects this will have on fuel consumption and CO_2 emission of his vehicle. Besides considerable CO_2 reductions, significant reductions in fuel consumption may lead to noticeable cost reductions which, connected with environmental costs (CO_2 certificates, compensation costs), result in a sustainable improvement of the CO_2 footprint, as consumption and emission are directly linked to one another.

Therefore, an ITS (Intelligent Transport Systems) application based on cellular communication, satellite position data and using smartphones, connected to the Cloud Computing and Big Data Computer Center of T-Systems, has been implemented to master the challenges of a growing traffic density and increasing pollutant burden.

After starting the application on the device, positioning data are being submitted continuously, this, in combination with the speed and the chosen profile of the vehicle, results in a real-time calculated efficiency profile, which is made available on the device during the drive and in parallel e. g. on the Web-Browser of a dispatcher.

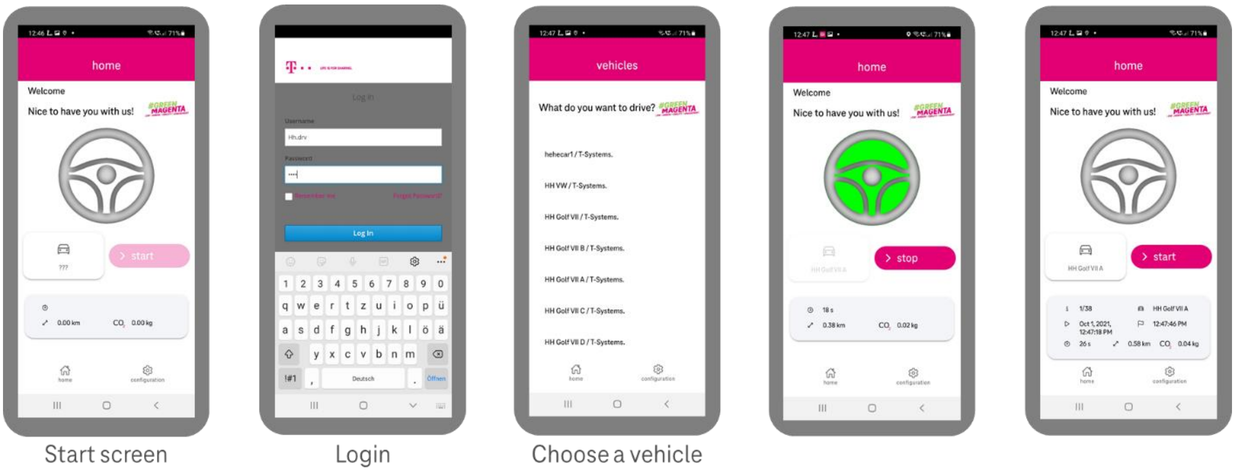


Figure 39: LCMM App Screens

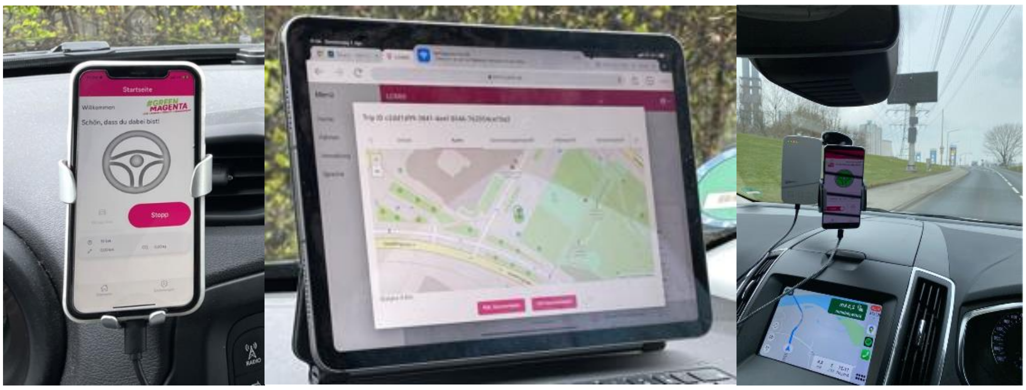


Figure 40: LCMM UI LL Hamburg

Details | Map | Speed Profile | Altitude Profile | Emission Profile | Way Profil

Vehicle RG Logi Jeep	Group name Loginnov.	Start time 06.04.2022, 11:11	End time 06.04.2022, 11:23
Duration 0:11:44	Distance 4,1 km	Speed 21,2 km/h	Fuel Consumption 5,8 l/100km
CO2 Emission 0,6 kg	Zero fuel distance 1.304 m	Standstill time 0:03:09	ACC Cycle 142,5 %
Aero Cycle 72,4 %	Percentage Standstill Cycle 58,8 %	Percentage Work Cyle 114,2 %	Energy Performance Index (EPI) 3,7 l/100km*t
Acceleration Performance Index (API) 5,4 kWh/100km*t	AccWork 1,1 MJ	AeroWork 0,1 MJ	Standstill work 0,1 MJ
RollWork 0,1 MJ	GradeWork 0,6 MJ		
Cross section area 2.35 m²	Efficiency 30 %	Fuel emissions factor 2.664 kg/l	Fuel value 35.712 MJ/l
Mass 1600 kg	Rollfriction coefficient 0.0015	Standstill fuel consumption 0.5 l/h	Motorheating ☐
Airconditioning ☑	Start-Stop automatic ☑		

Figure 41: LCMM Trip results: Overview numbers

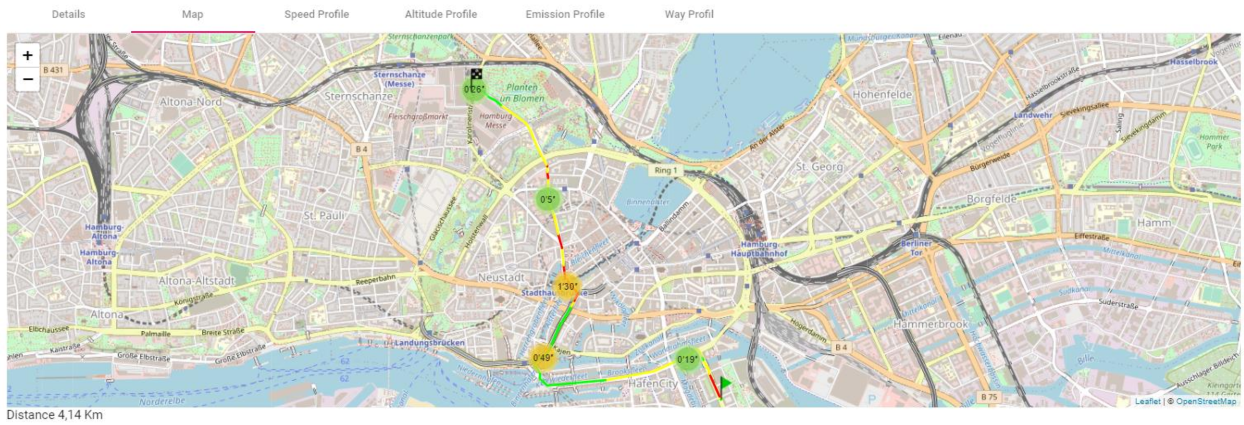


Figure 42: LCMM Trip results: Mapped trip data

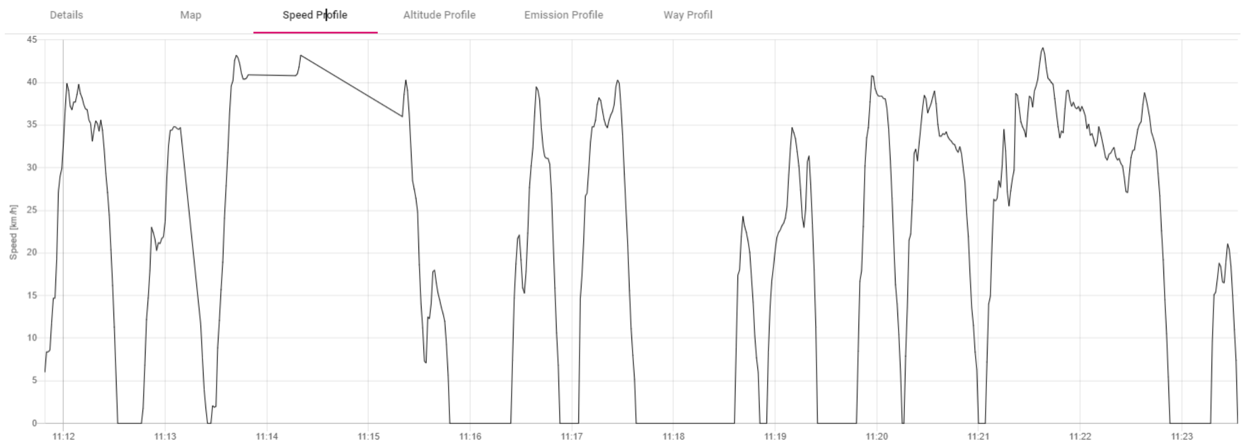


Figure 43: LCMM Trip results: Speed profile

Figure 44: LCMM Trip results: Altitude diagram

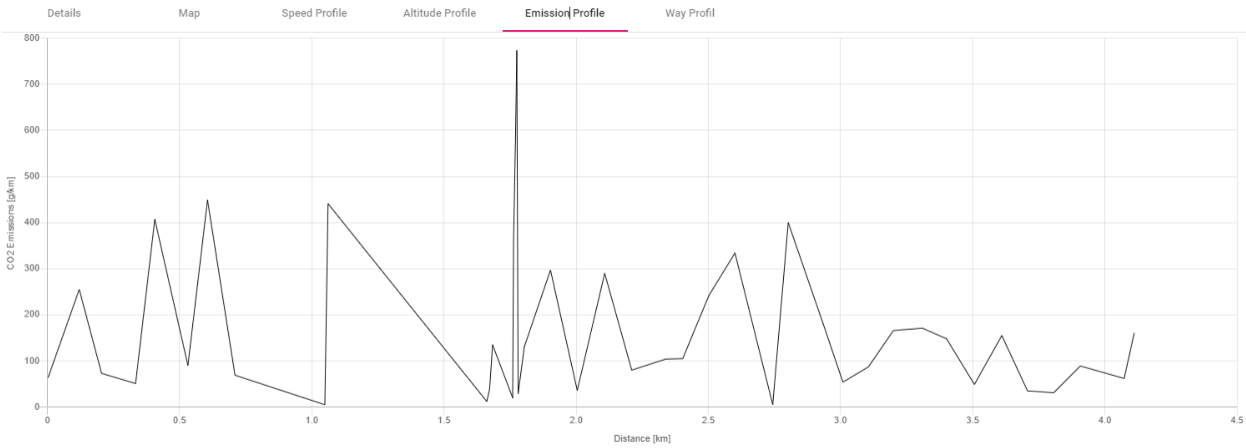


Figure 45: LCMM Trip results: Emmision diagram

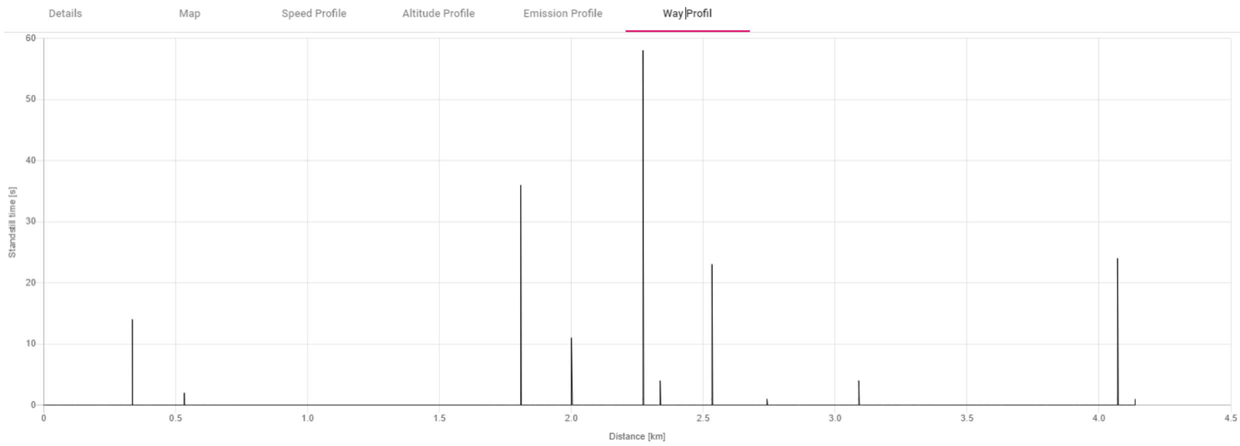


Figure 46: LCMM Trip results: Way profile

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
1	Time[s]	Latitude	Longtitude	Speed[m/s]	Altitude[m]	Flag	Acceleration[	AccWork[J]	AeroWork[J]	GradeWork[J]	RollWork[J]	StandStillWor	TotalWork[J]	StandStillTime	Fuel[l]	CO2[kg]
2	1649319962	53,5402427	10,0105972	2,94	9,5	0										
3	1649319963	53,5402604	10,0104833	5,27	9,6	0	2,33	15303	74	1569,6	124	0	17070,6	0	0,00159336	0,00424471
4	1649319964	53,5402683	10,0103871	5,88	9,6	0	0,61	5441	103	0	138	0	5682	0	0,00053035	0,00141286
5	1649319965	53,5402799	10,0102832	5,88	9,6	0	0	0	103	0	138	0	241	0	2,2495E-05	5,9926E-05
6	1649319967	53,5403145	10,0100158	7,98	9,5	0	1,05	23284	517	-1569,6	375	0	22606,4	0	0,00211007	0,00562122
7	1649319968	53,5403275	10,0099015	7,98	9,5	0	0	0	258	0	187	0	445	0	4,1536E-05	0,00011065
8	1649319969	53,5403411	10,0097936	7,75	9,4	0	-0,23	-2895	237	-1569,6	182	0	0	0	0	0
9	1649319970	53,5403546	10,0096867	7,59	9,4	0	-0,16	-1964	222	0	178	0	0	0	0	0
10	1649319971	53,5403669	10,0095874	7,09	9,4	0	-0,5	-5873	181	0	166	0	0	0	0	0
11	1649319972	53,5403785	10,0094863	7,09	9,4	0	0	0	181	0	166	0	347	0	3,2389E-05	8,6284E-05
12	1649319973	53,5403911	10,0093786	7,09	9,3	0	0	0	181	-1569,6	166	0	0	0	0	0
13	1649319974	53,5404009	10,009258	7,27	9,2	0	0,18	2067	195	-1569,6	171	0	863,4	0	8,0589E-05	0,00021469
14	1649319975	53,5404122	10,0091066	8,66	9,3	0	1,39	17714	330	1569,6	203	0	19816,6	0	0,00184967	0,00492751
15	1649319976	53,5404081	10,0089744	9,11	9,3	0	0,45	6397	385	0	214	0	6996	0	0,000653	0,0017396
16	1649319977	53,5404159	10,008829	9,28	8,8	0	0,17	2501	407	-7848	218	0	0	0	0	0
17	1649319978	53,5404252	10,0086962	9,22	8,9	0	-0,06	-888	399	1569,6	217	0	1297,6	0	0,00012112	0,00032266
18	1649319979	53,5404413	10,0085584	9,47	9	0	0,25	3737	432	1569,6	222	0	5960,6	0	0,00055636	0,00148214
19	1649319980	53,5404484	10,0084179	9,43	9	0	-0,04	-605	427	0	222	0	44	0	4,1069E-06	1,0941E-05
20	1649319981	53,5404642	10,008282	8,93	9,3	0	-0,5	-7344	362	4708,8	210	0	0	0	0	0
21	1649319982	53,5404763	10,0081566	8,46	9,3	0	-0,47	-6539	308	0	199	0	0	0	0	0
22	1649319983	53,540481	10,0080382	7,93	9,2	0	-0,53	-6950	253	-1569,6	186	0	0	0	0	0

Figure 47: LCMM Trip results: Extract collected and calculated data

4.3.2. GLOSA, FTED and Truck Platooning

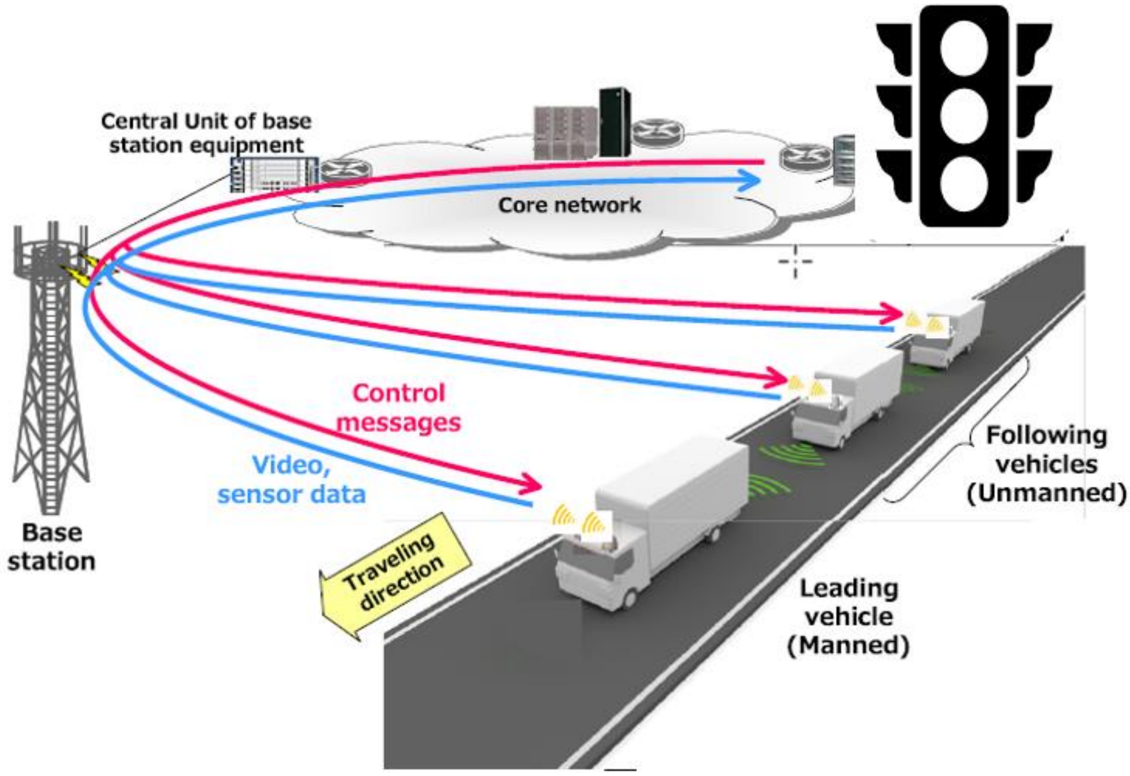


Figure 48: Hardware and Use Case Components for Living Lab Hamburg

Figure 49: GLOSA UI LL Hamburg

Functional components of GLOSA based Truck Platooning as planned for the City of Hamburg are shown in Figure 48. The Truck Platoon with 3 different Telematic On-Board Units (Conti, enTruck and LCMM) is travelling in the indicated direction exchanging sensor data and video control data with the Mobile Base Station, in this case the Deutsche Telekom mobile network.
Complementary to this, Figure 50 presents decision gates to operate trucks platooning safe and driving at constant distances. Control messages also refer to the different roles of the lead platoon with a driver on board and the follow platoons which will be operated in the long-term (beyond project duration) driverless SAE-level 5. The GLOSA APP analyses the lead vehicle and its driver behaviour to adapt the GLOSA speed advice for the follow vehicles of the platoon.
Figure 50 also shows how the GLOSA enabled Truck Platooning could be operated by applying state of the art traffic light priority technology. First, it is needed to keep a minimum distance □x between Lead

and Follow platoon vehicles. From the Physics of Driving aspect, the minimum distance should lie in the range of 3 to 5 meters balancing safety and stability of the platoon's operation.
Then, Figure 51 shows the acceleration interval for harsh braking emergency events which might take place along the urban path of the platoon. Here an urban speed up to 30 km/h was assumed with regards to approaching traffic light-controlled intersections, see Figure 50. Additionally, the equation used in Figure 51 assumes run-times between Lead Truck to base station to Follow Truck of <25 ms as already published in [1] and other research papers, e.g. [2] where truck platooning was analysed with reference to 5G technology components.

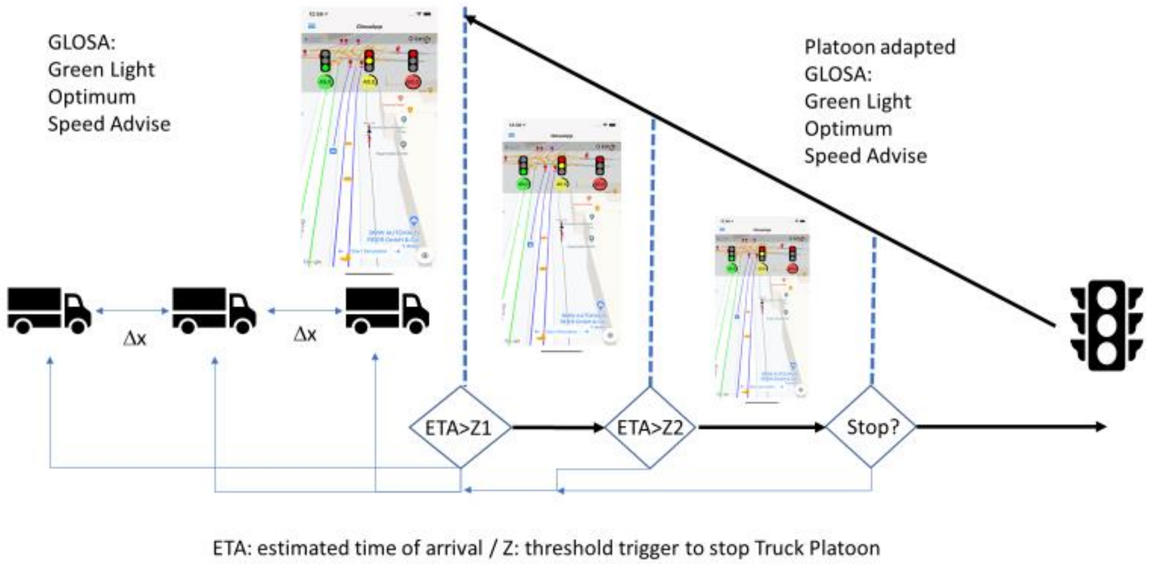


Figure 50: Truck Platooning with 5G-GLOSA – Decision Gates

plot	$b = v \times 0.025 + 0.5 \times \frac{v^2}{3.6 \times 3.6\, s}$	$s = 3$ to 5
		$v = 10$ to 30

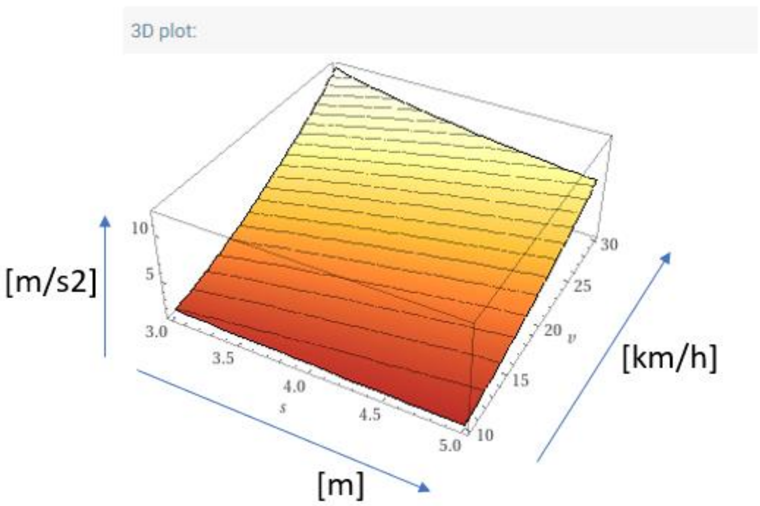


Figure 51: Mathematical relationship of distance, acceleration, and speed in urban traffic conditions

4.3.3. EnTruck (tec4u CarPC):

Entruck is a vendor independent telematics platform with enhanced analytical capabilities that connects assets (e.g. vehicles, trailers, containers, machinery) with their asset management. Entruck is used in logistics and R&D applications by e.g.

- freight forwarders for order planning and scheduling
- approval associations for enhanced tyre / component testing
- Fleet operators for vehicle management, monitoring and maintenance
- OEMs for R&D related testing and benchmarks

Figure 52: Entruck, Overview and main application areas

Within the Living Lab Hamburg, Entruck connects vehicles with the infrastructure and enable a two-channel communication between vehicle and infrastructure by 5G. The collected vehicle data will be enriched by third party data as e.g. infrastructure and weather information, analysed on manoeuvre level and fed back to other stakeholder as LCMM and traffic management. The results will be inter:

- segmentation of the route into manoeuvres forced by the infrastructure
- segmentation of the route into manoeuvres forced by the traffic
- influence of the infrastructure to fuel consumption, emissions and wear
- influence of the traffic to fuel consumption, emissions and wear
- influence of the driver to fuel consumption, emissions and wear
- influence of the logistics operation (e.g. load, task, etc..) to fuel consumption, emissions and wear
- influence of the used vehicle and components (e.g. hp, tyres, power train) to fuel consumption, emissions and wear

This analysis and information will be fed back and provided in various indicators as e.g. active acceleration, active deceleration, constant driving, coasting, and speed and route classes.
The data collection on the vehicle will be done by the Entruck OBU with CAN bus / FMS access. The Entruck OBU is a full spec. vehicle pc for various mobility application and interfaces to:

- 2G / 3G / 4G and 5G communications networks
- GNSS
- CAN bus / FMS
- TPMS
- display for driver or service / maintenance
- RFID network and applications (e.g. driver license verification, container management)
- Remote load room monitoring by camera
- Other sensors, as e.g. door, temperature, flow sensors, etc.

Figure 53:Entruck OBU

For the four Living Lab Hamburg uses cases, the Entruck OBU will collect - besides GNSS information - following data in a frequency of 2 Hz from the vehicle for further analysis:

Parameter	Unit
odometer	km
actual vehicle speed	km/h
actual engine speed	RPM
actual engine torque	%
kick down switch	0 / 1
accelerator pedal position	%
brake switch	0 / 1
clutch switch	0 / 1
cruise switch	0 / 1
PTO	0 / 1
fuel level	%
actual fuel consumption	l
engine temperature	°C
turbo pressure	bar
axle weight (per axle)	kg

Table 17: Vehicle raw data used for Living Lab Hamburg

Figure 54: Tec4u onboard device

Figure 55: Entruck and Conti IoT devices installed in LL Hamburg

4.3.4. Continental IoT-Box:

The Continental 5G IoT device allows the collection of telemetry data both via the vehicle CAN interface (e.g. fuel consumption), as well as from the on-board GNSS module (speed, acceleration, standstill time etc.).

Continental IoT device features	
Feature	**Description**
Cellular	5G modem, 3GPP Release 15 (>3 Gbps)

eUICC	1 x M2M eSIM (physical SIM card as option)
Positioning	L1, Dead Reckoning, PPP/RTK
WiFi/Bluetooth (optional)	Wi-Fi 6 802.11 a/b/g, n, ac, ax 2x2 MIMO, SDB
	Bluetooth v5.2
Vehicle interfaces	Gbit Ethernet, Power, 1 x CAN, USB 2.0 (for development phase)
BuB	Optional back-up battery

The device can operate in several RF bands; below are the proposed bands:

Continental IoT device proposed 5G cellular bands	
Cellular network	**RF bands**
5G NSA (SA)	n7, n78

Figure 56: Top view of IoT device

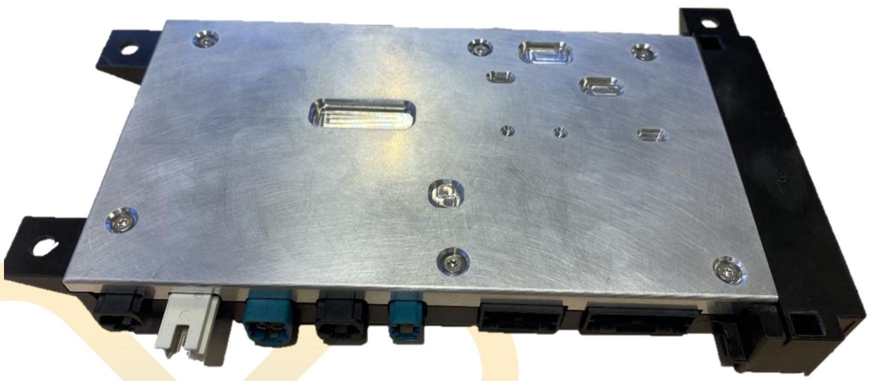


Figure 57: Bottom view of IoT device

The explained equipment will be used in the urban test area which is located in the city centre of Hamburg. With an estimated speed of 25 km/h, this area is suited to have improvements outside rush hour and especially during weekends. The speed is also collected by taxis, to generate adequate statistics. The port road network is close to the southern part of the city and the river "Elbe". The road network around that area is still to be chosen.

Figure 58: Trial area LL Hamburg

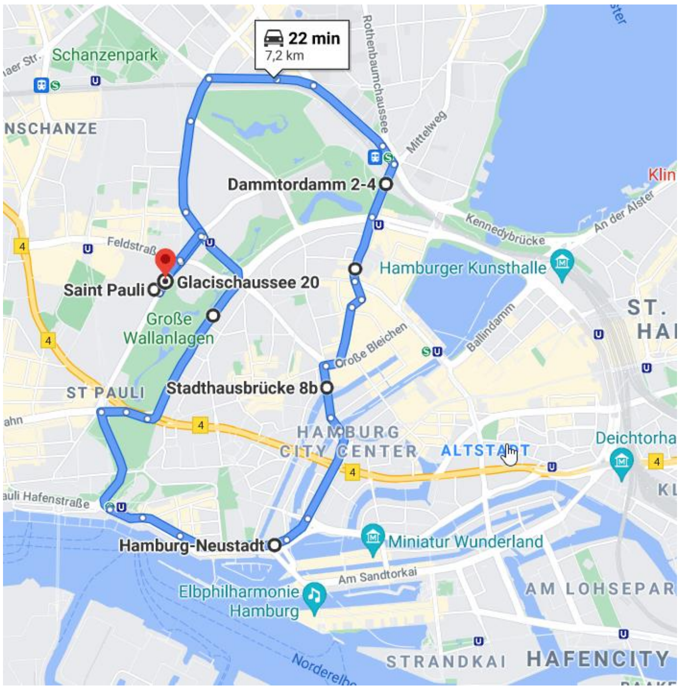


Figure 59: Test area urban roads LL Hamburg

The second test area has critical infrastructure in the port area, which will be next to Kattwyk bridge.

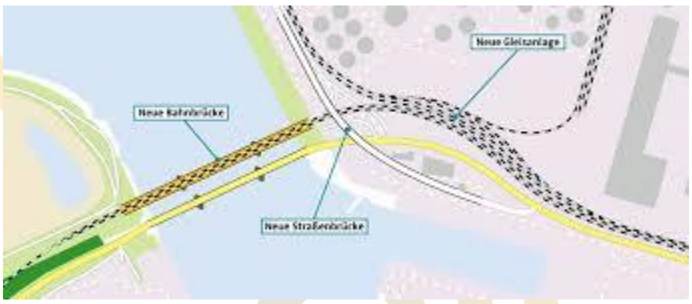


Figure 60: Port area LL Hamburg

The scenario for setting up the platoon tests as well as the single mode tests will be aligned with the operational phase of the field trial as described in the storyboards #1, #2, #3 and #4 linked to the specific road characteristics. The devices will include a strategy how to collect data in a synchronized way with the GLOSA App as well as with the synchronized datasets for the platoon testing (see floating car data setup in storyboard #1, #2, #3 and #4).

Figure 61: Skylark device equipped

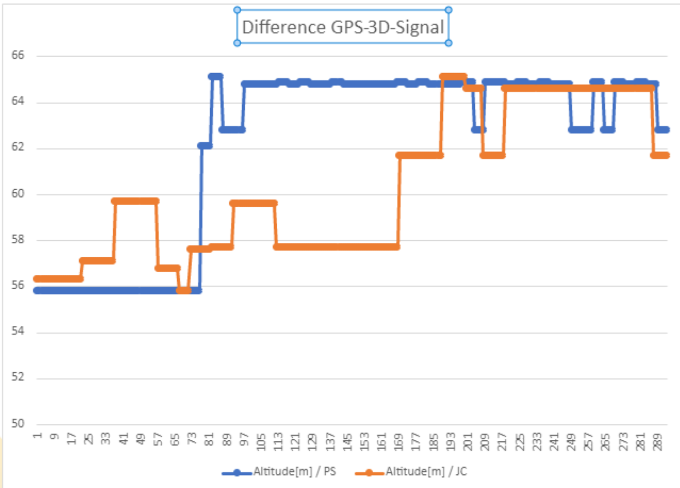


Figure 62: Example of signal quality GNSS LL Hamburg

For the trials overall, the LL Hamburg has defined 6 Storyboards (for further details see D3.1). The LL KPIs are defined in deliverable D1.4 V1.4.

Storyboard ID	LL_Hamburg_Storyboard_#1
UC	Related UC 8/9: 5G-LOGINNOV Floating Truck & Emission Data (FTED)
KPIs	H-KPI1; H-KPI2; H-KPI3 Increase average truck speed, reduce acceleration and standstill in single vehicle

	mode with equipped vehicles (vehicles for LL Hamburg will be equipped with devices of Entruck, Continental IoT and LCMM).
Storyboard ID	LL_Hamburg_Story_#2
UC	Related UC 10: 5G-LOGINNOV 5G GLOSA & Automated Truck Platooning (GTP)-under 5G-LOGINNOV green initiative
KPIs	H-KPI4; H-KPI5; H-KPI6 Increase average truck speed and reduce acceleration and standstill in platooning vehicle mode with equipped vehicles (platoon vehicles for LL Hamburg will be equipped with devices of Entruck, Conti IoT and LCMM).
Storyboard ID	LL_Hamburg_Story_#3
UC	Related UC 8/9, 10, 11: 5G-LOGINNOV Floating Truck & Emission Data (FTED) 5G-LOGINNOV 5G GLOSA & Automated Truck Platooning (GTP)-under 5G-LOGINNOV green initiative 5G-LOGINNOV dynamic control loop for environment sensitive traffic management actions (DCET)
KPIs	H-KPI7; H-KPI8, H-KPI9; H-KPI10 Reduction of fuel consumption and CO_2 emissions in single mode (vehicles for LL Hamburg will be equipped with devices for Entruck, Conti IoT and LCMM) up to 10% Reduction of fuel consumption and CO_2 emissions in platoon mode (vehicles for LL Hamburg will be equipped with devices for Entruck, Conti IoT and LCMM) up to 20%
Storyboard ID	LL_Hamburg_Story_#4
UC	Related UC 10: 5G-LOGINNOV 5G GLOSA & Automated Truck Platooning (GTP)-under 5G-LOGINNOV green initiative
KPIs	H-KPI-11 and H-KPI-12 H-KPI-11: Optimize Energy Performance Index 'EPI - cl per ton and km' (platoon vehicles for LL Hamburg will be equipped with devices for LCMM) H-KPI-12: Optimize Acceleration Performance Index 'API - KWh per ton and km' (vehicles for LL Hamburg will be equipped with devices for LCMM) Target: Increase value of 'EPI - cl per ton and km' and 'API – kWh per ton and km' up to 10% for vehicle trips
Storyboard ID	LL_Hamburg_Story_#5
UC	Related UC 8/9, 10, 11: 5G-LOGINNOV Floating Truck & Emission Data (FTED) 5G-LOGINNOV 5G GLOSA & Automated Truck Platooning (GTP)-under 5G-LOGINNOV green initiative 5G-LOGINNOV dynamic control loop for environment sensitive traffic management actions (DCET)
KPIs	H-KPI-13, H-KPI-15, H-KPI-16 Extended cellular bandwidth on urban roads by 5G network 5G communication systems will be able to support dedicated bandwidths (per user) over 500MBit/s - depending on deployed network structure. LL Hamburg will use the production network of T-Mobile with 5GNR (in 3.5 GHz spectrum) to get this high capacity.
Storyboard ID	LL_Hamburg_Story_#6
UC	Related UCs 8/9, 10, 11: 5G-LOGINNOV Floating Truck & Emission Data (FTED) 5G-LOGINNOV 5G GLOSA & Automated Truck Platooning (GTP)-under 5G-LOGINNOV green initiative 5G-LOGINNOV dynamic control loop for environment sensitive traffic management actions (DCET)
KPIs	H-KPI-14 Positioning quality on urban road networks with 5G by 10 cm The product solution of Deutsche Telekom with the partner Skylark will provide a precision level of 10 cm (comparable with 3 - 10 m for uncorrected GNSS signal). This solution will be integrated in the LL Hamburg UC to increase the precision by factor 10 and to reduce the complexity of the solution (map matching will be much

	simpler).

Table 18: LL Hamburg Storyboards

4.4. Data Collection

The Hamburg Living Lab will mostly provide processed data to the central data collection tool. As long as applicable, data available from all Living Lab partners (Continental, tec4u, SWARCO and T-Systems) will be collected and aggregated in a Living Lab data collection instance whose main purpose lies in acting as the main interface to transfer data to the central data collection instance via Fluentd. As the data foreseen for the evaluation tool is the result of complex algorithms it is not applicable for detailed processing by the evaluation tool and is only intended for limited aggregation and visualisation.

The data collection process foresees each individual partner to collect their own data in their own infrastructure and, if applicable, process the data with their algorithms or aggregations. Afterwards each partner sends their processed data to the LL Hamburg Data API, where the data is further aggregated and fused before being send to the 5G-LOGINNOV central data collection instance.

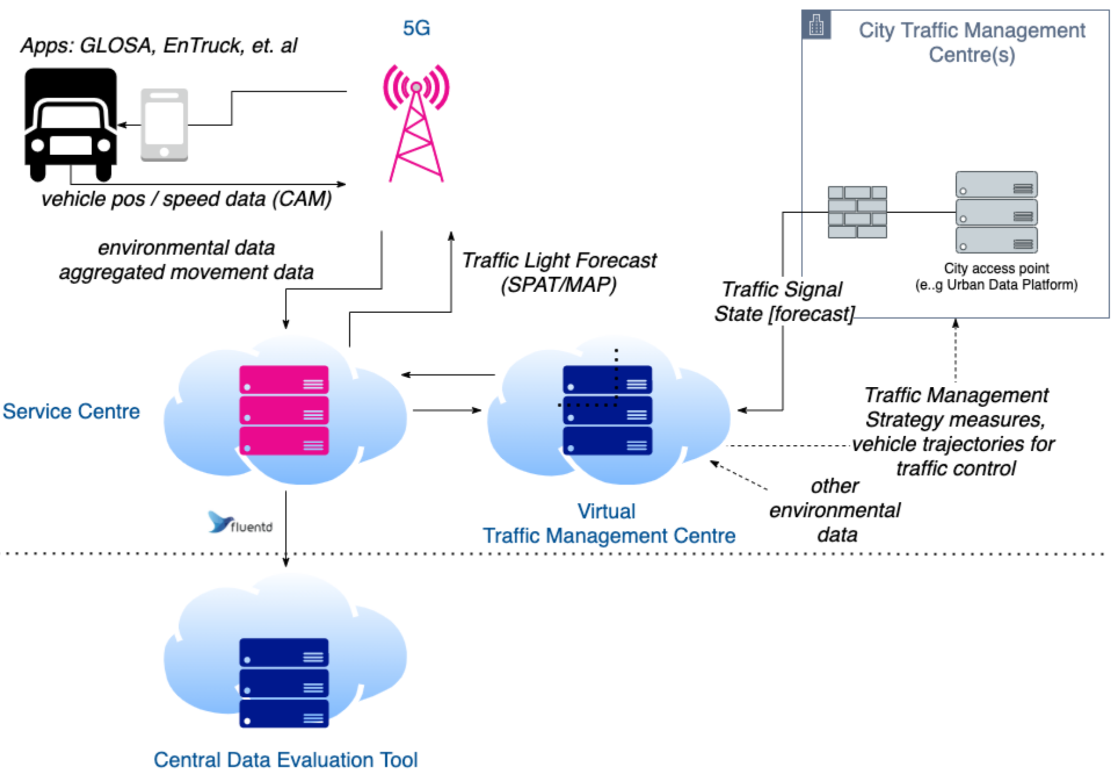


Table 19: Service Architecture Living Lab Hamburg for data collection

Component	Description	Relevant KPIs	Responsible
LL Hamburg Data API	LL central data collection tool, responsible for collecting, aggregating and transferring LL data	• H-KPI1-15	T-Systems

LCMM	Various data collection devices (e.g. Smartphones, Taxi roof signs) for ISO 23795 conform fuel consumption data.	• H-KPI1-12	T-Systems
Skylark High-precision positioning device	High precision positioning device collecting location data and derived LCMM calculations	• H-KPI1-12, H-KPI14	T-Systems
Tec4u car-pc	In-car PC to collect and analyse (e.g. manoeuvre detection) CAN-Bus data from the vehicle.	• H-KPI1-12	Tec4u
Conti IoT Device	5G enabled IoT device connected to the CAN-Bus collecting and transferring data.	• H-KPI1-12	Continental
Mobileum 5G analyser	5G network scanner tool to analyse characteristics of the public 5G NSA network of Hamburg	• H-KPI13, H-KPI15	T-Systems

The following tables define the relevant data fields per KPI:

Avg. truck speed single mode (H-KPI1)				
Field	**Type**	**Unit**	**Required/Optional**	**Description**
Speed	Float	m/s	Required	Average Speed
StartDate	Date	-	Required	Start date and time of this test drive
EndDate	Date	-	Required	End date and time of this test drive
IncludingGLOSA	Boolean	-		GLOSA in use at this test drive, YES or NO
VehicleType	String	-		Model and type of the test vehicle
Conditions	int	-		External conditions e.g. influencing the traffic situation
LocationID	int	-	Required	Location where this speed has been recorded

Avg. acceleration activities single mode (H-KPI2)				
Field	**Type**	**Unit**	**Required/Optional**	**Description**
Acceleration	Float	m/s^2	Required	Average Acceleration
StartDate	Date	-	Required	Start date and time of this test drive
EndDate	Date	-	Required	End date and time of this test drive
IncludingGLOSA	Boolean	-		GLOSA in use at this test drive, YES or NO
VehicleType	String	-		Model and type of the test vehicle
Conditions	int	-		External conditions e.g. influencing the traffic situation
LocationID	int	-	Required	Location where this speed has been recorded

Avg. stillstand time single mode (H-KPI3)				
Field	**Type**	**Unit**	**Required/Optional**	**Description**
Stillstand time	Float	s	Required	Stillstand time spent in area
StartDate	Date	-	Required	Start date and time of this test drive
EndDate	Date	-	Required	End date and time of this test drive
IncludingGLOSA	Boolean	-		GLOSA in use at this test drive, YES or NO
VehicleType	String	-		Model and type of the test vehicle
Conditions	int	-		External conditions e.g. influencing the traffic situation
LocationID	int	-	Required	Location where this speed has been recorded

Truck speed profile by platoon mode (H-KPI4)				
Field	**Type**	**Unit**	**Required/Optional**	**Description**
Speed	Float	m/s	Required	Average Speed
StartDate	Date	-	Required	Start date and time of this test drive
EndDate	Date	-	Required	End date and time of this test drive
IncludingGLOSA	Boolean	-		GLOSA in use at this test drive, YES or NO
VehicleType	String	-		Model and type of the test vehicle
Conditions	int	-		External conditions e.g. influencing the traffic situation

Acceleration profile by platoon mode (H-KPI5)				
Field	**Type**	**Unit**	**Required/Optional**	**Description**
Acceleration	Float	m/s^2	Required	Average Acceleration
StartDate	Date	-	Required	Start date and time of this test drive
EndDate	Date	-	Required	End date and time of this test drive
IncludingGLOSA	Boolean	-		GLOSA in use at this test drive, YES or NO
VehicleType	String	-		Model and type of the test vehicle
Conditions	int			External conditions e.g. influencing the traffic situation
LocationID	int		Required	Location where this speed has been recorded

Stillstand time profile by platoon mode (H-KPI6)				
Field	**Type**	**Unit**	**Required/Optional**	**Description**
Stillstand time	Float	s	Required	Stillstand time spent in area
Total Time	Float	s		Total time spent in area
StartDate	Date	-	Required	Start date and time of this test drive
EndDate	Date	-	Required	End date and time of this test drive
IncludingGLOSA	Boolean	-		GLOSA in use at this test drive, YES or NO
VehicleType	String	-		Model and type of the test vehicle
Conditions	int	-		External conditions e.g. influencing the traffic situation
LocationID	int	-	Required	Location where this speed has been recorded

Fuel consumption single mode (H-KPI7)				
Field	**Type**	**Unit**	**Required/Optional**	**Description**
Fuel consumption	Float	l/100km	Required	Average fuel consumption
StartDate	Date	-	Required	Start date and time of this test drive
EndDate	Date	-	Required	End date and time of this test drive
IncludingGLOSA	Boolean	-		GLOSA in use at this test drive, YES or NO
VehicleType	String	-		Model and type of the test vehicle
Conditions	int	-		External conditions e.g. influencing the traffic situation
LocationID	int	-	Required	Location where this speed has been recorded

CO2 emissions single mode (H-KPI8)				
Field	**Type**	**Unit**	**Required/Optional**	**Description**
CO2 Emission	Float		Required	Average CO2 emission
StartDate	Date	-	Required	Start date and time of this test drive
EndDate	Date	-	Required	End date and time of this test drive
IncludingGLOSA	Boolean	-		GLOSA in use at this test drive, YES or NO
VehicleType	String	-		Model and type of the test vehicle
Conditions	int	-		External conditions e.g. influencing the traffic situation
LocationID	int	-	Required	Location where this speed has been recorded

Fuel consumption platoon mode (H-KPI9)				
Field	**Type**	**Unit**	**Required/Optional**	**Description**
Fuel consumption	Float		Required	Average fuel consumption
StartDate	Date	-	Required	Start date and time of this test drive
EndDate	Date	-	Required	End date and time of this test drive
IncludingGLOSA	Boolean	-		GLOSA in use at this test drive, YES or NO
VehicleType	String	-		Model and type of the test vehicle
Conditions	int	-		External conditions e.g. influencing the traffic situation
LocationID	int	-	Required	Location where this speed has been recorded

CO2 emissions platoon mode (H-KPI10)				
Field	**Type**	**Unit**	**Required/Optional**	**Description**
CO2 Emission	Float	g/km	Required	Average CO2 emission
StartDate	Date	-	Required	Start date and time of this test drive
EndDate	Date	-	Required	End date and time of this test drive
IncludingGLOSA	Boolean	-		GLOSA in use at this test drive, YES or NO
VehicleType	String	-		Model and type of the test vehicle
Conditions	int			External conditions e.g. influencing the traffic situation
LocationID	int		Required	Location where this speed has been recorded

Energy performance index value (H-KPI11)				
Field	**Type**	**Unit**	**Required/Optional**	**Description**
EPI	Float	l/100km*t	Required	Energy performance index
StartDate	Date	-	Required	Start date and time of this test drive
EndDate	Date	-	Required	End date and time of this test drive
IncludingGLOSA	Boolean	-		GLOSA in use at this test drive, YES or NO
VehicleType	String	-		Model and type of the test vehicle
Conditions	int	-		External conditions e.g. influencing the traffic situation
LocationID	int	-	Required	Location where this speed has been recorded

Acceleration performance index value API (H-KPI12)				
Field	**Type**	**Unit**	**Required/Optional**	**Description**
API	Float	kWh/100km*t	Required	Acceleration performance index
StartDate	Date	-	Required	Start date and time of this test drive
EndDate	Date	-	Required	End date and time of this test drive
IncludingGLOSA	Boolean	-		GLOSA in use at this test drive, YES or NO
VehicleType	String	-		Model and type of the test vehicle
Conditions	int	-		External conditions e.g. influencing the traffic situation
LocationID	int	-	Required	Location where this speed has been recorded

Available 5G bandwidth on urban roads (H-KPI13)				
Field	**Type**	**Unit**	**Required/Optional**	**Description**
Timestamp	Date	-	Required	
Reference Signal Received Power	Float	dBm		Reference Signal Received Power (RSRP) in dBm
Reference Signal Received Quality	Float	dB		Reference Signal Received Quality (RSRQ) in dB
Upload Rate	Float	Mbps	Required	Upload Rate in Mbit/s
Download Rate	Float	Mbps	Required	Download Rate in Mbit/s
Location information	GPS			Location where this value has been tested

Positioning quality on urban road networks with 5G (H-KPI14)				
Field	**Type**	**Unit**	**Required/Optional**	**Description**
Timestamp	Date	-	Required	
GPS accuracy	Float		Required	GPS accuracy without correction
Corrected accuracy	Float		Required	Accuracy with correction

Latency by 5G cellular communication in urban areas (H-KPI15)				
Field	**Type**	**Unit**	**Required/Optional**	**Description**
Timestamp			Required	
Reference Signal Received Power		dBm		Reference Signal Received Power (RSRP) in dBm
Reference Signal Received Quality		dB		Reference Signal Received Quality (RSRQ) in dB
Upload Latency Edge		ms	Required	Upload Latency between device and Edge in ms
Download Latency Edge		ms	Required	Download Latency between Device and Edge in ms
Upload Latency Cloud		ms	Required	Upload Latency between device and Cloud in ms
Download Latency Cloud		ms	Required	Download Latency between Device and Cloud in ms
Location information				Location where this value has been tested

5. DEVELOPMENT AND DEPLOYMENT IN LIVING LAB KOPER

5.1. Site Overview

Living Lab Koper (LL Koper) targets development and deployment of novel 5G technologies (e.g., cloud-native and MEC driven infrastructures, MANO-based services and network orchestration, Industrial IoT, vehicle telemetry, AI/ML based video analytics, drone-based security monitoring) and cutting-edge prototypes supporting logistics operations in medium-sized European ports. The most demanding port logistic operational scenarios and mission-critical applications are supported through a combination of a national 5G NSA network extended by Mobile IaaS/MEC mechanisms used for the deployment of NSA assured local PGW/SGW gateways and independently operated private 5G SA system provided by ININ. NFV-MANO was prepared for orchestration of Private 5G SA system as it provides means to efficiently provision, deploy and manage the life cycle of the 5G network infrastructure and Industrial grade IoT services. Hybrid private-public 5G network operations enable verification of novel features, such as eMBB, mMTC and URLLC services, network slicing, NFVI and multi-IaaS scenarios operated in realistic port settings.

To assure the most advanced port logistic services, such as automation control of the container management and real-time and AI/ML-powered video surveillance, 5G components are deployed along with high-performance CCTV applications, such as body worn and drone-assisted video streaming, that can significantly benefit from low latency capabilities supported by the 5G ecosystem deployed in the LL Koper.

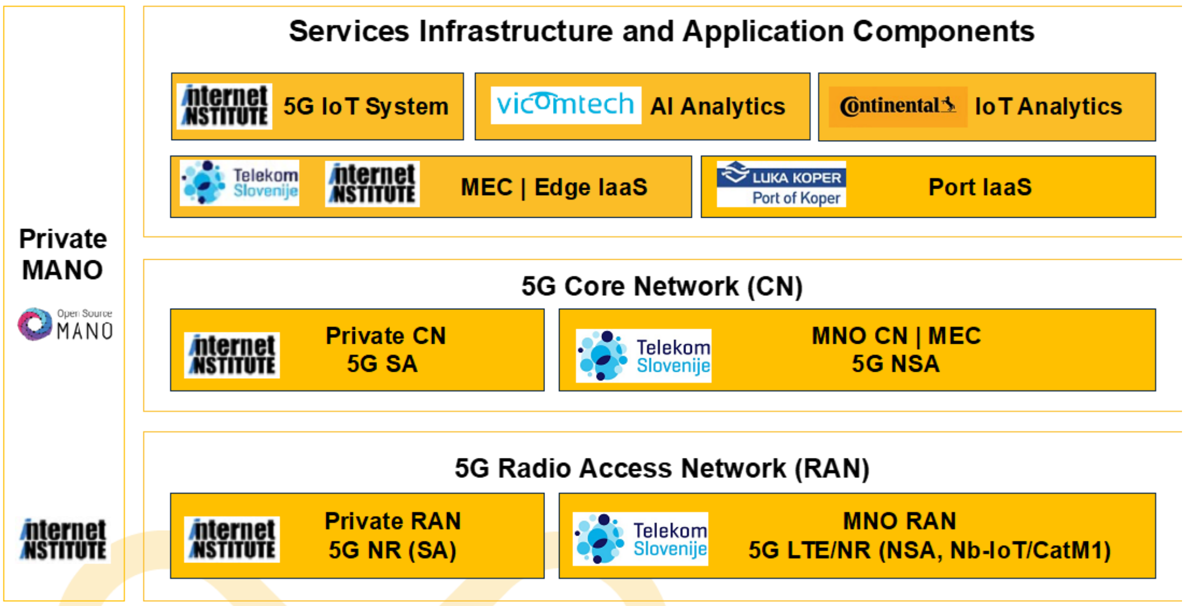


Figure 63: LL Koper - System Architecture

Figure 63 depicts high level system architecture of LL Koper, including application components (e.g. 5G IoT System, AI Analytics and IoT Telemetry Analytics) used to support deployment and verification of UC1, UC5 and UC6. As such, applications and services deployed within use cases UC1, UC5 and UC6 will be able to rely on two 5G networks provided by TSLO (Telekom Slovenije) and ININ (INTERNET INSTITUTE), IaaS provided by LK (Luka Koper) and MEC/Mobile IaaS assured by TSLO and ININ. This infrastructure will enable proper operating of both public and private 5G networks and running application/services related to port daily operations.

5.2. Deployed Components

Table 20 and Figure 64 summarizes prepared, verified and deployed components in LL Koper. Detailed hardware and software specifications and intended use as part of the use cases are presented in the following chapters.

Table 20: LL Koper – Deployed equipment

Living Lab Koper Deployed Components		
Equipment Description	**Addressed UC**	**Amount**
UHD cameras, wearable cameras	UC5, UC6	3**
Drones	UC6	2*
5G UE (phones, tablets)	UC5, UC6	5
Cranes equipped	UC5	1**
Yard trucks equipped	UC5	3*
5G IoT GW	UC1, UC5, UC6	6*
gNb (NSA mode)	UC1, UC5, UC6	2*
5G enabled EPC (NSA mode)	UC1, UC5, UC6	1
Mobile IaaS/MEC supporting local PGW/SGW (NSA mode)	UC1, UC5, UC6	1
Port IaaS	UC1, UC5, UC6	1
Private 5G System - gNb & 5G CN (SA mode)	UC1	1
Telemetry 5G-IoT device	UC5	3*

* Planned to be extended with additional units or upgraded with additional capabilities (e.g., n78 NR cells).

**UHD cameras were selected, operationally verified on the STS crane (all the 4 positions), waiting for selected cameras to be delivered.

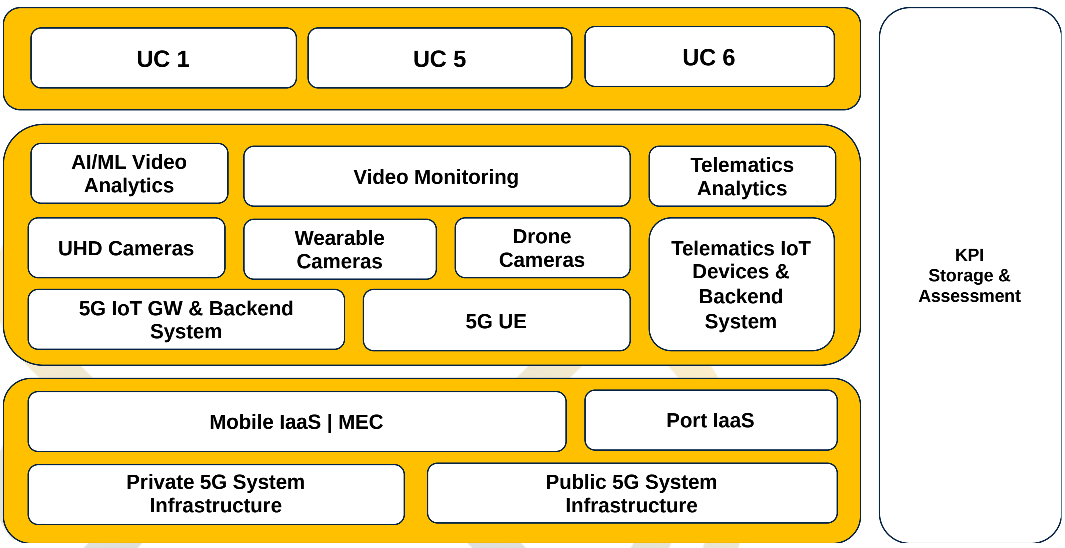


Figure 64: LL Koper - Infrastructure Components with Use Cases

5.2.1. Public 5G NSA System Infrastructure

The 5G RAN architecture of the 5G-LOGINNOV Koper LL is based on the deployment of the 5G Non-Standalone Architecture implemented with Option 3x as per 3GPP Release 15. The architecture provides both NR and LTE radio access. The initial 5G radio access network is deployed on NR 4x4 MIMO 20MHz at 2600 MHz FD mode (n7), with an LTE anchor layer 2x2 MIMO 10 MHz in B20 at 800 MHz and 2x2 MIMO 20 MHz in B3 at 1800 MHz. LTE carrier is 4x4 MIMO 15 MHz in B7 at 2700 MHz. Later in the project, we will install additional antennas NR NSA in band n78 (3500MHz) with 100MHz bandwidth and LTE anchor B3. TSLO deployed a dedicated EPC core that we physically installed inside the LL Koper. Core is embedded in the commercial architecture of the 5G public network, where the local data plane provides a local breakout. In this way, we met the strict needs of the Port of Koper to keep the data within the campus.

Table 21: LL Koper - Public 5G (NSA) network specifications.

Private 5G Network (NSA Mode)					
Radio Access Network	**CN**	**Frequency Bands**	**Channel BW**	**Max Throughput**	**Other**
5G NR (Release 15) NSA	5G Core (Release 15) NSA	n7, @2.6Ghz	20Mhz	400 Mbps DL and 75 Mbps UL (average IP rates)	Capable up to 4x4 MIMO

Figure 65: LL Koper - Deployed Dedicated EPC Core Network (NSA assured)

5.2.2. Private 5G SA Network (ININ)

Private 5G SA mobile network has been provided by the ININ (Table 22); the private 5G network was designed to operate in 5G SA mode (NR and Core Network) and is prepared as a compact and portable solution deployed over the mobile IaaS/MEC infrastructure provided by ININ. Compact form of the mobile solution (Figure 66) enables fast and simple reallocation of the gNb and core network services inside the port area and can be used to assure additional resilience of the deployed communication infrastructure even in the most demanding situations caused by natural or man-made disasters.

Table 22: LL Koper - Private 5G (SA) network capabilities.

Private 5G Network (SA Mode)				
Radio Access Network	**CN**	**Frequency Bands**	**Channel BW**	**Max Throughput**
5G NR (Release 15) / SA mode	5G CN / SA mode (Release 15)	3500 MHz	50MHz	300Mbps DL 190Mbps UL
1 cell, 2 ports 2x2 MIMO 200mW - 20 W	Compact 5G CN (UPF, AMF, SMF, UDM)	n78	TDD Mode	Throughput depends on the configured UL/DL TDD split ratio

Omni Directional Ant. (beamwidth 360º) Directional Ant. (beamwidth 120º)

Private 5G system was assured by using mobile IaaS/NFVI environment to support automated deployment of 5G BBU (5G NR gNb) and 5G Core (AMF, SMF, UPF, AUSF; 3GPP Release 15) in a form of a single network function (Figure 67, Figure 68). IaaS/NFVI environment was realized on container-based deployment of network functions, MANO/OSM-compliant orchestration and other cloud-native mechanisms such as self-healing, scaling etc. The 5G BBU and 5G CN components are operationally deployed as a network function (NF) and corresponding network service (NS) using cloud-native deployment principles and orchestrated by OSM/MANO orchestrator.

Modular architectural design of HW and SW (Figure 66) enables independent scaling of the private 5G system components: providing additional power supply modules that can assure system energy source redundancy; adding extra RRUs that can scale system radio capacity (radio BW and coverage) on the gNb level.

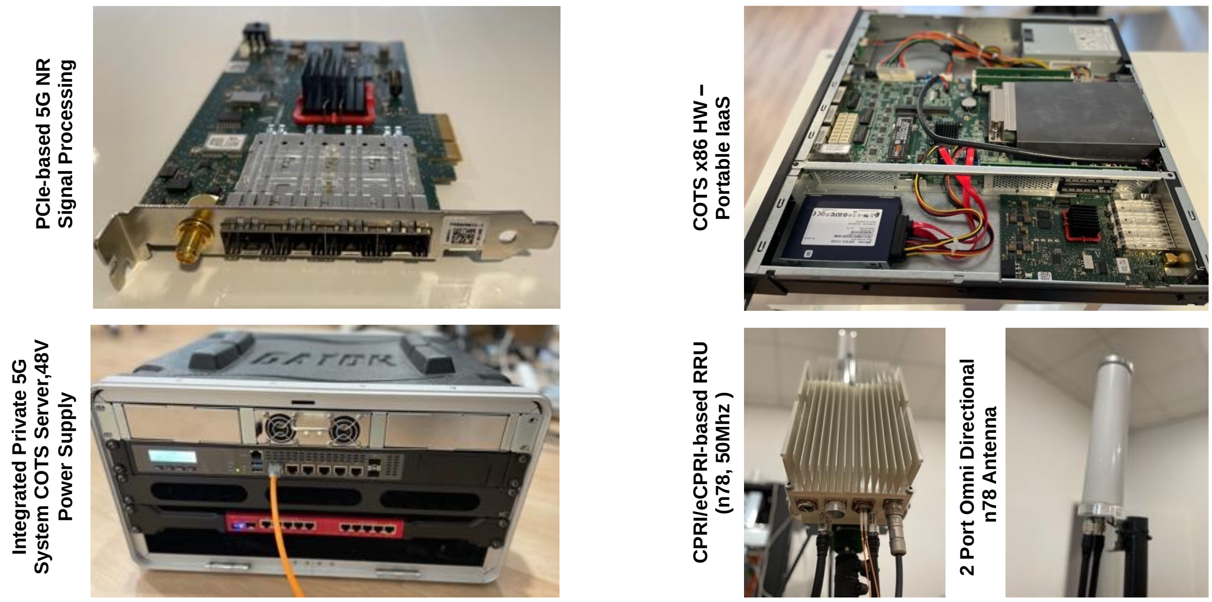


Figure 66: LL Koper - Private 5G System prepared as compact portable solution / integration phase

As depicted on Figure 67 and Figure 68 Virtual network function descriptor (VNFD) and network service descriptor (NSD) were provided and allow the configuration of selected range of 5G System parameters (i.e. ARFCN, Channel BW, PCI, MCC/MNC, Network Name, AMF address, etc.).

Figure 67: LL Koper - Private 5G System / Prepared VNF Descriptor

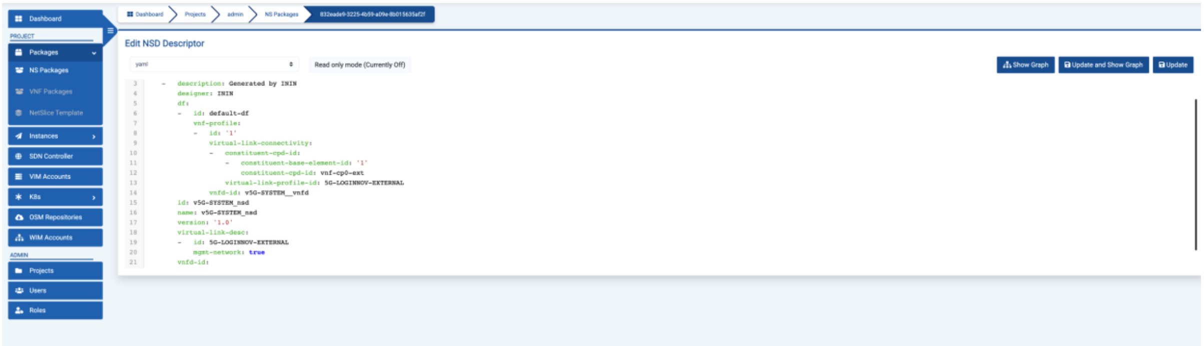


Figure 68: LL Koper - Private 5G System / Prepared NSD Descriptor

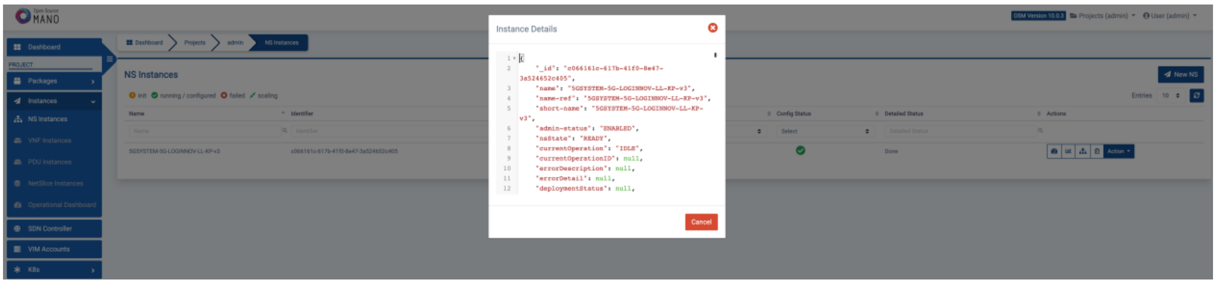


Figure 69: LL Koper - Private 5G System / Deployed 5G System as Network Service

5.2.3. Port IaaS

To support specific port operations related services, Luka Koper has prepared dedicated Port IaaS capabilities. Port IaaS extends capabilities of Mobile IaaS/MEC deployed by ININ and TSLO and provides additional compute resources with dedicated GPU cards supporting swift AI/ML operation. The Port IaaS requirements are covered by placing dedicated physical server at the data centre in the LL Koper location and it serves as a private IaaS in terms of NFV-based terminology. Applications/services running on the Port IaaS are AI/ML-assured video analytics, telematics analytics and 5G KPI monitoring.

5.2.4. Mobile IaaS/MEC

Prepared mobile IaaS/MEC will serve as compute and storage infrastructure used for deployment of several 5G network and services components local in LL Koper; providing capabilities for running Public and Private network components (e,g, Local PGW/SGW components extended with NSA), management and orchestration technologies, i.e., MANO, as well as backend for IoT platform elements, including monitoring network parameters.

As already presented for the selected LL Koper elements (e.g. Private 5G system and 5G IoT backend components) deployment is provisioned using NVF-based concepts and includes CNF assured elements (BBU/gNb, 5G CN, Collector, Reference server). OpenSource MANO (OSM 10) orchestrator is used to efficiently deploy and manage the containerized applications (CNFs). For testing and monitoring purposes, the qMON monitoring tool was deployed and will allow continuous end-to-end 5G network service monitoring as already mentioned. On the application layer, the private 5G deployment will support hosting additional 3rd party applications, such as video proxy supporting drone-based video streaming in the UC6. Within this architecture, the only requirements for such applications are the application is containerized (Figure 70, Figure 71) and that it fully support OSM orchestration via CNF and NS.

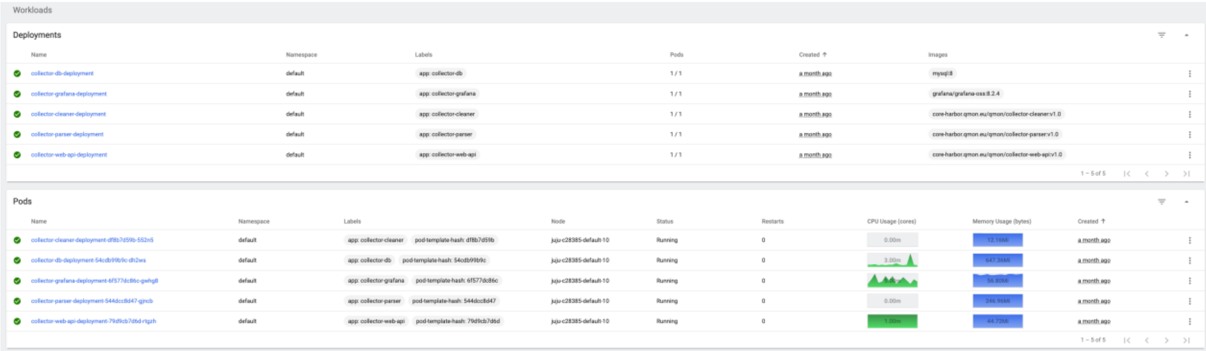


Figure 70: LL Koper - Mobile IaaS/MEC / Deployed qMON Collector CNF containerized components

```yaml
apiVersion: apps/v1
kind: Deployment
metadata:
  name: collector-db-deployment
  labels:
    app: collector-db
spec:
  replicas: 1
  selector:
    matchLabels:
      app: collector-db
  template:
    metadata:
      labels:
        app: collector-db
    spec:
      restartPolicy: Always
      imagePullSecrets:
      - name: regcred
      initContainers:
      - name: collector-db-tables-parser
        image: core-harbor.qmon.eu/qmon/collector-db-tables-parser:v1.0
        volumeMounts:
        - name: mysql-table-config
          mountPath: /app/data/
        env:
        - name: DB_NAME
          valueFrom:
            configMapKeyRef:
              name: collector-db-configmap
              key: database-name
        - name: gitlab_read_access_token
          valueFrom:
            secretKeyRef:
              name: collector
              key: gitlab_read_access_token
      containers:
      - name: collector-db
        image: mysql:8
        resources:
          requests:
            memory: "250Mi"
            cpu: "250m"
          limits:
            memory: "1Gi"
            cpu: "1"
```

Figure 71: LL Koper - Mobile IaaS/MEC / Prepared Kubernetes manifest for the Collector DB (CNF) component

5.2.5. 5G IoT System (ININ)

5G IoT system was developed as an extension of ININ's industrial IoT portfolio to assure 5G connectivity to non-5G devices, such as UHD cameras and other industrial sensors, used in ports. It is a distributed solution with 5G (NSA and SA mode supported) and NFV-ready system capabilities designed for deployment of IoT/M2M based remote sensing in industrial environments. It features a distributed architecture and comprises a centralised cloud-based management supporting remote control (OTA – Over the Air) of the deployed (Figure 73) 5G IoT gateways (5G IoT GW). 5G IoT GW supports various communication modules (4G/5G, Ethernet, Serial and USB) and other supportive capabilities presented in the Table 23.

Table 23: LL Koper - 5G IoT Gateway capabilities

5G IoT Gateway - NSA/SA Mode		
Feature	**Capability**	**Comment**
LTE/4G	B1, B2, B3, B4, B5, B7, B8, B12, B13, B14, B18, B19, B20, B21, B25, B26, B28, B29, B30, B32, B34, B38, B39, B40, B41, B42, B43, B46, B48, B66, B71	Operational bands are depended on the used region (Europe, North America, Australia, Japan, Africa, APAC)
5G NSA/SA	n1, n2, n3, n5, n7, n8, n12, n20, n25, n28, n38, n40, n41, n48, n66, n71, n77, n78, n79	Operational bands are depended on the used region (Europe, North America, Australia, Japan, Africa, APAC)
LAN / Ethernet	1 x 10/100/1000/2.5G Base-Tx 1 x 10/100/1000Base-Tx	2 x RJ-45 GbE compatible
COM Port	2 x COM RS232/422/485	
USB port	2 x USB 3.1 Gen.2 (10Gbp/s) 2 x USB 3.1 Gen.1 (5Gbp/s)	
GNSS	GPS, GLONASS, Galileo, BeiDou	
CPU	11th generation Intel Core i3	Available options i3/i5/i7
RAM	4 GB	Extendable to 64 GB
Storage	SSD 128 GB	
Watchdog	HW Watchdog	
Management	Local & Centralised	
Operating temperature	-30 °C – 70 °C	Fanless operation, IP50
Form Factor	Wall mount kit (standard)	DIN RAIL (optional)
DC input	DC in 12/24V (+9V ~ +32V)	Wide voltage single power input
Weight	2,1 kg	

The following figures (Figure 72, Figure 73) depict prepared hardware components (5G antennas with 5G modem, developed M2 PCB adapter, pigtails and x86 industrial board with heat dispersive enclosure) used as part of a final gateway assembly and integration process.

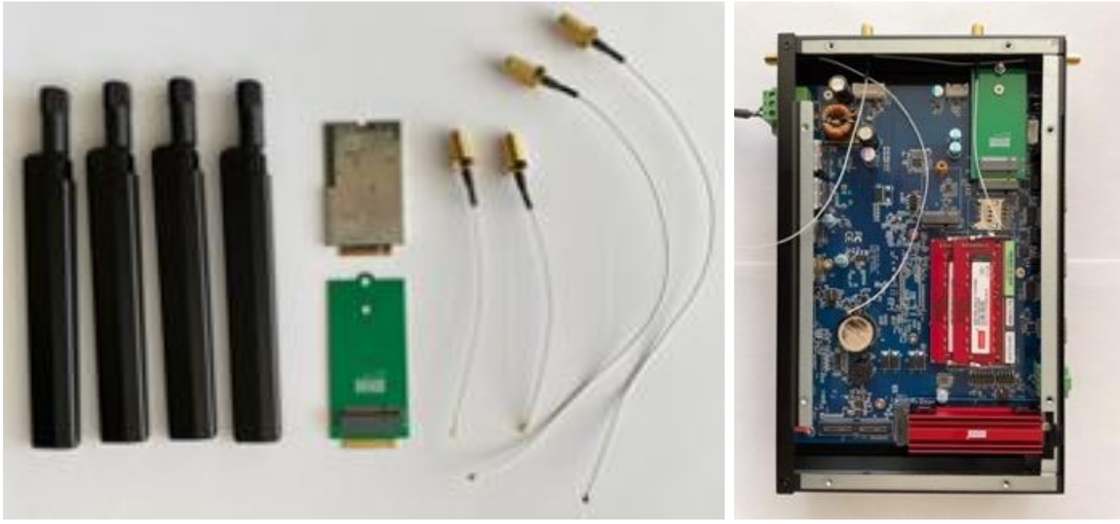


Figure 72: LL Koper - 5G IoT Gateway / HW Integration Process Showcasing 5G Antennas, 5G modem, M2 PCB adapter, pigtails and industrial board with enclosure.

Figure 73: LL Koper - 5G IoT Gateway / Assembled HW ready for the software deployment.

Open system architecture with cloud-native principles and API support (Figure 74) was used in the design and development of the 5G IoT GW operating system capabilities. Supported software functionalities (API, UI, qMON Agent, etc.) are prepared and deployed as containers that are running on the Linux OS. Environment SW design and its HW capabilities (11th generation Intel Core CPU i3/i7) are flexible enough to support also deployment and operation of 3Pty services, such as Deep Packet Inspection (Figure 75) and other compute intensive AI/ML applications.

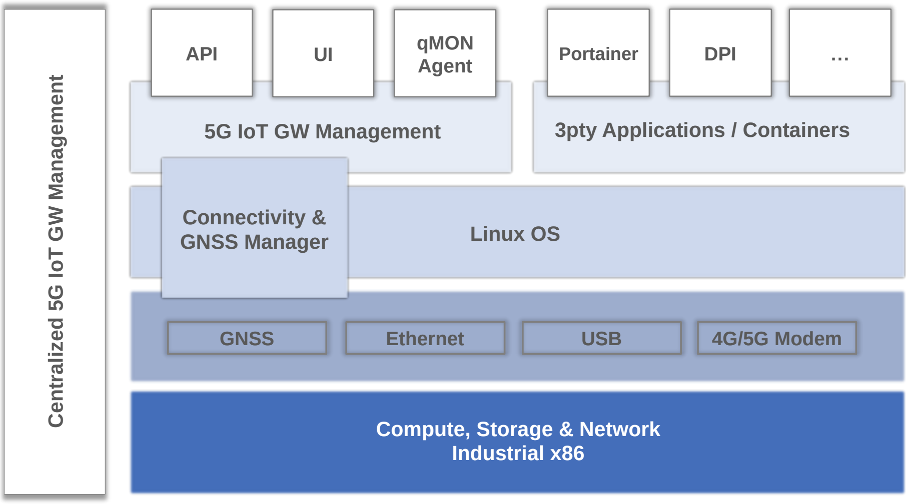


Figure 74: LL Koper - 5G IoT Gateway / Open System Architecture.

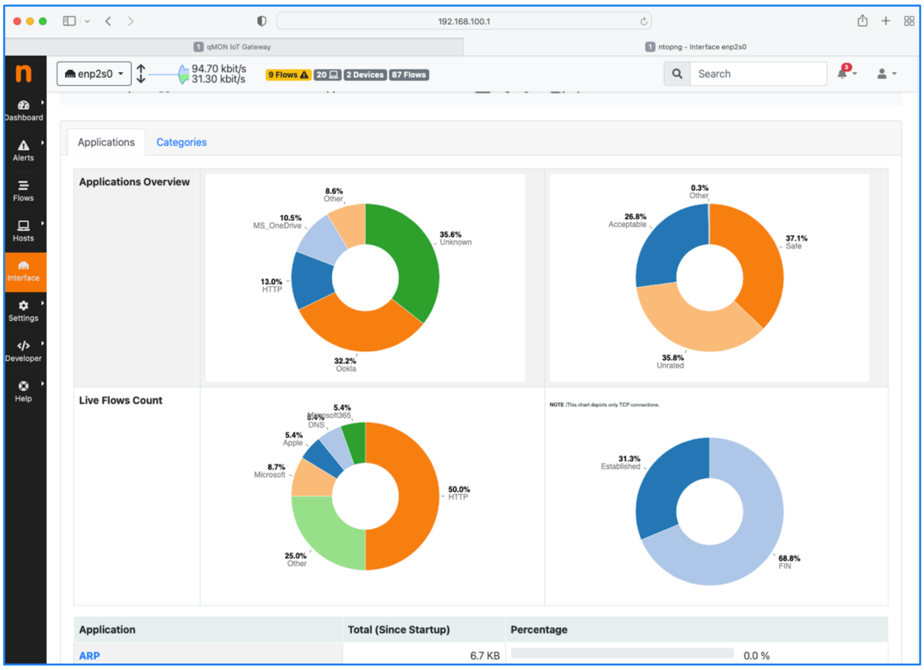


Figure 75: LL Koper -5G IoT GW Management / DPI Agent with Analytics Deployed as 3pty Container Option.

The following figures depict: developed local management capabilities with 5G IoT GW operational status and 5G NR signal overview (Figure 76); active gateway settings (Figure 77); supported debug capabilities that are exposing in real time 5G network's operational details and radio signal levels (Figure 78).

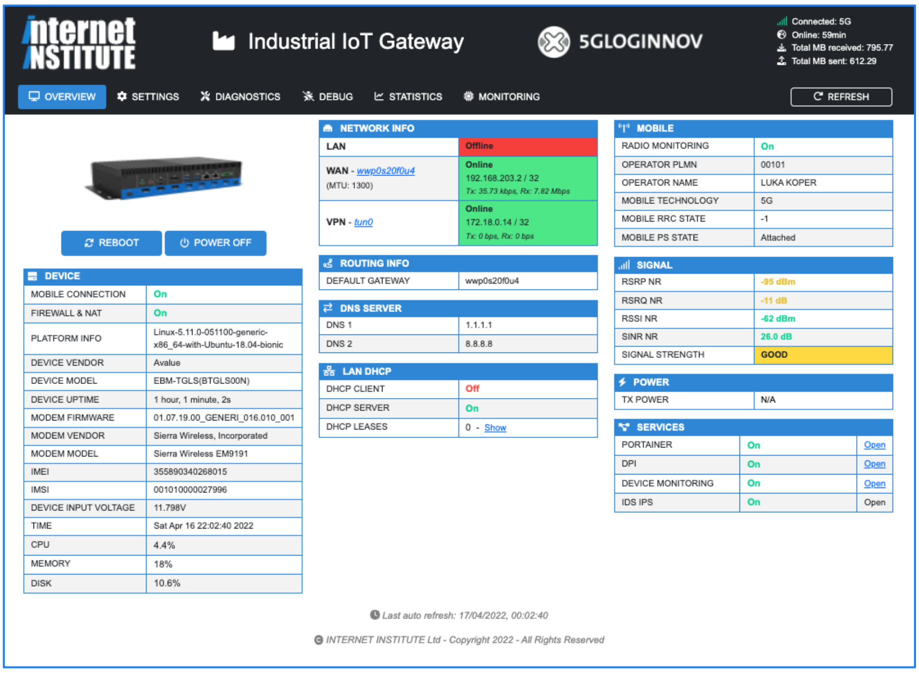


Figure 76: LL Koper - 5G IoT GW Management / Overview with Main Status.

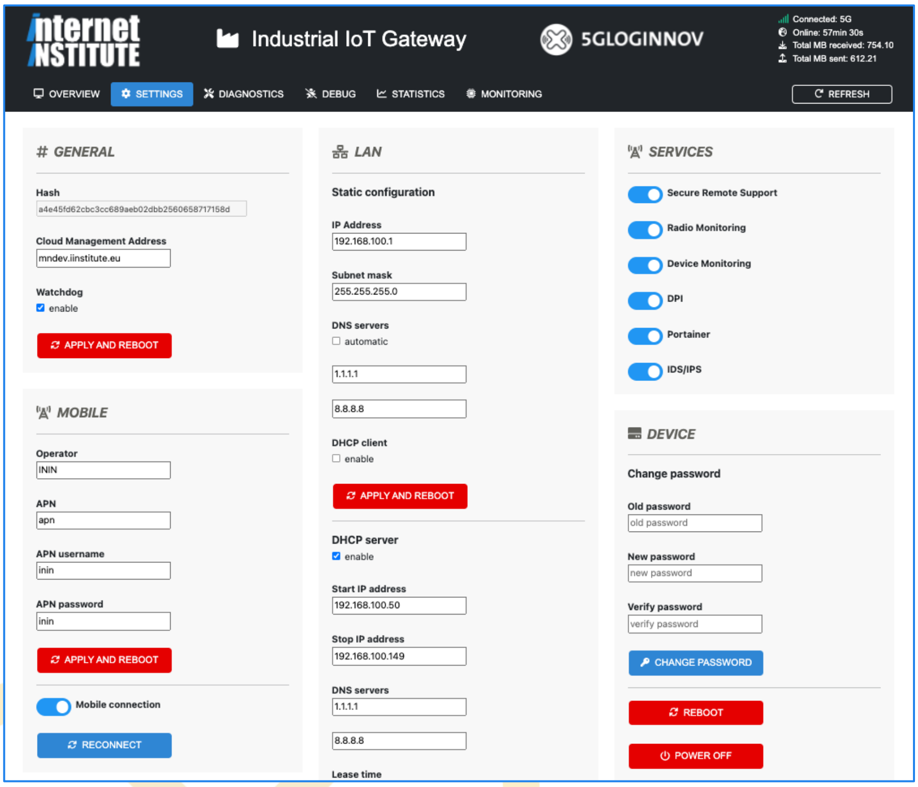


Figure 77: LL Koper - 5G IoT GW Management / Exposed configuration options.

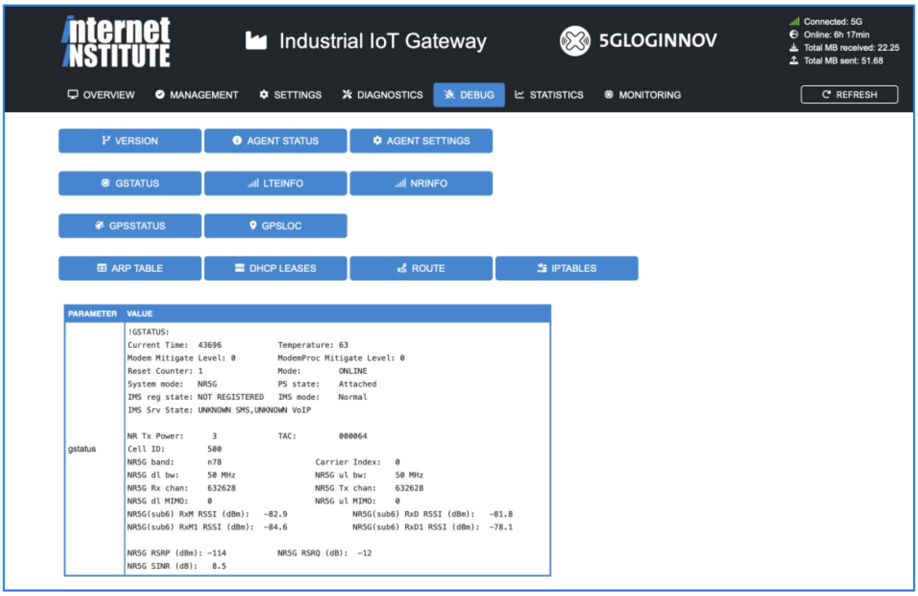


Figure 78: LL Koper - 5G IoT GW Management / 5G NR (SA) radio status.

To complement gateway's local management capabilities, centralised cloud-based management for the deployed 5G IoT GWs was prepared to assure streamlined system monitoring (Figure 79) and remote maintenance (Figure 80).

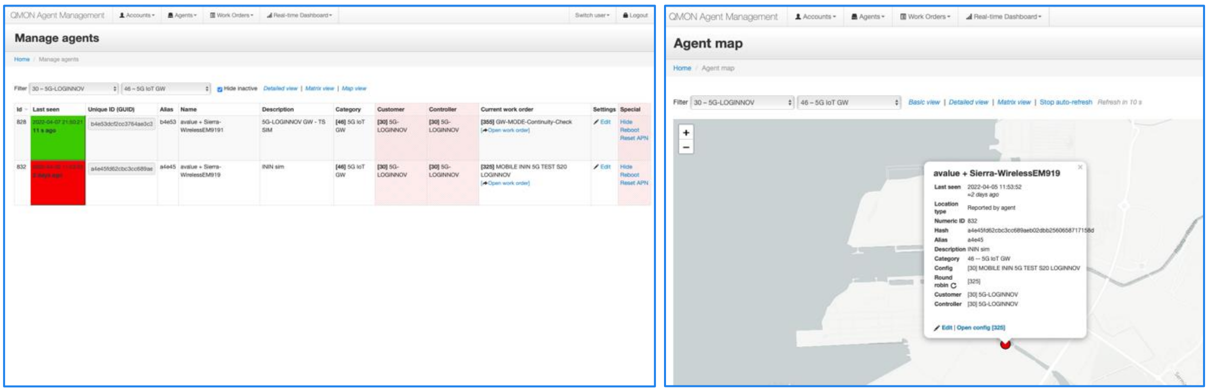


Figure 79: LL Koper - Centralised Cloud-based Management / Basic (left) and GIS Status (right) view.

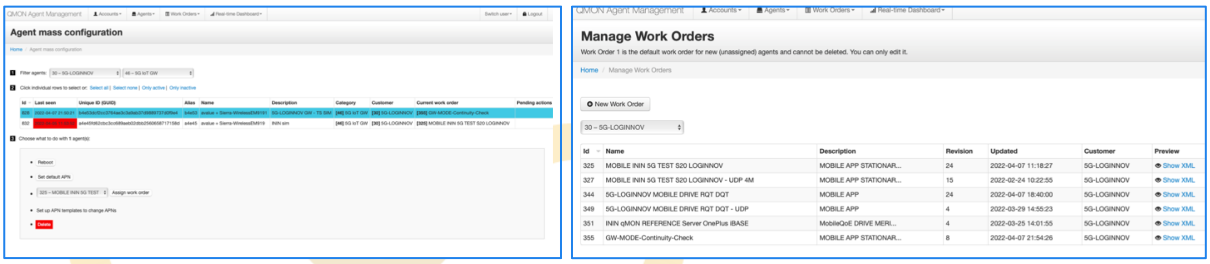


Figure 80: LL Koper - Centralised Cloud-based Management / Remote configuration and management options (left and right).

5.2.6. Telemetry IoT System (CONTI)

The Continental 5G IoT device allows the collection of telemetry data both via the vehicle CAN interface (e.g. fuel consumption), as well as from the on-board GNSS module (speed, acceleration, standstill time etc.).

Telemetry IoT device features	
Feature	**Description**
Cellular	5G modem, 3GPP Release 15 (>3 Gbps)
eUICC	1 x M2M eSIM (physical SIM card as option)
Positioning	L1, Dead Reckoning, PPP/RTK
WiFi/Bluetooth (optional)	Wi-Fi 6 802.11 a/b/g, n, ac, ax 2x2 MIMO, SDB
	Bluetooth v5.2
Vehicle interfaces	Gbit Ethernet, Power, 1 x CAN, USB 2.0 (for development phase)
BuB	Optional back-up battery

The device can operate in several RF bands; below are the proposed bands:

Telemetry IoT device proposed 5G cellular bands	
Cellular network	**RF bands**
5G NSA (SA)	n7, n78

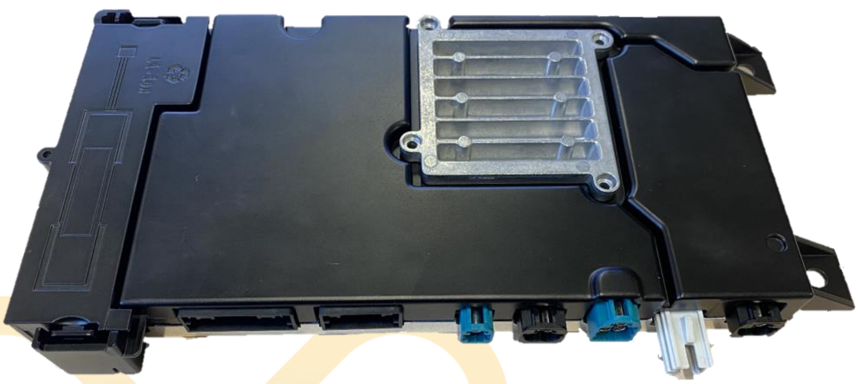


Figure 81: LL Koper - Top view of IoT device.

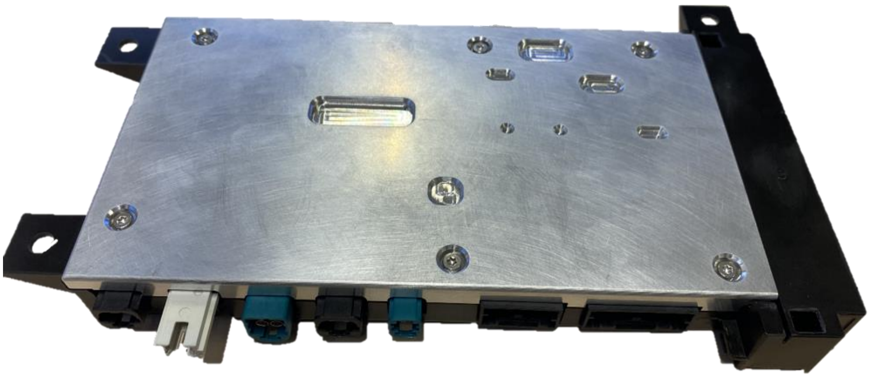


Figure 82: LL Koper - Bottom view of IoT device.

5.2.7. IoT/M2M Devices

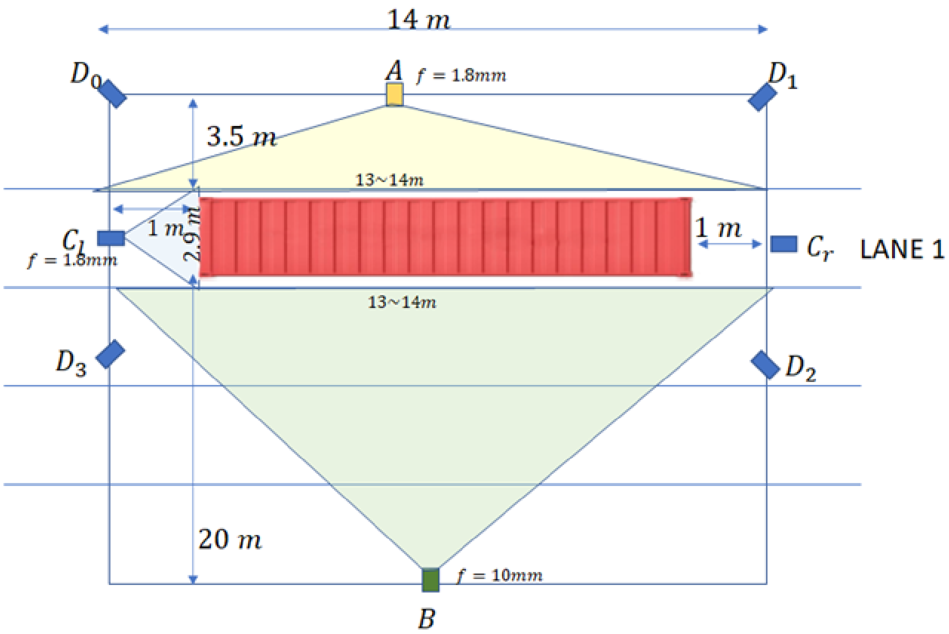
In addition to already presented IoT/M2M devices (e.g., 5G IoT GWs, telematics IoT devices), additional IoT/M2M and other types of devices were prepared to complement LL Koper 5G capabilities and to fulfil planned UCs scenarios: UHD and wearable cameras, drones and 5G UE handheld terminals (Table 24). These devices are used as smart extensions of the existing port infrastructure (e.g., cranes and yard trucks). Current maturity and 5G technology redness of the selected devices in the LL Koper relies on the availability of commercial/industrial 5G components and products, especially those related to the support of 5G eMBB features (e.g., 5G NSA and SA support on industrial UE and drones). Terminal device vendors usually roll out devices only after chipset is ready and generally available for the reasonable price. Due to the current limited market availability some of the initially selected and used devices (i.e., 5G body worn cameras) were substituted with the most suitable prototypes: using USB-based body worn cameras integrated with the commercial 5G smart phones (OnePlus 8T) was used for the real-time video streaming support over the 5G (Figure 112).

Table 24: LL Koper – IoT/M2M Devices

User devices		
Type/Model	**Features**	**Comment**
5G Smart Phone /OnePlus 8T	5G NSA/SA	Used for 5G KPI testing, drone- and wearable camera-based video streaming
5G Smart Phone /OnePlus 9	5G NSA/SA	Used for 5G KPI testing, drone- and wearable camera-based video streaming
Samsung Galaxy S21	5G NSA	Used for 5G KPI testing
Samsung Galaxy S22	5G NSA	Used for 5G KPI testing
Wearable camera		5G UE (NSA and SA) with appropriate streaming application will assure connectivity to the 5G network
Drone		5G UE (NSA and SA) with appropriate streaming application will assure connectivity to the 5G network
UHD camera		5G IoT GW provided by ININ will assure connectivity to the 5G network (NSA and SA)

For the selection of industrial UHD cameras used on the STS crane special test and verification procedure was taken. Targeted STS crane has been tested with industrial cameras for capturing and transferring of UHD streams to the cloud-based video analytics system for identification of container markers and detection of structural damage of containers using advanced AI/ML based video processing techniques. 4 Camera positions were prepared and verified on the STS crane:

- 2 cameras on the lower crane beams, which are positioned parallel to quay (A, B)
- 2 cameras on the upper horizontal crane beams, which are positioned perpendicular to quay (Cl, Cr)



The following cameras have been proposed for each position:

- Position A: AXIS M2026-LE,
- Position B: AXIS P1378-LE,
- Positions Cl, Cr: AXIS M3058-PLVE.

Figure 83: LL Koper – Collected images from the 4 cameras; A)Top-left; B)Top-right; C)Bottom-left; D)Bottom-right

In this way, cameras cover at least 4 different container angles (surfaces) - left, right, front, and door side. As part of the UC5 testing and verification procedures collected information (images) will be transferred through 5G NSA network to the Koper LL backend system (Port IaaS) for further image processing:

- Container ID detection
- Detection and classification of damages in containers
- Detection and classification of IMDG labels.

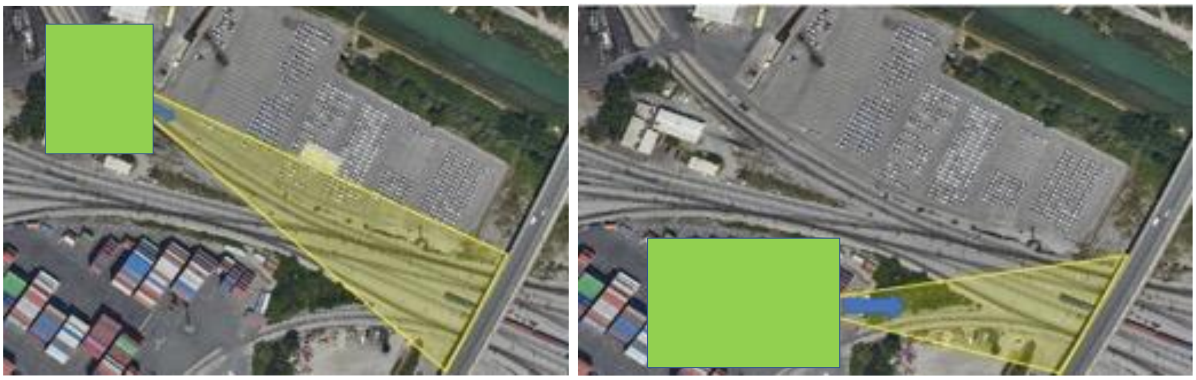


Figure 84: LL Koper - Selected location for the deployment of UHD cameras supporting UC6

5.2.8. Analytics system

AI/ML based algorithms have been developed for 2 main purposes:

- On the one hand, related to tasks performed within UC5, there have been implemented the following modules:
    - **Container IMDG label detection and identification**: to identify IMDG labels yolov5 detection model has been used. This model is built directly in Pytorch and presents some major advantages compared to its predecessors. In the first place, it presents a new backbone structure known as CSP backbone. Also, the neck part of the model changes to a PA-NET. The major improvements include mosaic data augmentation and autolearning bounding box anchors. All this produce a smaller model in disk and a faster model when doing the inference. We take into advantage of the training of this detector and add new classes that also can add redundancy and robustness to the detection process. Thus, container bounding box and text is also detected, although there will be other processes that will detect those elements as well.

The training was carried out with the following hyperparameters:

- epochs: 150
- batch: 16
- input size: 640
-

The training is not started from scratch, but weights are initialized to ones learning with CoCo dataset.

- **Container text detection and identification**: regarding this issue, first, a detection step in which a text detection model is involved and then a recognition step where the different letters composing the word are recognized.

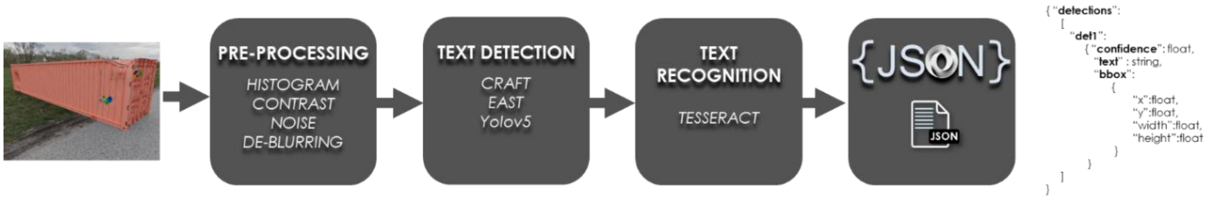


Figure 85: LL Koper - Block diagram of the text identification architecture

On the one hand, detection is carried out using a text detection model called CRAFT and combining its output with a text recognition model called tesseract.

Craft detection main objective is to localize the individual character regions and link them to a text instance. Craft uses as backbone VGG16 in a stage that is used to extract features, that is, to encode the networks input into a certain feature representation. The decoding segment of CRAFT is like a UNET network.

Craft predicts two scores for each character:

- Region score that gives the region of the character, i.e., where the character is located.
- Affinity score: the degree to which a character tends to combine with another.

On the other hand, the output of this detection stage is a list of bounding boxes detections that contain text within. This image regions are cropped and sent to the text recognition modules where tesseract detector recognizes the text inside them and returns the recognition and a score associated to it.

- **Container Door detection:** for the door detection task, we tackle this use case as a classification. It is used the popular neural network ResNet50 as a backbone and two fully convolutional layer. Only the images from cameras Cl and Cr are used to this purpose.

- **Damage detection and classification** (hole, dented, etc.): regarding the damage detection there has been used an open-source toolbox for object detection and segmentation called MMDetection. Concretely, the Cascade Mask RCNN r50 FPN. We are having solid results on our synthetic data with a 75% mean Average Precision on detection and a 55% of mean Average Precision on segmentation.

- On the other hand, within UC6, people detection in risk areas has been performed. Video surveillance will be implemented using UHD cameras covering the railway entrance area to support on-site security operations and to increase security level in the Port of Koper. The baseline data for the UC6 KPIs (Real-time video surveillance) refer to inbound/outbound railway freight traffic (i.e. trains entering the port from the public railway network) and will be set out as number of trainsets passing the railway entrance.

Within this UC the tasks there have been developed algorithms for people detection in risk areas. In relation to the analysis performed within the different regions of interest, a deep-learning based approach has been followed. In this case a YoloR detection model has been used, that is because it achieves better performance when detecting small objects in the image, which is the case in the proposed scenarios.

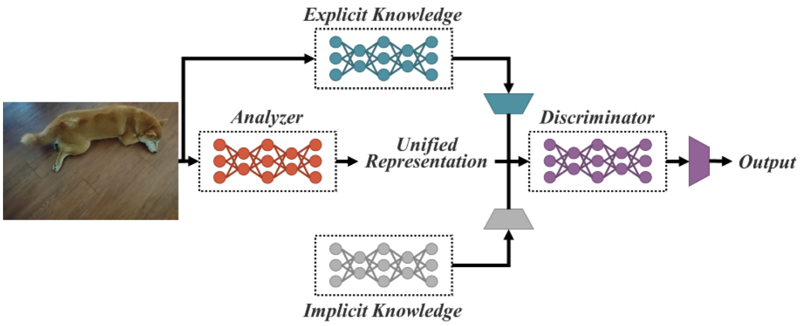


Figure 86: LL Koper – Person/animal detection pipeline

YoloR combines explicit and implicit knowledge to do the detection process. Different classes are detected with this model. However, the classes of interest to the proposed analysis are a subset of the classes that can be detected. The classes taken into account when performing the analysis are as follows:

- Train
- Car
- Truck
- motorcycle
- Person

The rest of the classes will be ignored.

5.3. Use Cases and Storyboards

As presented in previous chapters LL Koper will explore different 5G system deployment options and operational models, where private mobile services can be assured across public or private communications infrastructure, which is extended with cloud principles and IaaS/MEC functionalities. To evaluate the 5G technology reediness and its performance in real port environment, three distinctive use cases were selected: UC1: 5G-LOGINNOV Management and Network Orchestration platform (MANO), UC5: 5G-LOGINNOV automation for ports: port control, logistics and remote automation and UC6: 5G-LOGINNOV 5G mission critical communications in ports.

5.3.1. (UC1) Management and Network Orchestration platform (MANO) - components deployment and verification

Based on a 5G network deployment as the first step of the Use Case 1 (UC 1) development, the use case addresses MANO architecture (ETSI Management and Network Orchestration) and its cloud extensions intended for the demonstration of an automated deployment and life cycle management of a network and applications operated in a 5G-enabled port environment targeting Industrial IoT applications (Figure 67, Figure 68). Novel virtualization and cloud-based principles such as VNF (Virtual

Network Functions) and CNF (Cloud Native Functions), as well as industry-proven infrastructures (e.g., Kubernetes), represent the baseline technology to build private 5G system in LL Koper. The open-source MANO orchestrator integrated with Kubernetes mechanisms enables on-demand provisioning of Private 5G mobile network and 5G IoT services, it assures the expected network and application performance metrics and KPIs, and finally it enables onboarding, deployment and provisioning automation and other required functions such as scalability, high availability and resilience of the services and applications.

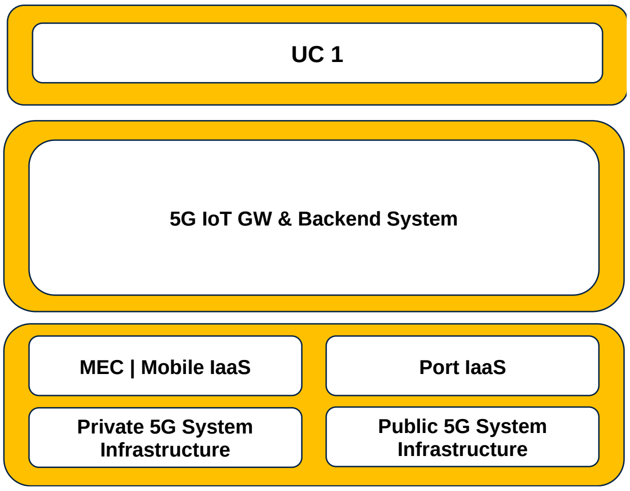


Figure 87: LL Koper – Technology Building Blocks of UC1.

Figure 87 depict used 5G capabilities and complementary technologies supporting UC1 deployment and verification. Initial verification of UC1 components in the LL Koper premises took place between the 16th of February and the 5th of April 2022. As part of the initial testing the following components were prepared and operationally verified in the LL Koper area:

- Public 5G System Infrastructure (operating in NSA mode).
- Private 5G System Infrastructure (5G NR and 5G CN operating in SA mode) deployed on Mobile IaaS/MEC infrastructure.
- 5G IoT Gateway with backend system components deployed on Mobile IaaS/MEC (e.g. Reference server).

In addition, as part of the UC1 activities setup and verification of security components (drone- and wearable camera-based 5G video streaming) of the UC6 were also tested and verified (Figure 89).

Figure 88: LL Koper - Private 5G SA system / 5G NR with 5G CN (left), 5G IoT GW (right).

Figure 89: LL Koper - Drone- and wearable camera-based video streaming components (left), deployment team (right).

For the 5G network performance and related KPI testing a dedicated qMON test automation solution from ININ (http://www.iinstitute.eu/#qmon) was deployed in the LL Koper (Figure 90). qMON System was prepared to be used for the following LL Koper testing and verification scenarios:

- 5G mobile network drive testing where test equipment is placed in a vehicle and drive campaign over the Port area is performed (Figure 91, Figure 92).
- Continuous 5G network and services monitoring where test equipment is strategically placed in the LL and it is used to monitor 5G KPI on the continuous bases (Figure 93, Figure 94, Figure 95 and Figure 96). KPIs that are collected as part of active traffic generation process (e.g. UL/DL Throughput) and as such consume 5G network resources are taken in 10min interval, and the KPIs that don't need active traffic generation (e.g. radio parameters such as RSRP, RSRQ, SINR, RSSI) are sampled per 1.5s interval.

Figure 90: LL Koper - qMON Application for Android (Samsung Galaxy S21 5G) presenting network, application and radio KPIs with detailed test log.

Figure 91: LL Koper - qMON Android Agents deployed in a vehicle as part of 5G network drive test in Koper LL.

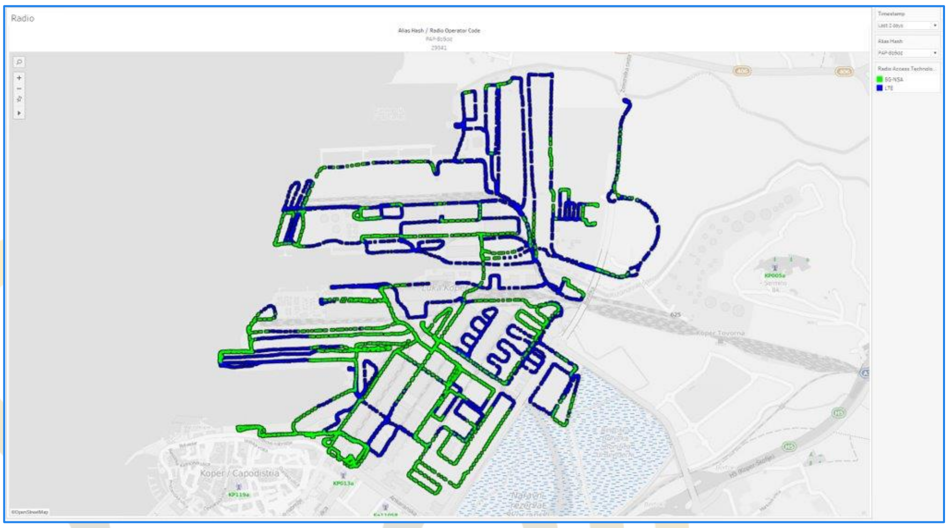


Figure 92: LL Koper - qMON Insight Analytics / 5G Drive testing in Koper LL / 4G vs 5G coverage results.

Figure 93: LL Koper - qMON Android Agent deployed in Koper LL as stationary test unit used for continuous 5G network and services monitoring.

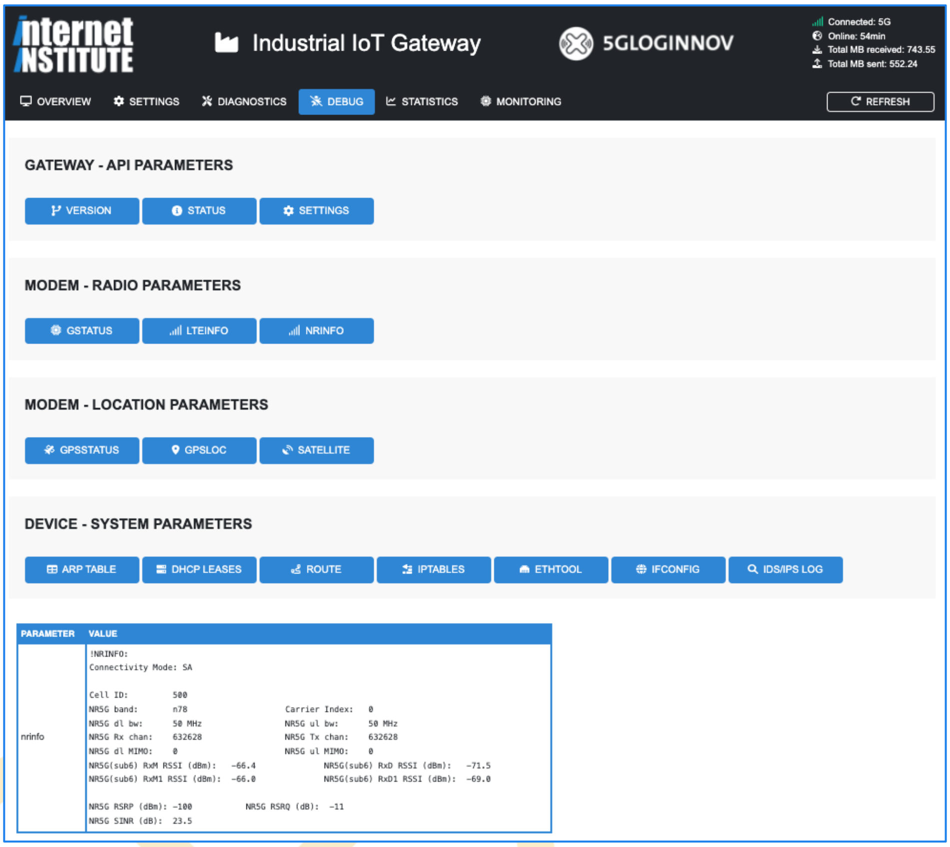


Figure 94: LL Koper - qMON Agent deployed as part of 5G IoT Gateway / monitoring 5G NR Radio KPIs.

Figure 95: LL Koper - qMON Reporter Analytics / 5G network and services continuous testing mode / Monitoring UL and DL Throughput KPIs in Koper LL.

Figure 96: LL Koper - qMON Reporter Analytics / Continuous testing mode / monitoring LTE/NR parameters in Koper LL.

5.3.2. (UC5) Automation for ports: port control, logistics and remote automation - components deployment and verification

UC5 targets a family of sub-use cases related to port control, logistics and remote automation (logistics sector and Industry 4.0). More specifically, a logistics support use case scenario was implemented where operating port machinery (STS cranes) will use industrial cameras for capturing and transfer of UHD video/images over the 5G network to the AI/ML-assured application deployed in port IaaS. AI/ML will automate the process of the identification of container markers and detection of structured damage to containers using advanced image processing techniques. Next to this, telemetry data will be collected from some of the vehicles (e.g. terminal trucks) that operate within LL Koper (Figure 98). This data will be further transmitted via the 5G network, to the backend to be further processed/analysed.

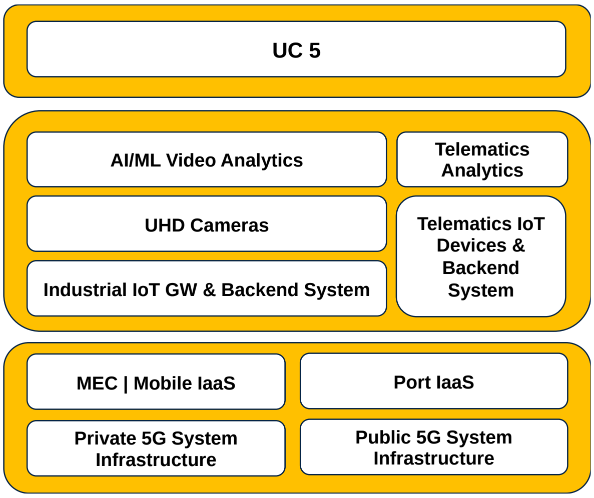


Figure 97: LL Koper - Building blocks of UC5

Monitoring Port Terminal Trucks with Telematics IoT device

Vehicles operating in the Luka Koper/Port of Koper were equipped with Continental Telemetry IoT devices supporting 5G, that allow the collection of telemetry data (e.g. fuel consumption, speed, acceleration, standstill time etc.).

Figure 98 LL Koper - Installing Telemetry IoT Device in Port Terminal Trucks

The Continental IoT device requires a connection to a 12V power supply, for powering the device, and a connection to the vehicle FMS interface, for collecting information from the vehicle (e.g., fuel consumption). GNSS information (i.e., position, altitude, speed, acceleration) are collected directly by the IoT device's GNSS module.

Once installed and powered on, the Telemetry IoT device sends data periodically to a backend system.

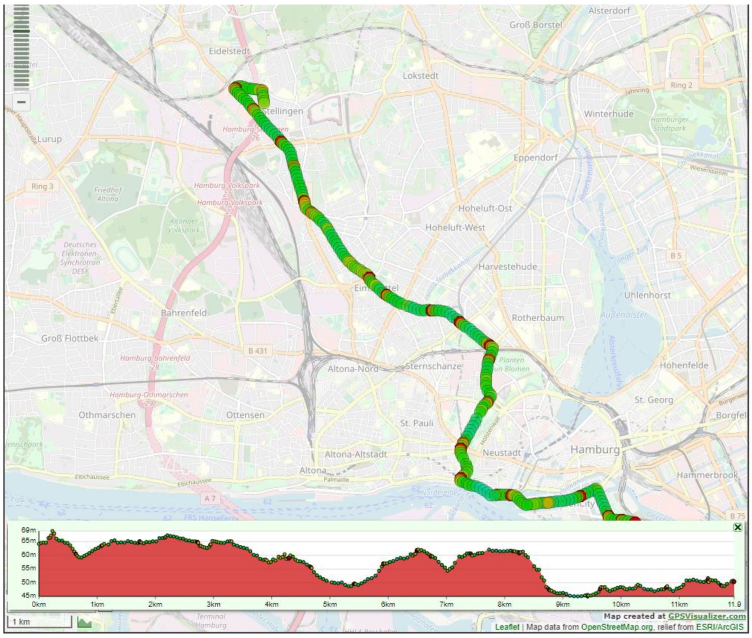


Figure 99: LL Koper - Example of positioning information (speed, location, altitude) collected by Telemetry IoT device.

Prior to the installation of the devices on the field, they were tested by Telekom Slovenije in the verification laboratory, to check performance and conformal with the 5G network:

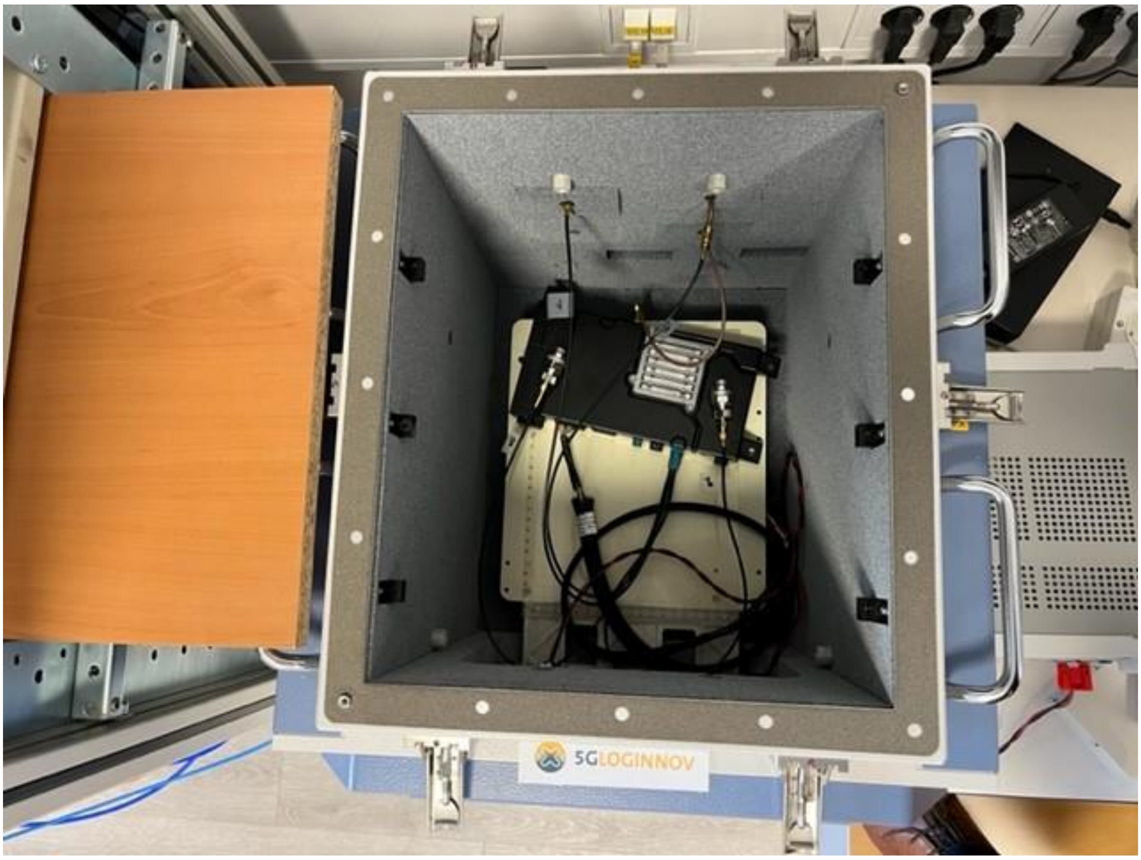


Figure 100: LL Koper - Test setup in Telekom Slovenije, for the Telemetry IoT device.

Figure 101: LL Koper - Test setup in Telekom Slovenije, for the Telemetry IoT device.

Automating logistics process with AI/ML

Captured video streams from the UHD cameras are transferred in real time over the deployed 5G network in the LL Koper to the video analytics platform, where streaming management module identifies and prepares video streams to be processed by the markers' detection and damages' detection modules.

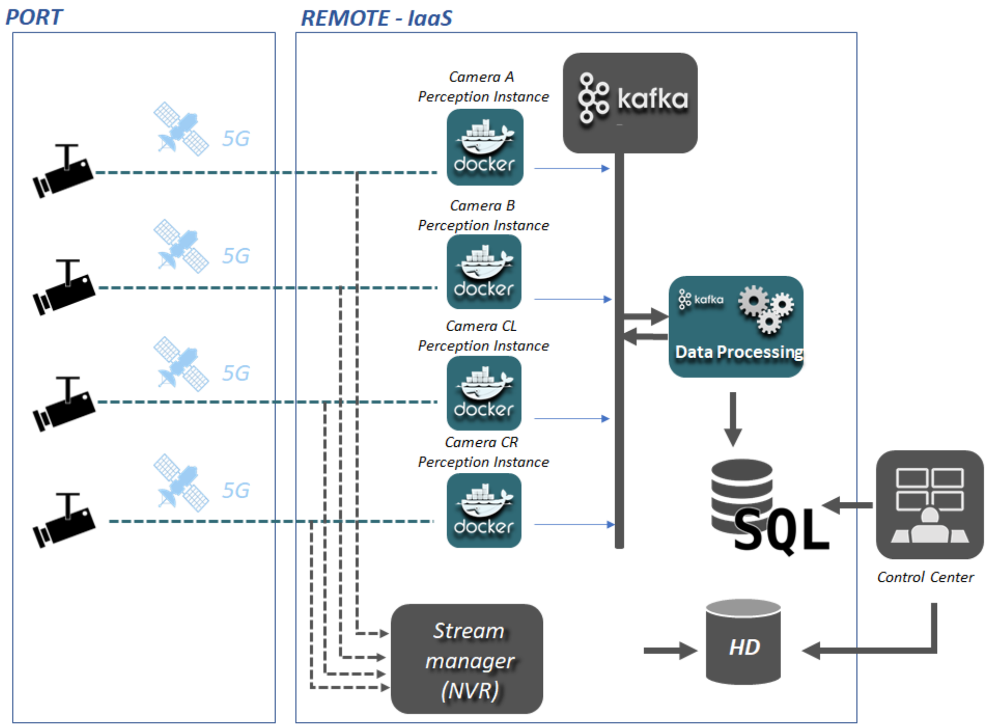


Figure 102: LL Koper - Development pipeline for UC5.

The pipeline receives 4 continue (24/7) streams from the cameras (A, B, Cl, Cr). The pipeline is mainly based on 2 phases:

- **Perception instances**: each of the instances receives the IP streaming (corresponding to each of the cameras) input from the 5G network and makes the detection of the different elements (containers, damages, markers, labels, doors). Output data is published in the specific topic of Kafka.
- **Data processing**: Upper leverage of intelligence is provided in this stage for making relations among the data extracted from different streams to relate data coming from the same container. This module is subscribed to the specific topics of Kafka and the result are published in a different topic (additionally, a dedicated database is considered).

1) Perception Instances:

There is a Perception Instance for each of the cameras installed in the STS Crane. Thus, 4 PIs will be considered, thus:

- Stream-A PI
- Stream-B PI
- Stream-Cl PI
- Stream-Cr PI

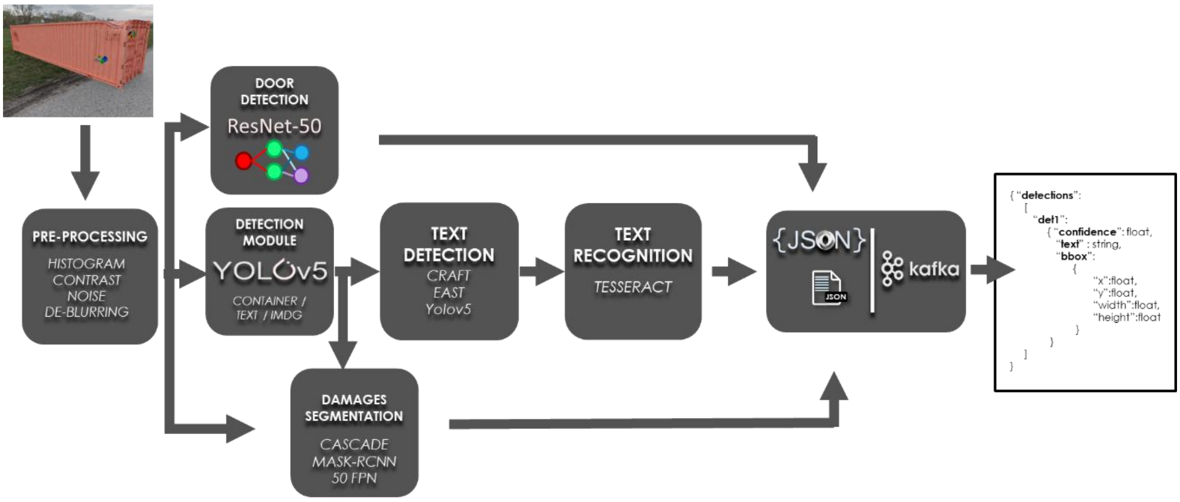


Figure 103: LL Koper - Perception Instance for UC5.

The output of each of the PI will be a Json that will be published in a specific Topic of Kafka. Example of Stream-A&B PI Output JSON:


```
{
        "camera_id": A,
        "timestamp": 23049102039,
        "container": {
                "val": [[23, 54, ...], ...],
            "confidence": [0.7,...]
            },
        "Text": {
                "Code": ["BICU123456", "BICU12345678", "BI456"],
                "bbox": [[0.2,0.5,0.6,0.1], [0.2,0.5,0.6,0.1], [0.2,0.5,0.6,0.1]],
                "Confidence": [0.7, 0.5, 0.4]
        },

        "IMDG_labels":{
            "type": ["",...],
            "bbox":[[0.2,0.5,0.6,0.1],...],
```


Stream-Cl&Cr PI Output JSON:

```
{
    "camera_id": A,
    "timestamp": 23049102039,
    "container": {
        "val": [[23, 54, ...],...],
        "confidence": [0.7,...]
    },
    "Text": {
        "Code": ["BICU123456", "BICU12345678", "BI456"],
        "bbox": [[0.2,0.5,0.6,0.1], [0.2,0.5,0.6,0.1], [0.2,0.5,0.6,0.1]],
        "Confidence": [0.7, 0.5, 0.4]
    },

    "IMDG_labels":{
        "type": ["",...],
        "bbox":[[0.2,0.5,0.6,0.1],...],
```


2) Data processing

After the PI are executed, some rule decisions must be defined so that the data detected by the Perception Instances can be post analysed. In order to process the data, we must divide everything into container sequences. This means that when a container is detected in a camera, data will start to be considered. However, on the first instants of the sequence, this module might only receive a minimum of 1 JSON message up to 4 in total from multiple streams. We will consider that the container sequence has ended when no detection has been provided during a given time.

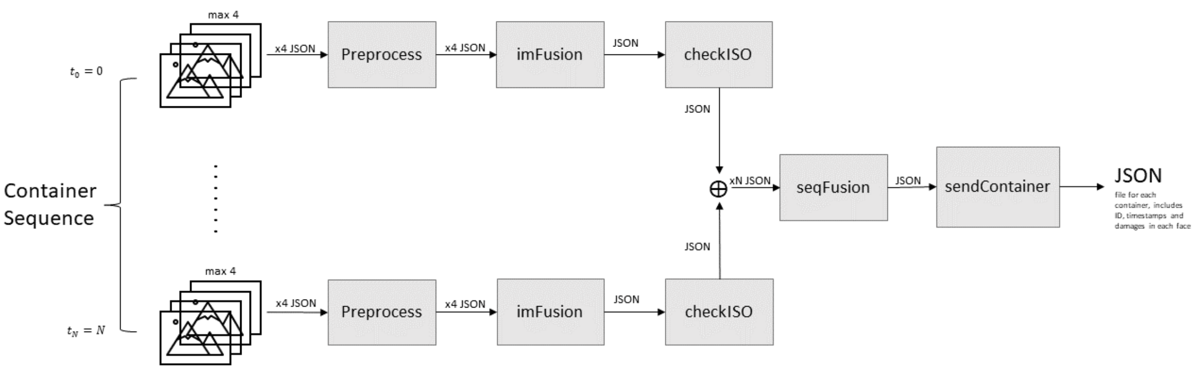


Figure 104: LL Koper - Data post-processing for UC5.

<u>Preprocess:</u>

- Check if multiples containers are one next to each other and their IoU (Intersection over Union) is less than 10%.
- Eliminate those detections with confidence below a certain threshold.
- Check that all elements detected are inside the container
- Input: From 1 up to 4 JSON messages.
- Output: From 1 up to 4 JSON messages.

imFusion:

- Aggregate elements detected in each stream
- Modify the confidence of detected text with the weight assigned to each stream (higher to Cr and Cl).
- Input: From 1 to 4 JSON messages.
- Output: JSON with all possible text detected (with previous logic already applied), container location, IMDG and damages.

CheckISO:

- Check how many texts from the JSON pass the ISO6346 and eliminate those which do not fix.
- Input: JSON with all the data.
- Output: JSON with all the data with and those and text that pass the ISO. If no ISO is found, ID will be set as unknown.

seqFusion: a sequence is a set of frames-timesteps that refers to the same element(s) (one or two containers).

- Fuse data regarding the same container(s) over the time
- Input: Multiple JSON with all data.
- Output: JSON with final the final ID that passed the ISO and other information (damage, IMDG, door/no door).

sendContainer:

- Send a message with all the information of all data detected.
- Input: JSON with final the final ID that passed the ISO and other information.
- Output: JSON message file for each container, includes ID, timestamps, and damages in each face.

For each timestamp, the module will process the text within the container, fuse the different data streams into a single JSON, weighting greatly those that we can see clearer, and it will finally check if any of the detected text meets the ISO6346. Once we finish the container sequence, we will have a list of JSON that we will post process.

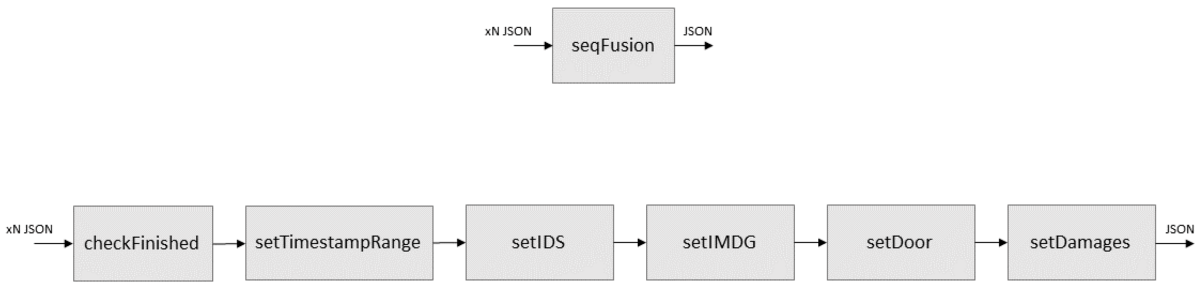


Figure 105: LL Koper - Sequence Fusion pipeline.

On this postprocessing will fuse all the data from the different instances and provide a single JSON. This submodule will set the timestamp range, the identifiers, the IMDG, the doors, the damages and finally provide a JSON file with all the information.

- checkFinished: check if previous timestamp is further than given a period of time, if so, start calculating and reset the timer.
- setTimestampRange: Set the timestamp from the beginning to the end.
- setIDS: Set one or more identification numbers that passed the ISO check. Set them based on the median from all detections. If no text just set as unknown. If multiple ID, check coordinates and decide which one is on the left and on the right.
- setIMDG: Get the median from all IMDG detections, those that are appear more than a given threshold for a sequence of detected containers are kept. Set the face where it was located. In case multiple containers are present, location will determine in which containers they should go.
- setDoor: For JSONs Cl and Cr, set door face as the maximum occurrences predicted. In case there are multiple containers, and their doors is not visible, set to NO_VISIBLE.
- setDamages: Similar to IMDG, get the median for all detections. Those that appear more than a given threshold for a sequence of detected containers are kept. Set the face where located. In case of multiple containers, location will determine in which containers they should go.

Output Metadata of the Data Processing Instance (JSON Format):


```
{
 “timestamp”:“”,
  "object": "container",
  "marker_id": "BICU12345645G1",
  "IMGD_labels": [
 {
    "container_face": "front"
   “type”: “”
},
{
    "container_face": "front"
“type”: “”
}
],
  “door_face”: “CI”,
  "damages": [
{
    " type": "hole",
    "container_face": "front"
  },
{
    " type": "dented",
    "container_face": "back"
  }
]
}Processed data model
```


Initial testing of the developed AI/ML components have been performed, for this purpose, some extra synthetic data has been generated for training the detection and classification models.

Figure 106: Koper LL - Synthetic data from the 4 cameras perspectives.

The cameras have been placed in the same position and with the same focal length as the real port cameras, to obtain images with similar distortion. The size of the final render has also been matched to that of the images captured by the cameras.

Preliminary tests offer satisfactory results (Figure 107, Figure 108).

Figure 107: Koper LL - First results in UC5 over synthetic images.

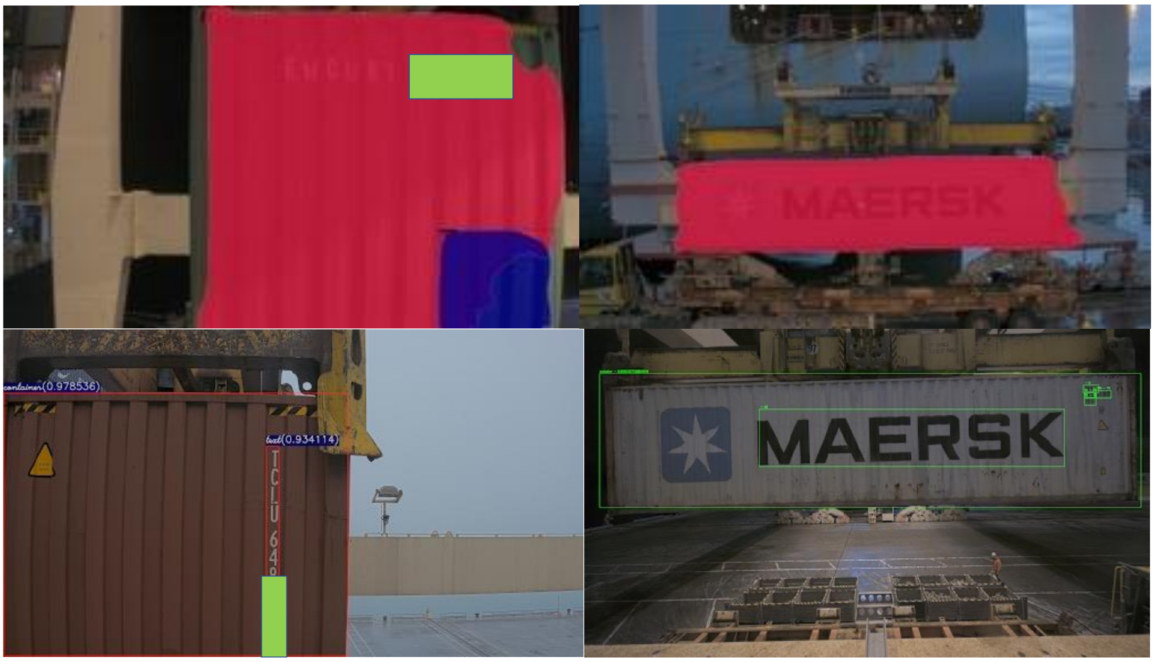


Figure 108: LL Koper - Results in UC5 over real images.

5.3.3. (UC6) Mission Critical Communications in Ports - Components Deployment and Verification

To showcase how 5G can enhance security operations in the port environment a family of sub-use cases in UC6 were prepared: (1) A real-time video surveillance use case was implemented using body-worn cameras carried by security personnel to support their regular and mission critical operations and to provide additional personnel security; (2) portable video surveillance cameras with night vision capabilities were prepared to monitor specific port areas; (3) drone-based video surveillance was implemented for extended and on-demand video-surveillance support.

Prepared UC6 infrastructure (HW and SW) presents a baseline for WP3 work, where activities will be focused on optimizing mobile services and introducing novel surveillance technologies and mechanisms (drone-based, wearable cameras, AI/ML based video analytics) into security operational procedures of LL Koper. In particular, the reliability and resilience of the multi-faceted real-time video surveillance in scope of mission-critical needs using public and stand-alone 5G networks will be investigated.

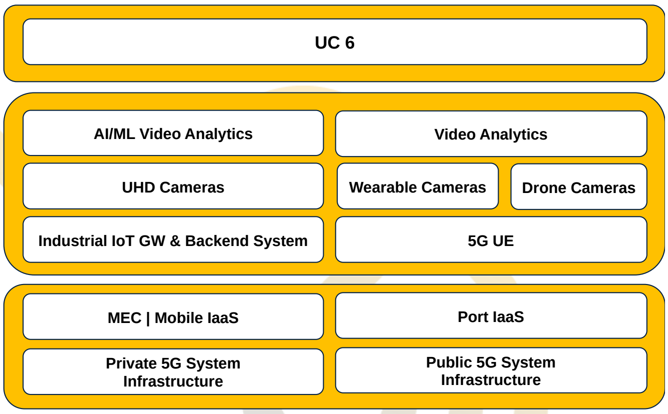


Figure 109: LL Koper - Building blocks of UC6.

To support UC 6 activities several LL Koper building blocks (Figure 109) were developed (Figure 110), integrated and tested (Figure 112).

AI/ML assured automated movement detection module

In the case of portable video surveillance cameras, the automated movement detection scenario was verified (AI/ML based video analytics). Captured video streams were additionally analysed by the video analytics platform, where streaming management module was used to support video stream preparation to be processed by the object presence detection, vehicle counting and classification modules.

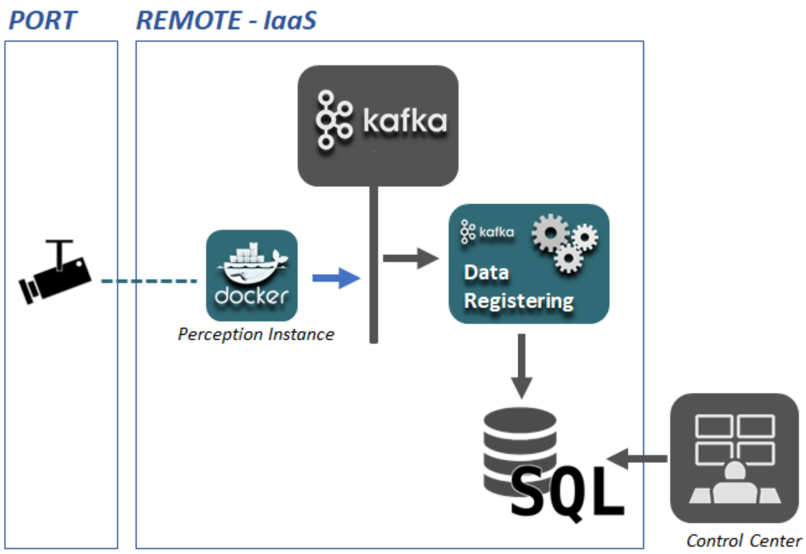


Figure 110: LL Koper - General Pipeline for UC6.

The prepared processing modules are:

- **Perception instance**: each of the instances receives the streaming input from the 5G network and makes the detection of the people in the risk area (note that people out of the area of interest will not be registered as output of the Perception Instance). Output data will be published in the specific topic of Kafka.
- **Data processing**: this module prepares the output data, which are the events occurred. This output data is published in a different topic of Kafka (additionally stored in a database).

1) Perception Instance

The output of the PI will be the following:

{
“timestamp”: “”,
“camera_id”: “X”,
"Objects_list": [
{
“type”: “person”,
“bbox”:[0.2,0.5,0.6,0.1],
“confidence”:0.8
}
]
}

2) Data processing

The processing module registers those events, events when the status of “presence” changes.

Output Metadata of the Data Processing Instance (JSON Format):


```
{
 "timestamp":"",
  "presence": "true"
}
```


As part of initial components verification AI/ML-assured engines were verified on live streams captured by LL Koper security cameras. In these results different elements have been detected and classified, such as people presence in specific risk areas, arriving train, motorcycle, and cars etc. Due to the security reasons and internal LL Koper security procedures real test results were omitted from the document (Figure 111) and are available only under the NDA.

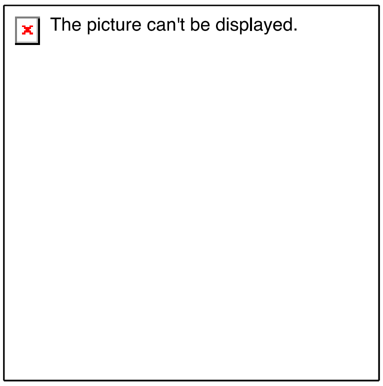


Figure 111: LL Koper – test of automated detection of security events assured by AI/ML (omitted image from the document!).

Real time video streaming assured by drones and wearable cameras

As part of initial components verification activities drone- and wearable camera- based video streaming over the 5G network was prepared and tested (Figure 112) and are now available to be used as part of the planned WP3 testing and verification activities.

Figure 112: LL Koper - UC6 drone surveillance with RT-video streaming over the 5G SA network.

5.4. Data Collection

To automate the data and KPI collection process LL Koper deployed centralized collection point based on Fluentd, which will provide multiple inputs (data/KPI collected from the LL components systems used for the UC deployment and verification) on one side and act as a single output to 5G-LOGINNOV's central data collection tool.

Data/KPI sources for multiple inputs to the Koper LL central collector are realized with Fluentd-based KPI collectors that provides deployment flexibilities and data/KPI export control per use case partner (i.e. ININ, VICOM, CONTI, TSSLO, LK). In the case of ININ KPI collector, the existing qMON Collector (responsible for gathering and parsing KPIs from qMON Agents) entity us used and is extended to support the extraction of relevant 5G-LOGINNOV KPIs from the native qMON KPI datasets to Fluentd supported format. For the other partners, dedicated Docker containers are to be used to allow the Fluentd agents processing the files from the partner's use case scenarios.

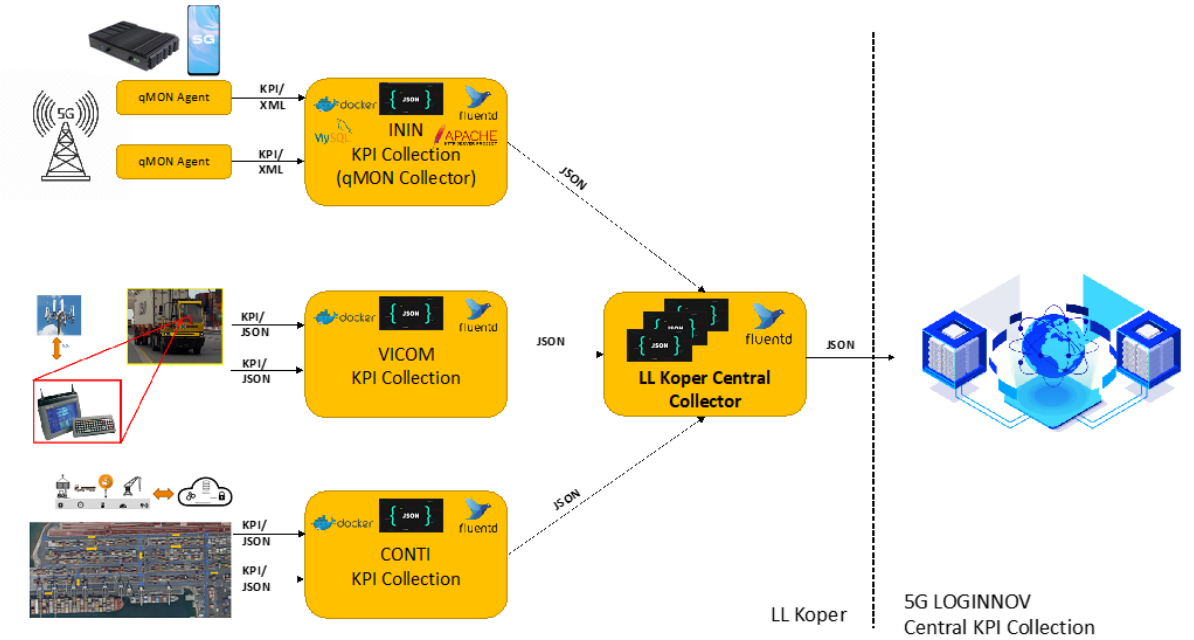


Figure 113: LL Koper - Internal infrastructure for collecting data/KPI

This way, the only requirements from the LL partners are to provide JSON-based files containing relevant 5G-LOGINNOV KPIs and be able to put those files in selected folders (as shown in the Figure 114). Used data collection concept is extendable to new deployed components and to new partners that will extending LL Koper capabilities in the future (i.e., Triton UC).

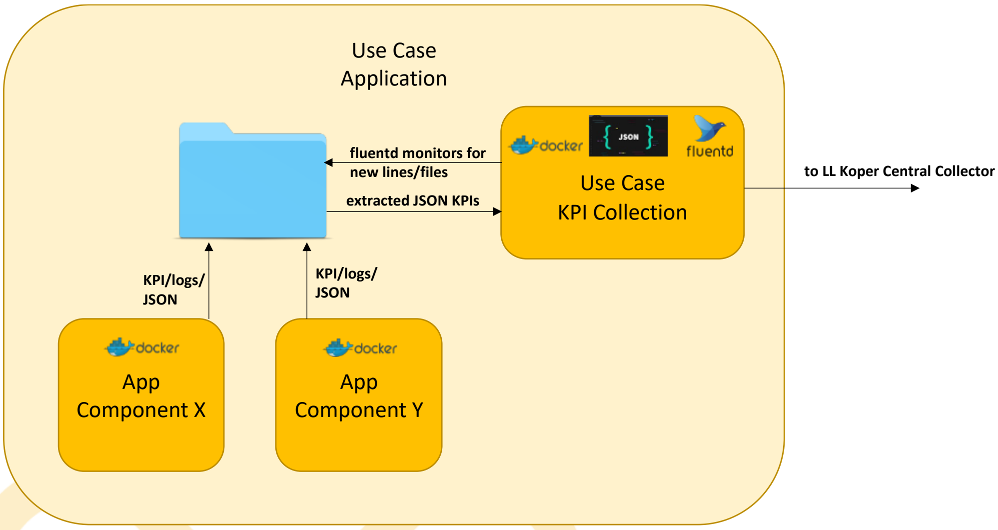


Figure 114: LL Koper - Data/KPI collection process using Docker concept.

6. CONCLUSION

The aim of this deliverable is to provide a detailed view on the development and deployment tasks across all Living Labs. Due to delivery delays caused by chip supply shortages and COVID-19 pandemic, some equipment will be received later than the deadline of this deliverable. Consequently, *an update on this document will be provided* when the equipment has been received and installed to illustrate the full view of the 5G LOGINNOV Ports.

The current document illustrated the deployed components in terms of software and hardware across all Living Labs. Details on data management for evaluation are presented, including the central data collection tools and architecture that binds all data aggregated across the different ports, as well as local (i.e., per Port) data collection and software components used for pilot site data gathering. Deviations in KPIs are presented, referring also to D1.4 [4] (Initial specification of evaluation and KPIs), to facilitate the project's evaluation taking place in WP3. Details on a per use case basis has been provided per Living Lab, including all relevant hardware and software components. The use cases are described from the perspective of architecture, but also from the end users view with relevant UIs, dashboards, etc. Additionally, the assets (i.e., trucks, cranes, IoT nodes, vehicles, etc.) that will be exploited for the trials and evaluation have been specified. Finally, a brief update on the open call winners and SMEs development status is depicted (dates, winners, meetings, etc.).

7. REFERENCES

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[5] Aruna Kumar, et al., “The P-DESTRE: A Fully Annotated Dataset for Pedestrian Detection, Tracking, Re-Identification and Search from Aerial Devices,” in *IEEE Transactions on Information Forensics and Security*, 2020.

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