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Deliverable D3.2

First results of Use Cases implementation for ITSS domain

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List of Acronyms and Abbreviations

Acronym	Description
5G	5th Generation of mobile communications
5GC	5G Core Network
5Tonic	5G Telefonica Open Innovation Laboratory
6G	6th Generation of mobile communications
AGV	Automated Guided Vehicle
AI	Artificial Intelligence
AIA	Athens International Airport
API	Application Programming Interface
APN	Access Point Name
AR	Augmented Reality
B5G	Beyond 5G
CLAHE	Contrast Limited Adaptive Histogram Equalization
CMU	Compact Mobility Unit
CNIT	Consorzio Nazionale Interuniversitario per le Telecomunicazioni
COCO	Common Objects in Context
COTO	Comune di Torino
CP	Control Plane
CPE	Customer Premises Equipment
CPF	Control Plane Functions
CROSEU	Crossmedia Europe
DAEM	Dimos Athinaion Epicheirisi Michanografisis
DC	Data Center
DL	Down-Link
DT	Digital Twin
E2E	end-to-end
ERC	Engineering Research Center
GPS	Global Positioning System
GPU	Graphic Processing Unit
HLS	HTTP Live Streaming
HTTP	Hypertext Transfer Protocol
HTTPS	Hypertext Transfer Protocol Secure
ID	Identifier
IoT	Internet of Things
IP	Internet Protocol
IPsec	IP Secure
iSOC	Information Security Operation Center
ITSS	Infrastructure, Transportation and Security & Safety
KPI	Key Performance Indicator
KVI	Key Value Indicator
LiDAR	Light Detection and Ranging
MCR	Metaverse Control Room
MIMO	Multi-Input Multi-Output
ML	Machine Learning
MPTCP	Multipath Transmission Control Protocol
MQTT	Message Queuing Telemetry Transport
NMS	Network Monitoring System
NR	New Radio
NSA	Non-Stand Alone
OAM	Open Application Model
ORO	Orange Romania
OS	Operating System
PC	Personal Computer
PHY	Physical Layer
PoliTO	Politecnico di Torino
PTZ	Point, Tilt, and Zoom
RAN	Radio Access Network
REST	Representational State Transfer
ROS	Robot Operating System
RTSP	Real-Time Streaming Protocol
SA	Stand Alone
SD card	Secure Digital memory card
SW	Software
TDD	Time Division Duplex
TIM	Telecom Italia Mobile
TUIASI	Universitatea Tehnica Gheorghe Asachi din Iasi
UC	Use Case
UL	Up-Link
UP	User Plane
UPF	User Plane Functions
URLLC	Ultra-Reliable Low-Latency Communications
VM	Virtual Machine
VPN	Virtual Private Network
VRU	Vulnerable Road User
WebRTC	Web Real-Time Communication
WP	Work Package
XR	Extended Reality

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Executive Summary

This public deliverable D3.2 provides in the context of the "Work Package 3" (WP3) the firsts achieved results for the use cases (UC) implementation related to Infrastructure, Transportation, Security & Safety (ITSS) domain, as a step to achieve the principal objective of the TrialsNet project to deliver compelling use cases that can improve the livability of the urban environment in many areas. D3.2 is based on the use cases described in the first WP3 deliverable D3.1 [1] that are currently developed in the four main clusters located in Greece, Italy, Romania, and Spain.

The preliminary results presented in this deliverable, together with the other domains WPs (i.e., WP4 and WP5) outcomes, are based on the first platform and network solutions deployed in the context of WP2 based on the use cases requirements defined in D3.1 [1]. In addition, the results reported in this document benefits of the harmonization activity performed by WP6 for what concern the Key Performance Indicators (KPIs) and Key Value Indicators (KVIs) terminology as well as the Data Management Plan adopted by the project. Finally, it has to be highlighted that ethics implications are continuously considered in tight connection with WP8 "Ethics requirements" in accordance with the deliverable D8.1 "H - Requirement No. 1" [2] and in line with the guidance reported in the deliverable D1.2 "Ethics Assessment Plan" [3].

A short summary for each use case scope and activities performed including first results is given below. As the Use Case 1 "Smart Crowd Monitoring" is performed in two sites, Madrid and Iasi, are detailed in different subsections.

Use Case 1 "Smart Crowd Monitoring" (Madrid): This use case is carried out in sports or spectacles venue in Madrid for the Spanish cluster. To mitigate the security risks that occur during the sporting events with participation of a large number of people, the use case focuses on building an application and infrastructure environment to test and detect abnormal situations such us crowds preventing the free access to the facility, violent activity such as people fighting or riots, vandalism, weapons, suspicious activity such as loitering, or person running and abandoned bags. In this use case application components have been integrated for the first laboratory tests**.** Activities were carried out in two phases, at lab scale (at Prosegur premises) and at 5G Telefonica Open Innovation Laboratory (5Tonic). Lab scale trials were oriented to select the adequate software to centrally manage the devices from the Information Security Operation Center (iSOC) and to integrate the video streams and signals. Tests at this stage were initially carried out in a local network to validate the correct configuration, integration and functioning of the systems. In the second phase, the solution components were interconnected using a commercial 5th Generation of mobile communications (5G) network available at the laboratory. Three setups have been implemented for testing purposes including different devices configuration with robot, camera and Light Detection and Ranging (LiDAR). KPIs were measured and verified in relation to the application requirements.

Use Case 1 "Smart Crowd Monitoring" (Iasi): This use case is carried out in large public areas in Iasi, for the Romanian cluster. The use case focuses on outdoor public events by managing people counting, density, and dynamics of large numbers of persons (flow directions, spread) and detecting special situations during normal traffic scenarios (e.g., presence of various objects such as cars, trucks, motorcycles, etc. in restricted access areas). For the first tests of UC1, preparatory activities were done for the 5G network part, such as installation of cameras and 5G Customer Premises Equipment (CPE), Wi-Fi Access Points and the development of the image processing application, and dashboard. People counting and people density estimation tests have been performed using Wi-Fi Access Points. For the smart crowd monitoring tests with cameras connected by 5G, preliminary tests have been performed to demonstrate the video analytics application capabilities. These tests were focused on optimal setup parameters, estimation of the detection accuracy, and development of the video analytics dashboard. KPIs measurements have been performed during normal days and during a special event with large number of people attending large public ceremony in October 2023. Special attention has been considered for the ethical aspects including technical solution for downgrading the image resolution to remove personal data details from the video streaming.

Use Case 2 "Public Infrastructure Assets Management" (Athens): This use case offers a solution to improve the management and maintenance of infrastructure assets in Athens International Airport (AIA) and Dimos Athinaion Epicheirisi Michanografisis (DAEM)'s public infrastructure in Athens. The solution utilizes advanced technologies such as Artificial Intelligence (AI)-powered algorithms and unmanned vehicles to enhance the effectiveness of data collection and assessment of infrastructure assets. AI techniques analyzes data from multiple sources to evaluate infrastructure assets, generate alerts and recommendations for maintenance tasks, improve worker safety, while unmanned vehicles will assist with the necessary maintenance operations. Augmented Reality (AR) is used to provide on-site views of assets' blueprints and live communications with remote experts. In addition, Digital Twins (DT) of public construction sites is created, allowing for validation of technical plans and for real-time monitoring. For UC2, the software application has been tested to validate the architecture of the application, demonstrating that it is capable of video analysis, streaming, real-time processing, restreaming of the video with the road damage model output and visualization of the basic analytics data. The preliminary tests showcase that the software is capable of handling multiple Internet Protocol (IP) cameras as well as other devices (i.e., drones and Automated Guided Vehicles - AGVs) in parallel, detecting different classes of damages as well as their severity, and calculates a severity score. Application algorithm precision and video stream and re-streaming KPIs have been also measured.

Use Case 3 "Autonomous APRON" (Athens): This use case demonstrates how autonomous and smart systems can perform ground handling operations at the airport APRON, such as passenger handling, fueling, and baggage handling, using unmanned vehicles and collaborative robots. The development of Digital Twins enables real-time monitoring and remote control of vehicles, ensuring safer and more efficient operations. AI techniques are used to analyze data from sensors and cameras, generating alerts and suggestions for improving operations. The integration of a Network Monitoring System (NMS) enables continuous monitoring and automated mitigation of network anomalies. In this use case the robot autonomy has been tested showcasing that the robot's operational autonomy is impacted due to the high energy demands of the onboard computational processes. The preliminary tests consisted mainly in end-to-end (E2E) latency measurement using both Wi-Fi and 5G networks. Comparative results for the two environments, Wi-Fi and 5G, are presented. Early demo of the Autonomous APRON use case in the WINGSChariot platform has been also performed.

Use Case 4 "Smart Traffic Management" (Iasi): This use case is piloted in the Podu Roș Intersection Area (Iasi city, Romanian Cluster) with a focus on traffic comfort and safety functions. From a comfort perspective, the traffic flow is monitored to create predictive models and suggest intersection rules adaptation to reduce congestion. Safety is increased especially by protecting the Vulnerable Road Users (VRUs) by creating a digital traffic model, capable of identifying hazardous traffic situations. Based on the same infrastructure of UC1 Iasi, the new platform ingests available data from arrays of sensors and cameras deployed throughout the city, communicating over reliable Beyond 5G (B5G) and output insights and actionable intelligence on traffic monitoring system. The tests in UC4 were carried out directly on the field because the devices were installed on the premises in the final positions, in field, in the summer of 2023. The same application as for UC1 Iasi was integrated and used for the preliminary activities. Early demos are available as videos that show the video feeds from the cameras, the definition of the areas of interest and insights from the actual video scenes in terms of total count of traffic participants and heatmaps estimating car density. A series of tests were conducted, focused on assessing the accuracy of the models in low-light conditions and adverse weather scenarios. KPIs have been measured under poor 5G coverage environment and evaluation against application requirements have been presented.

Use Case 5 "Control Room in Metaverse" (Turin): The purpose of this use case is to employ Extended Reality (XR), Metaverse, DT, and Internet of Things (IoT) technologies for remote, multi-agency and environment tailored XR training and real-time visualization of behavioral anomalies/ movement patterns. UC5 enhances the management of large events and panic situations by contributing to improved decision-making and reduced intervention times in an emergency on the side of emergency responders. The target environment is the events area at Valentino Park. In this use case the first tests were performed mainly to validate the functionalities of the system. The virtual space for the Metaverse Control Room (MCR) has been constructed within the metaverse. The IoT platform has been also installed in the servers of the PoliTO premises. During the tests in laboratory, video camera streaming has been trialed with different parameters to assess the load per camera. Video camera streaming application KPIs have been measured.

It should be noted that the results presented in this deliverable are based on the preliminary laboratory and/or on field evaluation set-ups which will evolve into the trial results, based on each use case final applications implementation and network deployments that will be presented in the last WP3 deliverable, D3.3, considering also the inputs coming from the other WPs.

1 Introduction

This document represents the second deliverable for WP3, aiming to report the first results of use cases implementation for ITSS domain in terms of preliminary tests in laboratory and on-field contexts and quantitative KPIs measurement for each use case. The analysis of the collected results will be the basis to further progress towards the final implementation of the use cases that will be trialed in large-scale or experimental 5G and beyond networks deployments that will be supported by specific network innovation functionalities, optimized operations, and the value assessment of the proposed solutions by the end-users. The main sections of this deliverable are described in the following.

Section 2 provides an overview for each use case related to final application design in terms of architecture, modules, functionalities, interfaces and describe the activities that have been performed in terms of Graphical User Interface (GUI) development, algorithms implementation/integration, metaverse environment development, contents production, etc.

Section 3 details the main information related to the trial, report about the tests performed in the laboratory or field and early demo considered as «stable test» to be disseminated. The reported test section includes test setup description, test summary including objective, description, test results in terms of measured KPIs and analysis, conclusions (general outcomes of the test activity including any preliminary expectations towards 6G requirements, if applicable) and next steps (in terms of final tests to be performed and additional KPIs to be measured).

Section 4 reports the time schedule for each use case implementation and provides a review of the milestones presented in the previous deliverable D3.1 [1].

Finally, Section 5, summarizes the conclusions as main outcomes of the document, and reports the next steps related to WP3 activities.

2 Use Cases implementation status

2.1 UC1: Smart Crowd Monitoring (Madrid)

2.1.1 Use Case recap

The "Smart Crowd Monitoring" (UC1) in Madrid focuses on deploying technology solutions to ensure the security and safety of people in highly crowded areas. The use case will be carried out in a sports venue in Madrid for the Spanish cluster. The goal is to mitigate security risks that occur during sporting events with large numbers of people, by building an application and infrastructure environment to test and detect abnormal situations such as crowds preventing free access to the facility, violent activity, vandalism, weapons, suspicious activity, and abandoned bags. The use case will use surveillance cameras, LiDARs, and AI algorithms to support the security tasks. Two ground robots equipped with cameras and artificial vision will also be used for autonomous and remote-controlled security inspection rounds. The use case will utilize a 5G/B5G Ericsson Non-Public Network infrastructure for the trial. Tests in this UC are oriented to measure network performance during the transmission of video streaming and LiDAR cloud points and during the remote control of the robots. Moreover, the quality and precision of the different AI algorithms applied to the detection of different types of events is evaluated.

The main components of the UC solution are:

- **ISOC position:** Security Operations Control center has remote access to cameras and robots to visualize the images transmitted by them and to take control of them to modify orientation, position and movement. The iSOC also centralizes the reception of alerts launched by the AI algorithms, LiDAR processing software and/or the robots. While cameras launch alerts related to security events, the alerts sent by the robots correspond to technical problems or malfunction detection.
- **Video Surveillance network**: Point, Tilt, and Zoom (PTZ) and fix cameras are deployed on site and send the video stream to the cloud for artificial vision processing and to the Video Management System Software deployed in the iSOC position. The iSOC operator is able to take control of the PTZ camera and orient it towards the point of interest. A video stream from the camera is sent to the Cloud for video processing and events identification.
- **LiDARs**: Those devices represent the environment as a dataset of points that is sent to the LiDAR management software deployed on a cloud. Through this software, pre-alert and alert areas are defined so that intrusions in those spaces are converted into an alert that is received at the iSOC position for video verification of the intrusion through PTZ camera.
- **Robots**: Two types of robots are considered for this use case with different payloads and capabilities. Both are intended to carry out programmed and telecontrolled security rounds. Both are equipped with cameras and Kiiro also contains a Graphic Processing Unit (GPU) for edge processing of algorithms. Both robots can be controlled remotely from unique software installed in the iSOC station although they differ in their mobility capabilities (dog type robot has more complex mobility options than the wheeled robot). The goal is to compare usability and level of response of each of the robots when remotely controlled from the iSOC.

Operational validation of this UC encompasses the following situations:

- **Case 1**: The AI on cloud detects suspicious objects or risky behavioural events, such as riots, fighting or vandalism, and launches an alert that is received at the Alarms Management System in the iSOC. The security guard at the iSOC takes control of the PTZ camera and verifies the alert. If the event is out of the scope of view of the PTZ camera, then the guard sends one of the robots to that point and the video verification is made through the cameras of the robot. Once verified, he/she warns the security guard on site to proceed with the security protocols on place.
- **Case 2**: AI running on edge (on the payload of the robots) identifies a risky event and sends the alert to the iSOC. As in Case 1, the alert is verified through the PTZ, and fixed cameras and robots are sent to provide closer information. Physical security guard will act according to the situation.
- **Case 3**: Alerts are detected by the LiDAR through the identification of intrusion in pre-defined prohibited zones. Video verification of the alert is made as in previous cases.

- **Case 4**: The robot performs automatically the security rounds that are launched from the iSOC position through the robot management platform. The video stream of the robot cameras is processed at the on-boarded AI-appliance (equipped with an NVIDIA GPU card). Alerts are sent to the iSOC, where they can take control of the robot for video verification of the event.

For the development of UC1, the Design Thinking + methodology is being followed. The process started with the map phase. The next step was the empathize phase. In this phase, the customer journey was analyzed, extracting hypotheses in each phase of the experience to be further validated, and research was conducted. With the aim of understanding security personnel context and their expectations and requirements for future experiences at sporting events, five semi-structured interviews were conducted with the security personnel of Prosegur, including security guards, a coordinator and the security officer. For the next step, the ideation phase, an ideation workshop with Prosegur security personnel is proposed. The main purpose of the workshop is to explore and ideate solutions that could enhance spectators' security at sporting events as well as security guards' performance, considering the technologies involved.

2.1.2 Final application design

As shown in Figure 1 the final application integrates the physical systems and cloud deployments with the iSOC position, where signals and video streams are received, and from where the control of the devices can be taken. Each module was considered as an independent setup that is interconnected with the iSOC through a Message Queuing Telemetry Transport (MQTT) Broker or an Application Programming Interfaces (APIs).

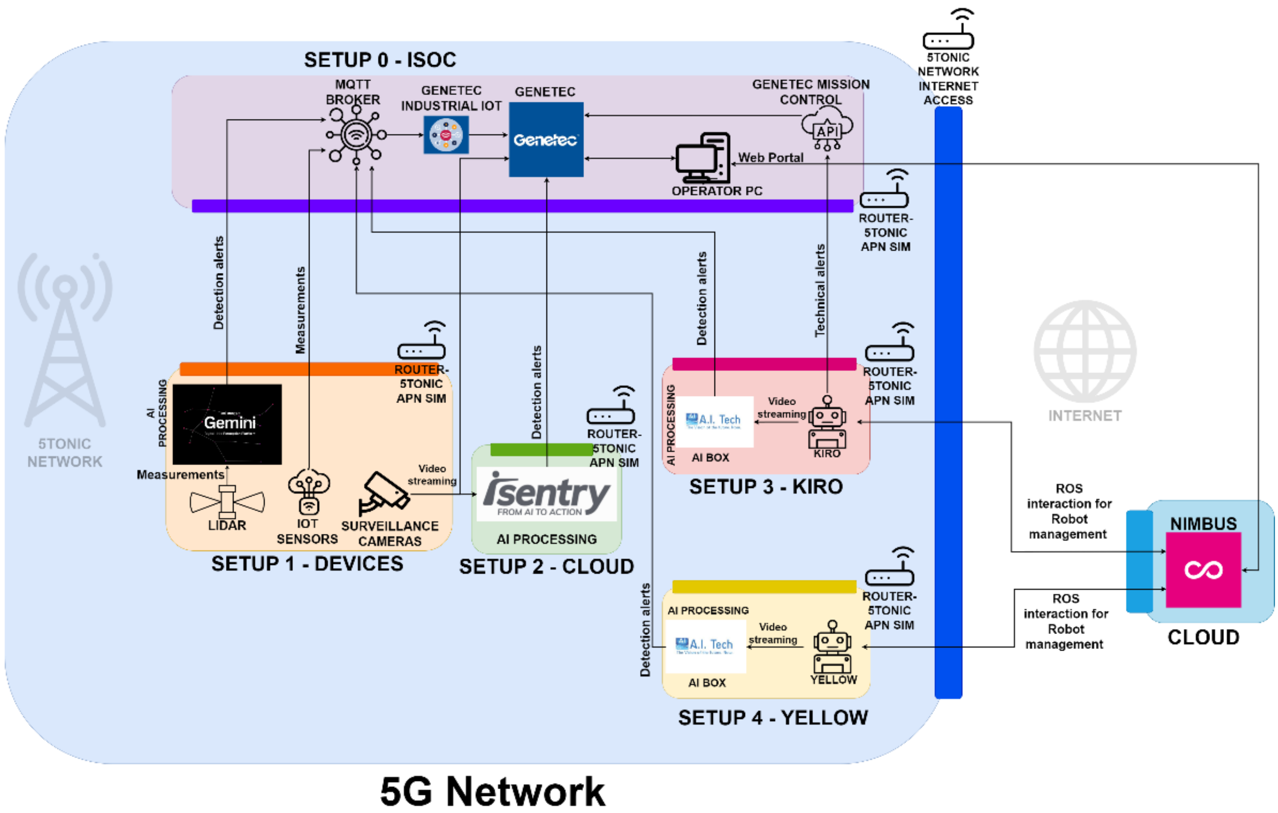

Figure 1. Final application design UC1-Smart Crowd Monitoring.

In the following, the main components of the final application design are described in detail.

SETUP 0 - iSOC

The hardware part of the security position consists of a Server DELL Precision 3930 Rack XCTO Base with Intel Xeon E-2136 processor. The main software installed in it is Genetec Security Centre, that showed better performance and flexibility than the other Vendor Management Systems (VMS) tested at the laboratory scale. Genetec allows the direct integration of cameras, and, through Genetec Industrial IoT, it can receive signals from sensors and Information Architecture (IA) alerts under MQTT protocol. A MQTT broker deployed in the server facilitates the management of the signals and enables future direct integrations with additional services if required. In parallel, the Application Programming Interface (API) Representational State Transfer (REST) plugin of Genetec permits the reception of the technical alerts emitted by Kiiro robot. These signals include low battery, emergency push button pressed, technical error, Global Positioning System (GPS) signal lost, and abnormal robot lift. Finally, web-based services (Gemini and Nimbus) [4], [5] are accessible from the control panel of Genetec through widgets.

SETUP 1 - Devices
The hardware of this setup consists of the perimetral protection devices which are: one LiDAR Ouster Operating System 0 (OS0), one fix camera (H5A), and one PTZ camera (AXIS Q6135-LE). The LiDAR cloud-point information is sent to its own perception platform called Gemini installed in a Personal Computer (PC), where different detection areas (pre-alert and alert) can be configured. Moreover, AI software lets us make the distinction between people, vehicles and animals, adapting the alert trigger to the nature of the intruder. These alerts are sent to Genetec through the MQTT broker.

SETUP 2 - Cloud
The AI platform for video analysis is Isentry, a video analytics platform that can detect and classify objects, people, and events in real-time. Isentry is integrated with the cameras and provide alerts and insights for the detection of unusual behaviors (fighting, vandalism, loitering etc). Isentry alerts are sent to Genetec.

SETUP 3 - Kiiro
Kiiro robot missions and routes are programmed through Nimbus, a cloud-based software that enables the management of Robot Operating System (ROS)/ROS2-based robotic platforms. Kiiro is equipped with cameras, sensors and has AI processing capabilities thanks to the NVIDIA GPU card contained in the AI Appliance that has been integrated in Kiiros's payload. This appliance runs different AI models to detect:

- people estimation in a crowded area based on learning;
- deep learning-based crowd estimation, overcrowding estimation, social distance assessment / deep learning-based crowd estimation in crowded areas, overcrowding estimation;
- people fall detection;
- detection of human presence in a restricted area;
- detection of the presence of abandoned or removed objects in areas of interest;
- evaluation of free and occupied parking lots.

Alerts for each of the models are sent to the MQTT broker in the iSOC to be forwarded to Genetec alerts panel.

Setup 4 that includes the Yellow robotic platform, has not been tested in 5 Tonic, but this setup will be included for the real environment tests performed during Q4 2024.

Cloud based Nimbus
Kiiro and Yellow robot missions and routes are programmed though Nimbus, a cloud-based software that enables the management of ROS/ROS2 based robotic platforms. Connection between the robots and Nimbus is made through internet.

Communications
The transmission of information among the different setups is made through the 5G network, both locally and to the internet. A private Access Point Name (APN) has been set up to secure communications between the devices and the iSOC.

2.1.3 Development activities

Activities in this period were carried out in two phases, at lab scale (at Prosegur premises) and at 5Tonic. Lab Scale trials were oriented to select the adequate software to centrally manage the devices from the iSOC and to integrate the video streams and signals. Tests at this stage were first done in a local network to validate the correct configuration, integration and functioning of the systems. In a later stage, and once validated the standalone functioning of the systems, they were interconnected using a commercial 5G network available at the laboratory.

To prepare the deployment of the systems in 5Tonic, different setups were designed. Each setup was independent and easily transportable and the interconnection between setups was made through Teltonika routers, [6].

5Tonic tests were oriented to interconnect all the Setups through the Ericsson 5G network to evaluate the capacity of the communications under different configurations of the systems.

Phase 1: Lab Scale

In an initial stage of this phase, the configuration and setup of the elements in the laboratory local network were done to test them in a standalone mode:

- Server configuration (Control Center): Server start-up and Windows 10 installation. Preparing for the installation of the rest of the iSOC software.
- Evaluation and comparison of different Video Management System solutions for video reception and alerts:
    - Genetec [7] vs. Milestone [8]: testing of basic functionalities, video connection and reception of alerts. Thanks to Genetec Mission Control and its IoT plug-in, Genetec is more versatile when it comes to integrating external solutions. Finally, Genetec was selected as the core Security Management Software to be installed in the iSOC for video and alarms centralization (Figure 2).

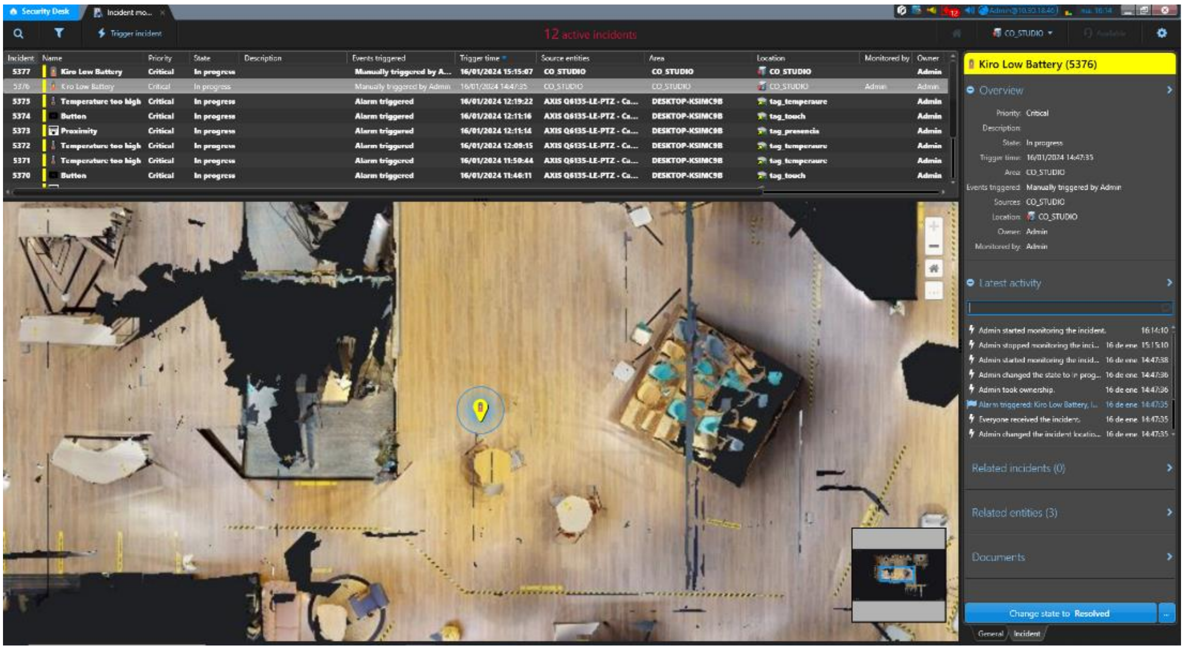

Figure 2. Genetec view: Alarms Management.

    - Surveill vs Gemini [9] for LiDAR management: Both LiDARs management software were tested with an Ouster OS0 LiDAR. Although Surveill has many more functionalities than Gemini, many of them overlap with those of Genetec, whose use is more widespread in the world of Security. Gemini reasonably complements Genetec's complementary needs for LiDARs management and the licensing cost is more affordable. In addition, Gemini is more user-friendly and do not require previous training of the operator to use it.
- Creation of local network and configuration of local Internet Protocols (IPs) for the interconnection of devices. The objective is to test the devices and receive alerts in isolation from the network to limit possible failures.
- Creation of local broker for the management and reception of alerts between the different equipment:
    - Tests with RabbitMQ [10] service running on main server.
    - Tests with Mosquitto [11] MQTT running in Raspberry PI

After testing, it was decided to choose MQTT, due to its simplicity in Raspberry PI.

- Tests for receiving video and alerts from the devices to the iSOC. A fictitious scenario was created within the laboratory to simulate the different risk situations detectable by cameras and sensors. At this stage, only the correct reception of the alerts in Genetec was tested, but the measurement of the AI KPIs is pending (accuracy and recall). Gemini was installed on a PC to which a Teltonika router and LiDAR were connected. Alert and pre-alert zones were defined, and intrusion was simulated to perform the first configuration tests and identification of alerts in defined areas.

- AI algorithms were deployed in a separated server and the alerts are sent to Genetec through the MQTT broker.
- Integration of robots on Nimbus platform. The Nimbus agent container was installed in Kiiro. As Kiiro Operating System (OS) is Ubuntu, the docker can be directly installed in the OS of Kiiro. However, as OS of Yellow is not ROS, but a proprietary solution of Boston Dynamics, it was necessary to install the Nimbus (Figure 3) agent on a Jetson Nano that acts as an intermediary between the robot and the platform, given that the agent contains the wrapper that allows Yellow to be controlled from ROS. Finally, components and configuration were created on the cloud platform to control the robots remotely and visualize the status information (location, battery, etc.).

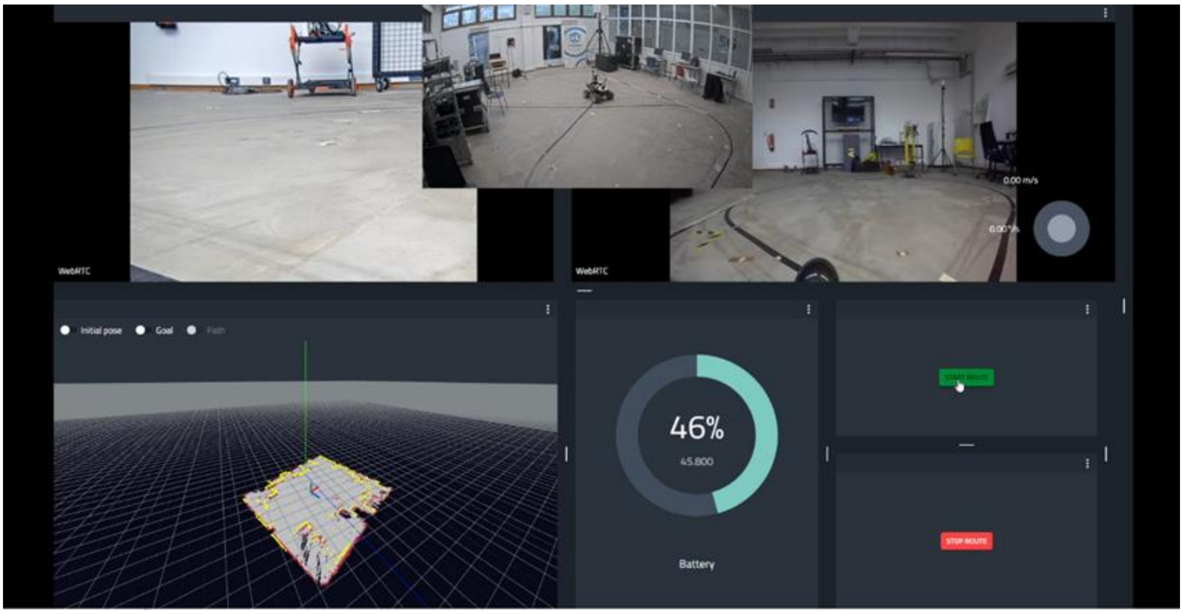

Figure 3. Nimbus (Cogniteam) UI.

The latest stage of this Phase1 considered the connection of the local networks to the external elements through 5G commercial network, which allowed the reception of alerts and video images from external elements to the iSOC. The different devices are separated by modules in separate local networks and the connection is made through the 5G router configuration. The tasks performed at this stage were:

- 5G Router Teltonika configuration and communication using private APN.
- Local network with Control center and MQTT Broker connected with 5G router. Each local network is assigned different IP address ranges to avoid overlaps.
- Local network with processing software and devices was connected with 5G router.
- Local network with robotics equipment was connected with 5G router.
- Integration via API-REST of the robot technical signals in the control center. A python script was developed to establish direct communication between ROS and the Genetec API.
- Tests for video reception and alerts from local networks to the Control Center.

Phase 2: 5Tonic

After laboratory developments, the setups were adapted for a mobile system which could be transported for testing at the 5Tonic laboratory. Each setup is made of devices connected in an individual local network interconnected to the other setups through the Ericsson 5G network. Setup 2 configuration in 5Tonic slightly differs from the configuration presented in section 2.1. This is because two different approaches were tested, one with cloud processing of video-analytics and the other with the algorithms installed on edge servers.

5Tonic has two independent Radio Access Networks (RAN) coverage areas called room X3 and room 5Tonic lab with 5G Core Network (5GC) Control Plane (CP) centralized in the data center (DC). The current 5G RAN equipment is in mid-band (n78 - 3.5 GHz) and Stand-Alone (SA) technology, where the Long-Term Evolution (LTE) as anchor is not needed and the Core supports both CP and User Plane (UP). Software installed in RAN and Core components are 3rd Generation Partnership Project (3GPP) Rel-16 compliant.

The iSOC tests were conducted in room 5Tonic lab, while the ones on devices (LiDAR, cameras and robots) were performed in room X3. In the following, the installation and configuration activities performed for each setup described in section 2.1.2 are reported.

SETUP 0 - iSOC (Figure 4)

- Design and configuration of the local network
- 5G connections configuration
- Installation of Genetec on the mobile server
- Installation and configuration of the MQTT Broker
- PTZ camera installation and configuration

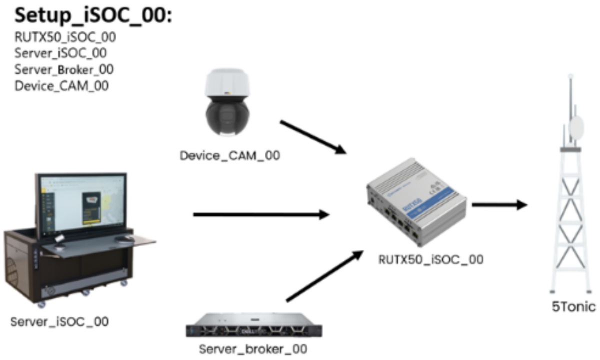

Figure 4. **SETUP 0 – iSOC.**

SETUP 1 - Devices (Figure 5)

- Local network design and configuration
- 5G connections configuration
- LiDAR device installation and configuration
- Linear camera installation and configuration

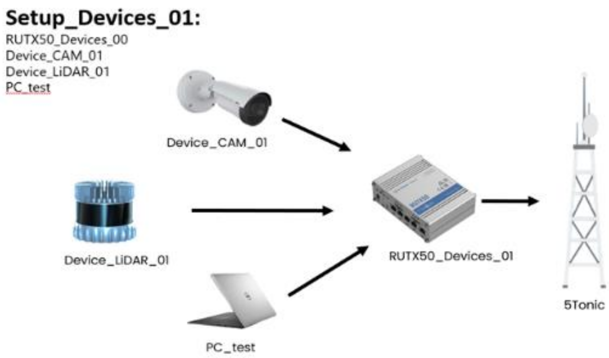

Figure 5. SETUP 1 – Devices.

SETUP 2 - Cloud (Figure 6)

- Local network design and configuration
- 5G connections configuration
- LiDAR device installation and configuration
- Linear camera installation and configuration
- LiDAR sensing SW installation and configuration
- Video analytics SW installation and configuration

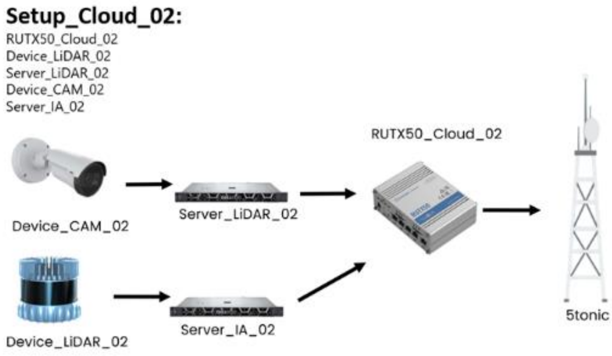

Figure 6. SETUP 2 – Cloud.

SETUP 3 - Kiiro (Figure 7)

- 5G connections configuration

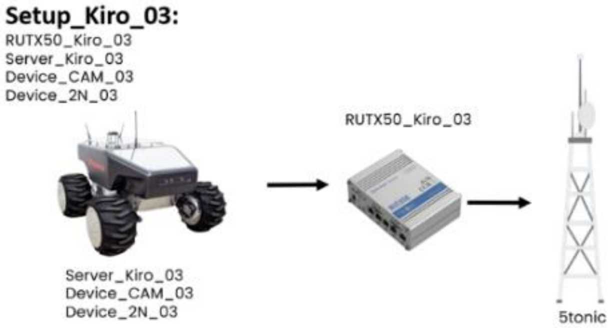

Figure 7. SETUP 3 – Kiiro.

For demonstration in a real environment, Yellow robot will be also integrated and the Lidar setup will count with two LiDARs, one of 128 beams and other with 62 beams. Moreover, the fix cameras will be sending the videostream to the Isentry cloud platform to analyze the images for events detection.

2.2 UC1: Smart Crowd Monitoring (Iasi)

2.2.1 Use Case recap

UC1 targets the smart monitoring of crowds from the Stefan cel Mare boulevard in Iasi, one of the busiest pedestrian alleys of the city. The use case aims to monitor public cultural or religious events, estimating the number of those present, as well as their dynamics. For its implementation, high-resolution video cameras with a panoramic view, wired to dedicated modem and connected to the Orange 5G network, were placed on the lighting poles in the vicinity of the heavily trafficked artery.

In terms of the technical infrastructure that is supporting the projects, several updates have been performed since the previous deliverable, according to the architecture in Figure 8. Most notably, in the context of the surveillance cameras installations, Nokia Fastmile 5G14-B 5G routers were installed on the lighting poles and connected to the cameras via dedicated CISCO switches. The 5G routers were fitted with specifically provisioned Subscriber Identity Cards (SIM) that support the TrialsNet project private APN (“trials”) and configured to support the connected cameras. Through the private APN, the video surveillance feeds can be reached directly from Orange Romania (ORO)’s Bucharest 5G Lab infrastructure. To streamline the access of Universitatea Tehnica Gheorghe Asachi din Iasi (TUIASI) to the cameras and feeds, an IP Secure (IPsec) Virtual Private Network (VPN) tunnel has been configured between ORO’s 5G Lab and TUIASI’s network infrastructure.

Based on this architecture, the UC1 video analytics application runs now on TUIASI’s servers, performing inference and data visualization tasks. The application is described in the next sections.

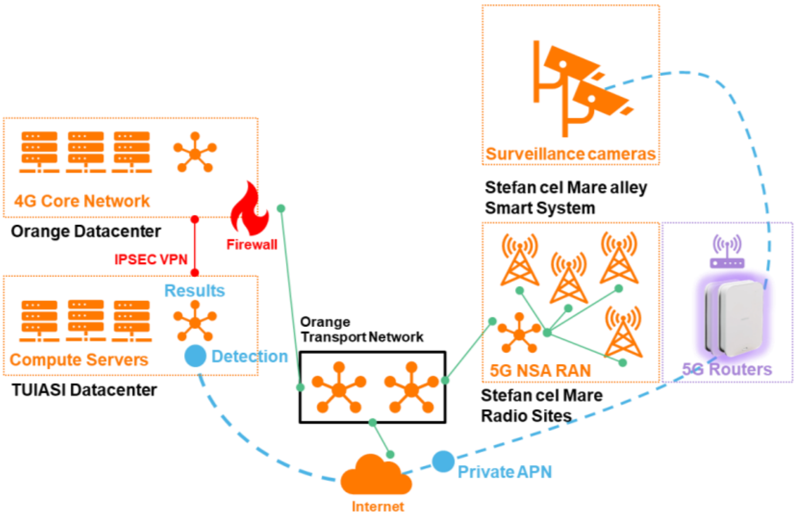

Figure 8. UC1 5G and Edge-Compute current architecture.

2.2.2 Final application design

The final version of the solution Edge-Compute architecture was finalized and is reported in Figure 9. The architecture will be implemented starting from the end of 2024 and will be based on the same on-field deployed hardware, the installed surveillance cameras, and the Nokia Fastmile 5G14-B 5G routers. In this approach, the RAN equipment that covers the Stefan cel Mare pedestrian area will be upgraded to support 5G SA & Non-Stand Alone (NSA) hybrid mode, allowing for the interconnection with ORO's Bucharest 5G Lab 5G SA Nokia Compact Mobility Unit (CMU) CN for the control-plane traffic and access to the available compute resources.

The Iasi 5G Lab datacenter is the central point of this updated architecture, hosting the 5G SA local User Plane Functions (UPF) unit and the edge-computing servers on which the UC1 video analytics application will be installed. The user-plane traffic coming from the Stefan cel Mare Blvd. 5G SA RAN units will be routed to the local UPF, and the video surveillance feeds will be transmitted directly to the Iasi 5G Lab datacenter edge servers over a dedicated Ultra Reliable Low Latency Communication (URLLC) slice that allows for a prioritized latency of about 8 ms E2E.

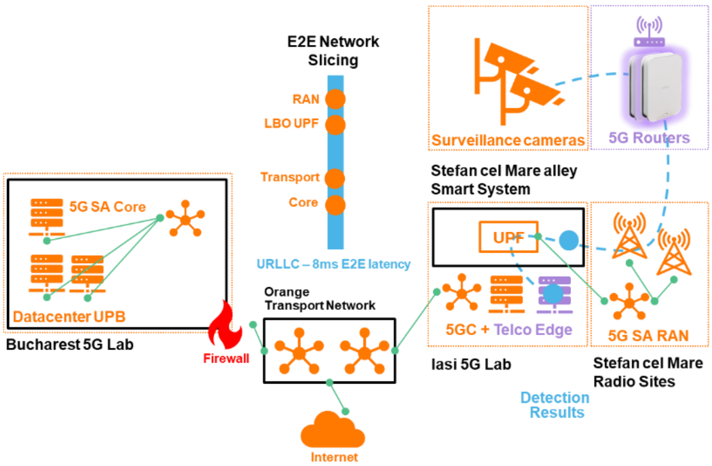

Figure 9. UC1 5G and Edge-Compute final architecture.

The application software is a containerized application consisting of several services operating together. The components are the following:

- A video processing service, which is responsible for all video processing and analytics operations. The service, which is built on top of the Nvidia DeepStream [12] software framework, enables the execution of separate pre-trained neural networks models for detecting both people and objects of interest (cars, motorcycles, etc.). The service ingests one or more video feeds and outputs the analytics output extracted from the video (people count in a selected area, heatmaps estimating people density, and bounding box coordinates of objects of interest), as well as output video feeds with the rendered detections.

- An instance of the Apache Kafka [13] streaming server, which is a message broker application serving output analytics to other applications in real-time, with minimal delay.
- An instance of the Grafana [14] dashboard software, which displays real-time analytics data to the user. The Grafana dashboard acts as a client of the Kafka server and reads data from it.
- An instance of the Go2RTC [15] video streaming server, responsible for streaming the output video feed from the video analysis service to the Grafana dashboard and can also act as a lightweight video player for the user.
- An instance of the Kafka-UI [16] service for configuring and monitoring the Kafka server.

The architecture of the services in the application and data flow of the application are illustrated in Figure 10. The Machine Learning (ML) models in the video processing service analyze the video data received from the cameras (and, optionally, pre-recorded videos). The analytics metadata extracted from the video feeds is published on the Kafka message broker, which in turn distributes it to various client applications (including the dashboard visualizations). The output video, with the rendered detections, is available via the streaming server to video clients.

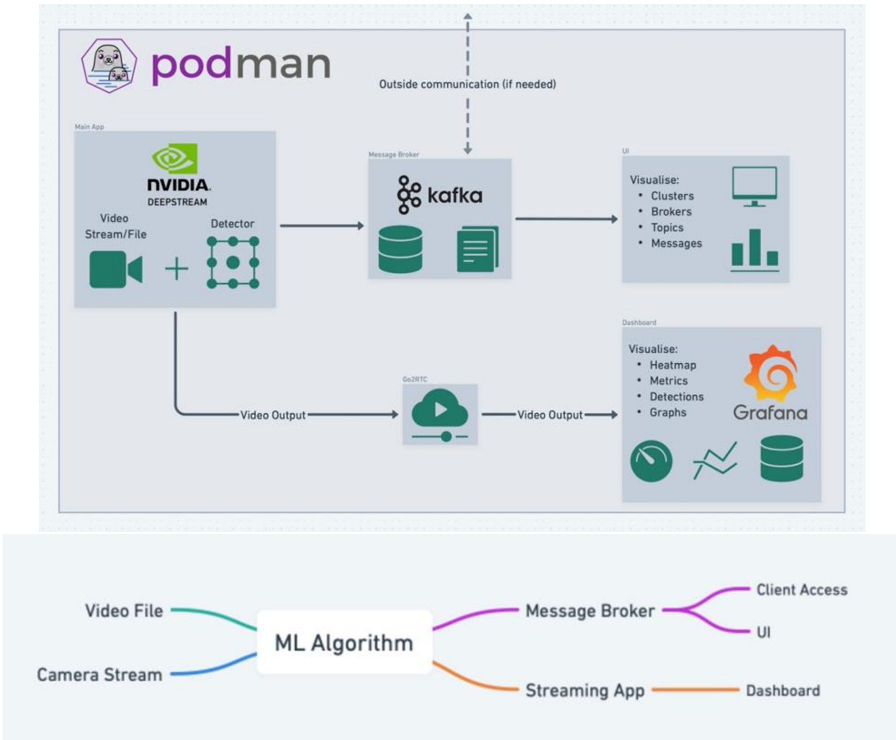

Figure 10. UC1 application architecture (up) and machine learning workflow (down).

2.2.3 Development activities

For the first tests of UC1, preparatory activities were done for the 5G network part, installation of cameras and 5G CPE, Wi-Fi Access Points and the development of the image processing application, and dashboard. This section presents the details related to the implementation of the devices and the application, while the details related to the 5G network deployment will be detailed in the next deliverable D2.2 from WP2. To cover the test area, cameras were installed in two locations in the pedestrian area of Stefan cel Mare Boulevard, as in Figure 11, and in Piata Palat, and as in Figure 12. The type and number of cameras installed in UC1 have been detailed in the first deliverable D3.1 [1].

The positions of these cameras have been selected to provide high visibility in the area in front of the main city church, Mitropolie where a special pilgrimage event takes place every year with the participation of tens of thousands of people. Also, in this area there is a large flow of participants during the winter holidays, as well as every weekend or in the middle of the day. The 5G site is also marked with orange circle in Figure 11. Considering the proximity of these devices to the 5G site, the 5G coverage is very good and this is also reflected in the KPI measurements.

Figure 11. Camera's position on Stefan cel Mare Boulevard.

Figure 12. Camera's position on Piata Palat.

Concerts are regularly organized in the Piata Palat area where a very large number of participants are concentrated in the area covered by the cameras installed in the framework of the TrialsNet project. The installed cameras configuration will allow the monitoring of such events also during the years 2024 and 2025, and the results will be presented in the next deliverable D3.3. Software development activities were focused on developing the main video analytics module and integrating the necessary components of the system into a single containerized application.

The same application software is designed to work for both Iasi UC1 and UC4 use cases, with differences only in the application configuration and the video input feeds. The current progress of the software development is summarized in Table 1. Status for software development activities UC1 and UC4below. A short description of each feature follows.

Table 1. Status for software development activities UC1 and UC4.

Software development activity / feature	Implementation status
Main video analysis pipeline	Done
Containerized application services	Done
Visualization dashboard	Ongoing – Target Q3 2024
Privacy protection methods on video	Ongoing – Target Q3 2024

Parallel display for multiple cameras	Done
Integrating additional object detection models	Ongoing - Target Q4 2024
Establish a deployment procedure	Ongoing - Target Q4 2024
Extrinsic calibration of video cameras	Planned for Q2 2025
User interface for application control	Planned for Q2 2025
Density analytics application	Planned for Q2 2025
Multi-model inference and display	Planned for Q2 2025
Advanced post-processing rules for object detection	Planned for Q2 2025

Main video analysis pipeline
This is the main application, responsible for video analysis, running the object detection models, analyzing the detections and publishing the results on the Kafka server. The application is developed in Python and is based on the NVIDIA DeepStream Software Development Kit (SDK). Most software features that will be developed in this project are integrated in this application.

Containerized application services
The overall system consists of several containerized services running on a single host machine, using Podman [17] (or Docker [18]) software tools, as explained in the application design: (i) the main video analysis service, (ii) an instance of Apache Kafka message broker, (iii) an instance of the Grafana dashboard visualization software, (iv) an instance of the Go2RTC video streaming server and (v) an instance of Kafka-UI configuration application for the Kafka server. Significant effort was involved in designing, implementing and maintaining the architecture and with all the services operating together.

Visualization dashboard
The Grafana framework is a web-based dashboard for real-time data visualization. A parameterized dashboard was designed and configured to read the analytics data from the Kafka server and display it in the form of time series (for object counts) and heatmaps (for location analytics / density), as well as displaying the output video feed from the video analysis service.

Privacy protection methods on video
The video processing service blurs the video frames prior to output from the video analysis module, after the detection models are run, in order to safeguard the privacy of individuals in the video. The method involves pixelating the video frames through down and up sampling, reducing the image resolution before outputting the video stream. These operations are carried out using DeepStream plugins to optimize performance. The down sampling factor is manually configured for each camera, depending on its view range, to ensure an appropriate low resolution. An illustration is provided in Figure 13. Several other processing methods are envisaged: gaussian blur of the whole image or blurring only the detected areas while maintaining the background at the native resolution. In addition, it is possible to permanently disable the video output from the application configuration, so that the application software generates only analytics metadata (counter, categories and locations of detected people and objects), without any video output. To be noticed also that only operators from consortium partners have access in the command monitoring center room.

Figure 13. Privacy solution via down sampling: full output image (left) and detail of the left image (right).

Parallel display for multiple cameras
The application must be able to run in parallel for multiple video feeds and display the separate dashboards in parallel for each camera or scenario. Figure 14 and Figure 15 illustrate this feature.

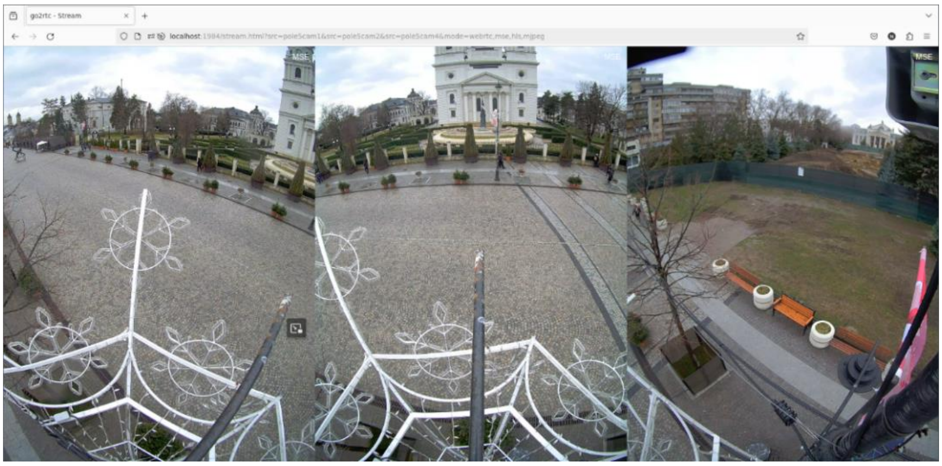

Figure 14. Three input video streams displayed in parallel in the Stefan cel Mare pedestrian area.

Integrating additional object detection models
Pretrained object detection models need to be integrated into the application by ensuring proper handling of input and output data. The application currently integrates two state-of-the-art models, the YOLOv7 [19] model trained on the Common Objects in Context (COCO) dataset [20], and the P2PNet [21] crowd counting model for people detection, trained on the ShanghaiTech Part A dataset [22]. However, several other models are planned to be integrated in the future.

Establish a deployment procedure
Since the overall application is complex, consisting of several containerized services together with their configuration files, some effort is needed to deploy and configure the system on a new target machine. Efforts are underway for defining and testing a streamlined deployment procedure which allows for easy deployment.

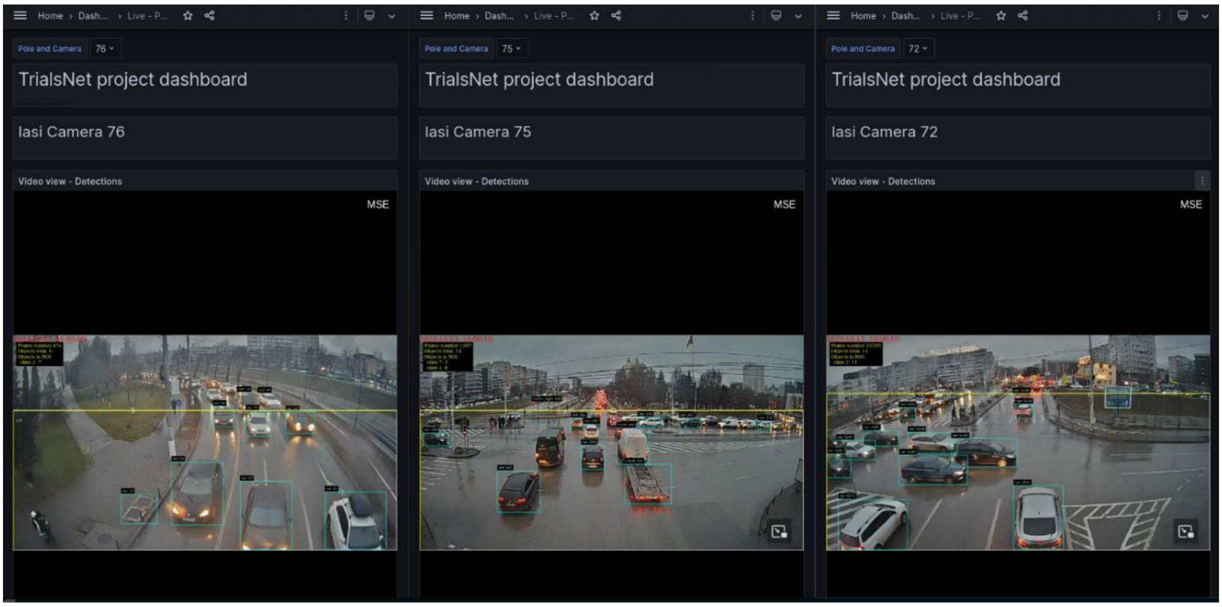

Figure 15. Three output video streams displayed in parallel in the Podu Ros intersection.

Extrinsic calibration of video cameras
To ensure accurate representation of the heatmaps that estimate the people density in the areas of interest, the coordinates of detected objects need to be transformed from image pixel coordinates to real-world coordinates. For this purpose, a procedure for extrinsic camera calibration has been designed. This procedure relies on identifying visible landmarks in a camera image and matching their pixel coordinates with their GPS coordinates,

either measured on the ground or extracted from available mapping tools (e.g. Google Earth). Based on the correspondence between pixel and GPS coordinates, software tools like CameraTransform [23] can estimate the extrinsic calibration parameters of the camera (heading/roll/tilt angles, position, elevation etc.), with good accuracy (Figure 16). These parameters describe the position and pose of the camera, enabling the transformation of the pixel coordinates of any image point into the GPS coordinates of the corresponding point on the ground. The procedure needs to be performed once for each camera view in the system. The calibration procedure has been established and used for calibrating two cameras, one on the Ștefan cel Mare Street and another in the Podu Roș intersection. In the future, calibration for all cameras within the system is planned.

Graphical user interface for application control
A simple graphical user interface to control the operation of the video analysis pipeline will be developed.

Density analytics application
A separate application for density analytics, running in parallel with the main video analysis, will be developed. The application ingests the detections data from the Kafka server and computes and publishes relevant features regarding crowd dynamics.

Multi-model inference and display
The video processing pipeline will be extended to support multiple object detection models running in parallel and merging the results in the same output stream.

Advanced post-processing rules for object detection
A custom module for post-processing the raw detections will be developed to implement more fine-grained rules for object detection, such as time-based alerts.

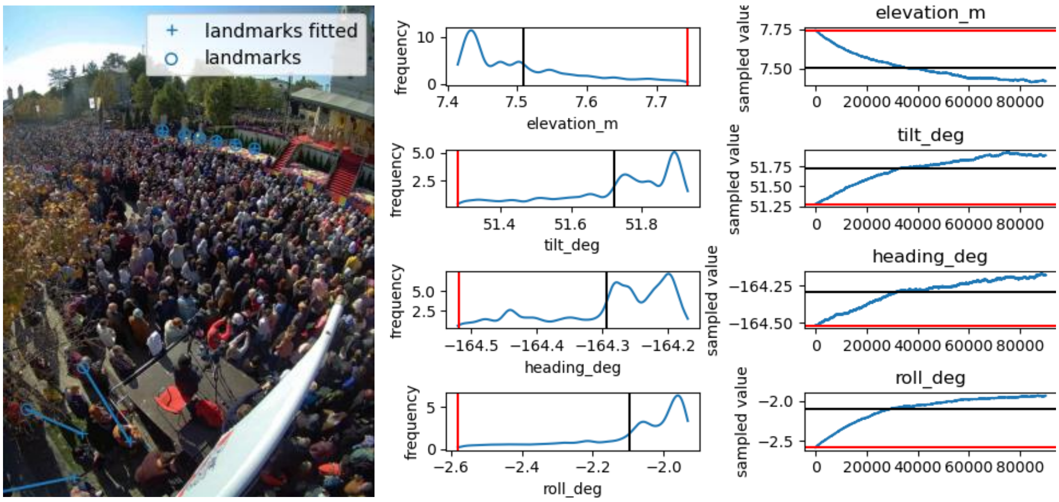

Figure 16. Camera calibration. Landmark points/fit accuracy (left); parameters distributions/values (right).

2.3 UC2: Proactive Public Infrastructure Assets Management

2.3.1 Use Case recap

This use case is trialed in Athens site, where a cutting-edge solution for Proactive Public Infrastructure Assets Management is implemented. This use case involves collecting data from various sources such as security cameras, drones, municipal vehicles, and AGV. The collected data are then processed using AI and Deep Learning mechanisms to provide relevant information about the condition of public infrastructure assets.

This use case will be trialed initially in a lab setting at WINGS premises and then in two areas within the Greek Cluster: the Athens International Airport and public infrastructure provided by DAEM in the Municipality of Athens. The solution utilizes data from various sources, as mentioned above, aiming to assess the structural health of buildings, pavements, and roads. The collected data allows for more efficient and effective proactive management of public infrastructure assets, leading to cost savings and improved operations and services. The initial description of the UC has been reported in D3.1, here we present how AR/VR technologies provide added value services as detailed below.

By means of AR technology the construction workers obtain an on-site view of buildings and make bidirectional communications with remote experts. The state of the infrastructure assets is evaluated by using remotely controlled vehicles. Alerts and suggestions for city authorities are generated based on AI techniques, allowing for predictive maintenance scheduling and workers' safety enhancing. A public infrastructure assets' Digital Twin will provide monitoring of the outcomes of the faults' detection without wasting physical resources on the site. Required faster and more reliable real-time data exchange will be attained by using a B5G communication network, enabling improved decision-making of city management.

2.3.2 Final application design

The final application design consists of the following components (Figure 17):

- **Data input**: can be any hardware such as Sensors, Robots, Drones, Cameras that communicates with the Data Processing layer. These devices are registered on the system with their details so that necessary information can be accessed by various parts of the system. Each of the devices can have one or more components (i.e. Sensors, Cameras) to collect further data.
- **Data Ingestion and Processing**: This part of the system is responsible for managing data streams from devices, processing it, and doing the necessary functionality for the various use cases. It receives the data from a device, either from an MQTT broker or a live camera/video feed. For example, in the case of a live camera feed that can be on a remote device or an IP camera. Depending on the type of device, different technologies are used to handle the frames, i.e. in the case of the camera being installed on a device each frame is sent to a remote server via ZMQ [24] to handle further processing. For each different use case the data is processed accordingly, for example it could be passed directly on the datastore or passed through intelligence module for further processing and detections.
- **Intelligence Module Integration**: Depending on the use case a specific intelligence module is activated to process the video feed (frames from a camera) and make any necessary detections and calculations. For example, for the road damage use case, it detects various types of damages and calculates their severity. Depending on the severity, the system is responsible for initiating any notifications required to indicate the issues on a dashboard. All communication with the main system is done through a remote REST API.
- **Streaming and Restreaming**: The restreaming module is responsible for receiving each processed frame or not and restreaming the frames via a restreaming media server. The restreaming media server is responsible for restreaming the videos in most of the streaming protocols, such as Real-Time Streaming Protocol (RTSP), Hypertext Transfer Protocol (HTTP) Live Streaming (HLS), Web Real-Time Communication (WebRTC) and more. Depending on the needs a specific streaming protocol can be activated.
- **APIs and Datastore modules**: Data generated from devices are stored in a timeseries database (InfluxDB [25]) for further processing if needed and for future analytics. Any other information needed are stored in PostgresDB [26] and are managed by the management server accessible via a RESTful API which is responsible for authentication/authorization, dashboard APIs, device configuration management possibly other needed functionality.
- **Dashboard**: The dashboard is the management dashboard and is responsible for managing and presenting data generated by the devices, showing devices camera streams (if available), warnings and notifications and any analytics generated over time. Further features are added depending on the use cases.

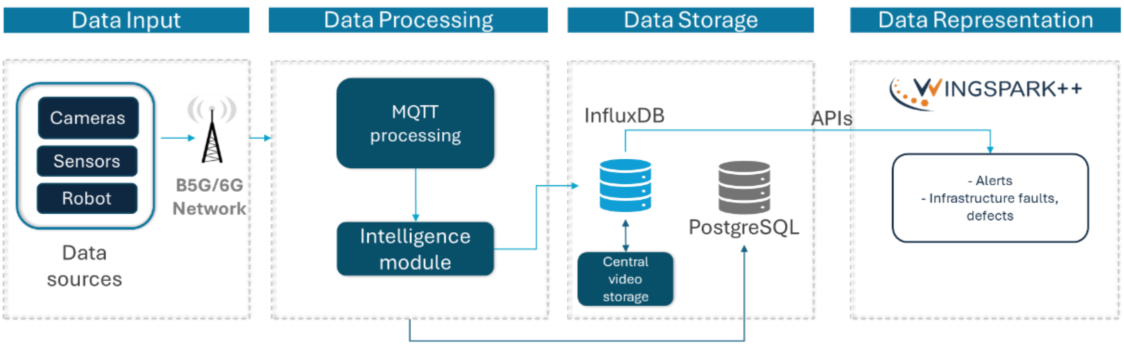

Figure 17. UC2 final application design.

2.3.3 Development activities

Activities in this period were carried at lab scale. Development of the platform took place in various stages; however, the following is the result of continuous integration and testing various aspects of the system and improving it to reach this stage. In the following, bold format denotes the modules of the WINGSPARK++ platform while the bullets reports the individual functionalities developed in this period for the specific modules:

WINGSPARK++ Platform

- **Authentication and Authorization**
  - Single Sign On (SSO), login and authenticate with Keycloak **- Completed**
  - Permissions - through Keycloak roles and groups **– Work in progress**
- **Development of Rest APIs for dashboard and device configuration management**
  - Support for devices, users, notifications **- Completed**
  - Public Infrastructure – Road damage specific: damages, inspections **- Work in progress**
- **Device Management – Admin Dashboard**
  - Device Configuration Management **- Completed**
  - Types of supported Devices:
    - Sensors, Robot/Drones (ROS integration) **- Work in progress**
    - WINGS On-Board Unit (OBU) with camera over 5G **- Completed**
    - IP Cameras **- Completed**
      - Ability to integrate an IP Camera (a remote independent device camera)
      - Configuration for disabling or selecting an AI model for detection
      - Configuration for video processing and other tools
- **Datastore**
  - Time Series Data with InfluxDB for AI model postprocessing data **- Completed**
    - Collect metrics for Intelligence model detections and outputs
  - Relational Database with PostgresDB **- Completed**
    - Stores device info configuration
    - Users of the system
- **WINGS Framewhisper component**
  - Frame Read, Processor / Intelligence Module, Writer **- Completed**
- **Restreaming Server:** Responsible for receiving a stream and enabling multiple protocols for further restreaming to multi clients **- Completed**

Development Operations (DevOps)

Development of each component as a dockerised services and further deployment tools for ease of deployment of the services using latest technologies such as docker and docker compose inside a Virtual Machine (VM) that was provisioned ansible. There are various deployment strategies such as dev, staging and production for different computer environment requirements.

Analytics

The aim of this use case is to assess the condition of the pavement and identify damage through image processing. For this purpose, after receiving the video source as input, object detection is performed to identify roadway damage and corrective interventions.

After the damage is collected for a specific area of the road (e.g., one kilometer), a second level of analysis is performed to assign a level of severity to the damage in that area. This will give a representative picture of the structural condition of the area.

Table 2 shows the status of development of the components of UC2 along with the plan for the next period.

Table 2. Status for UC2 software development activities.

Software development activity / feature	Implementation status
Main video analysis pipeline	Done
Containerized application services	Done

Streaming and Restreaming module	Ongoing – Target Q3 2024
Authentication and Authorization	Done
Data Ingestion and Processing	Done
Datastore setup	Done
Rest APIs device configuration management	Done
Device Management – Admin Dashboard	Ongoing – Target Q4 2024
Support for additional devices	Planned for Q4 2024
Integration of additional detection models	Ongoing - Target Q4 2024
Establish a deployment procedure	Ongoing - Target Q4 2024
Visualization dashboard	Ongoing – Target Q4 2024

2.4 UC3 Autonomous APRON

2.4.1 Use Case recap

This use case is intended for designing and deploying a solution for the Autonomous APRON scenario at AIA, based on B5G communications in order to optimize the airport operations, showcasing baggage and cargo ground handling using AGVs. An APRON Digital Twin will allow for a real-time depiction of the physical world inside the virtual one. Operators can intervene to remotely control the AGVs in critical situations. Data collected by sensors onboard the AGVs, such as cameras, LiDARs, and GPS are analyzed by means of AI techniques in order to make accurate predictions and to generate alerts, enabling a tight monitoring of airport activities and an increase of its efficiency.

An integrated distributed system will monitor simultaneously AGVs, collaborative robots, and other relevant resources, collecting data across the Edge and far Edge resources. Traffic profiling will allow for detecting network anomalies and preventing failures and security breaches. The use of B5G communication technology is crucial for attaining the proposed objectives as it enables low-latency, high-speed data exchange.

2.4.2 Final application design

For the realisation of the Autonomous APRON use case, a sophisticated architecture that leverages ROS2 and Docker containers has been designed, to enhance the efficiency and scalability of the underlying robotic system. Each robot deployed in the lab or in the field communicates seamlessly over ROS2, ensuring a standardized and interoperable communication protocol. The robotic layer is containerized using Docker, providing a modular and isolated environment for each robot's software components. To address high-computational demands, an edge compute device has been employed where resource-intensive nodes run, optimizing the robots' processing capabilities.

The solution relies on the WINGSChariot [27] platform, an orchestration tool residing on the cloud. This tool utilizes OpenHAB and MQTT protocols to collect data from the robots. To bridge the communication gap between MQTT and ROS2, an MQTT to ROS2 bridge has been designed and developed. The WINGSChariot platform processes the collected data and issues commands to the robots based on intelligent decision-making algorithms, enhancing the system's adaptability and responsiveness.

Furthermore, in the data representation layer of the solution lies the WINGSChariot Dashboard which serves as a centralized monitoring and diagnostic hub. This platform, built on MQTT and OpenHAB, facilitates real-time monitoring of the entire system. It plays a crucial role in diagnosing issues, ensuring smooth operations, and serves as the user interface for seamless interaction with the robotic fleet. This comprehensive architecture not only enhances the overall performance and coordination of the underlying robotic system but also provides a robust foundation for scalability and future developments. Lastly, the WINGSChariot Dashboard is uniquely enhanced by Unity [28] to support digital twinning of real robots. This advanced feature allows an immersive and accurate representation of the robots in a virtual environment, mirroring their real-world status and activities. The UC3 final application design is presented in Figure 18.

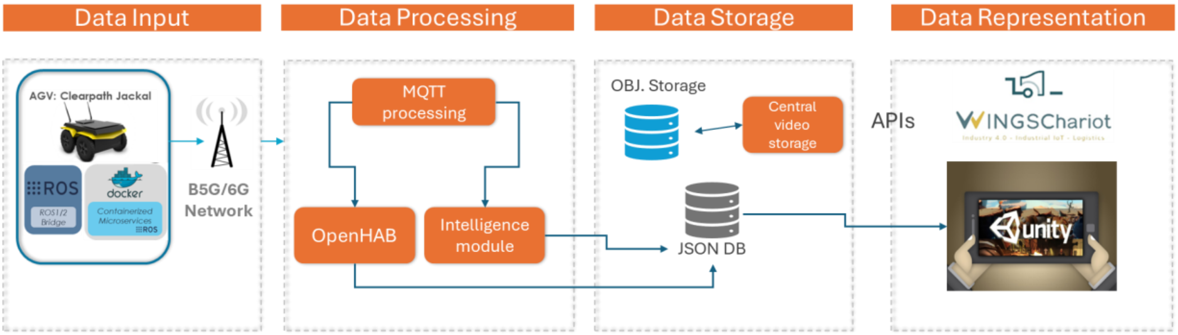

Figure 18. UC3 final application design.

2.4.3 Development activities

In this section, the progress and advancements of the development activities regarding the Autonomous APRON use case are presented. The solution is based on the Jackal platform from Clearpath [29]. The robot has undergone significant improvements and updates with various sensors to enable versatile and robust navigation across different outdoor environments. In particular, the robot is equipped with a stereovision camera, a 3D LiDAR, an Inertial Measurement Unit (IMU), and a Real-Time Kinematic (RTK) [30] system, empowering it to navigate autonomously in diverse settings (Figure 19). The sensors onboard the robot are detailed below.

- **Microstrain GX-5 imu** [31]: MicroStrain AHRS GX-5 is used in various applications across industries due to their ability to provide accurate and real-time information about the orientation and motion of objects. In this UC is used for Orientation Sensing.
- **Realsense 455 i** [32]: A depth camera is used due to several advantages it offers in the context of visual simultaneous localization and mapping (SLAM) applications. In this UC we use RTAB-Map (where RTK's performance drops). RTAB-Map is an open-source RGB-D SLAM approach that can build a 3D map of an environment while simultaneously estimating the camera's pose within that environment.
- **Fixposition RTK-2** [33]: Real-Time Kinematic (RTK) is a satellite navigation technique used for accurate positioning (x-y) in outdoor environments. Reasons why RTK is commonly used for outdoor localization are: high accuracy, fast convergence, real time positioning and good behavior in challenging environments (including areas with obstructions such as trees, buildings, and urban canyons).
- **Ouster OS-1 3D lidar** [34]: A 3D lidar offers Obstacle Detection and Avoidance, Mapping and Localization in Challenging Terrain. 3D LiDAR is well-suited for dynamic outdoor environments where the surroundings are changing rapidly. This is particularly important in applications like autonomous navigation, where real-time updates on the environment's structure are crucial for safe and efficient movement.

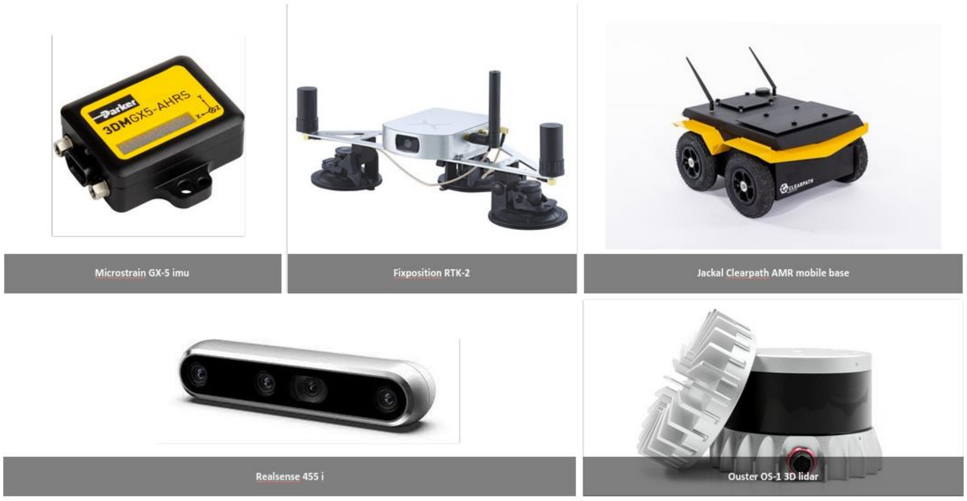

Figure 19. UC3 Robot Configuration.

The navigation strategy of the robot is tailored to the environment it operates in. In open areas lacking landmarks but wit, the robot employs the RTK technology to achieve centimeter-level accuracy in navigation. This precision is vital for environments where exact positioning is crucial. Conversely, in more challenging environments like urban canyons or areas with poor RTK signals, the robot switches to navigation based on RTAB-Map. This method uses the stereovision camera in conjunction with the robot's odometry and NavSat fixes, ensuring reliable navigation even under difficult conditions.

A key development goal involves creating an adaptive navigation mechanism. This mechanism intelligently switches between RTK navigation and RTAB-Map based navigation, depending on the RTK signal's covariance. When the covariance is reliable, the system uses RTK navigation for its precision. In scenarios with unstable RTK signals, the system automatically shifts to RTAB-Map based navigation, maintaining consistent and safe operation.

Adapting the robot for specific applications is an essential aspect of its development. The primary focus is on enabling efficient navigation in airport environments, which combine open spaces and structured areas. To this end, the robot is being configured to operate with a trolley, designed for carrying luggage. This adaptation involves both physical modifications and software enhancements to ensure the robot can smoothly and safely transport baggage.

Future development efforts are concentrated on refining the adaptive navigation mechanism, improving the robot's payload capacity, and ensuring its operational efficiency in complex environments like airports. Continuous testing and iterative development of both hardware and software components are critical to achieving these objectives, ensuring the robot meets the high standards necessary for its intended applications.

2.5 UC4: Smart Traffic Management

2.5.1 Use Case recap

Traffic management in cities is crucial for traffic efficiency and safety due to the increasing number of road users and the emergence of new transportation modes such as automated and micro-mobility vehicles. The use case presents the processed information related to the traffic statistics and identification of possible hazardous traffic situations.

In terms of the technical infrastructure that is supporting the projects, several updates have been performed since the last deliverable, according to the architecture indicated in Figure 20. Like UC1, the outdoor hardware infrastructure related to UC4 was finalized with the installation of a Teltonika RUTX50 5G router that aggregates the traffic from all the previously deployed surveillance cameras from the Podu Ros intersection area. The 5G router is fitted with a SIM card provisioned with the TrialsNet project private APN, through which the video feeds are directly accessed by TUIASI computing servers, through the IPsec VPN tunnel between them and ORO. Based on this architecture, the UC4 video analytics application runs now on TUIASI's servers, performing inference and data visualization tasks. The application will be described in the next sections.

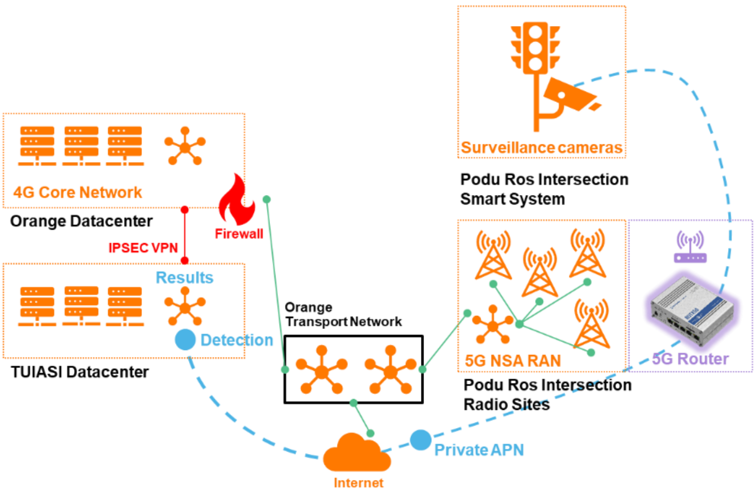

Figure 20. UC4 5G and Edge-Compute current architecture.

2.5.2 Final application design

The final 5G and Edge-Compute architecture for UC4 is indicated in Figure 21. Much similar to UC1, the RAN units that are covering the Podu Ros intersection area will be also upgraded to support 5G NSA & SA hybrid mode and will be connected to ORO's Bucharest 5G Lab 5G SA Nokia CMU Core Network for control plane traffic and access to the available compute resources. In a similar manner to UC1, the user plane traffic that flows through the UC4 RAN units will be routed directly to the Iasi 5G Lab local UPF unit over an URLLC slice capable of an 8ms E2E latency, allowing for a rapid interconnection between the video surveillance feeds coming from the cameras and the edge-computing servers that host the video analytics application developed by TUIASI.

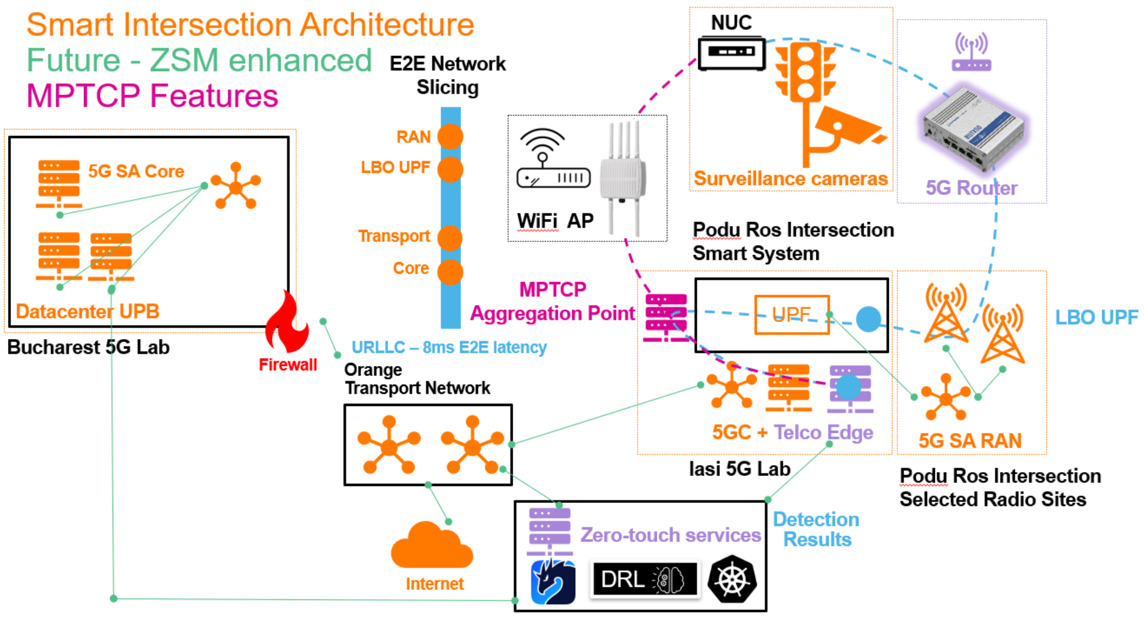

Figure 21. UC4 5G and Edge-Compute final architecture.

The future fully-fledged implementation of UC4 will also make use of the Zero-touch Network and Service (ZSM) framework to improve the overall performance of UC4 services by applying automated and intelligent network and service orchestration (details will be presented in D2.2). In particular, zero-touch services will be deployed as AI/ML functions that help orchestrators make more sophisticated decisions that in turn result in improved performance and sustainability aspects. These zero-touch services will be deployed at the Telco Edge environment in Iasi for the integration of intelligent decision makers (such as DRL-based decision-making processes) into the UC4 ecosystem. The details of the Multipath Transmission Control Protocol (MPTCP) architecture are described in section 2.5.3.

There is a single software application designed to operate for both Iasi's UC1 and UC4 use-cases, with differences only in the configuration setup and the actual input video feeds. As such, the reader is referred to the final application design description in UC1 (see section 2.3.2).

2.5.3 Development activities

For the implementation of the first tests from UC4, preparatory activities have been carried out for the 5G network part, installation of cameras and 5G CPEs and the development of the image processing application and dashboard. This section presents the details related to the implementation of the devices and the application, while the details related to the 5G network preparations will be detailed in the next deliverable D2.2 of WP2.

To cover the Podu Ros intersection, cameras were installed on 2 poles, as in Figure 22. The type and number of cameras installed in UC4 are detailed in the first deliverable D3.1 [1].

Figure 22. UC4 Podu Ros intersection surveillance cameras placement.

Since the software application is the same for both Iasi UC1 and UC4 use-cases, most of the development activities are the same. The reader is referred to the development activities described in section 2.3.3 for UC1.

As the extrinsic calibration procedure is done for each camera, the same calibration procedure has been also used for UC4 cameras, to obtain real-world coordinates of the detected objects in the video feeds. Figure 23 illustrates the calibration procedure for a UC4 video camera.

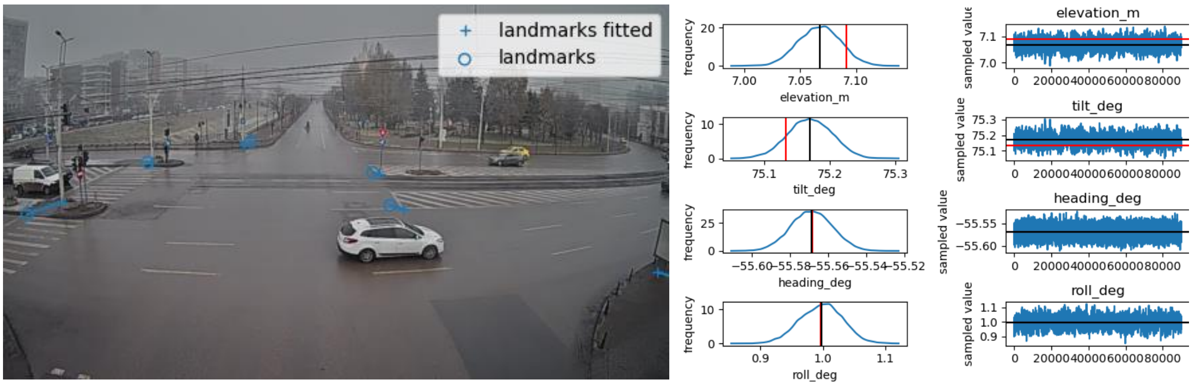

Figure 23. Camera calibration. Landmark points/fit accuracy (left); parameters distributions (right).

In the context of UC4, IMEC focuses the initial setup of a hybrid communication system that employs MPTCP, a sophisticated protocol enabling the simultaneous use of multiple network paths for data transmission to improve bandwidth and reliability. MPTCP is particularly beneficial for traffic and crowd monitoring by facilitating the concurrent transmission of video feeds over 5G New Radio (NR) and Wi-Fi networks, thereby enhancing the system's performance, reliability, and resilience. The primary focus is not merely limited to utilizing MPTCP, but to delve into its optimization for the efficient transmission of video data. This includes exploring strategies to dynamically allocate resources, minimize latency, and increase the resilience of the system against network failures or congestion.

An initial setup has been developed within IMEC's premises, laying the groundwork for the early stages of development and testing. This setup serves as a controlled environment where the system can be evaluated. Following this phase, IMEC will collaborate with ORO to replicate a similar setup at the UC location. This strategy will facilitate the early development while ensuring a smooth transition to the more complex testing phase at the UC location. The overview of the initial test setup in IMEC's premises is depicted in Figure 24. It consists of a server and a client, both powered by Intel Next Unit Computing devices, which serve as the endpoints of the MPTCP connection. The 5G NR network is implemented by integrating Open Source implementation for 5G Core and Evolved Packet Core (EPC) (Open5GS) for the core, software radio system RAN (srsRAN) [35], for the RAN, and Universal Software Radio Peripheral (USRP) as the radio unit. This setup can be seen in Figure 25. Throughout the tests, various KPIs, including the uplink throughput, downlink throughput, and E2E latency will be measured and optimized. The Wi-Fi link is established via a wireless access point.

Finally, the client utilizes a built-in Peripheral Component Interconnect Express (PCIe) Wi-Fi card to connect to the Wi-Fi network and a Quectel RM500Q-GL 5G module to connect to the 5G network.

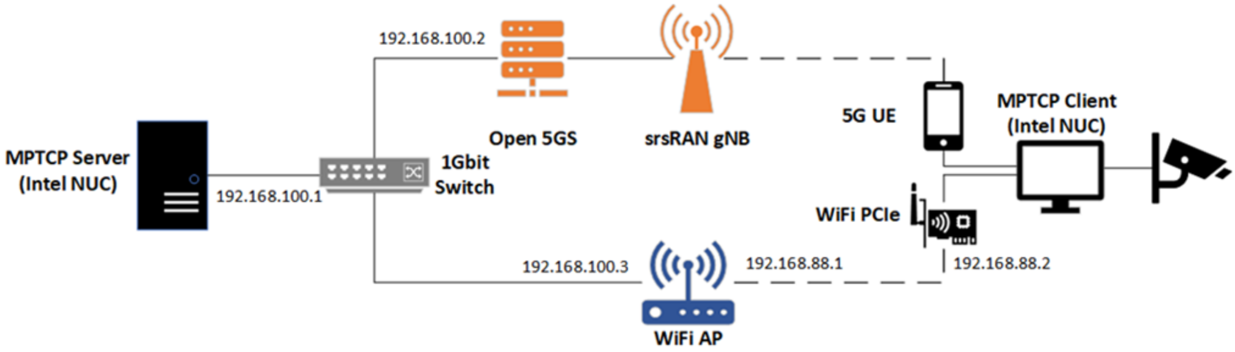

Figure 24. Schematic of IMEC-Ghent 5G testbed with MPTCP features.

Figure 25. IMEC-Ghent 5G testbed setup.

2.6 UC5: Control Room in Metaverse

2.6.1 Use Case recap

The use case aims to enhance the operational efficiency of security forces, including the Police, 112 emergency services, Ambulances, and Firefighters, within the Turin municipality. This is achieved through the establishment of a collaborative MCR accessible from any location using a secure access code. The scenario relates to a public event (e.g., concert, rally) where all security stakeholders have previously coordinated an emergency action plan. The assumption is that an accident will occur during the event.

In order to articulate the process on the basis of the user preferences, the design has followed the Design Thinking+ methodology, which is described in the Deliverable D6.1 [36]. The key components of the use case therefore include:

- **Simulation Setting**:
  - Some actors are located in a control room (emergency switchboard number 112), while others are mobile, moving from their respective stations to the incident location.
  - The simulated incident is in proximity to the hypothetical event, with dedicated security and safety agents present on-site.
  - An agreed-upon action plan exists for addressing incidents specific to the event.
- **Notification and Response**:
  - The emergency switchboard (112) receives a notification, typically one or more phone calls.
  - After gathering initial information, the 112 contacts the required agents, who then convene in the MCR.
  - Connectivity relies on 5G technology to facilitate real-time communication.

- **Metaverse Control Room Functionality**:
  - The MCR visually represents the incident location, overlaying information from the action plan and incorporating input from various agents (videos, pictures, alerts) and sensors (video cameras, people counting).
  - Despite agents being mobile, they remain connected and active in the MCR.
  - Agents can share images and videos within the MCR to enhance situational awareness.
  - Effective communication and collaboration occur among actors, whether they are physically together or in separate rooms within the metaverse.
- **Testing Intervention Scenarios**:
  - Once the system is operational, various intervention scenarios can be tested to evaluate its responsiveness and effectiveness.
- **Selected Area**:
  - The chosen area for the use case is the Area Eventi Parco del Valentino, which hosted the Eurovision contest in 2022.

The main objective of the use case is to increase the efficiency of the communication by demonstrating that virtual presence in a metaverse, enabling effective communication and information exchange among all actors, results in more efficient interventions with reduced mission completion time. On the other side, the use case aims also at testing the current 5G network technology with a focus on the capacity and stability under real-world conditions, showcasing its capabilities and limitations in supporting seamless communication and data exchange within the MCR. In summary, the use case is designed to validate the advantages of a collaborative metaverse approach in emergency response scenarios, with a focus on enhanced efficiency and the robustness of 5G network capabilities.

2.6.2 Final application design

In the first semester of the project, various software to build the metaverse application have been analyzed and compared. As described in D3.1 [1] the choice went to Mozilla Hubs [37] for its modularity, user friendliness as well as for being open source.

Mozilla Hubs offers a dynamic environment where developers can craft personalized virtual spaces, referred to as “rooms”, enriched with tailored 3D objects, images, and videos. The MCR has been designed for seamless sharing, allowing users/agents to join and engage with each other in real-time. Utilizing avatars, the agents will represent themselves, fostering a collective experience enhanced by voice and text chat communication. To access the MCR, a compatible web browser supporting WebVR, such as Firefox or Chrome, is required, along with a device featuring a keyboard and a mouse or a virtual reality headset.

The accessibility extends to various devices, including desktop computers, laptops, smartphones, and virtual reality headsets. Due to its inherent flexibility, scalability, user-friendly interface, and support for real-time, multi-player collaboration through voice and text chat among avatars in the same room - without capacity limits - Mozilla Hubs has found application in the implementation of the MCR. Specifically tailored to first responders and emergency personnel's needs, it serves purposes like mission planning and intervention protocol testing, along with real-time data analytics visualization.

Users can generate avatars and tailor their appearances, fostering a highly personalized and immersive experience closely mirroring real-life situations. This feature proves particularly valuable when crafting avatars for diverse roles such as firefighters, police officers, or civil protection agents, as opposed to solely focusing on 118 employees. This versatility ensures a remarkable level of fidelity, enhancing the authenticity of emergency management scenarios. To achieve a comprehensive simulation, a minimum of 10 to 12 avatars is envisaged. This allocation should include 8 to 10 avatars designed for first responders, encompassing roles like firefighters, police officers, and civil protection agents. A useful modification from the initial plan reported in D3.1 [1] involves replacing 3D scans of the Area Eventi with a map extracted from Google Maps. This adjustment was made to eliminate potential distractions caused by the avatars within the “Area Eventi”, directing viewer focus to material cameras and sensors uploaded by agents. Additionally, the decision to move away from 3D scans, which is rare, ensures greater adaptability for future use cases in different areas.

The metaverse application is going to relay on different type of information retrieved from sensors and video cameras deployed in the "Area Eventi" and properly managed by the Symphony IoT platform which installation and networking details will be reported in D2.2 of WP2.

2.6.3 Development activities

The virtual space for the MCR has been constructed within the metaverse using Mozilla Hubs software, and the interface is showcased in Figure 26. The interface comprises three distinct tables, each dedicated to a specific security entity such as police, ambulances, and firefighters. Avatars representing these entities will populate the room, distinguished by jackets of distinct colors: blue for the police, orange for the ambulances, and red for the firefighters.

Figure 26. MCR User Interface.

System integration has been facilitated by using Hyperbeam software [38] (see Figure 27), enabling seamless synchronization of audio and video across multiple participants on any third-party website or application, along with the added capability of multi-user control.

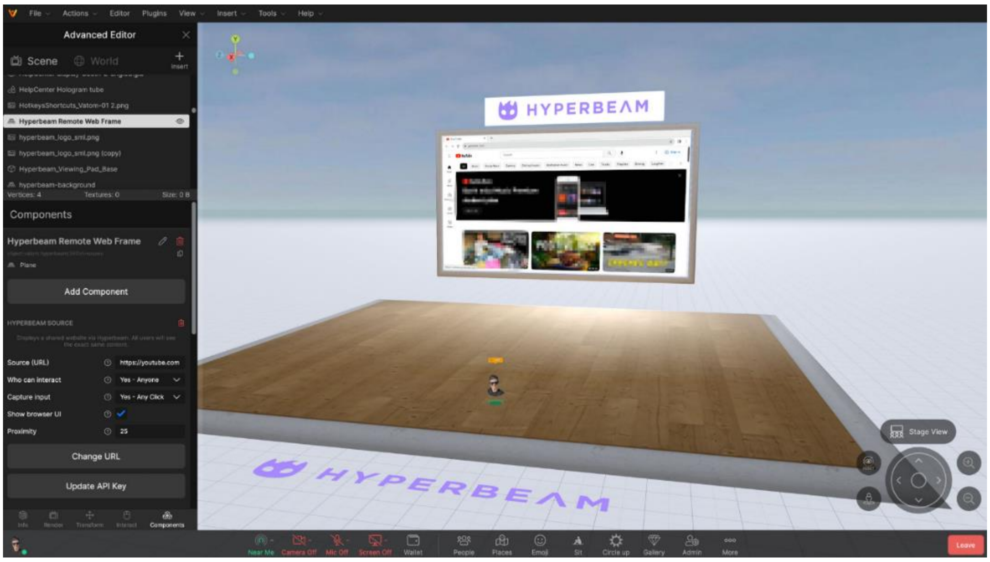

Figure 27. Editor of the Hyperbeam software.

In the following, the main development activities carried out to adapt Mozilla Hubs to the needs of UC5 are reported.

Identification of the tools and technologies

- Acquiring the know-how of the identified technologies for fast and efficient development
- Creation of summary documents with research results
- Cloning of Mozilla Hubs project and installation of dependencies for local start up

- Downloading Software Development Kit (SDK) and integrating it into the Hubs project
- Configuring Hyperbeam in the scene for displaying web pages in the metaverse
- Implementation of Mozilla Hubs and related functionality

3D modelling of the Control Room

- Use of the tool SPOKE [39]
- Gathering information about the room (dimensions, layout, architectural details, furniture and materials)
- Planning the room representation
- Setting the scale of the design so that the room dimensions match the actual dimensions

Adding furniture and objects

- 3D models of the objects included in the room
- Creating the floor and the ceiling
- Adding light sources to the room
- Configuring materials and textures to reflect light realistically
- Applying materials and textures to room surfaces, including floors, walls, furniture, etc.
- Exporting the 3D model to the compatible format from Mozilla Hubs

Spatialized audio

- **Study of Spatialized Audio**: research of the technologies and principles behind spatialized audio (or 3D audio), which simulates how sound is perceived in a three-dimensional environment
- **Integration with Mozilla Hubs**: exploring how to integrate spatialized audio into the Mozilla Hubs platform, ensuring that 3D audio is well integrated with existing Hubs functionality
- **Prototype Development**: create prototypes or demos to demonstrate the use of spatialized audio in Mozilla Hubs
- **Testing and Evaluation**: test prototypes to evaluate the quality of spatialized audio, usability, and user experience within Mozilla Hubs

Room resizing

- **Resizing Planning**: determine what new dimension is needed or desired for the 3D model within the Mozilla Hubs environment, taking into account how proportions and layout affect the user experience
- **Modifying the 3D Model**: using 3D modelling software to physically resize the room model, ensuring that all proportions and internal elements are properly adjusted
- **Optimizing the Model for Mozilla Hubs**: optimizing the resized model for use in Mozilla Hubs, which may include reducing the number of polygons, compressing textures, and making sure the model follows Hubs' guidelines for virtual reality
- **Integration Testing**: load the resized model into Mozilla Hubs to test its integration, verifying that it loads correctly and that the dimensions are appropriate for the intended use
- **Troubleshooting and Adjustments**: identify and fix any problems that have arisen from resizing, such as graphical distortions, texturing or collision problems
- **Consolidation**: Finalization and performance optimization, make final adjustments to ensure that the resized model is not only visually accurate, but also optimized for performance in Mozilla Hubs, especially for devices with limited hardware capabilities.

The main development activities carried out to apply Symphony IoT platform to the needs of UC5 are described in the following. For the identification of the sensor's communication protocols and data format, one of the most common and reliable protocol is MQTT [40]. For the moment, just one sensor type has been connected and it communicates messages via MQTT. Each sensor has its own topic name depending on where it has been installed (box, light pole). The data format published by the sensors is a JavaScript Object Notation (JSON) object. An example of the data published by the sensors is the following:

cnit/sensore_box {"timestamp": "2023-11-24 17:35:14.901390", "counting": 7, "bloom_filter": "00010000"}

As described by the payload of the message, each sensor reports the number of different devices detected in a certain time. Moreover, a vector of anonymized features related to the device is stored into the bloom filter array. For the sensors to publish some data using the MQTT protocols, they need the address of the broker. It has been necessary to deploy a RabbitMQ [10] instance with the MQTT protocol enabled, and to allow this instance to be reachable from outside the PoliTO machine itself. Once the RabbitMQ Broker has been properly installed and configured, the sensors published their data at a frequency of 2 minutes. The bloom filter is a string of 10,000 characters of '0' or '1'. To save space before storing it, an algorithm of aggregation have been applied reducing the size by around 80%. Since the messages are time based, one of the best DB choices is Influx DB. It means that the data have been formatted into the Influx-line protocol: the 'measurement' is the topic, the 'fields' are the counting and the bloom filter, and the 'timestamp' is the one present in the original message. The proper symphony plugin has been developed in order to store and retrieve information in the InfluxDB. The visualisation is done with Grafana [14]. This is a powerful data visualized that, upon proper configuration (e.g.: data source to use), allows to depict data in tabular of graphical format. One 'Dashboard' with two panels have been developed. Each of the panel depicts the number of devices over time in the zone covered by the sensors itself. The data received by the Wi-Fi sensors are collected and processed by the Symphony IoT platform to provide a convenient dashboard for their visualization and processing. The data received by the sensors to infer crowd flows is anonymized through the adoption of bloom filters. The initial on-the-field evaluation of the Wi-Fi scanners is aimed at assessing the different trade-off between counting accuracy, reactivity and privacy achieved by the two types of sensors (commercial and experimental).

The development activity of the application will continue in the next months, taking also into account the outcomes of the Design Thinking+ session held in February. During this session, representatives from security and safety agencies recommended exploring the integration of the following additional features into the system:

- Incorporating video feeds captured by drones equipped with video cameras, typically deployed during large events.
- Establishing a connection to Apps that are currently use by some security forces for geolocalisation and messaging such a "112-Where-U-are" and "Flagme" [41].
- Developing a standardized protocol for intervention and operation that aligns with the protocols of various agencies involved.

These enhancements are crucial for ensuring the effectiveness and compatibility of the system with existing procedures and technologies utilized by emergency response teams.

3 First integration and test activities

This section details the main activities related to the trials, presenting reports about the preliminary tests performed in laboratory or on-field contexts and describes also early demos. The reported test section includes test setup description, test summary including objectives description, test results in terms of measured KPIs and analysis, remarks and next steps. KPIs measurements have been performed using the harmonized terminology provided by WP6 in D6.1 [36]. The definition of related KPIs IDs that are measured during the tests are presented in Annex A. Finally, it has to be highlighted the datasets collection and identification follows the guidelines reported in the Data Management Plan defined by the project.

3.1 UC1: Smart Crowd Monitoring (Madrid)

Elements corresponding to the different setups detailed in Section 2.1.3 were deployed in 5Tonic lab in Madrid by Ericsson and Prosegur to characterize the uplink and downlink and to check out the performance on the 5G network in the actual evolution. Tests were carried out from October 23rd to 26th, 2023.

Ericsson provided the 5G network and the tests were conducted in the RAN coverage area called X3 with the 5GC CP in the data center. The current 5G RAN equipment is mid-band (n78 - 3.5 GHz) and Stand-alone technology. In 5Tonic lab room the iSOC sends traffic to 5G network through 5G CPE. This traffic can be measured directly in the RAN: Down-Link (DL) throughput/Up-Link (UL) throughput. The RAN KPI are stored in influx database located in 5Tonic DC and showed in Grafana tool. In 5Tonic X3 room, the Prosegur devices are connected to the Mini PC. This Mini PC is connected to the 5G CPE using an ethernet cable, and it includes a probe to measure DL throughput / UL throughput / latency. The probe sends the measurements to an InfluxDB database using the Open Application Model (OAM) interface to avoid disturbing 5G traffic. The result is then shown in Grafana tool.

The following Table 3 describes the radio network configuration during the tests in both coverage areas in 5Tonic lab room and 5Tonic X3 room. Such configuration is the same for all the tests performed in the context of Trial 1.1 and Trial 1.2 defined in D3.1 [1] and the related tests (three within the scope of Trial 1.1 and one within Trial 1.2) which differentiates in terms of the device types (i.e., robots, LiDARs and cameras) that have been connected to the network.

Table 3. Radio Network configuration.

Test setup parameters	Test setup ID: 5Tonic1-4
Radio access technology	5G NR
Network type	Laboratory
Standalone / Non-Standalone	Standalone
Cell Power	N/A
Frequency band	n78
Bandwidth per component carrier	100 MHz
Sub-carrier spacing	30 kHz
Multi-Input Multi-Output (MIMO)	4X4
Duplex mode	Time Division Duplex (TDD) (pattern: DDDSUDDSUU)
Slice Configuration	Private APN
Background traffic	Low

To ensure the correct operability of the different interconnected systems, the minimum network performance requirements are:

Robotics (for two robots)

- **Maximum latency**: 300 ms;
- **Maximum number of packages lost**: 0.5%;

- **Throughput min** (up and down): 10 Mbps
- **Throughput recommended**: 20 Mbps

LiDARS (for two LiDARs, one with 64 beams and the other with 128)

- **Maximum latency**: 10 ms
- **Throughput recommended** (up and down): 250 Mbps

Cameras (for two cameras, 1 fix and one PTZ)

- **Throughput min**: 20 Mbps

3.1.1 Trial 1.1 - Crowd monitoring through static infrastructure and artificial vision

3.1.1.1 Laboratory tests

Laboratory tests for Trial 1.1 consist of three different tests (i.e., Camera test, LiDAR test, and Saturation test) performed on the network configuration described in Table 3.

Camera test

In this test, uplink and downlink throughput and latency for fixed camera connection at different image qualities were measured. The network setup (Figure 28) was distributed between the 5Tonic lab room (iSOC position) and the 5Tonic X3 room (camera). This setup consists of mainly one PTZ camera and one server acting as iSOC position (Table 4). The camera is connected to a mini-PC where a probe will measure the KPIs. The probe is sending the measurements to a database located in 5Tonic DC using the OAM interface to avoid disturbing 5G traffic.

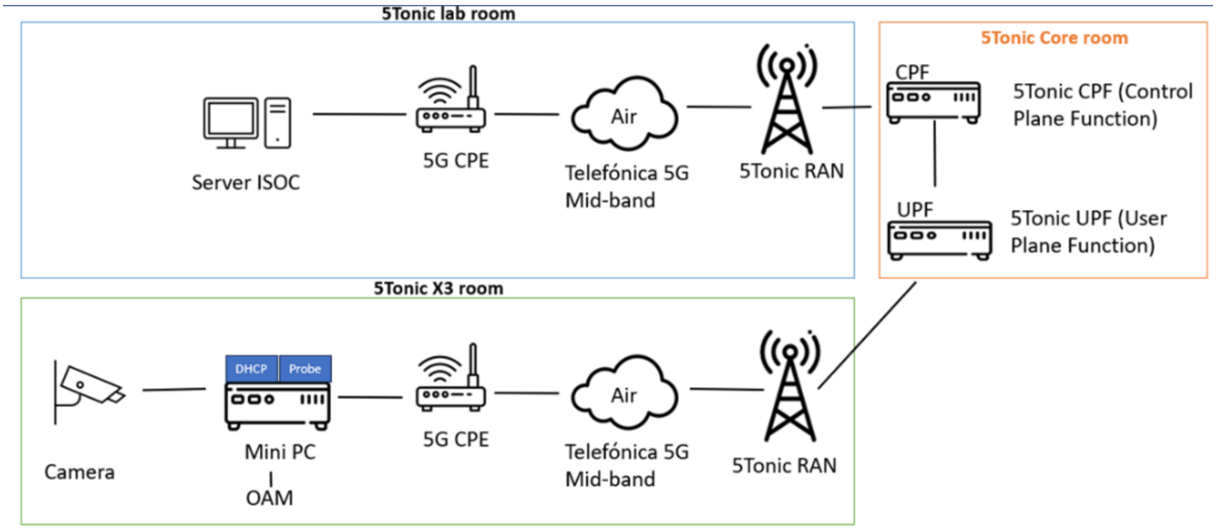

Figure 28. Network setup for Camera test.

Table 4. Test setup parameters for Camera test.

Test setup parameters	Test setup ID: 5Tonic1
Device type	iSOC Server
Device number	1
Device type	Camera PTZ AXIS Q6135-LE
Device number	1

This test was oriented to determine the traffic generated by the camera under different quality and compression configurations. Furthermore, latency, uplink and downlink throughput were measured to evaluate the capacity of the 5G network to transmit the generated information (Table 5).

Table 5. Test summary for Camera test.

Test summary	
Trial ID	1.1
Test setup ID	5Tonic1
Facility/Site	5Tonic
Objective	Demonstration of the video streaming transmission to iSOC
Description	The test has evaluated uplink and downlink throughput as well as latency
Executed by	PROS & Engineering Research Center (ERC)
Components involved	5G network, Routers, mini PC, iSOC server, PTZ Camera, 5Tonic Control Plane Functions (CPF)&UPF
Targeted KPIs	KPI#03 (Downlink aggregate throughput) KPI#04 (Uplink aggregate throughput) KPI#09 (Application one-way latency)
Measurement tools	RAN KPI and Probe in Mini PC
Ethics requirements implementation	Tests have been performed in laboratory with operators from the TrialsNet consortium and there are no ethical requirements implications. No images were recorded, and video streaming was made in a private environment.
Involvement of beta-users	No

Table 6 summarizes the results extracted from graphs shown in Figure 29. Without applying video compression, the generated traffic is transmitted at a lower speed than expected. It is expected that the latency will be increased over the 300 ms due to the additional latency of the AI processing, that could impact the real time reaction to incidents.

Table 6. Test cases results for Camera test.

Test case ID	Test requirement (for 1 camera)	Measurement result	Description	Validation
1.1_5Tonic1_01	KPI#03: 10 Mbps KPI#04: 10 Mbps KPI#09: 300 ms	KPI#03: 1.2 Mbps KPI#04: 20 Mbps KPI#09: 700 ms	3072 x 1728 25 fps (16:9) No video compression	Uplink throughput over minimum. Latency above the limit.
1.1_5Tonic1_02	KPI#03: 10 Mbps KPI#04: 10 Mbps KPI#09: 300 ms	KPI#03: 4 Mbps KPI#04: 25 Mbps KPI#09: 650 ms	3072 x 1728 12 fps (16:9) No video compression	Uplink throughput over the minimum. Latency above the limit.
1.1_5Tonic1_03	KPI#03: 10 Mbps KPI#04: 10Mbps KPI#09: 300 ms	KPI#03: 1.3 Mbps KPI#04: 24.5Mbps KPI#09: 400 ms	3072 x 1728 05 fps (16:9) No video compression	Uplink throughput over the minimum. Latency above the limit.
1.1_5Tonic1_04	KPI#03: 10 Mbps KPI#04: 10Mbps KPI#09: 300 ms	KPI#03: 0.9 Mbps KPI#04: 22 Mbps KPI#09: 100 ms	3072 x 1728 25 fps (16:9) compression 100	Uplink throughput over the minimum. Latency far below the limit
1.1_5Tonic1_05	KPI#03: 10 Mbps KPI#04: 10Mbps KPI#09: 300 ms	KPI#03: 0.9 Mbps KPI#04: 22 Mbps KPI#09: 100 ms	3072 x 1728 25 fps (16:9) compression 50	Uplink throughput over the minimum. Latency far below the limit.

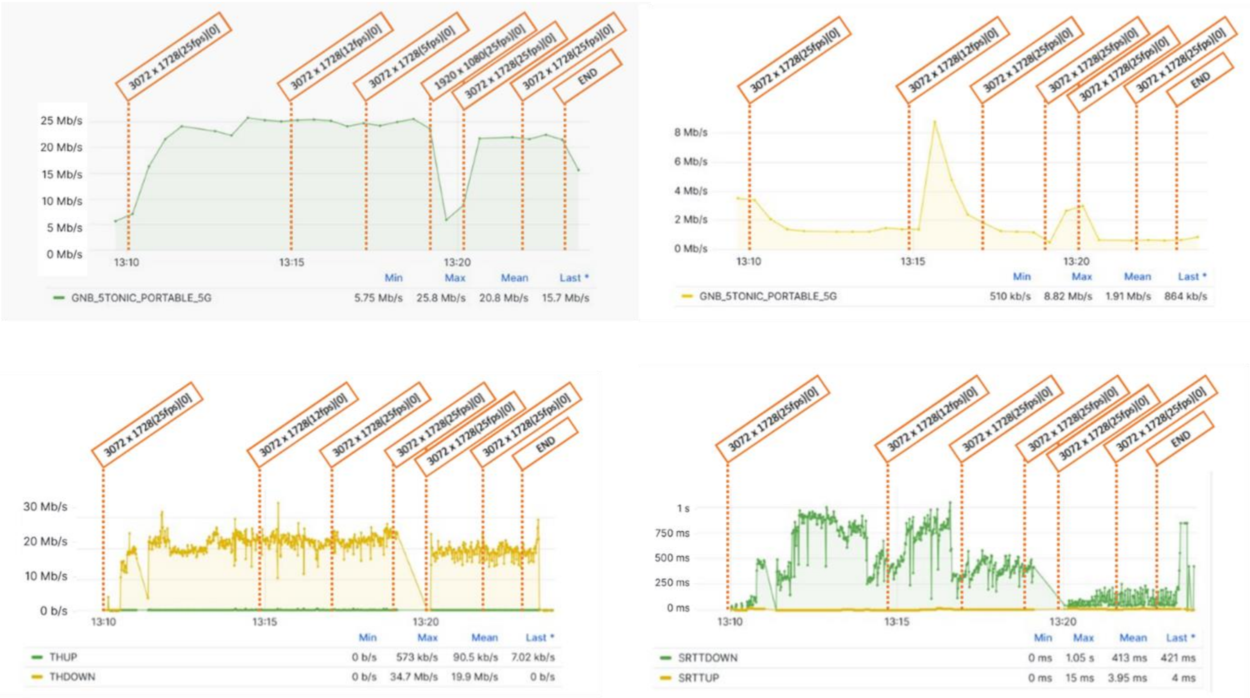

Figure 29. Uplink throughput (up, left), Downlink throughput (up, right), User data rate (down, left), and Latency (down, right).

LiDAR test

In this test, uplink throughput for the LiDAR was measured. Main devices deployed in these setups were a 64-beams LiDAR and a server simulating the iSOC position (Table 7). The network setup (Figure 30) was distributed between the 5Tonic lab room (iSOC position) and the 5Tonic X3 room (LiDAR). LiDAR is connected to a mini-PC where a probe will measure the KPI. The probe is sending the measurements to a database located in 5Tonic DC using the OAM interface to avoid disturbing 5G traffic.

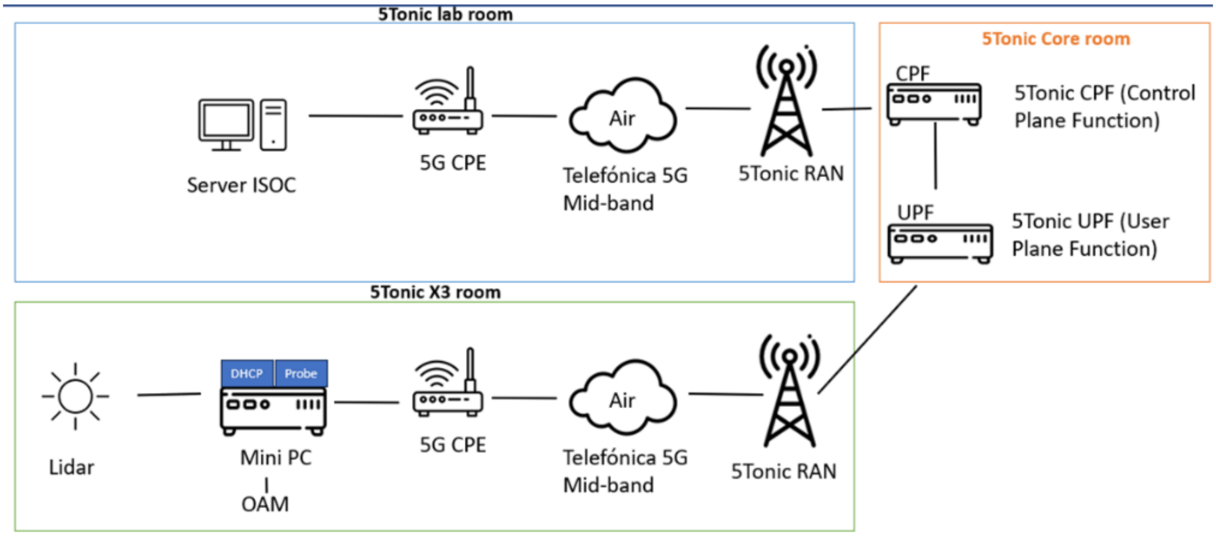

Figure 30. Network setup for LiDAR test.

Table 7. Test setup parameters for LiDAR test.

Test setup parameters	Test setup ID: 5Tonic2
Device type	iSOC Server
Device number	1
Device type	LiDAR Ouster OS0
Device number	1

Given the important expected traffic from the LiDAR, in this test the most critical KPI to be measured was the uplink throughput (Table 8).

Table 8. Test summary for LiDAR test.

Test summary	
Trial ID	1.1
Test setup ID	5Tonic2
Facility/Site	5Tonic
Objective	Demonstration of the cloud point transmission from LiDAR to iSOC
Description	The test has evaluated uplink throughput
Executed by	PROS & ERC
Components involved	5G network, Routers, mini-PC, iSOC server, LiDAR OS0, 5Tonic CPF&UPF
Targeted KPIs	KPI#04 (Uplink aggregate throughput)
Measurement tools	RAN KPI and Probe in Mini PC
Ethics requirements implementation	Tests have been performed in laboratory with operators from the TrialsNet consortium.
Involvement of beta-users	No

Table 9 summarizes the results of the measurements extracted from Figure 31. At maximum quality configuration of the LiDAR, the device produced an important amount of information, but less than expected. In all cases, the 5G network could transmit the information without getting saturated.

Table 9. Test cases results for LiDAR test.

Test case ID	Test requirement (1 LiDAR with 64 beams)	Measurement results	Description	Validation
1.1_5Tonic2_01	KPI#04: 83 Mbps	KPI#04: 19 Mbps	512 x 10 RNG19_RFL8_SIG16_NIR16	Traffic generated by the LiDAR is low.
1.1_5Tonic2_02	KPI#04: 83 Mbps	KPI#04: 39 Mbps	1024 x 10 RNG19_RFL8_NIR16	Traffic generated by the LiDAR is low.
1.1_5Tonic2_03	KPI#04: 83 Mbps	KPI#04: 50 Mbps	2048 x 10 RNG19_RFL8_SIG16_NIR16	Uplink throughput is below the minimum but not saturation limit is reached.
1.1_5Tonic2_04	KPI#04: 83 Mbps	KPI#04: 45 Mbps	512 x 20 RNG19_RFL8_SIG16_NIR16	Uplink throughput is below the minimum but not saturation limit is reached.
1.1_5Tonic2_05	KPI#04: 83 Mbps	KPI#04: 70 Mbps	1024 x 20 RNG19_RFL8_SIG16_NIR16	Uplink throughput is below the minimum because saturation limit is reached.

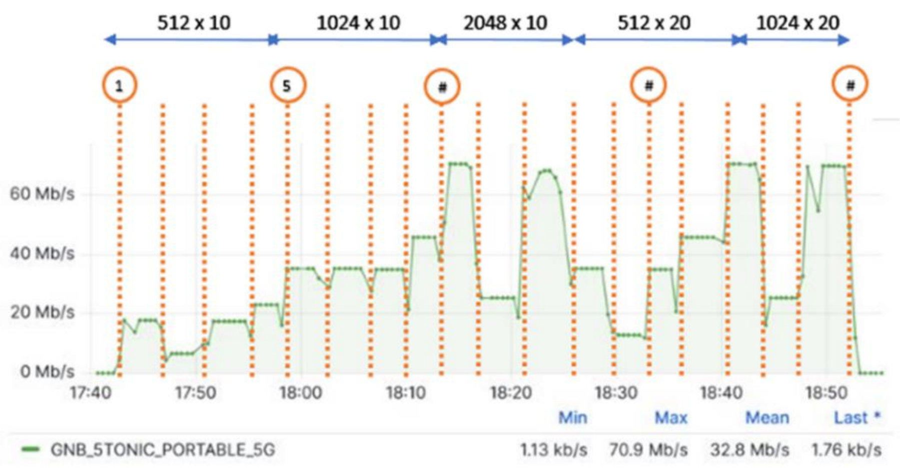

Figure 31. Test LiDAR - Setup_iSOC0 + Setup Devices 01 Uplink throughput.

Saturation test

In this test, uplink and downlink throughput and latency were measured when all the setups (robot, LiDAR and cameras) are connected to the 5G network. The network setup (Figure 32) was distributed between the 5Tonic lab room (iSOC position) and the 5Tonic X3 room (LiDAR, Camera and Robot). LiDAR is connected to a mini-PC where a probe will measure the KPI. The probe is sending the measurements to a database located in 5Tonic DC using the OAM interface to avoid disturbing 5G traffic. This test is oriented to determine if 5G networks can support the traffic simultaneously generated by all the devices of the different setups (see Table 10).

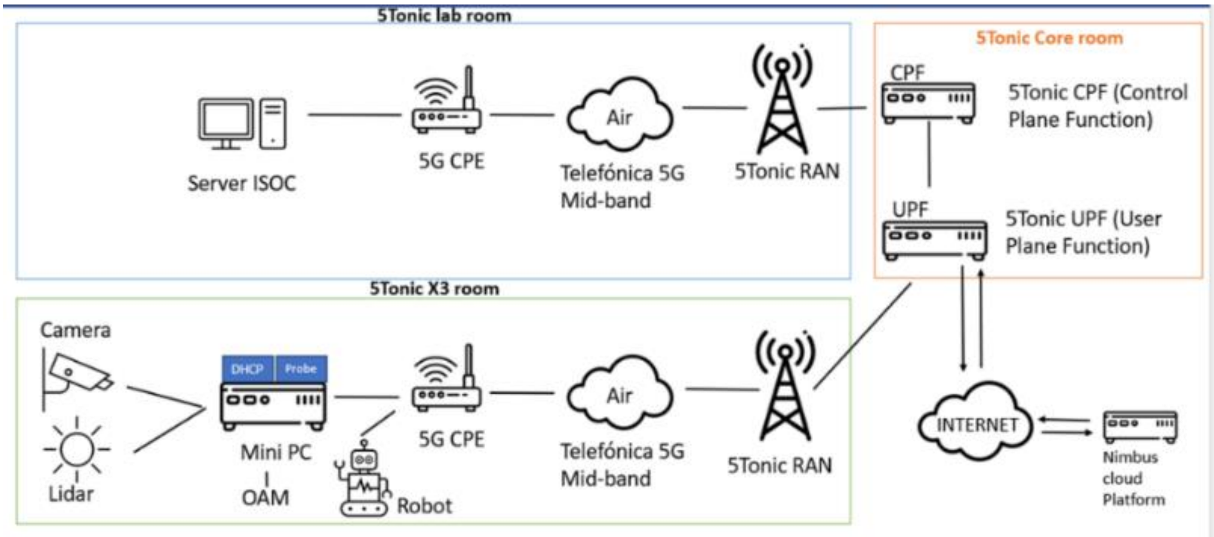

Figure 32. Network setup for Saturation test.

Table 10. Test setup parameters for Saturation test.

Test setup parameters	Test setup ID: 5Tonic3
Device type	iSOC Server
Device number	1
Device type	LiDAR Ouster OS0
Device number	2
Device type	Camera PTZ AXIS Q6135-LE
Device number	1
Device type	Robot Robotnik Summit XL
Device number	1

In Table 11 test objectives and conditions are summarized.

Table 11. Test summary for Saturation test.

Test summary	
Trial ID	1.1
Test setup ID	5Tonic3
Facility/Site	5Tonic
Objective	The goal of this test was to demonstrate that 5G network gets saturated when all de devices are connected
Description	The test has evaluated uplink and downlink throughput
Executed by	PROS & ERC
Components involved	5G network, Routers, mini-PC, iSOC server, LiDAR OS0, 5Tonic CPF&UPF; Kiiro robot with payload; Cloud based Nimbus
Targeted KPIs	KPI#03 (Downlink aggregate throughput) KPI#04 (Uplink aggregate throughput) KPI#09 (Application one-way latency)
Measurement tools	RAN KPI and Probe in mini PC
Ethics requirements implementation	Tests have been performed in laboratory with operators from the TrialsNet consortium
Involvement of beta-users	No

As can be seen in Figure 33 and Table 12, uplink throughput is reached twice during the test, when it reaches 80Mbps. This saturation resulted in a malfunctioning of the whole system. As shown in Figure 34, the average latency value is also over the expected limit of 300 ms, which will increase the difficulty in the future to use of AI algorithms to analyze video streams and cloud points from the LiDAR.

Table 12. Test cases results for Saturation test.

Test case ID	Test requirement (recommended)	Measurement result	Description	Validation
1.1_5Tonic3_01	Evaluation of Max KPI#04	KPI#03: 6 Mbps KPI#04: 80 Mbps KPI#09: 503 ms	The objective is to determine when saturation of net-work is achieved.	Saturation is reached at uplink throughput of 80Mbps. Latency is over the expected value.

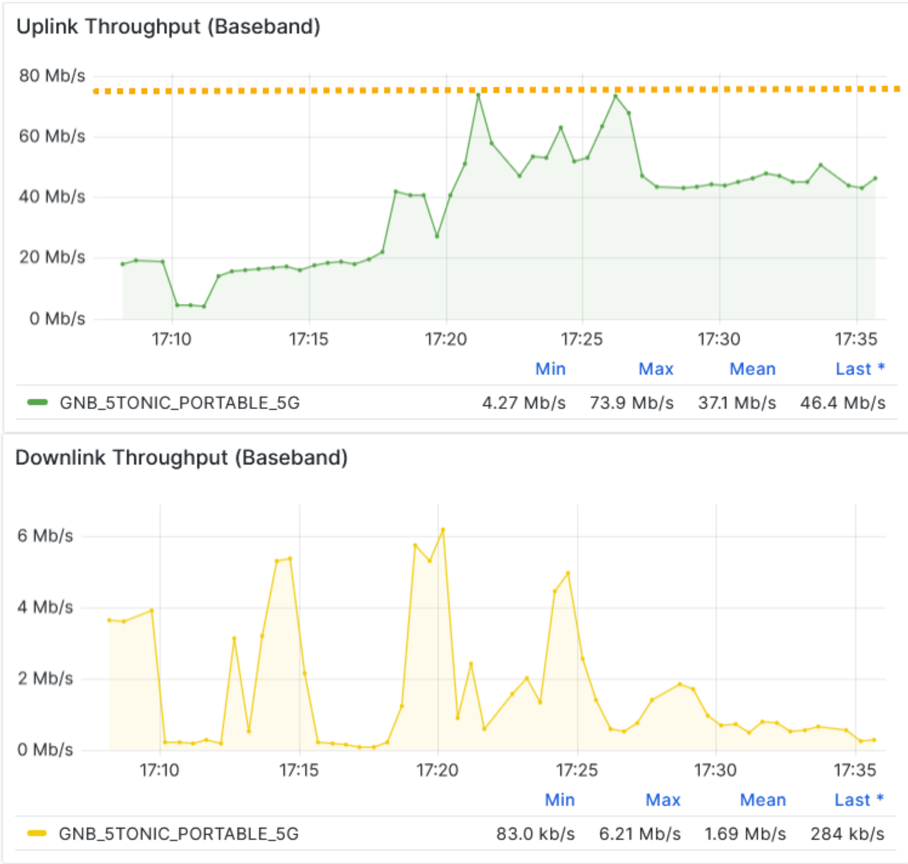

Figure 33. Uplink and downlink throughputs.

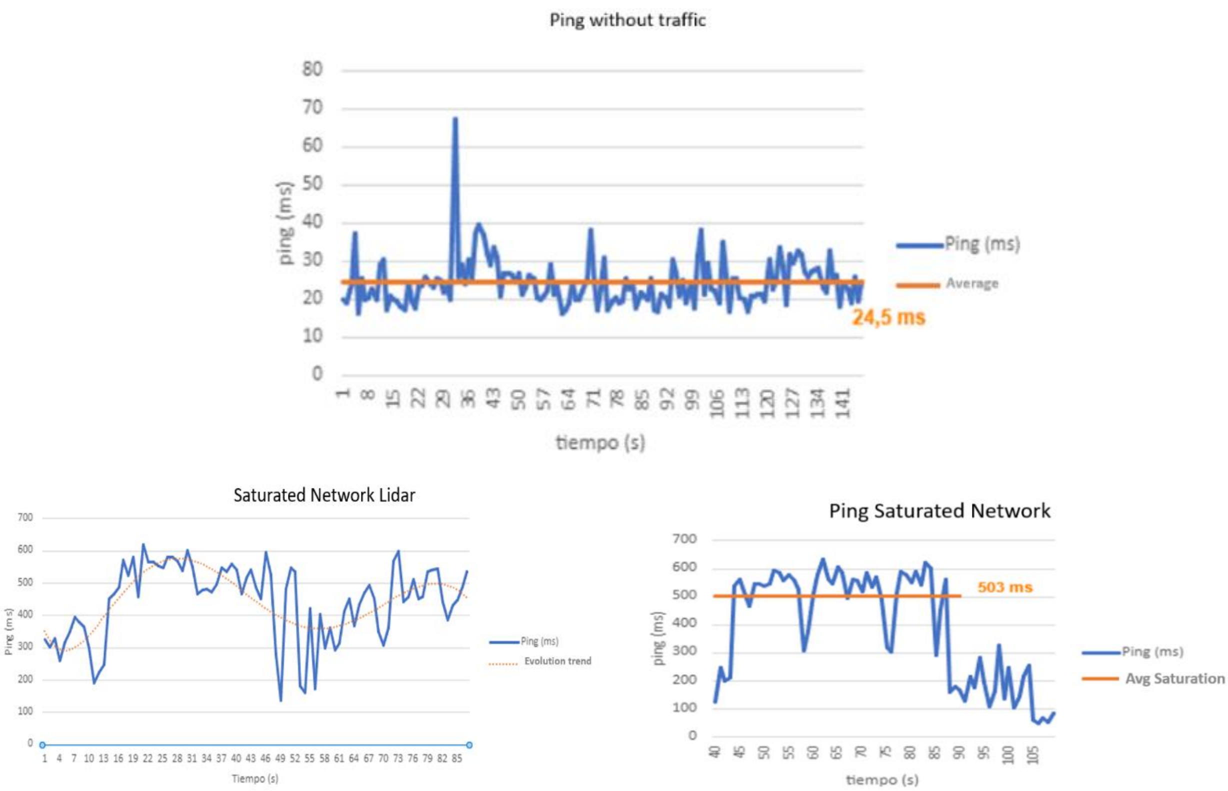

Figure 34. Latency: without traffic (up), LiDAR (down left), and all devices (down right).

3.1.1.2 Field test

Field test will be planned in the next activities as described in Section 3.1.2.2.

3.1.1.3 Early demos

Early demos activities are detailed in Section 3.1.2.3 as Trial 1.1 and Trial 1.2 are presented and disseminated together.

3.1.2 Trial 1.2 - Crowd monitoring through programmed or tele-controlled robots with AI

3.1.2.1 Laboratory tests

Laboratory tests for Trial 1.2 consist of one single test performed using Kiiro robot on the network configuration described in Table 3.

Kiiro test
In this test, uplink and downlink throughput to the Kiiro robot was measured under different combinations of the operational modes: robot in static mode, robot in movement, onboard PTZ sending video streaming (at different quality configurations), onboard LiDAR on, teleoperation from Nimbus. The connection to Nimbus cloud platform is made through the internet.

As shown in Figure 35 and Table 13, the setup installed at the 5Tonic Lab Room allows the devices to connect through 5G RAN to the 5G CORE. The Server iSOC and the robot are wireless connected to two different 5G CPEs. These CPEs uses the 5G RAN over Telefónica 5G Mid-band spectrum. In the 5G CORE side, the CPF and the User Plane Function (UPF) are located in the 5Tonic Core Room.

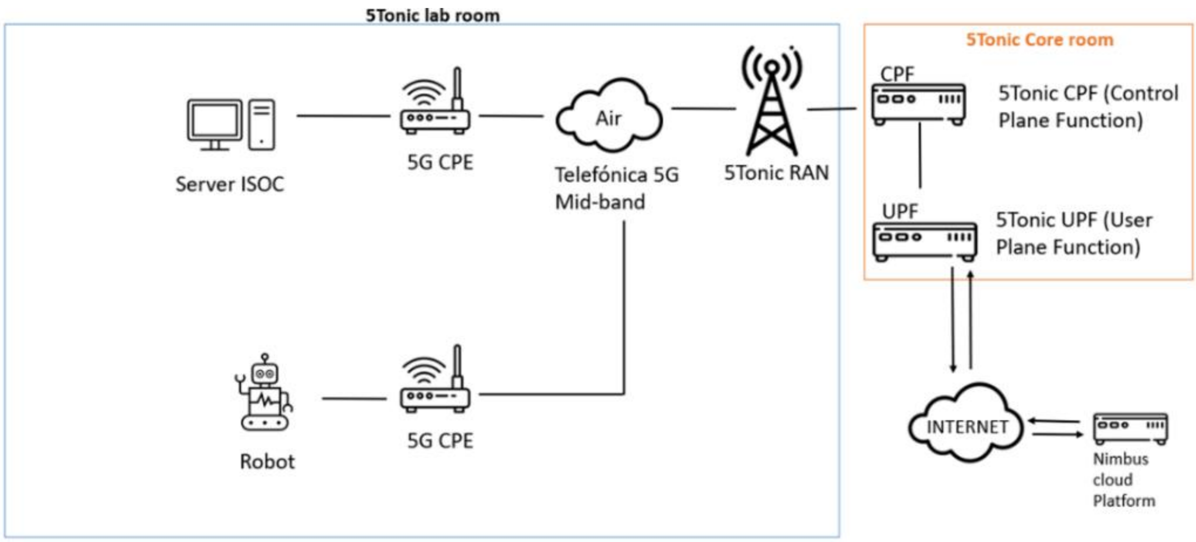

Figure 35. Network setup for Kiiro test.

One robot and one server acting as an iSOC position were the main devices of the tested setups.

Table 13. Test setup parameters for Kiiro test.

Test setup parameters	Test setup ID: 5Tonic4
Device type	iSOC Server
Device number	1
Device type	Robot Robotnik Summit XL
Device number	1

As described in Table 14, the test was oriented to evaluate uplink and downlink throughput to determine the traffic generated by the robot and to validate the capacity of the 5G network to support this traffic.

Table 14. Test summary for Kiiro test.

Test summary	
Trial ID	1.2
Test setup ID	5Tonic4
Facility/Site	5Tonic
Objective	Demonstration of the remote inspection and teleoperation of robots using 5G Network. D
Description	The test has evaluated uplink and downlink throughput variation with the activation of the different capacities of the robot (video streaming, on-board LiDAR, teleoperation). Information is received at the cloud-based Nimbus platform reached through the internet. Teleoperation is commanded from the Nimbus platform.
Executed by	PROS & ERC
Components involved	5G network, Routers, iSOC server, Kiiro robot with payload, 5Tonic CPF&UPF; Cloud based Nimbus
Targeted KPIs	KPI#03 (Downlink aggregate throughput) KPI#04 (Uplink aggregate throughput)
Measurement tools	RAN KPI
Ethics requirements Implementation	Tests have been performed in laboratory with operators from the TrialsNet consortium. No images were recorded, and video streaming was made in a private environment.
Involvement of beta-users	No

Test results are shown in Table 15 and Table 16 with the values of the KPIs extracted from graphs shown in Figure 36 and Figure 37. In the test it was demonstrated that only the full functioning of the robotic system (including LiDAR, high quality video stream and teleoperation of the robot) produced the expected uplink traffic of 10 Mbps. The 5G network could transmit this traffic without reaching a saturation point.

Table 15. Test cases results for Kiiro test (a).

Test case ID	Test requirement (for 1 robot)	Measurement result	Description	Validation
1.2_5Tonic4_01	KPI#03: 10 Mbps KPI#04: 10 Mbps	KPI#03: 0.25 Mbps KPI#04: 7.4 Mbps	Robot stopped 1 Video-Stream: low quality	Min. throughput not achieved because not enough traffic is generated.
1.2_5Tonic4_02	KPI#03: 10 Mbps KPI#04: 10 Mbps	KPI#03: 0.25 Mbps KPI#04: 7.4 Mbps	Robot on movement 2 Video-Stream: max quality LiDAR off	Min. throughput not achieved because not enough traffic is generated.
1.2_5Tonic4_03	KPI#03: 10 Mbps KPI#04: 10Mbps	KPI#05: 0.2 Mbps KPI#04: 8Mbps	Robot on movement Video-Stream: max quality LiDAR on	Min. throughput not achieved because not enough traffic is generated.
1.2_5Tonic4_04	KPI#03: 10 Mbps KPI#04: 10 Mbps	KPI#03: 0.3 Mbps KPI#04: 10 Mbps	Robot on movement Video-Stream: max quality LiDAR on Teleoperation from Nimbus	Min downlink throughput not achieved because not enough traffic is generated. Uplink throughput reaches the minimum requirements.

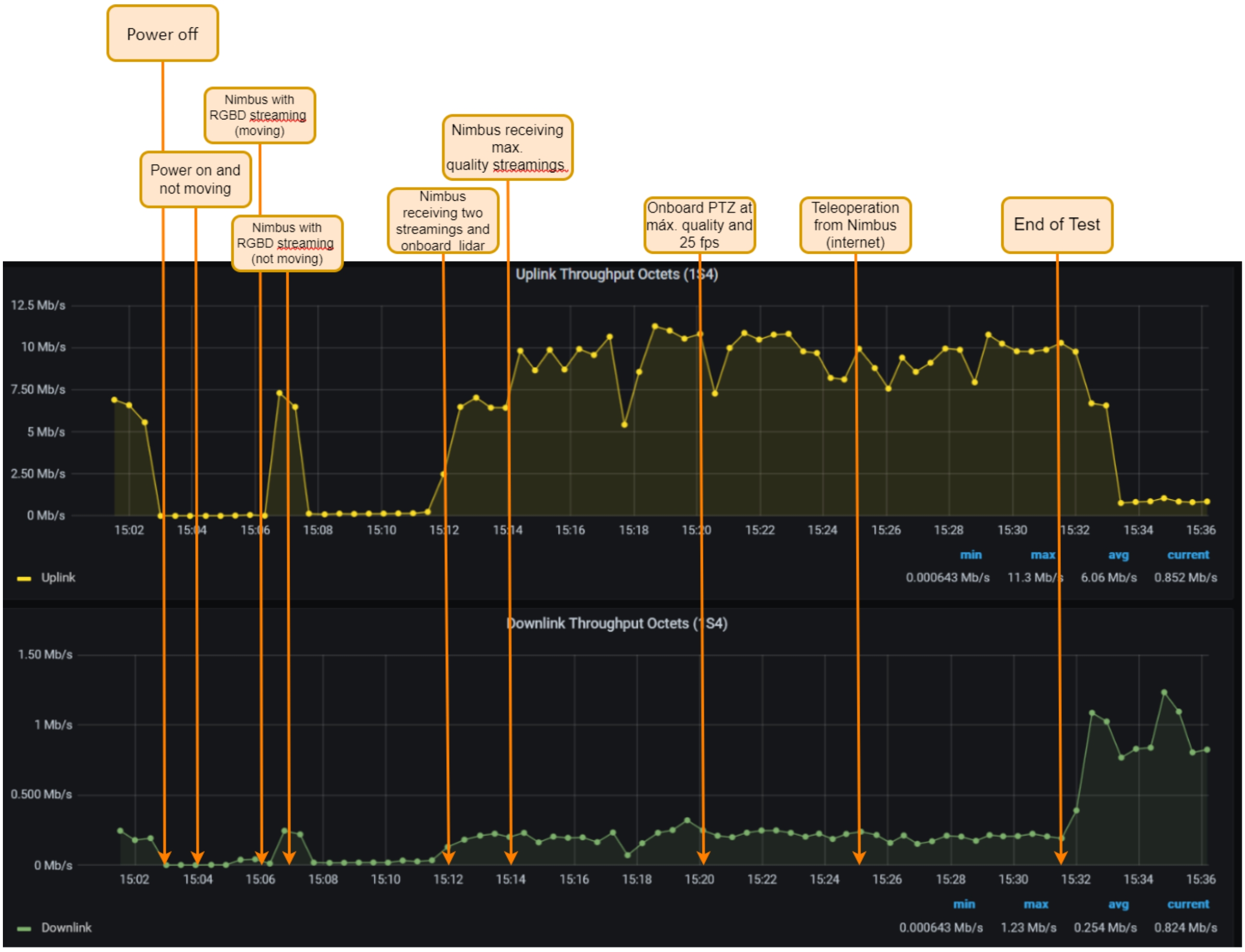

Figure 36. Uplink and downlink throughput for for Kiiro test (a).

Table 16. Test cases results for Kiiro test (b).

Test case ID	Test requirement (recommended)	Measurement result	Description	Validation
1.2_5Tonic4_05	KPI#03: 10 Mbps KPI#04: 10 Mbps	KPI#03: 11 Mbps KPI#04: 12 Mbps	Teleoperation from Nimbus with two streaming and LiDAR	5G Network transmit at higher speed than required.
1.2_5Tonic4_06	KPI#03: 10 Mbps KPI#04: 10 Mbps	KPI#03: 2.5 Mbps KPI#04: 2.5 Mbps	Teleoperation from HMI	Teleoperation from HMI generates very low traffic
1.2_5Tonic4_07	KPI#03: 10 Mbps KPI#04: 10Mbps	KPI#03: 0.25 Mbps KPI#04: 0.25 Mbps	Robot sending video stream to iSOC (Genetec)	Not much traffic generated by video stream
1.2_5Tonic4_08	KPI#03: 10 Mbps KPI#04: 10 Mbps	KPI#03: 0.25 Mbps KPI#04: 1 Mbps	Robot sending video stream to iSOC (Genetec) and 10 consecutive technical alerts sent to Genetec	Not much traffic generated by video stream and technical alerts.

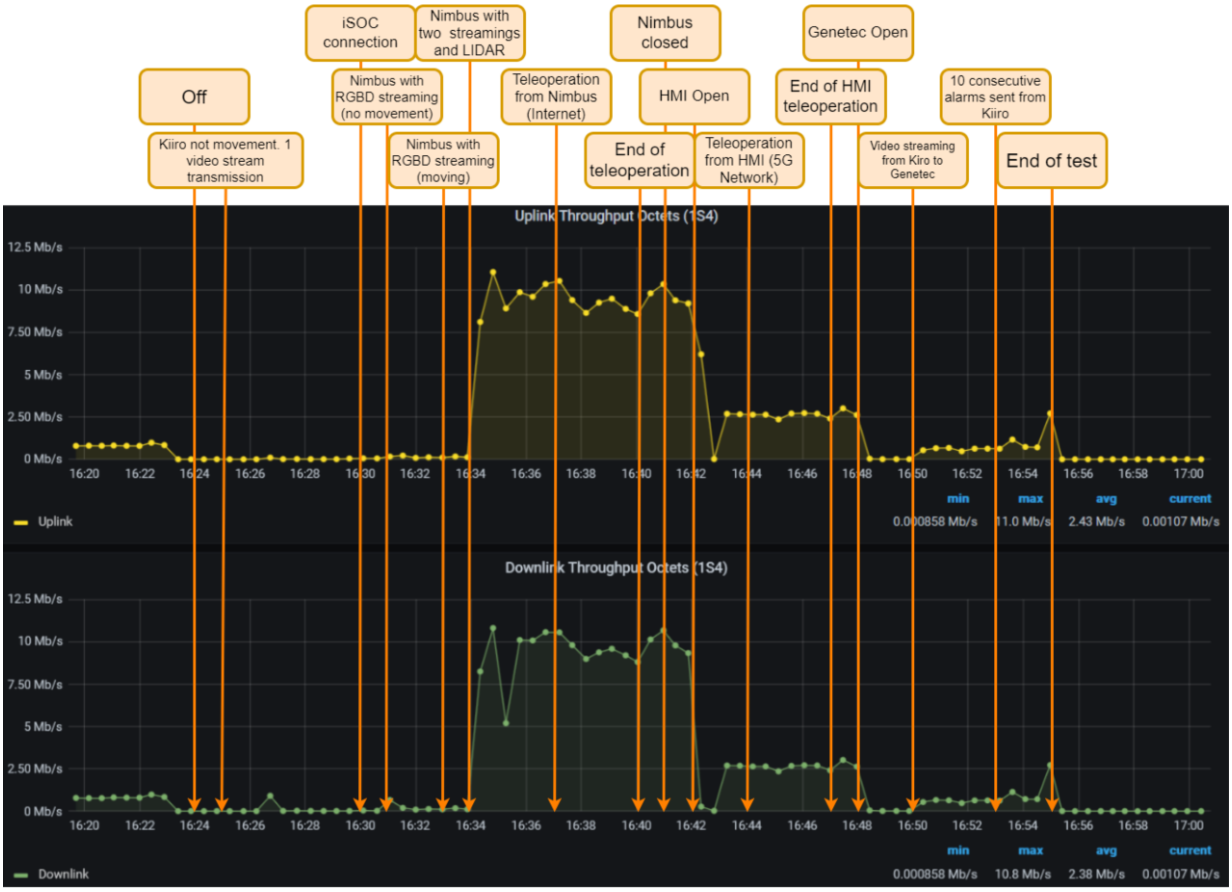

Figure 37. Uplink and downlink throughput for Kiiro test (b).

3.1.2.2 Field test

Field test will be carried out during Q4 2024 at Wizink Center during a basket match. In order to prepare for the real environment test, several actions will have to be done:

- TID has to book a band in the millimetre wave band for the selected location and dates for the pilot.
- ERC will provide PROS with the new routers ready for B5G
- PROS will enlarge the setups with one more camera, one more Lidar and one more robot, and configurate the system to communicate through the new routers
- ERC will have to plan the setup of the antennas in the field test environment
- TID will carry out pre-test and post-test interviews with the different operators of the security team to evaluate the KVIs

3.1.2.3 Early demos

Moreover, a brief self-explained video [42] was prepared and inserted in the post in order to provide more visual information about the trial and achieved results (see Figure 38).

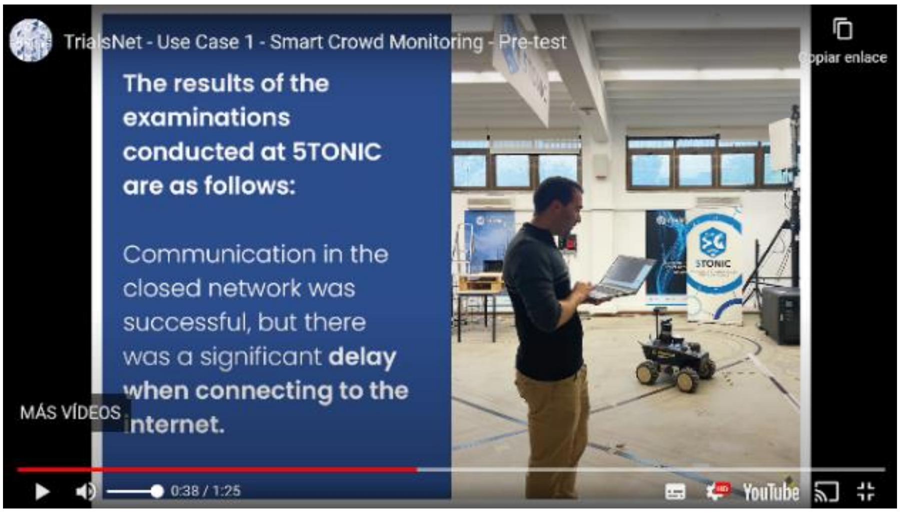

Figure 38. Captures from the dissemination video of UC1 tests in 5Tonic.

3.1.3 Remarks and next steps

As the outcome of the testing activity, the following remarks can be made:

- 5G network can support the operation of the Kiiro robot under the required network quality parameters
- The network offers adequate latency for video stream only if compression is applied but fall short of the requirements for high quality stream transmission
- LiDAR traffic is supported at low quality levels but for high resolution the network saturates at an uplink throughput of 70 Mbps
- When all the devices are connected, 5G networks reaches a state of saturation and operation is not possible. Saturation is achieved with only one robot, one LiDAR and one camera. In the real environment trial, one more camera, robot and LiDAR will be added so 5G network will not stand the expected generated traffic. B5G networks providing an increased bandwidth and reduced latency will be required for that demonstration
- The next step involves revisiting the pre-test after optimizing the 5G network, to test jitter and latency values under the improved bandwidth capacity
- VPN would be advisable to facilitate the integration between the devices (LiDAR and cameras) with the processor and the server, both being in different networks

Based on the above, the next steps and coming tests are summarized below:

- The next step involves revisiting the pre-test after optimizing the 5G network, to test jitter and latency values under the improved bandwidth capacity
- VPN would be advisable to facilitate the integration between the devices (LiDAR and cameras) with the processor and the server, both being in different networks
- Edge computed algorithms analyzing images from the robot and cloud algorithms analyzing images from the cameras will be tested in order to evaluate their precision, recall, accuracy and F1 score
- Simultaneous use of two robots, two LiDARs and two cameras will be included in the real environment setups to stress the B5G network and identify the uplink throughput limits of this type of network

3.2 UC1: Smart Crowd Monitoring (Iasi)

3.2.1 Trial 1.3 - Crowd monitoring using Wi-Fi information

Trial 1.3 focuses on outdoor public events by managing people counting, density, and dynamics of large numbers of persons (flow directions, spread, speed) by using Wi-Fi data collected by the Access Points installed on Stefan cel Mare Boulevard and in Piata Palat. Details on the area in which the Wi-Fi Hotspot has been deployed can be seen from the Figure 39. The diagram also depicts the coverage within the Wi-Fi Hotspot in both 2.4 GHz and 5 GHz while showing the points at which the field tests have been performed (red circles).

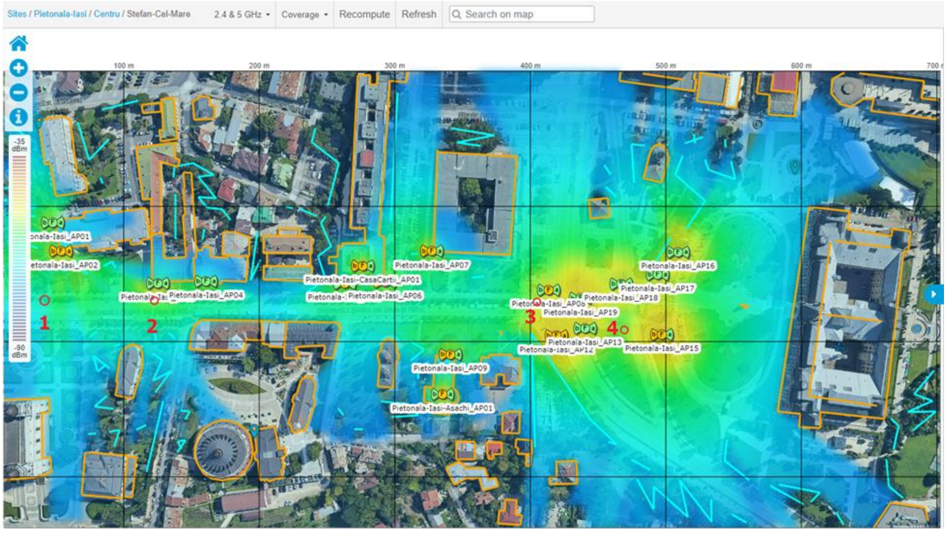

Figure 39. Wi-Fi Coverage Map – Stefan cel Mare Bd. Piata Palat, Iasi.

The tests proposed for this use case present the benefits offered by open spectrum technologies (Wi-Fi) with the scope of providing crowd information statistics. Wi-Fi analytics technologies were used together with the camera analytics technologies to achieve the proposed objective: improving the protection of people in crowded public spaces. The measurement techniques that have been used in this first trial imply the delivery of crowd information dynamics during events vs during normal traffic weeks while also verifying through on-site Wi-Fi service KPI measurements that the quality of the service is normal for the Wi-Fi Analytics service to perform its functions properly.

Crowd characterization in terms of people counting, density, and dynamics of large numbers of persons (flow directions, spread, speed) as well as Wi-Fi service KPIs were measured both in laboratory and on-field testing activities as detailed in the following sections.

3.2.1.1 Laboratory tests

The first set of tests were performed remotely, during the "Sf. Parascheva" event, which is a very important religious event that took place in the Wi-Fi hotspot area in the middle of October 2023.

Figure 40. Wi-Fi Presence Analytics Heatmap.

During the "Sf. Parascheva" event a dataset was gathered. After one week (this time a normal week in terms of crowd mass and dynamics), another gathering of dataset was performed. After the 2 datasets were gathered, a comparison in Wi-Fi Analytics metrics was performed between the two and the results are presented in the following. Note that the trial setup is always on and gathering analytics data, but for the scope of this trial, certain time intervals were used.

From the Wi-Fi Coverage Map the Wi-Fi analytics heatmap (Figure 40) is used, which shows people presence density according to the number of people detected by the Wi-Fi access points using wireless beaconing / triangulation technologies.

Note that the Wi-Fi presence heatmap is generated by the interaction between the Access Points of the Wi-Fi Hotspot and the client devices that have the Wi-Fi connection on. As most mobile devices have Wi-Fi turned on by default, multiple messages are exchanged between the device and the Wireless Access Point, without even the device being connected to the Wi-Fi network. Information such as wireless signal strength and device Medium Access Control (MAC) address are exchanged between the device and the APs through a process called beaconing. Using radio signal data and triangulation technology, the devices are mapped on a 2D map by the Wi-Fi Analytics Engine and displayed on a web dashboard. The numbers on the map represent the number of clients connected to a wireless Access Point. The percentage may vary, but usually, the Wi-Fi beaconing to Wi-Fi connected devices ratio is somewhere between 1:5 to 1:10.

In the following the laboratory tests performed during this phase are detailed. All tests were performed with a deployed Wi-Fi infrastructure, end to end connected to obtain data as accurate as possible. The application focuses on some test metrics of interest for crowd analysis scenarios, such as estimated crowd density, total people in a region, user dwell time in the location, dense areas vs less dense areas, and basic crowd density dynamics. For most of the metrics (where applicable), a comparison was made between the values obtained during an event (Sf. Parascheva vs a normal weekend).

People counting in pedestrian areas (event vs normal)
For the people counting tests in pedestrian areas, the Wi-Fi Analytics platform (powered by Cisco CMX) was used based on which the Visitor Count, Dwell Time, and Dwell Time Breakdown metrics have been measured. In particular, the tests focus on the differences in values for the specific metrics, between an event weekend and two normal weekends. Results are reported in the following.

Visitor Count (the appearance of a device in an area on a single day connected to Wi-Fi or by Wi-Fi beaconing): As can be seen from the comparative charts in Figure 41, in the Event Weekend, the Wi-Fi hotspots detected, using Wi-Fi beaconing techniques, more than double the amount of Wi-Fi enabled devices in the same timeframe than in Normal (Non-Event) Weekends.

Figure 41. Visitor Count: Weekend (left), Normal Weekend 1 (center), Normal Weekend 2 (right).

Dwell Time (median length of visits to an area - or areas - for the given time): In terms of Dwell Time, there are very little differences between an Event Weekend and a Non-Event/Normal Weekend (Figure 42). What can be observed is that in a Normal Weekend, at night (between 12 am – 5 am, there is a spike in Dwell Time which means that there even though there are less devices in the Wi-Fi zone (connected or not), the same devices spend substantial more time than in the rest of the day. In comparison, on an Event Weekend, although there are more devices, these devices are in “motion” (which might resemble the moving pilgrims on a religious event).

Figure 42. Dwell Time: Weekend (left), Normal Weekend 1 (center), Normal Weekend 2 (right).

Dwell Time Breakdown (the Dwell Time metric split in groups): These metrics have higher values than the classic Dwell Time, because it takes into consideration Visits of 5 minutes and under and 8 hours or above. The data reported in Figure 43 can offer some interesting insights on what happened in terms of crowd dynamics. For example, the high peak in the Event Weekend happened on Saturday, morning to mid-day (10 AM to 2 PM), the 0-5min Dwell Time was double as that in a Normal Weekend – which would suggest higher crowd mobility.

Figure 43. Dwell Time Breakdown – Event: Weekend (left) and Normal Weekends (center, right).

People density estimation (event vs normal)

In this test case, Wi-Fi Network Management Systems statistics are used to compare the level of people density between a special event (Sf. Parascheva, 13th-15th of October Weekend) and one or two normal weekends (20th-22nd of October Weekend, 27th-29th of October Weekend). For these weekends, metrics such as Unique Users and Wi-Fi traffic statistics have been generated in .csv files and the numbers have been compared. All these statistics have been generated for devices that have connected to the Wi-Fi network. Results are reported in the following.

Traffic results: Using the Wi-Fi NMS, data regarding Download and Upload traffic is measured in an Event Weekend and two other weekends. After the initial data is gathered and listed in a table, a simple average is applied on the two values of Normal Weekend 1 and 2. Then, that average is compared to the Event Weekend value. From the Table 17, higher values of Traffic (Upload + Download) can be observed in the event weekend when compared with normal weekends.

Table 17. Wi-Fi Aggregated Traffic Data.

Days	Upstream (GB)	Downstream (GB)	Total Traffic (GB)
TOTAL 13-14.10.2023	19.16	78.01	97.17
TOTAL 20-22.10.2023	8.12	59.41	67.53
TOTAL 27-29.10.2023	11.95	58.88	70.83

Table 18. Wi-Fi Unique Daily Users.

Day	Event Weekend (13-15.10.2023)	Normal Weekend 1 (20-22.10.2023)	Normal Weekend 2 (27-29.10.2023)
Day 1	4213	3588	3944
Day 2	7473	4275	3981
Day 3	7377	5630	5522

Unique Daily Users results: Using the Wi-Fi NMS, data about Unique Users that have connected to the public wireless service on the Stefan cel Mare Bd. and in Piata Palat can be extracted for analysis. Again, the time intervals of interest are an Event Weekend (Sf. Parascheva) vs two Normal (Non-Event) Weekends. In order to have a relevant comparison between the Event Weekend and the two Normal Weekends (Non-Event Weekends), numbers from the normal weekends are added, then divide it by two, to obtain an average and then compare that average with the Event Weekend data. From Table 18, and considering the method described above, the following can be observed (Event Weekend vs Normal Weekend Average):

- An increase of about +11.82% of Unique Users on Friday.
- An increase of + 81.03% of Unique Users on Saturday (main day of event).
- An increase of + 32.29% of Unique Users on Sunday (day after the event)
- During the main event (October 14th) the number of Unique Users is almost double. Also, on Sunday, although the day with the highest Unique Users count in a Normal Weekend, there are still over +32% of Unique Users

Both confirm the fact that there were a lot more people in the venue during the event when compared to a normal weekend.

3.2.1.2 Tests on field

Tests on crowd characterization in terms of people counting, density, dynamics of large numbers of persons (flow directions, spread, speed), and detecting special situations have been performed by implementing the test setup as detailed in Table 19. The summary of the tests is presented in Table 20 while the results of the tests are presented in Table 21.

Table 19. Field setup description for Trial 1.4.

Test setup parameters	Test setup ID: Field01
Radio access technology	Wi-Fi
Network type	Experimental
Wi-Fi Standard	Wi-Fi 5 (802.11 ac wave 2)
Cell Power (Maximum Conducted Transmit Power)	Cisco 1562: 2.4 GHz, 5 GHz: 27 dBm Cisco 1572: 2.4 GHz, 5 GHz: 30 dBm
Frequency band	2.4 GHz & 5GHz
Bandwidth per component carrier	312.5 kHz
Sub-carrier spacing	Orthogonal Frequency Division Multiplexing (OFDM)
MIMO	4x4 MIMO, 3 Spatial Streams
Duplex mode	Half-Duplex
Device type	Wi-Fi Access Point
Device number	Cisco AIR-AP1562E-E-K9, Cisco AIR-AP1572EAC-B-K9
Device speed	Up to 450 Mbps on 2.4 GHz, 1300 Mbps on 5 GHz
Background traffic	Medium (Public Wireless Frequencies)

Table 20. Field test summary for Trial 1.3.

Test summary	
Trial ID	1.3
Test setup ID	Field01
Facility/Site	Iasi
Objective	Demonstration of the Wi-Fi analytics application capabilities (1st version) and performance testing for the supporting backhaul network
Description	The application focuses on several distinct scenarios of practical interest: a) estimation of crowd density in the surveyed area; b) total count of people passing through a specific access facility; c) crowd density dynamics and its real-time evolution.
Executed by	TUIASI & ORO
Components involved	Wi-Fi network, Access Points, Switches and Routers, edge-compute infra-structure, Wi-Fi analytics application
Targeted KPIs	KPI#03 (Downlink aggregate throughput) KPI#04 (Uplink aggregate throughput) KPI#09 (Application one-way latency)
Measurement tools	Wi-Fi Network Signal, nPerf, SpeedTest,
Ethics requirements implementation	No personal data have been involved in the test.
Involvement of beta-users	N/A

Table 21. Test cases results for Trial 1.3.

Test case ID	Test requirement	Measurement result	Validation
4.1_Field01_01	KPI#03: > 55% of Physical Layer (PHY) KPI#04: > 55% of PHY KPI#09: < 40 ms	PHY: 100 Mbps KPI#03: 78.53 Mbps KPI#04: 42.41 Mbps KPI#09: 27 ms	Medium Distance Test- Passed. Test was performed during the winter holidays fair that was happening on the Stefan cel Mare Boulevard.
4.1_Field01_02	KPI#03: > 55% of PHY KPI#04: > 55% of PHY KPI#09: < 40 ms	PHY: 135 Mbps (> 74.24 Mbps) KPI#03: 120.1 Mbps KPI#04: 101.41 Mbps KPI#09: 30 ms	Proximity Test-Passed Test was performed during the winter holidays fair that was happening on the Stefan cel Mare Boulevard.
4.1_Field01_03	KPI#03: > 55% of PHY KPI#04: > 55% of PHY KPI#09: < 40 ms	PHY: 150 Mbps KPI#03: 67.82 Mbps KPI#04: 75.41 Mbps KPI#09: 35 ms	Medium Distance Test-Passed Test was performed during the winter holidays fair that was happening on the Stefan cel Mare Boulevard.

4.1_Field01_04	KPI#03: > 55% of PHY KPI#04: > 55% of PHY KPI#09: < 40 ms	PHY: 200 Mbps KPI#03: 175.74 Mbps KPI#04: 96.92 Mbps KPI#09: 32 ms	Proximity Test-Passed. Test was performed during the winter holidays fair that was happening on the Stefan cel Mare Boulevard.

As stated in the previous sections, the main scope of the field tests were the Wi-Fi Quality of Service metrics evaluations of the Wi-Fi hotspot and comparing the on-field results with the parameters reported by the Network Management Systems. All tests were performed by the TUIASI team during November, on a higher-than-average traffic day. As can be seen from the table, in some tests, performance on only some parameters is mildly degraded in some tests, while for most tests, all parameters are in normal value ranges, which means that both the Wi-Fi service and the Wi-Fi Analytics service functioned correctly during all the test sessions.

3.2.1.3 Early demo

The laboratory tests described in section 3.2.1.1 will be used for demo purposes during the dissemination events that will be organized with Iasi City Hall, as project vertical partner, during the second part of 2024 and 2025.

3.2.2 Trial 1.4 - Crowd monitoring using cameras

Trial 1.4 focuses on crowd monitoring using surveillance cameras connected over 5G. The target venues for this trial are the pedestrian area of the Stefan cel Mare Boulevard from Iasi, as well as the place in front of the Palace of Culture. The trial focuses on several distinct scenarios of practical interest such as a) estimation of crowd density in the surveyed area, and b) detecting objects entering within a restricted access area. Pre-trained neural networks people counting models were ingested into the Triton Server from the DeepStream framework. Video analytics are computed and displayed in terms of total number of people in a user-defined area of interest, and heatmaps estimating people density on the same area.

3.2.2.1 Laboratory tests

The tests in UC1 were carried out directly on-field because the cameras were installed in the final positions during the summer of 2023. These tests are detailed in the following section.

Figure 44. Laboratory room- Command and monitoring center.

However, a laboratory area was also defined, which became the command and monitoring center of UC1 and UC4, as in Figure 44. Calibrating the image processing algorithm and dashboard development for the use case application were also done in the laboratory. Camera connectivity tests were run from the laboratory room as well. Initial lab tests were performed using pre-recorded videos including images with much data. Restricted access and only for the consortium partners have been implemented in the control room.

3.2.2.2 Tests on field

Since the hardware installations that happened in early October in Iasi, that involved the mounting and configuration of the surveillance cameras and 5G routers on lighting poles in the use case area, field tests were performed periodically by TUIASI, together with ORO.

The tests proposed for this use case present the benefits offered by B5G (towards 6G) technologies for improving the protection of people in crowded public spaces. Test on crowd characterization in terms of people counting, density, dynamics of large numbers of persons (flow directions, spread, speed) and detecting special situations scenarios (i.e., people/car detection in forbidden areas) were performed by implementing the test setup as detailed in Table 22, while the test summary is presented in Table 23.

Table 22. Field setup parameters for Trial 1.4.

Test setup parameters	Test setup ID: Field01
Radio access technology	5G NR
Network type	Commercial
Standalone / Non-Standalone	Non-Standalone
Cell Power	50 dBm (~120 W)
Frequency band	n78
Bandwidth per component carrier	100 MHz
Sub-carrier spacing	30 kHz
MIMO	64TX 64RX
Duplex mode	TDD
Device type	5G CPEs / 5G Camera
Device number	6
Device speed	0 km/h
Slice Configuration	Private APN
Background traffic	Low

Table 23. Field test summary for Trial 1.4.

Test summary	
Trial ID	1.4
Test setup ID	Field01
Facility/Site	Iasi
Objective	Demonstration of the video analytics application capabilities (1st version) and performance testing for the supporting 5G network
Description	The application focuses on several distinct scenarios of practical interest: a) estimation of crowd density in the surveyed area; b) total count of people passing through a specific access facility; c) detecting objects entering within a restricted access area.
Executed by	TUIASI & ORO
Components involved	5G network, Cameras and Routers, edge-compute infrastructure, video analytics application
Targeted KPIs	KPI#01 (Downlink throughput per user) KPI#02 (Uplink throughput per user) KPI#04 (Uplink aggregate throughput) KPI#06 (Uplink throughput per device) KPI#08 (Application round-trip latency)

Measurement tools	SpeedTest, ping
Ethics requirements implementation	Privacy preserving solution preventing people identification based on reducing video resolution. Restricted access in the control room. No personal data monitored or stored.
Involvement of beta-users	During the field tests, the current state of the video analytics application was showcased to the Iasi Municipality team for initial feedback on the implemented features.

Several field tests were performed to assess the solution's performance; the results showcased in Table 24.

Table 24. Network level test cases results for Trial 1.4.

Test case ID	Test requirement	Measurement result	Validation
1.4_Field01_01	KPI#01: 500 Mbps KPI#02: 150 Mbps KPI#04: > 50 Mbps KPI#08: < 50 ms	KPI#01: 130 Mbps KPI#02: 62 Mbps KPI#04: > 50 Mbps KPI#08: 39 ms	Test case 01 was performed during the Sf. Parascheva religious celebration, when over 100000 people were present in the Stefan cel Mare boulevard area. Because of this huge demand on the network, the downlink and uplink throughput were significantly lower than expected, indicating the increased demand for connectivity in the UC1 area, and the E2E latency was approaching the considered limit. Even if the cell started to get congested, the needed > 50 Mbps uplink cell capacity was still ensured.
1.4_ Field01_02	KPI#01: 500 Mbps KPI#02: 150 Mbps KPI#04: > 50 Mbps KPI#08: < 50 ms	KPI#01: 720 Mbps KPI#02: 110 Mbps KPI#04: > 50 Mbps KPI#08: 28 ms	Test case 02 was performed during the winter holidays fair that was also happening on the Stefan cel Mare boulevard. By this time, downlink throughput was closer to the target and E2E latency was significantly better.

Application-level tests were done by capturing and analyzing the video traffic streamed from one or more the camera devices up to the 5G Lab Edge Compute infrastructure. The cameras are mounted on three different poles (#1, #2, #3). All video streams have H264 encoding with compression level set to 30 and have the Axis Zipstream compression technology enabled. Note that the throughput value depends on various factors, including the actual movement content in the view. The results are shown in Table 25 below.

Table 25. Application-level test cases results for Trial 1.4.

Test case ID	Test requirement	Measurement result	Description	Validation
1.4_Field01_02.1	KPI#06: > 7.78 Mbps KPI#08: < 50 ms	KPI#04: 11.36 Mbps KPI#08: 28 ms	1 camera only (pole #3, camera 1), resolution 2592x1944, streaming at 20fps	Camera captures a busy pedestrian street.
1.4_Field01_02.2	KPI#06: > 31.12 Mbps KPI#08: < 50 ms	KPI#04: 40.48 Mbps KPI#08: 28 ms	All 4 cameras at pole #1, resolution 2592x1944, at 20fps	Average activity in all 4 camera views.

1.4_Field01_02.3	KPI#06: > 45.24 Mbps KPI#08: < 50 ms	KPI#04: 27.00 Mbps KPI#08: 28 ms	All 5 cameras at pole #2, resolutions 4x 2592x1944 and 1x 3840x2160, at 20fps	Cameras are partly masked, capture more static areas.
1.4_Field01_02.4	KPI#06: > 34.65 Mbps KPI#08: < 50 ms	KPI#04: 31.92 Mbps KPI#08: 28 ms	All 5 cameras at pole #3, resolutions 4x 2592x1944 and 1x 1920x1080, at 20fps	3 cameras capture the street, 2 cameras mostly static areas.
1.4_Field01_02.5	KPI#06: > 111.01 Mbps KPI#08: < 50 ms	KPI#04: 97.68 Mbps KPI#08: 28 ms	All 14 cameras at poles #1, #2, #3, resolutions 12x 2592x1944, 1x 3840x2160, 1x 1920x1080, at 20fps	All cameras on the three poles are streaming simultaneously

The throughput and latency performance of the network was assessed using the CPE provided testing capabilities, using Speed Test by Ookla, as showcased in Figure 45 and Figure 46. The latency values were also validated using ping probes between the 5G CPEs and a virtual machine from the 5G Lab Edge Compute infrastructure as can be seen in.

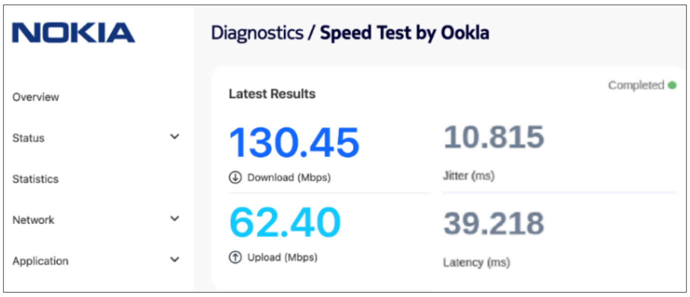

Figure 45. Field01_01 test case measured KPIs at the 5G CPE level.

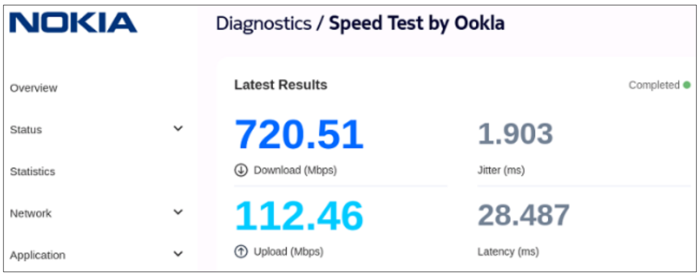

Figure 46. Field01_02 test case measured KPIs at the 5G CPE level.

```
PING 172.27.61.228 (172.27.61.228) 56(84) bytes of data.
64 bytes from 172.27.61.228: icmp_seq=1 ttl=55 time=33.5 ms
64 bytes from 172.27.61.228: icmp_seq=2 ttl=55 time=31.7 ms
64 bytes from 172.27.61.228: icmp_seq=3 ttl=55 time=29.1 ms
64 bytes from 172.27.61.228: icmp_seq=4 ttl=55 time=28.0 ms
64 bytes from 172.27.61.228: icmp_seq=5 ttl=55 time=16.3 ms
64 bytes from 172.27.61.228: icmp_seq=6 ttl=55 time=24.6 ms
64 bytes from 172.27.61.228: icmp_seq=7 ttl=55 time=22.5 ms
64 bytes from 172.27.61.228: icmp_seq=8 ttl=55 time=20.8 ms
64 bytes from 172.27.61.228: icmp_seq=9 ttl=55 time=24.5 ms
64 bytes from 172.27.61.228: icmp_seq=10 ttl=55 time=17.5 ms
64 bytes from 172.27.61.228: icmp_seq=11 ttl=55 time=20.8 ms
64 bytes from 172.27.61.228: icmp_seq=12 ttl=55 time=19.3 ms
64 bytes from 172.27.61.228: icmp_seq=13 ttl=55 time=32.7 ms
64 bytes from 172.27.61.228: icmp_seq=14 ttl=55 time=16.7 ms
64 bytes from 172.27.61.228: icmp_seq=15 ttl=55 time=15.2 ms
^C
--- 172.27.61.228 ping statistics ---
15 packets transmitted, 15 received, 0% packet loss, time 14022ms
rtt min/avg/max/mdev = 15.280/23.594/33.587/6.010 ms
```

Figure 47. Field01_02 test case measured E2E latency from the Edge-Cloud infrastructure to the 5G CPEs.

Moreover, the UC1 CPEs were also integrated in ORO's monitoring platform as shown in Figure 48, thus allowing for the recording of the traffic volume and data throughput for both 4G and 5G links from the NSA architecture. The integration between the CPEs and the monitoring platform is done through a TR-069 server, which queries all the traffic and radio quality data from the CPE and then forwards it to ORO's Google Cloud Platform (GCP) data aggregation instance which stores and analyzes the data. The monitoring values are then forwarded to ORO's dashboard platform, Qlik, based on which several graphs with the time evolution of the network parameters can be showcased as seen in Figure 48.

Figure 48. UC1 CPEs integration in ORO's monitoring platform - data throughput metrics.

3.2.2.3 Early demo

Early demo has been performed to showcase the video analytics application capabilities in a real context. In particular, the application focuses on several distinct scenarios of practical interest such as a) estimation of crowd density in the surveyed area, b) total count of people in a region of interest, and c) detecting objects entering within a restricted access area. Initial tests were performed using pre-recorded videos including many people. The tests focused on optimal setup parameters, estimation of the detection accuracy, and development of the video analytics dashboard. After that, preliminary tests were also performed using actual feeds provided by the cameras installed on the premises. The tests envisaged optimal positioning of the cameras, confirmed stable video feed from all cameras, and saving the actual records both locally, on the Secure Digital memory cards (SD cards) attached to the cameras, and remotely, on the storage servers at TUIASI. In the following, the three demonstrations of the video analytics application are described.

People counting in pedestrian areas

The first demo aims to count the number of people on the Ștefan cel Mare pedestrian street in Iași, gathered during the large public ceremony of Sf. Parascheva, on October 14th, 2023. Demo location is presented in Figure 49.

The software uses the P2PNet people detection neural network model [21], which detects people heads in the video frames. The algorithm analyzes each frame of the video, detects the heads in a predefined region of interest, and counts the number of detections in each frame. The time series is then smoothed using an exponential moving average filter with configurable smoothing factor. The estimated number of people in every frame is published on the Kafka messaging system, for consumption by other clients. The data is then read by the dashboard software which displays the values to the user. The camera view showing the area of interest (yellow) and the actual detected people (light blue dots on the image) is shown in Figure 50.

Figure 49. UC1 demo in Sf. Parascheva, on October 14th, 2023.

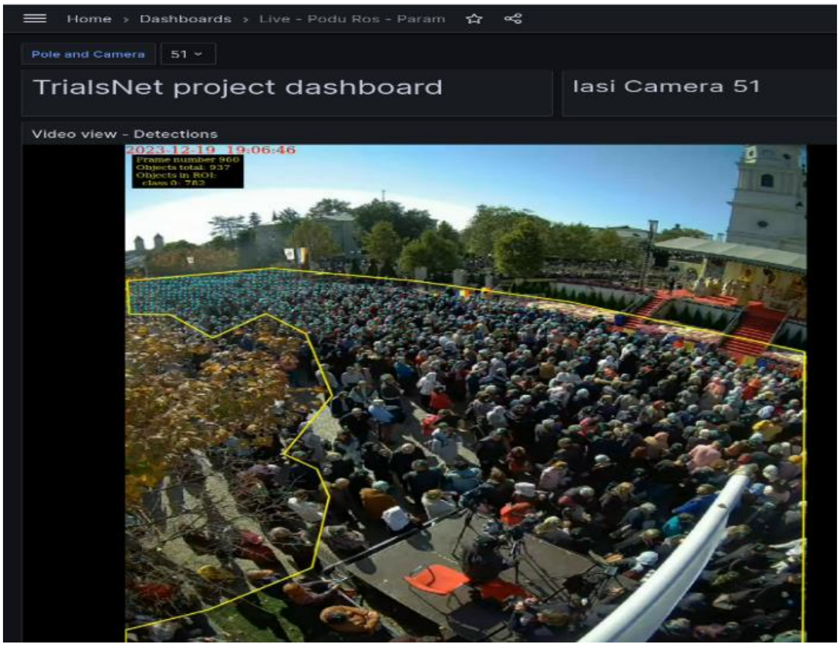

Figure 50. Area of interest and detected people for UC1 demo in Sf. Parascheva, on October 14th, 2023.

A screenshot of the dashboard displaying the number of people on the street during the event is shown in Figure . The dashboard includes the video with the region of interest and the detected heads. Even though the analysis was offline, the processing is fast enough to be used in real-time. The output video stream is rendered at the same 20 FPS rate as the input video, which shows that the processing can be used in real-time without incurring any processing delays.

Figure 51. Dashboard displaying the evolution of the total number of people counted.

People density estimation

The second demo aims to estimate the density of people on the Ștefan cel Mare pedestrian street in Iași, during the same event as in test Field01_01. Figure 50 presents the area of interest.

Figure 52. UC1 demo Sf. Parascheva, on October 14th, 2023.

Using the same software as in UC1, the positions of the detected heads are recorded. The coordinates of the heads are transformed from the image space (pixel locations) into GPS coordinates. For this purpose, the camera must first undergo a calibration process, determining the extrinsic parameters (camera location and orientation angles). The GPS coordinates of the detections for every frame are published on the Kafka messaging system. The dashboard software reads these coordinates and plots the points on a heatmap illustrating the density of people on the street in every frame.

The crowd density is illustrated graphically in the dashboard as a heatmap overlayed on a geomap visualization, with dots placed at the GPS coordinates of the detected people. The heatmap evolves in time as new frames are analyzed, showing the dynamics of the crowd. A snapshot of the dashboard is displayed in Figure 53. The detections on the map correspond to the locations of people in the camera view in Figure 50, which validates the GPS coordinate transformation procedure. The system operates at the same 20 FPS rate as the input video.

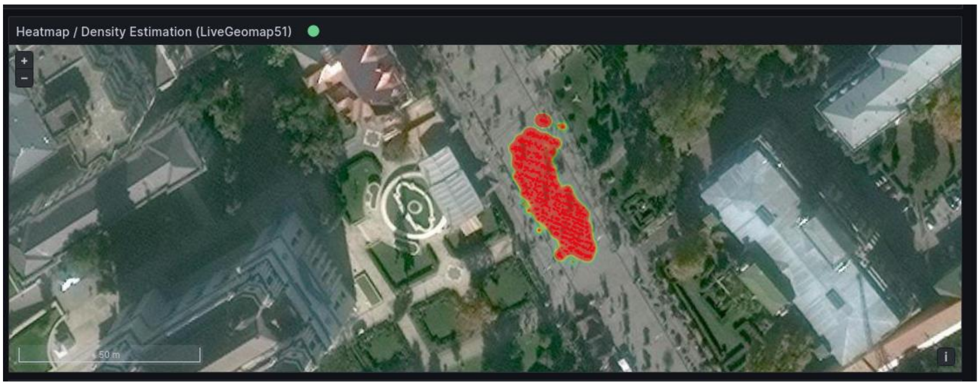

Figure 53. Dashboard displaying the crowd density heatmap.

People/Car detection in forbidden areas

The third demo aims to detect dangerous situations on the Ștefan cel Mare pedestrian street. Two specific scenarios are considered: (i) vehicles inside a pedestrian area and (ii) pedestrians crossing the street outside the crosswalks. The conditions for this demo are presented in Figure 54.

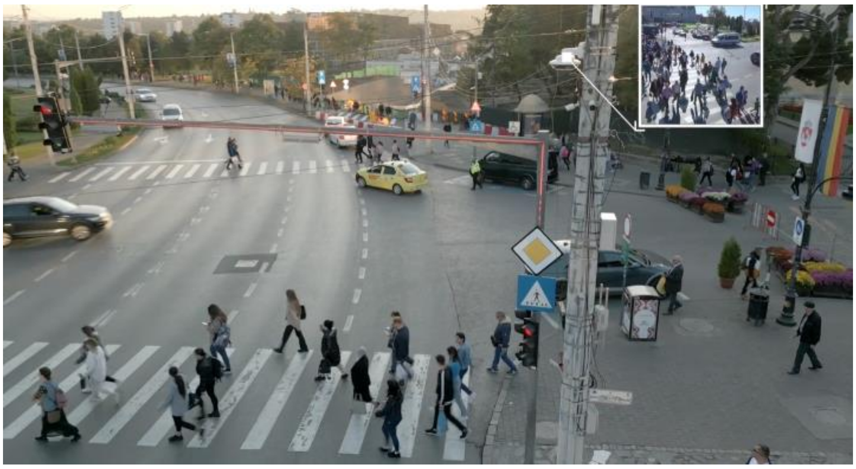

Figure 54. UC1 demo in December 2023.

The software uses the YOLOv7 neural network model [19] to detect objects that are prohibited in specific zones. Exclusion zones and detection categories not permitted in each zone are configured in advance. When a detected object overlaps with an exclusion zone, the system triggers a visible alarm on the dashboard video, alerting the user. Two screenshots of the dashboard are shown in Figure 55, illustrating both scenarios.

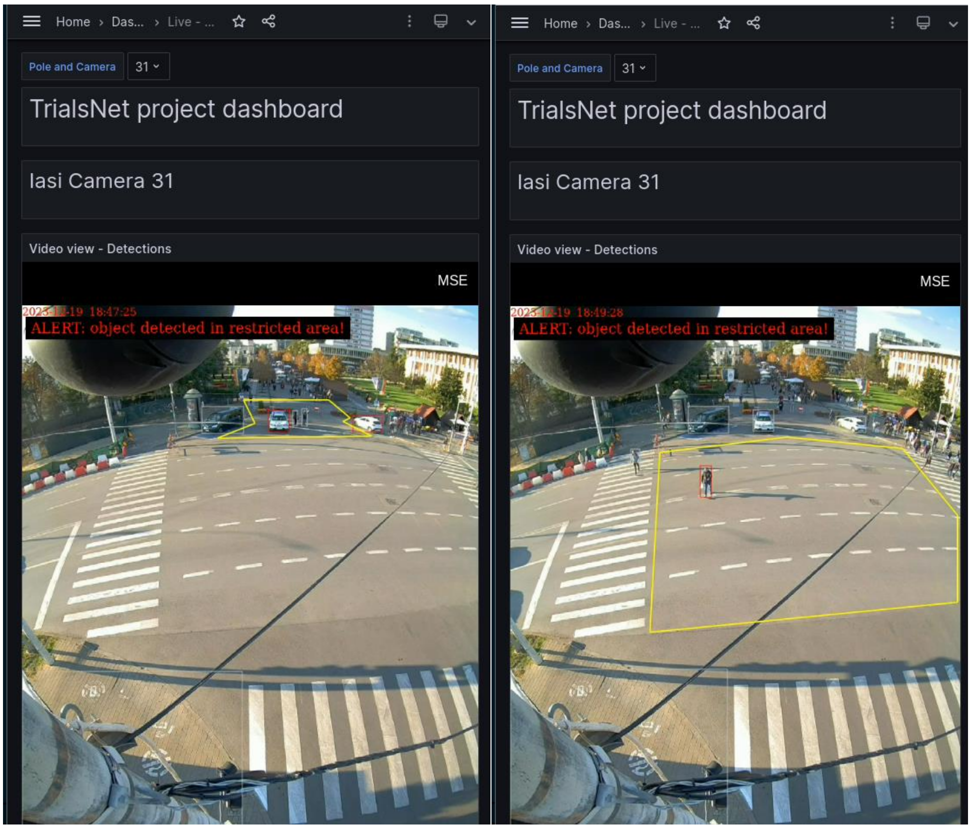

Figure 55. UC1 demo application dashboard.

Early demos have been showcasing with camera feeds, the definition of areas of interest, and insights from the actual video scenes including the total count of people and heatmaps estimating people density. Small colored dots are superimposed on the head of each person; providing the user with a visual confirmation of the accuracy of people detection.

Dissemination activities were carried out in several events organized in collaboration with TUIASI and ORO in 2023 and beginning of 2024. During these events, UC1 and UC4 implementation details and first demo results were presented. Figure 56 shows an image from the dissemination film made together with the Iasi City Hall. During the demo, the current state of the video analytics application was showcased to the Iasi Municipality team for initial feedback on the implemented features.

Figure 56. UC1 demonstration activities with ORO Business Customers.

As conclusions, the demo was successful in showcasing the main capabilities of the application software developed. They validate the overall architecture of the application, showing it can video analysis, real-time processing, publishing and visualization of the basic analytics data. The software can handle multiple cameras in parallel, detecting and counting people and vehicles from each video feed. The video analysis pipeline can integrate pretrained object detection models available in the literature; two were used for these demos, but the system can be extended to support more.

Future demos are entwined with the planned development of the application software, focusing on more advanced features, among which are included analyzing the same video feed with multiple object detection models, as well as more advanced rules for alerts and exclusion zones. A fundamental topic is to develop methods for analyzing the crowd density dynamics to gain insight into crowd movement patterns. In addition, measuring the processing delay for each element in the video analysis pipeline is important to quantify the real-time performance of the software.

3.2.3 Remarks and next steps

Concerning Trial 1.3, both Wi-Fi traffic data and Wi-Fi unique user data confirm that the Event Weekend (Sf. Parascheva) was a timeframe that registered abnormal data when compared to similar timeframes – in this case a substantial increase in metrics (over +40% in traffic in event weekend, over +80% in unique users in event day). This test demonstrates that a Wi-Fi network can be used as an Analytics tool in tandem with the video analytics capabilities in order to evaluate crowd density order of magnitude (e.g., how big is the crowd in a crowded day vs a normal day). Also, when analyzing Wi-Fi Presence Analytics metrics (taking into consideration all the Wi-Fi-enabled devices, not just the ones connected to the Wi-Fi Network), more than double the visitor count was observed.

Future testing sessions using the Wi-Fi infrastructure deployed on Stefan cel Mare Bd. and Piata Palat are described hereafter:

- **Test parts / the entire Wi-Fi Hotspot on 5G backhaul connectivity**: In the first trial sessions, the Wi-Fi hotspot used a fixed cable (fiber-based) connection. In the subsequent trials, parts of the Wi-Fi hotspot will have 5G backhaul connectivity to observe network performance parameters.
- **Correlate field tests with laboratory tests**: In the first trial session, field tests could not be performed at the same time with laboratory tests, so for the next trials sessions, to achieve maximum accuracy, the laboratory tests must be done at the same time with the field tests.
- **Crowd dynamics by using Wi-Fi Location Analytics**: In the initial trial, the Wi-Fi hotspot was defined as one Analytics zone, and all metrics were measured for one zone. In subsequent trials, the Wi-Fi zone will be split into at least two zones and crowd dynamics will be measured to and from those zones.

In relation to Trial 1.4, the tests performed under the first iteration of field trials for UC1 were in-line with the expectations on the network side, the 5G NSA commercial setup working fine when there was not a lot of congestion on the network, but failed to deliver the expected performance when the Stefan cel Mare pedestrian alley area was crowded with 100.000s of people, paving the way towards the advancements and tests that will be performed with the next technical iteration using 5G SA and B5G solutions.

Regarding the next steps that should be performed on the network side, the upgrade to outdoor 5G SA is expected to be performed at the end of 2024, while all the edge-compute related prerequisites (local UPF and computing servers installations in Iasi) are to be finalized in June 2024. These advancements will lead to a new wave of tests for uplink/downlink throughput, E2E network latency and edge-compute latency. KVIs assessment will also be provided in the next WP3 deliverable D3.3 scheduled for completion by the end of October 2025.

3.3 UC2: Proactive Public Infrastructure Assets Management

3.3.1 Trial 2.1 - Public Infrastructure Assets Management

The tests related to the Trial 2.1 aims at evaluating the road damage detection using IP cameras.

3.3.1.1 Laboratory tests

Datasets
Open-Source Data. An open dataset called “RDDC 2022 Dataset”, the official dataset of the Crowdsensing-based Road Damage Detection Challenge (CRDDC) 2022 is used. The open data consists of 35.152 road images collected from India, Japan, the Czech Republic, Norway, the United States, and China in order for the model to learn to detect road damages in diverse scenarios. These images were examined one by one and 23.818 road images were kept which have distinct damage.

Custom Data. The Hardware & Backend teams worked together to collect images, while the company car was driving around the city. The custom data consists of 4.127 road images collected in Athens, so that the model can learn to detect road damage in more realistic scenarios. These images were annotated by a team of data analysts.

Final Dataset. After merging these datasets, the total images passed through the augmentation procedure. Multiple images are produced from the original ones. These generated images have combinations of different features (blur, brightness, temperature, contrast, rotate, zoom, noise). This expansion of the dataset will help the model to learn better under varying conditions. Finally, the dataset consists of a total of 136.542 road images.

Classes
The classes of the annotated dataset are as follows:

- Longitudinal Crack
- Lateral Crack
- Alligator Crack
- Pothole
- Repair
- Manhole

Classes 1-4 relate to road damage while classes 5-6 relate to corrective interventions. The distribution of the classes found in the dataset is shown in the diagram reported in Figure 57.

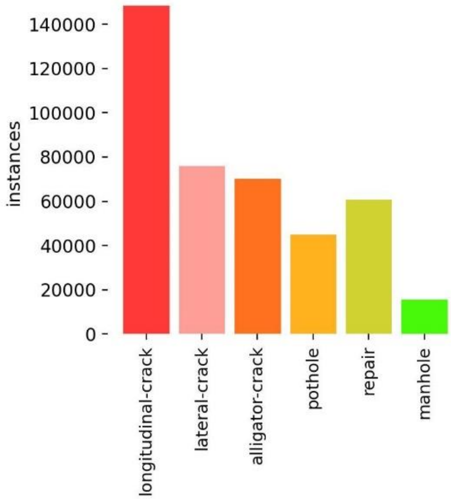

Figure 57. Classes distribution of the dataset.

Detection model

Pre-processing. As the sequence of images (video/stream) is given as an input, every frame passes through the Contrast Limited Adaptive Histogram Equalization (CLAHE) Algorithm [43]. This algorithm is used to improve the contrast of the image. The two following figures (Figure 58, Figure 59) show the difference.

Figure 58. Image captured from the IP camera before passing through CLAHE Algorithm.

The CLAHE algorithm increases the visibility of a foggy image and brings out the texture of the road. This will help the model, as it will be easier for it to detect damage.

Figure 59. Image captured from the IP camera after passing through CLAHE Algorithm.

Object detection. An object detection model based on the YOLOv8 [44] architecture is built. This model can detect multiple objects of the 6 classes in a single image. The analysis of a video/stream is therefore performed frame-by-frame. The preprocessed frame is given as an input to the model and the detections are the output of the model. An indication on how this works is depicted in Figure 60. For each individual input frame, the detected damage's cropped image and the damage's class are collected along with the frame ID and frame shape. For a configurable frame window, this information is collected and passed to the postprocessing stage.

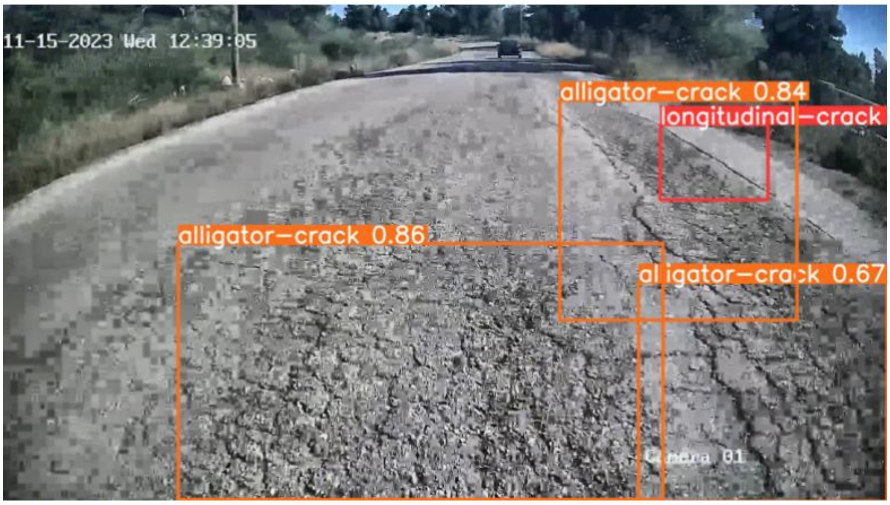

Figure 60. Output of the road damage model detecting different classes of damages in the same frame.

Post-processing. In this final stage, the aim is to estimate the severity of the damage found in the frame window. For this reason, 3 coefficients are calculated:

- **Size coefficient**: the ratio of the size of the bounding box to the size of the frame.
- **Class coefficient**: an indicator of importance for each class.
- **Texture coefficient**: a representation of the anomaly of the road surface. This method is further explained in the diagram below.

Filters

Laplacian of Gaussian Filter. This filter highlights regions of rapid intensity change of the image and is therefore used to make the crack more distinct (see Figure 61). This filter, when applied to a pothole, highlights the area around the pothole, so it does not apply to this type of damage.

Gaussian Blur. This filter blurs the cropped image and is used to soften the "healthy" part of the asphalt.

Pixels Value Threshold Filter. This filter makes dark pixels black and light pixels white and is used to keep only the part of the image that has strong texture.

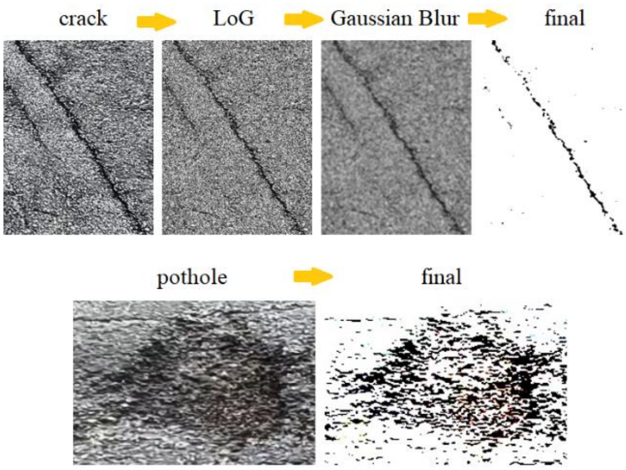

Figure 61. Output images after passing through the Laplacian of Gaussian Filter and Gaussian Blur.

After estimating the damage severity, the image severity is calculated as the sum of its individual damage severity. The total severity of the examined area is the average image severity.

A test set was retained to evaluate the detection model. This set contains 413 labeled images. Another set is created that contains 413 road images that have no object to detect. The test summed up a total number of 826 images. The following evaluation strategy was followed: interference tests were run, so that the True Positives and the False Negatives appear on the first set, and the False Positives as well as the True Negatives appear on the other set. Inference was performed for multiple confidence thresholds and the best results were obtained when the threshold was set at 0.2. A summary of the results is detailed Table 26. Precision is the number of positive predictions that are actually positive, Recall is the number of positive predictions made from all positive ground truths while the F1-score is the harmonic mean of Precision and Recall.

Table 26. UC2 road damage detection results.

		Actual	
	Class	**0**	**1**
Predicted	**0**	TP (357)	FP
	1	FN (56)	TN (376)

Metric	Result
Precision	0.9061
Recall	0.8644
F1-score	0.8847

Test summary for Trial 2.1 is presented in Table 27.

Table 27. Test summary for Trial 2.1.

Test summary	
Trial ID	2.1
Test setup ID	Lab01
Facility/Site	Athens – WINGS Lab
Objective	Demonstration of the performance of the road damage detection model
Description	Demonstration of the performance of the road damage detection model using the RDDC 2022 Dataset and custom data
Executed by	WINGS
Components involved	5G network, WINGS OBU, Analytics component
Targeted KPIs	KPI#11 (Precision) KPI#12 (Recall) KPI#13 (F1-score)
Measurement tools	-
Ethics requirements implementation	The tests have so far been performed only in the lab without involving users. In the future, a questionnaire will be submitted to participants for assessing KVI, along a release form regarding possible privacy and ethical concern. The recorded videos only show the road used for the road damage detection, no need for ethical considerations.
Involvement of beta-users	N/A

In terms of KPIs, Table 28 details the requirements and results of the tests.

Table 28. Test cases results for Trial 2.1.

Test case ID	Test requirement	Measurement result	Validation
2.1_Lab01_01	KPI#11: 0.80	KPI#11: 0.9061	Comply
	KPI#12: 0.60	KPI#12: 0.8644	Comply
	KPI#13: 0.68	KPI#13: 0.8847	Comply

3.3.1.2 Tests on field

Tests on field related to Trial 2.1 are planned in the next months.

3.3.1.3 Early demo

The Figure 62 depicts the road damage model output visualisation on the WINGSPARK++ dashboard. The different colours depicted in the video output denote different classes of damage detected as well as the calculated probability of the damage belonging to the detected class. Visualisation of the list of inspections along with datetime and other characteristics such as location, severity, type (i.e., detected class) and related metrics (i.e., length) are also reported. Finally, Figure 63 depicts the statistics related to a specific inspection with respect to the damages detected, thus providing a summary of the inspection and other useful insights for the authorities to consider when scheduling maintenance works.

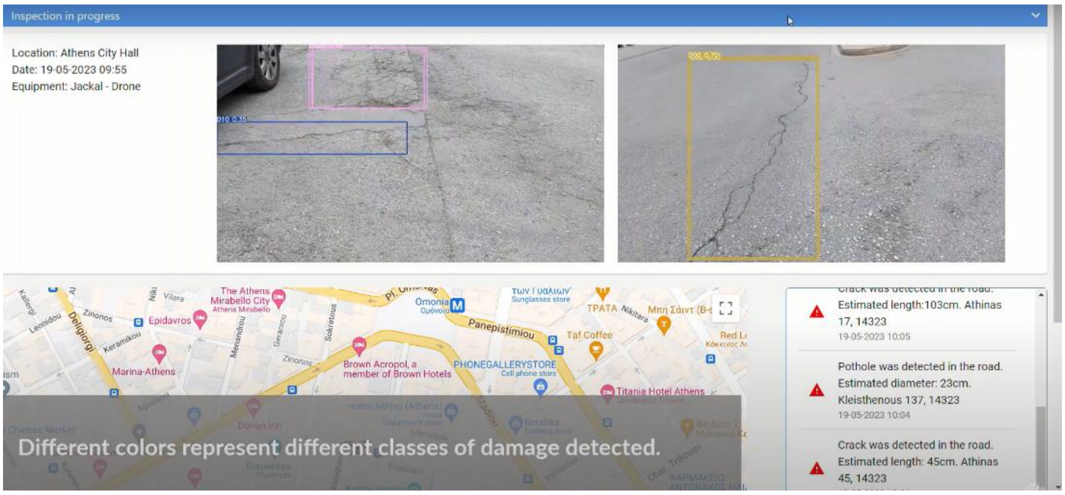

Figure 62. Road damage model output visualisation on the dashboard.

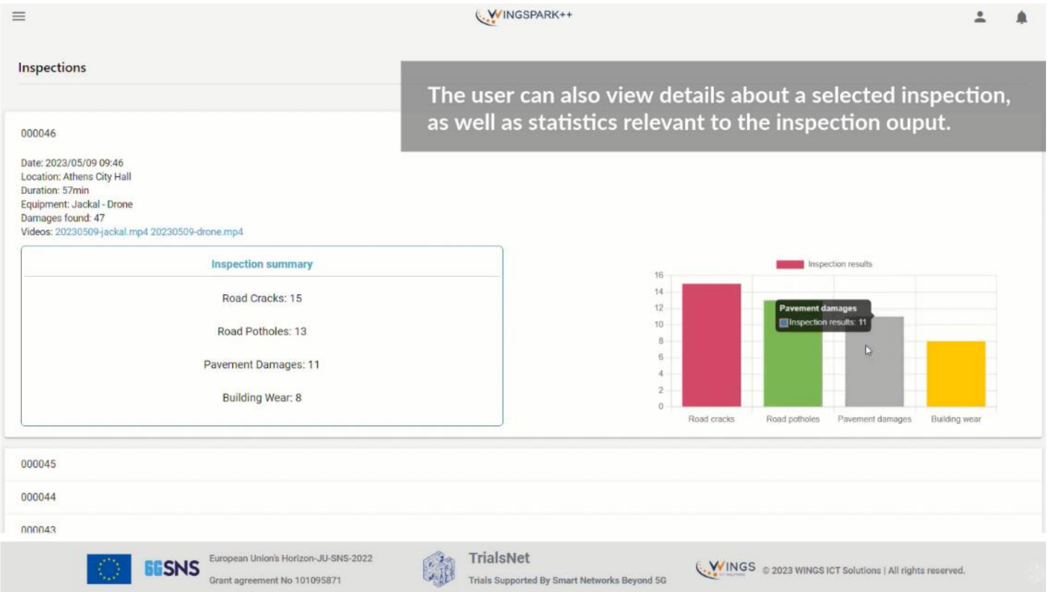

Figure 63. Visualisation of statistics related to a specific inspection with respect to the damages detected.

3.3.2 Trial 2.2 - Public Infrastructure Assets Management

The test related to Trial 2.2 aims at evaluating the performance of streaming and restreaming modules for road damage detection using IP cameras.

3.3.2.1 Laboratory tests

The objective was to test the optimal configurations of the camera first so that the KPIs, as mentioned in D3.1 [1], can be measured. However, additional measurements were taken to estimate the optimal configurations for a streaming camera without or with a model enabled i.e., restreaming with detections or just streaming the camera feed. The restreaming with the detections would enable the near-real time inspection of the faults from the operator. As such, it was critical to achieve that in the optimal time in order to enable real-time remote inspections. Without the restreaming component the video would be captured in real-time but the detections would not show. Then the operator would need to inspect one by one the video captured from the area of interest during an inspection in order to check on the detected faults from the post processing and schedule maintenance accordingly.

Test summary for the Trial 2.2 is presented in the Table 29.

Table 29. Test summary for Trial 2.2.

Test summary	
Trial ID	2.2
Test setup ID	Lab02
Facility/Site	Athens – WINGS Lab
Objective	Demonstration of the performance of the streaming and restreaming modules of WINGSPARK++ platform
Description	The idea was to test the optimal configurations of the camera first to properly measure the KPIs mentioned in D3.1[1].
Executed by	WINGS
Components involved	Streaming and restreaming module
Targeted KPIs	KPI#08 (App round-trip latency) KPI#15 (Service Reliability) KPI#17 (Service Availability)
Measurement tools	Windows Task Manager, iPerf
Ethics requirements implementation	The tests have so far been performed only in the lab without involving users. In the future, a questionnaire will be submitted to participants for assessing KVI, along a release form regarding possible privacy and ethical concern. The recorded videos only show the road used for the road damage detection, no need for ethical considerations.
Involvement of beta-users	N/A

It was expected that CPU only restreaming would be a bottleneck, so it was additionally tested on a GPU server. The two systems configurations are depicted in the Table 30 below:

Table 30. Trial 2.2 system configurations.

Characteristics	VM running on CPU	VM running on GPU (AWS deployment)
Instance type	N/A	g4dn.xlarge
Processing	6 cores @ 2294 MHz	VCPUs 4, Cores 2
Memory	8 GB ram	16 GB Ram
GPU size / type	N/A	GPU NVidia T4 16GB memory

Initially the performance of the integration with CPU VMs was tested, but Computer Vision (CV) models based on the literature provide better when tested on GPU, and thus the decision was to also perform the same experiments on a GPU server to find the optimal configurations on both.

The approach that was followed is detailed below:

- High-definition camera's settings were researched step by step in order to be able to identify which settings will be optimal for the environment, performing tests using different combinations of the following camera characteristics:
  - Video Encoding,
  - Resolution,
  - Video Quality,
  - Framerate,
  - Max Bitrate

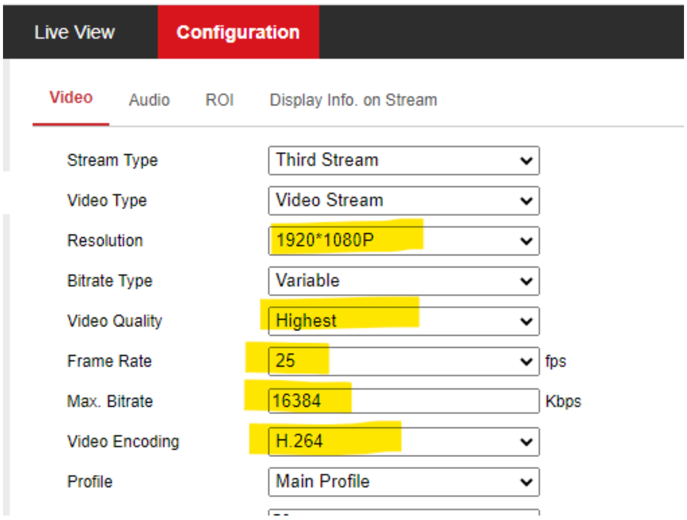

Figure 64. Camera settings.

By utilizing the above-mentioned procedure, the smoothness and responsiveness of the live restreaming from a source IP Camera through the WINGS FrameWhisper module were tested. FrameWhisper processed frame by frame and restreamed the frames on the media server to identify whether the simplest integration will cause any issues. Based on this first testing different options have been researched to identify the optimal camera configuration (Figure 64). As a next step, tests have been done with and without the detection model which demanded high CPU/GPU usage for processing each frame to generate the detections. Then, for each different camera configuration, tests have been performed to evaluate the perceived performance and usability of the total restreaming process under different configurations and utilized specific metrics to identify any limitations. The different parameters and values utilized for testing are presented in Table 31 below.

Table 31. Trial 2.2 parameter and values utilised for testing.

Par. No.	Parameter	Value
1	**Protocol**	HLS
		WEB RTC
2	**Resolution**	1920x1080
		1280x720
		704x576
3	**Batch size (only when analytics model is used)**	6000
4	**Video Quality**	Highest
		Medium
5	**Frame Rate (fps)**	25/20/15/10/6
6	**Max bitrate**	16384 / 8192 / 4096 / 2192
7	**Video Encoding**	H.264

Furthermore, to test the total performance of the system from the source (IP camera) to restreaming different options were enabled or disabled:

- **Intelligence Model analysis**: The process that does the object detection for each frame that detects any of the classes of the road damage detection model (potholes etc.)
- **Intelligence model post processing**: The process required to estimate various analytics about the perceived stream i.e., severity of a damage, length etc.
- **Time window**: every 1 /5/ 10 minute (i.e., keep all the frames in a buffer)
- **One or Multiple cameras**: with intelligent analysis enabled or disabled.

Based on the preliminary tests, the perception was that some camera configurations were unusable and as such did not perform any further testing with intelligence analysis module enabled. Furthermore, for each of these different settings tests have been done for both restreaming protocols (HLS and WebRTC), which are widely supported.

Table 32. Trial 2.2 configurations used for testing.

Conf. #	Test #	Setup
1	**4**	**Protocol:** HLS**, Batch size:** N/A**, Resolution:** 1920x1080, **Video Quality:** Medium**, Frame Rate:** 20**, Max bitrate:** 8192**, Video Encoding:** H.264, **No. of Cameras:** 1, **Time Window:** 10min
2	**5**	**Protocol:** HLS**, Batch size:** N/A**, Resolution:** 1920x1080, **Video Quality:** Medium**, Frame Rate:** 20**, Max bitrate:** 4096**, Video Encoding:** H.264, **No. of Cameras:** 1, **Time Window:** 5min
3	**6**	**Protocol:** Web RTC**, Batch size:** N/A**, Resolution:** 1920x1080, **Video Quality:** Medium**, Frame Rate:** 20**, Max bitrate:** 8192**, Video Encoding:** H.264, **No. of Cameras:** 1, **Time Window:** 10min
4	**10**	**Protocol:** HLS/Web RTC**, Batch size:** 6000**, Resolution:** 1280x720, **Video Quality:** Medium**, Frame Rate:** 15**, Max bitrate:** 4096**, Video Encoding:** H.264, **No. of Cameras:** 1, **Time Window:** 5min, **Intelligence Model analysis:** Enabled
5	**14**	**Protocol:** HLS/Web RTC**, Batch size:** 6000**, Resolution:** 1280x720, **Video Quality:** Medium**, Frame Rate:** 15**, Max bitrate:** 4096**, Video Encoding:** H.264, **No. of Cameras:** 1, **Time Window:** 5min, **Intelligence Model analysis:** Disabled
6	**16**	**Protocol:** HLS/Web RTC**, Batch size:** 6000**, Resolution:** 1280x720, **Video Quality:** Medium**, Frame Rate:** 15**, Max bitrate:** 2192**, Video Encoding:** H.264, **No. of Cameras:** 2, **Time Window:** 5min, **Intelligence Model analysis:** Disabled
7	**17**	**Protocol:** HLS/Web RTC**, Batch size:** 6000**, Resolution:** 1280x720, **Video Quality:** Medium**, Frame Rate:** 15**, Max bitrate:** 2192**, Video Encoding:** H.264, **No. of Cameras:** 4, **Time Window:** 5min, **Intelligence Model analysis:** Disabled
8	**20**	**Protocol:** HLS/Web RTC**, Batch size:** 6000**, Resolution:** 704x576, **Video Quality:** Medium**, Frame Rate:** 10**, Max bitrate:** 2192**, Video Encoding:** H.264, **No. of Cameras:** 2, **Time Window:** 5min, **Intelligence Model analysis:** Enabled
9	**22**	**Protocol:** HLS/Web RTC**, Batch size:** 6000**, Resolution:** 704x576, **Video Quality:** Medium**, Frame Rate:** 6**, Max bitrate:** 2192**, Video Encoding:** H.264, **No. of Cameras:** 3, **Time Window:** 5min, **Intelligence Model analysis:** Enabled

Based on the configurations detailed above (Table 32), the following metrics were measured:

- Inference time per frame (Intelligence model analysis)
- Post Processing time (Intelligence model post processing)
- Intelligence Model Analysis Total Time (without post processing)
- Intelligence Model Analysis Total Time (with post processing)
- Estimated the possibly max FPS a camera can use
- Latency (Jitter) as per KPIs reported in D3.1 [1]
- Service Availability as per KPIs reported in D3.1 [1]
- Service Reliability as per KPIs reported in D3.1 [1]

The results obtained for each of the configurations presented in Table 32 are presented in Table 33.

Table 33. Trial 2.2 laboratory test results.

Conf. No.	Inference Time	Restream time (without MS) (sec)	Analytics Time	Total Time (With Analytics)	Total Time (without Analytics)	Latency (jitter) ms	Service Availability (%)	Service Reliability (%)
1	N/A	0.0064765	N/A	N/A	0.0064765	0.517	99.95	99.99
2	N/A	0.0057407	N/A	N/A	0.0057407	0.514	99.98	99.99
3	N/A	0.0058902	N/A	N/A	0.0058902	0.529	99.9	99.99
4	0.044589	0.0025646	11.481128	0.0471796	N/A	0.599	99.92	99.99
5	0.045875	0.0025651	N/A	N/A	0.0470523	0.605	99.82	99.99
6	0.048705	0.0025884	10.768367	0.0546136	N/A	0.613	99.89	99.99
7	0.050982	0.0026284	11.105502	0.0534231	N/A	0.606	99.78	99.99
8	0.037939	0.0011319	8.8626864	0.0391275	N/A	0.593	99.91	99.99
9	0.037176	0.0011155	8.0480323	0.0374508	N/A	0.636	99.933	99.99

In terms of KPIs, Table 34 details the requirements and results of the tests.

Table 34. Test cases results for Trial 2.2.

Test case ID	Test requirement	Measurement result	Validation
2.2_Lab02_01	KPI#08: 800ms	KPI#08: 517ms	Comply
2.2_Lab02_02	KPI#15: 99.99%	KPI#15: 99.99%	Comply
2.3_Lab02_03	KPI#17: 99.99%	KPI#17: 99.95%	Not comply

3.3.2.2 Tests on field

Test on field related to Trial 2.2 are planned in the next months.

3.3.2.3 Early Demo

The figures below present the outputs of the streaming and re-streaming modules of the WINGSPARK++ platform as well as other features available in the platform to support UC2. Figure 65 presents the home page of the WINGSPARK++ dashboard, which provides the facility management staff with real-time monitoring of the public assets infrastructure while providing useful insights regarding detected faults in the monitored infrastructure. Figure 66 depicts the road damage model output visualisation with the use of the restreaming module of the WINGSPARK++ platform. The different colours depicted in the video output denote different classes of damage detected as well as the calculated probability of the damage belonging to the detected class. Furthermore, other useful information is displayed such as the date that the inspection took place as well as the location of the assets that were inspected and the equipment that performed the inspection.

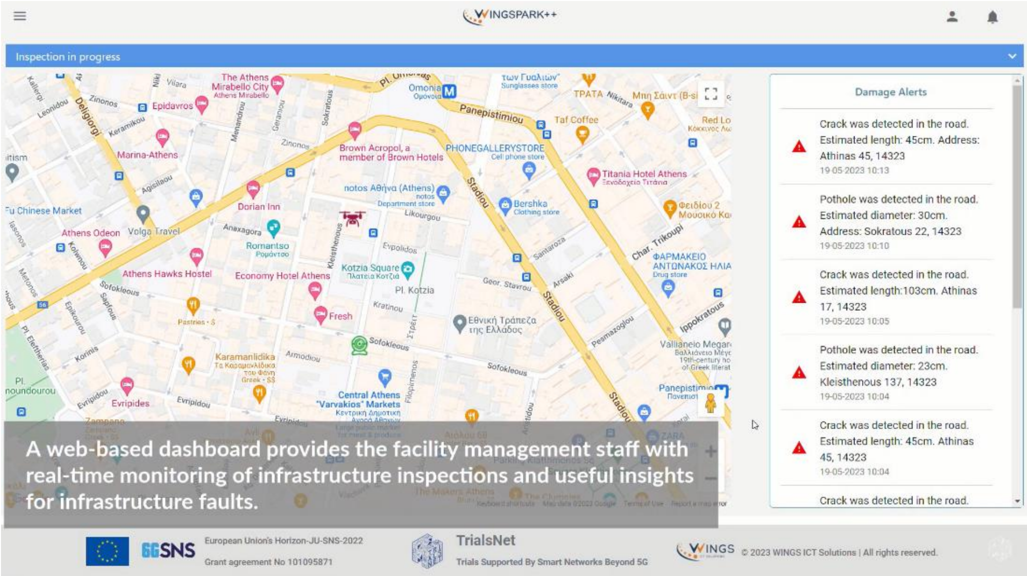

Figure 65. WINGSPARK++. dashboard view- real time monitoring of the public assets' infrastructure.

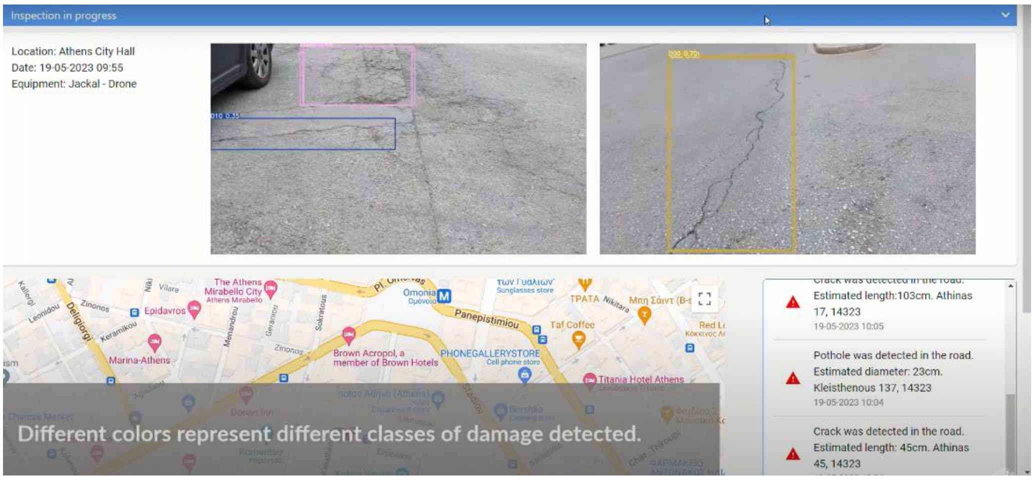

Figure 66. Road damage model with the use of the restreaming module of the WINGSPARK++.

Visualisation of the list of inspections along with datetime and other characteristics such as location are also depicted. The facility management staff by selecting "inspections" from the main menu can view the list of the inspections performed historically.

The list of notifications provides insights on the severe faults detected in the infrastructure based on the road damage model output, along with the location for each fault that was detected, the type of fault and the related metrics (e.g., length, etc.). From there, the facility management staff can select to "Resolve" by scheduling when maintenance works will be executed or "dismiss" the notification as not severe. Figure 67 presents the list of available / deployed equipment in the monitored infrastructure. The facility management staff can view useful information regarding the type of equipment, status, battery level, current position, etc. Finally, they can view live video streamed from the device by selecting the option "View live video feed" for the selected equipment (Figure 68).

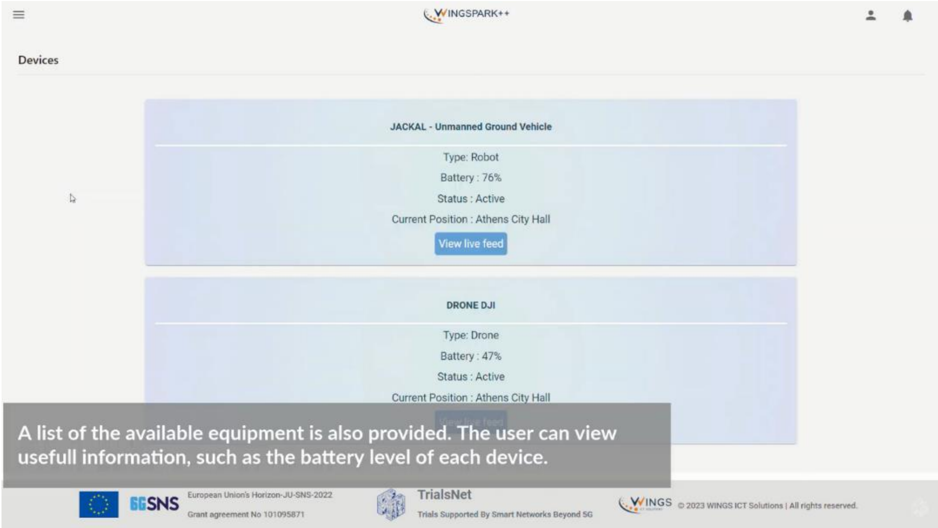

Figure 67. List of available equipment to be used in the infrastructure monitoring.

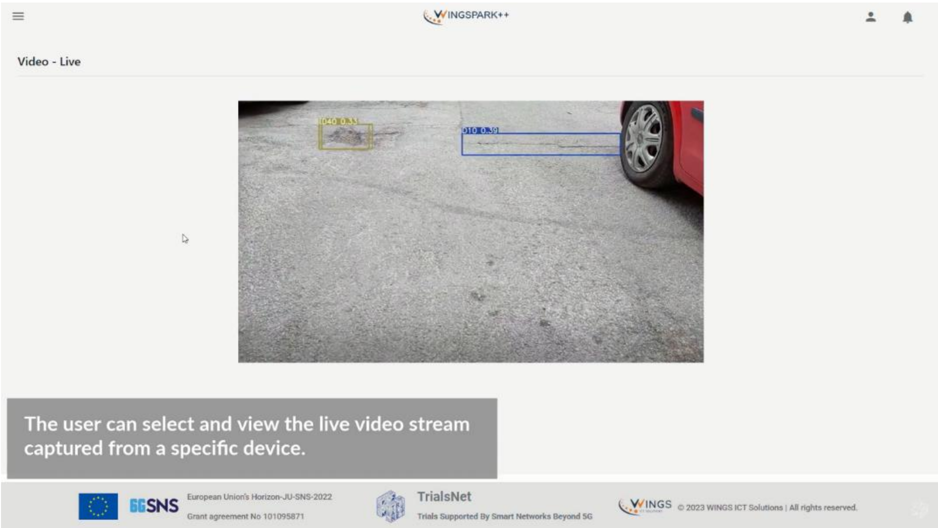

Figure 68. Output of the restreaming module, live video restreamed directly from the device.

3.3.3 Remarks and next steps

Preliminary tests were performed using actual feeds provided by the cameras installed on WINGS corporate vehicles. The tests envisaged optimal positioning of the cameras, confirmed stable video feed from all cameras, and saving the actual records both locally, on the SD cards attached to the On-Board Units (OBU), and remotely, on the storage servers both at WINGS premises and AWS deployment.

Early demos were done by presenting videos showcasing the camera feeds, the road damage detection model output as well as the capabilities of the streaming and the restreaming modules developed in the scope of the UC2. Initial KPIs were measured for the road damage detection model and for the streaming and re-streaming module for the deployment at WINGS and the AWS deployment.

In conclusion, the tests were successful in demonstrating the main capabilities of the application software developed. They validate the application's overall architecture, showing it can be video analysis, streaming, real-time processing, restreaming the video with the road damage model output and visualization of the basic analytics data. The software can handle multiple IP cameras and other devices (drones/ AGVs) in parallel, detecting 6 different classes of damage and their severity, and calculating a severity score. Then, based on this score the most severe are prioritized for inspection. The video analysis pipeline can integrate both pretrained object detection models available in the literature but also custom models; For the tests performed both a pre-trained model as well as a custom one have been tested, but the system can be extended to support more.

As for the next steps, the plan is to integrate further devices, such as AGVs and drones, and perform field tests at DAEM and AIA. The focus will also be on the further development of the visualization dashboard and its integration with the back end. Finally, additional KPIs will be measured.

3.4 UC3: Autonomous APRON

3.4.1 Trial 3.1 – Autonomous APRON

The tests related to Trial 3.1 aim at measuring the robot's autonomy as well as the service layer latency.

3.4.1.1 Laboratory tests

During the laboratory tests that took place at WINGS labs, a critical observation was made regarding the rapid depletion of the robot's battery power (Figure 69). Within just 15 minutes of operation, a significant drop in available voltage was noted. Upon analyzing the current consumption diagram, it became evident that the robot's onboard computer is the primary consumer of battery power. In the current architecture, all nodes essential for the robot's operation, including data processing and decision-making algorithms, are localized within this computer.

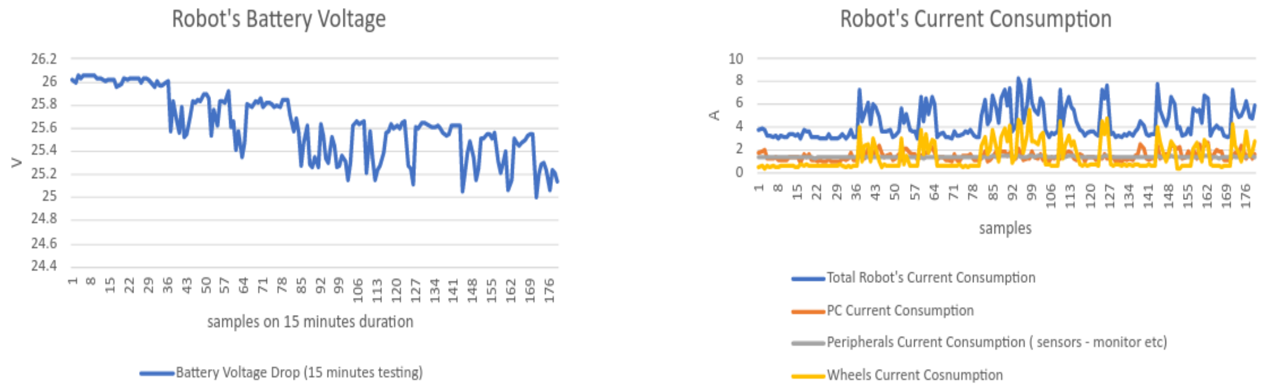

Figure 69. Battery voltage and robot's current consumption during 15 minutes of operation.

This setup, while functional, poses a substantial limitation on the robot's operational autonomy due to the high energy demands of the onboard computational processes. A strategic analysis suggests a viable solution lies in the utilization of advanced network technologies, specifically 5G and beyond. These cutting-edge networks offer unprecedented data transmission speeds and reduced latency, making them ideal for offloading computational tasks from the robot to the cloud or edge computing platforms.

By transferring most of the robot's computational nodes to the cloud or edge, facilitated by the robust capabilities of 5G and 6G networks, it is expected to be a dramatic improvement in the robot's battery life and, consequently, its operational autonomy. This shift not only alleviates the power consumption burden on the robot's onboard systems but also opens new avenues for more complex and computationally intensive tasks to be handled more efficiently.

The necessity for such advanced networking infrastructure in the robotic system is not merely a matter of enhancing performance but a crucial step towards ensuring sustainable and extended operational capabilities. The implementation of 5G and beyond technologies is, therefore, not just an upgrade; it is a pivotal transformation that aligns with the evolving demands of autonomous robotic systems and the inexorable march towards smarter, more efficient technological ecosystems.

The graph reported in Figure 70 provides a comparison of the service layer latency between Wi-Fi and 5G commercial networks, with a focus on a demanding bit rate (15-30 Mbps). More in detail, the blue line shows the latency measurements for a high data rate Wi-Fi connection. The latency varies significantly over time, with several spikes that exceed 80 ms and multiple instances where the latency is below 20 ms. This variability suggests that while Wi-Fi can offer low latency, it can also experience periods of high latency, possibly due to interference, congestion, or other factors affecting Wi-Fi stability. On the other side (orange line), the latency for the 5G commercial network also varies, but with fewer and lower spikes compared to Wi-Fi. Most of the latency readings are between 20 and 60 ms. It shows better consistency than Wi-Fi but still has moments of higher latency, which could be due to network congestion or other issues within the commercial network infrastructure. In summary, Wi-Fi offers variable latency, which might not be suitable for applications requiring consistent and low-latency communication, while the 5G Commercial network offers improved latency over Wi-Fi, with less variability, but still not as low or consistent as might be desired for critical applications.

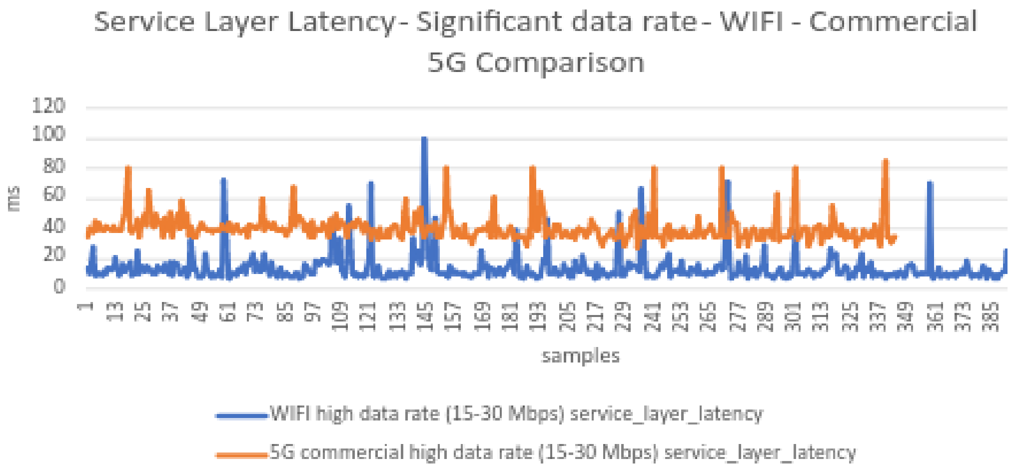

Figure 70. Service layer latency across Wi-Fi and 5G Commercial networks.

The test setup configuration used in Trial 3.1 is presented in the Table 35.

Table 35. Test setup parameters for Trial 3.1.

Test setup parameters	Test setup ID: Lab01
Radio access technology	5G NR
Network type	Commercial
Standalone / Non-Standalone	Non-Standalone
Cell Power	50 dBm (~120 W)
Frequency band	n78
Bandwidth per component carrier	100 MHz
Sub-carrier spacing	30 kHz
MIMO	64TX 64RX
Duplex mode	TDD
Device type	5G communication module deployed on Jackal
Device number	1
Device speed	2 m/s
Slice Configuration	Private APN

Test summary for Trial 3.1 is presented in Table 36.

Table 36. Test summary for Trial 3.1.

Test summary	
Trial ID	3.1
Test setup ID	Lab01
Facility/Site	Athens – WINGS Lab
Objective	Demonstration of the performance of the robot's autonomy and service layer KPI measurement
Description	Demonstration of the performance of the robot's autonomy and service layer KPI measurement
Executed by	WINGS
Components involved	Jackal robot, WINGSChariot platform
Targeted KPIs	KPI#08 (Application round-trip latency)
Measurement tools	-
Ethics requirements implementation	The tests have so far been performed only in the lab without involving users. In the future, a questionnaire will be submitted to participants for assessing KVI, along a release form regarding possible privacy and ethical concern.
Involvement of beta-users	N/A

In terms of KPIs, Table 37 details the requirements and results of the tests.

Table 37. Test cases results for Trial 3.1.

Test case ID	Test requirement	Measurement result	Validation
3.1_Lab01_01	KPI#08 (WiFi): <80ms	KPI#08 (WiFi): 20-80ms	Comply
3.1_Lab01_02	KPI#08 (Commercial 5G): <80ms	KPI##08 (Commercial 5G): 20-60ms	Comply

3.4.1.2 Tests on field

Test on field related to Trial 3.1 are planned in the next months.

3.4.1.3 Early demo

Figure 71 showcases the Jackal robot, which has been adapted with a cart for suitcases and cargo transfer to serve the Autonomous APRON use case. Figure 72 depicts one of the preliminary tests that were performed in an outdoor environment in order to check the coverage of the 5G commercial network. Finally, Figure 73 presents a view of the digital twin of the area that the AGV moves checking the 5G coverage within the WINGSChariot platform in the context of the demo for the Autonomous APRON use case.

Figure 71. The Jackal robot adapted for the Autonomous APRON use case.

Figure 72. A view of the robot in an outdoor environment, testing the 5G network coverage.

Figure 73. Live view of the robot in the WINGSChariot dashboard.

3.4.2 Remarks and next steps

In the next period development activities are planned in enhancing robotic platform's capabilities. The immediate focus is on transitioning from ROS1 to ROS2. This upgrade is crucial as it unlocks a plethora of advanced features and improvements in efficiency, security, and system management inherent in ROS2, aligning the technology with the latest in robotic software frameworks. Concurrently, a significant development is the integration of the robotic system with the WINGSChariot platform. This integration involves establishing communication through MQTT, enabling seamless interaction with WINGSChariot 's OpenHAB-run system and its Unity engine-driven digital twin. This pivotal step not only streamlines the control processes but also enhances the monitoring and management capabilities through the digital twin representation.

Furthermore, a key strategic decision lies ahead regarding the robot's navigation methodology in an airport environment. Two primary approaches are under evaluation: the first involves the robot moving along predefined strict lines, offering predictability and simplicity in navigation. The second approach leans towards a more dynamic method, where the robot navigates autonomously using smaller, RTK or RTAB-Map based waypoints. This method promises greater flexibility and adaptability in complex environments. The decision will be made considering factors like environmental complexity, safety standards, and operational efficiency to ensure optimal performance of the robotic platform in the targeted setting.

3.5 UC4: Smart Traffic Management

3.5.1 Trial 4.1 - Smart Traffic Monitoring and Safety Application

Trial 4.1 focuses on traffic monitoring using surveillance cameras connected over 5G. The trial is conducted at the busiest intersection from Iasi, Romania – Podu Ros, which features several cameras installed on traffic poles.

Insights are provided in terms of the total count of cars passing through the area of interest, identification of situations when cars are parked on restricted areas, and heatmaps indicating the car density on the premises.

3.5.1.1 Laboratory tests

The tests in UC4 were carried out directly on the field because the devices were installed on the premises in the final positions in the summer of 2023. These tests are detailed in the following section. However, a laboratory area was also defined, which became the command and monitoring center of UC1 and UC4, as in Figure 74, and preliminary calibrations tests have been performed there. The access in the command and monitoring center is allowed only for consortium partners.

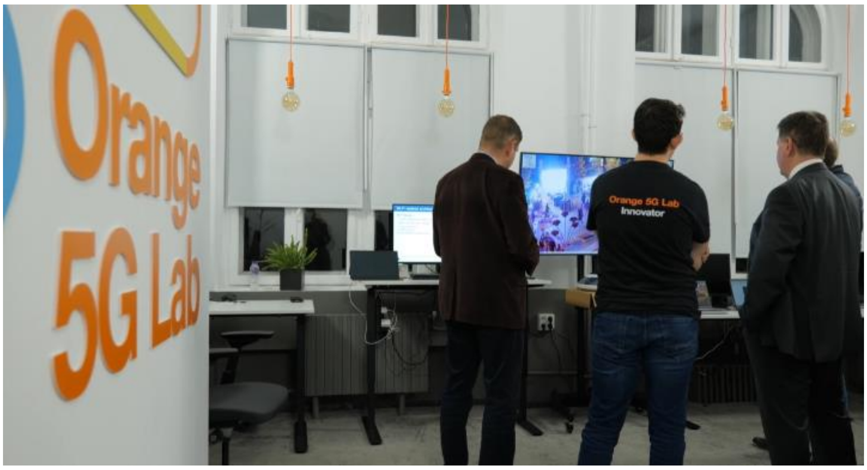

Figure 74. UC4 Laboratory room- Command and monitoring center.

During the laboratory tests, pre-trained neural networks models were ingested into the Triton Server from the Deep-Stream framework. Tests were performed using pre-recorded videos exhibiting normal traffic scenarios. Video analytics are computed and displayed in terms of the total number of cars entering a user-defined area of interest, and heatmaps estimating car density on the same area, to demonstrate the first version of the video analytics application capabilities. The application focuses on sensing the traffic information by camera surveillance, detecting the traffic participants, classifying and localizing them.

3.5.1.2 Tests on field

Since the hardware installations that happened in early December in Iasi, that involved the mounting of a 5G router inside the intersection technical box and its configuration to aggregate the connections from all the installed cameras, field tests were performed periodically by TUIASI, together with ORO.

The tests selected for this use case provide methods to improve traffic management in a very crowded intersection in Iasi and to detect and prevent potentially dangerous situations. The UC4 tests explores the usage and applications of B5G (towards 6G) networks as essential building blocks of Smart Cities and provides key advantages in public safety and security, environmental monitoring, and intelligent traffic monitoring. Different testing aiming at sensing traffic participants in areas of interest, estimating car flow, and detecting cars in forbidden were performed in December 2023 by TUIASI and ORO experts using the test setup as detailed in Table 38. The summary of the tests is presented in Table 39.

Table 38. Field setup parameters for Trial 4.1.

Test setup parameters	Test setup ID: Field01
Radio access technology	5G NR
Network type	Commercial
Standalone / Non-Standalone	Non-Standalone
Cell Power	50 dBm (~120 W)
Frequency band	n78
Bandwidth per component carrier	100 MHz

Sub-carrier spacing	30 kHz
MIMO	64TX 64RX
Duplex mode	TDD
Device type	5G CPE
Device number	1
Device speed	0 km/h
Slice Configuration	Private APN
Background traffic	Low

Table 39. Field test summary for Trial 4.1.

Test summary	
Trial ID	4.1
Test setup ID	Field01
Facility/Site	Iasi
Objective	Demonstration of the video analytics application capabilities (1st version) and performance testing for the supporting 5G network
Description	The application focuses on several distinct scenarios of practical interest: a) Sensing the traffic information by camera surveillance, detecting the traffic participants, classifying them and localizing them to create a digital traffic model at the monitoring facility together with extracting basic traffic statistics b) Disseminate relevant safety information extracted from the digital traffic model to traffic participants with the aim of enhancing safety of the VRUs
Executed by	TUIASI & ORO
Components involved	5G network, Cameras and Routers, edge-compute infrastructure, video analytics application
Targeted KPIs	KPI#01 (Downlink throughput per user) KPI#02 (Uplink throughput per user) KPI#04 (Uplink aggregate throughput) KPI#06 (Uplink throughput per device) KPI#08 (Application round-trip latency)
Measurement tools	SpeedTest, ping
Ethics requirements implementation	Privacy preserving solution preventing people identification based on reducing video resolution. Restricted access in the laboratory room
Involvement of beta-users	During the field tests, the current state of the video analytics application was showcased to the Iasi Municipality team for initial feedback on the implemented features.

Network level tests have been performed with the results depicted in Table 40.

Table 40. Network level test cases results for Trial 4.1.

Test case ID	Test requirement	Measurement result	Validation
4.1_Field01_01	KPI#01: 500 Mbps KPI#02: 150 Mbps KPI#04: > 6x7 Mbps KPI#08: < 50 ms	KPI#01: 14 Mbps KPI#02: 17 Mbps KPI#04: < 6x7 Mbps KPI#08: 140 ms	Test case 01 was performed during December 2023 over the commercial 5G NSA network. Because the intersection technical box is made from metal, the 5G router installed inside was shielded and could not sustain high throughput values, nor it could achieve proper E2E latency results. In the near future, an

			external 5G combo antenna unit will be installed outside the metal cabinet and the tests will be rerun. However, even considering this deficiency, the surveillance streams were processed without any bothering issue since their resolution was dropped to 1080p. The required uplink cell capacity for streaming 2K footage from UC4's 6 cameras was not reached.

Application-level tests were done by capturing and analyzing the video traffic streamed from one or all the cameras up to the 5G Lab Edge Compute infrastructure. All video streams have H264 encoding with identical resolution and settings, except for frame rate. Note that the throughput value depends on various factors, including the actual movement content in the view. The results are shown in Table 41.

Table 41. Application-level test cases results for Trial 4.1.

Test case ID	Test requirement	Measurement result	Description	Validation
4.1_Field01_01.1	KPI#06: > 2.23 Mbps KPI#08: < 50 ms	KPI#06: 4.44 Mbps KPI#08: 140 ms	1 camera only, resolution 1280x720, streaming at 25fps	During normal traffic hours, average movement content.
4.1_Field01_01.2	KPI#06: > 13.38 Mbps KPI#08: < 50 ms	KPI#06: 22.25 Mbps KPI#08: 140 ms	All 6 cameras at resolution 1280x720, 4 at 25fps, 1 at 15fps and 1 at 10 fps	During normal traffic hours, average movement. Throughput value scales almost linearly with number of cameras.

The throughput and latency performance of the network were assessed using the CPE provided testing capabilities, using Speed Test by Ookla, as showcased in Figure 75. The latency values were also validated using ping probes between the 5G CPEs and a virtual machine from the 5G Lab Edge Compute infrastructure as shown in Figure 76.

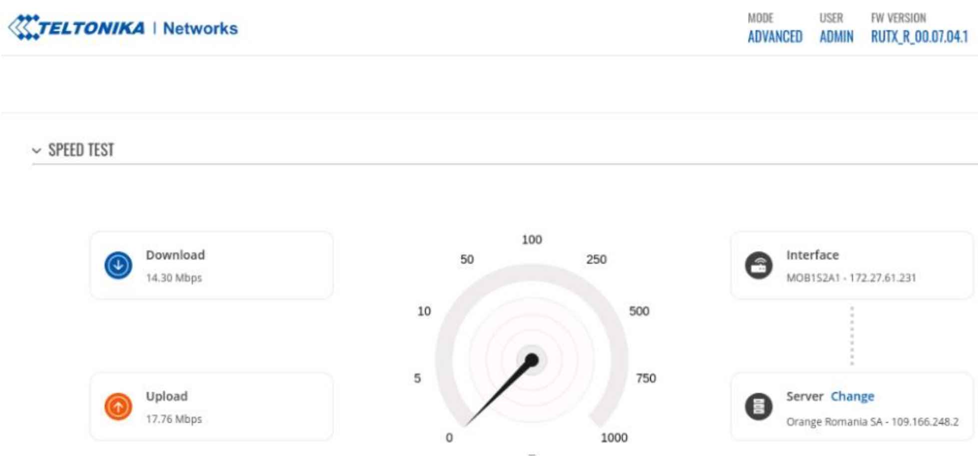

Figure 75. Field01_01 test case measured throughput related KPIs at the 5G CPE level.

```
PING 172.27.61.231 (172.27.61.231) 56(84) bytes of data.
64 bytes from 172.27.61.231: icmp_seq=1 ttl=55 time=168 ms
64 bytes from 172.27.61.231: icmp_seq=2 ttl=55 time=127 ms
64 bytes from 172.27.61.231: icmp_seq=3 ttl=55 time=148 ms
64 bytes from 172.27.61.231: icmp_seq=4 ttl=55 time=124 ms
64 bytes from 172.27.61.231: icmp_seq=5 ttl=55 time=83.1 ms
64 bytes from 172.27.61.231: icmp_seq=6 ttl=55 time=185 ms
64 bytes from 172.27.61.231: icmp_seq=7 ttl=55 time=95.5 ms
64 bytes from 172.27.61.231: icmp_seq=8 ttl=55 time=158 ms
64 bytes from 172.27.61.231: icmp_seq=9 ttl=55 time=188 ms
64 bytes from 172.27.61.231: icmp_seq=10 ttl=55 time=162 ms
64 bytes from 172.27.61.231: icmp_seq=11 ttl=55 time=169 ms
64 bytes from 172.27.61.231: icmp_seq=12 ttl=55 time=128 ms
64 bytes from 172.27.61.231: icmp_seq=13 ttl=55 time=200 ms
64 bytes from 172.27.61.231: icmp_seq=14 ttl=55 time=110 ms
64 bytes from 172.27.61.231: icmp_seq=15 ttl=55 time=133 ms
64 bytes from 172.27.61.231: icmp_seq=16 ttl=55 time=195 ms
64 bytes from 172.27.61.231: icmp_seq=17 ttl=55 time=65.5 ms
64 bytes from 172.27.61.231: icmp_seq=18 ttl=55 time=168 ms
64 bytes from 172.27.61.231: icmp_seq=19 ttl=55 time=63.5 ms
^C
--- 172.27.61.231 ping statistics ---
19 packets transmitted, 19 received, 0% packet loss, time 18024ms
rtt min/avg/max/mdev = 63.596/140.947/200.001/41.345 ms
```

Figure 76. Field01_01 test case measured E2E latency from the Edge-Cloud infrastructure to the 5G CPE.

3.5.1.3 Early demo

Early demos have been performed to showcase the first version of the video analytics application capabilities. Preliminary tests were performed using actual feeds provided by the cameras installed on the premises. The tests envisaged optimal positioning of the cameras, confirmed stable video feed from all cameras, and saving the actual records both locally, on the SD cards attached to the cameras, and remotely, on the storage servers at TUIASI.

Early demos have been done showcasing the video feeds from the cameras, the definition of the areas of interest and insights from the actual video scenes in terms of total count of traffic participants and heatmaps estimating car density. A series of tests were conducted, focused on assessing the accuracy of the models in low-light conditions and adverse weather scenarios.

Pre-trained neural networks models were integrated in the software application. Tests were performed using live video feeds exhibiting normal traffic scenarios. Video analytics are computed and displayed in terms of the total number of cars entering a user-defined area of interest, and heatmaps estimating car density on the same area. The application focuses on sensing the traffic information by camera surveillance, detecting the traffic participants, classifying and localizing them. In the following, the three demos are described.

Sensing traffic participants in areas of interest

This demo aims at counting the number of pedestrians and vehicles passing through the intersection of Podu Roș in Iași (Figure 77). The demo uses the video feed from each camera separately. Only the objects in a pre-defined region of interest, which includes most of the visible intersection area, are considered.

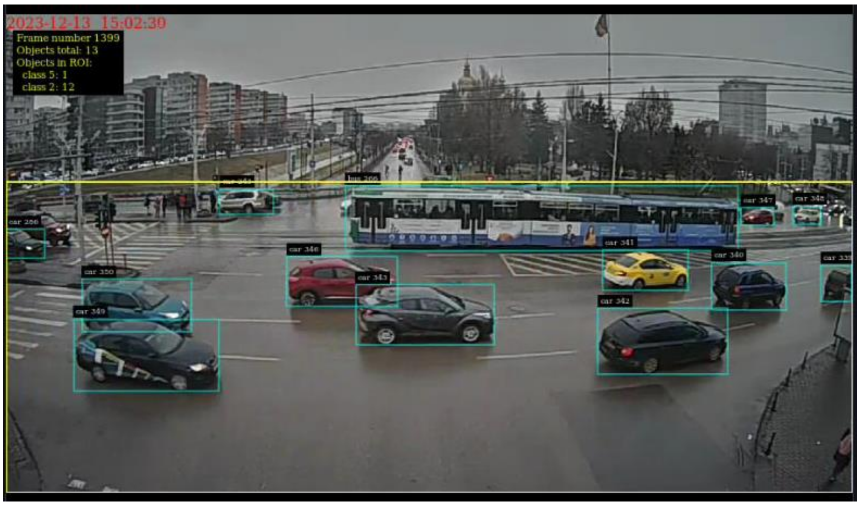

Figure 77. UC4 demo detecting traffic participants in areas of interest.

The same software application software described for UC1 is used, with difference only in configuration. Detection is achieved using the YOLO v7 neural network model [19], detecting the objects of interest in each frame and counting the detections inside a region of interest, per category. The time series are smoothed using an exponential moving average filter, and the values are published in real-time on the Kafka messaging system. The data is then ingested by the dashboard software which displays the values to the user.

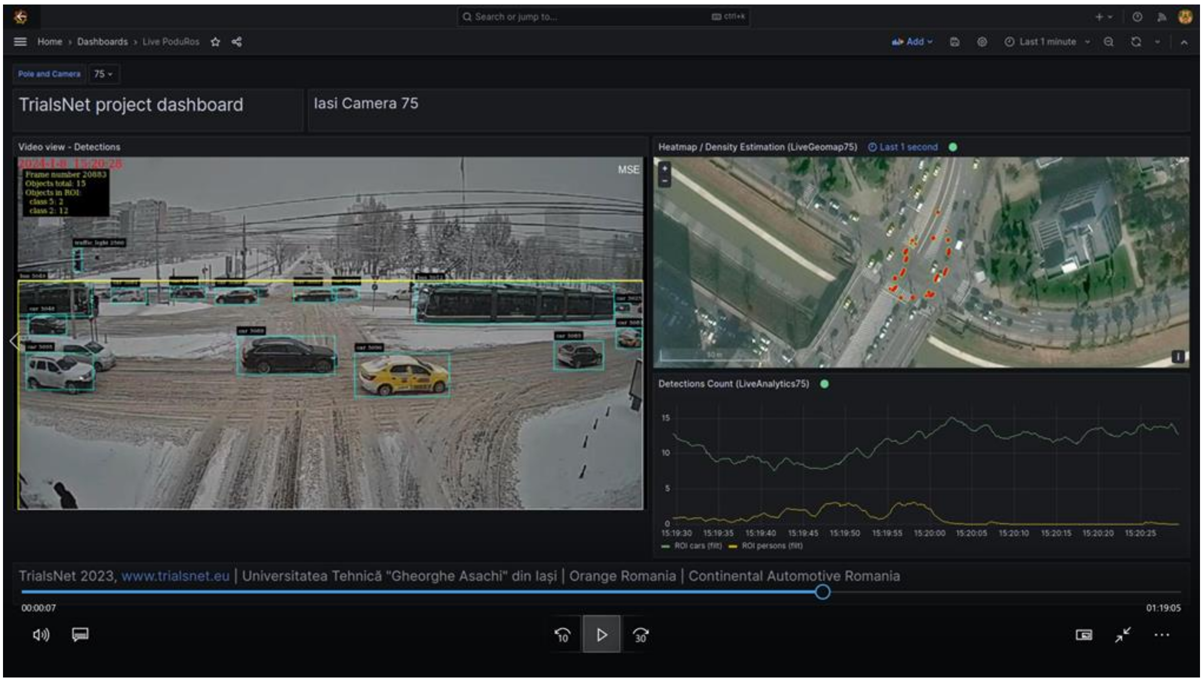

Figure 78. Application dashboard view.

A screenshot of the dashboard displaying the number of people and the number of vehicles in the region of interest on the street during the event is shown in Figure 78. The dashboard includes the video with the detected objects. The analysis and display are in real-time, at the FPS value of the video feed provided by the camera (25 fps), which shows that the processing does not incur significant delays.

A screenshot containing only the output counter values from one camera is displayed in Figure 79.

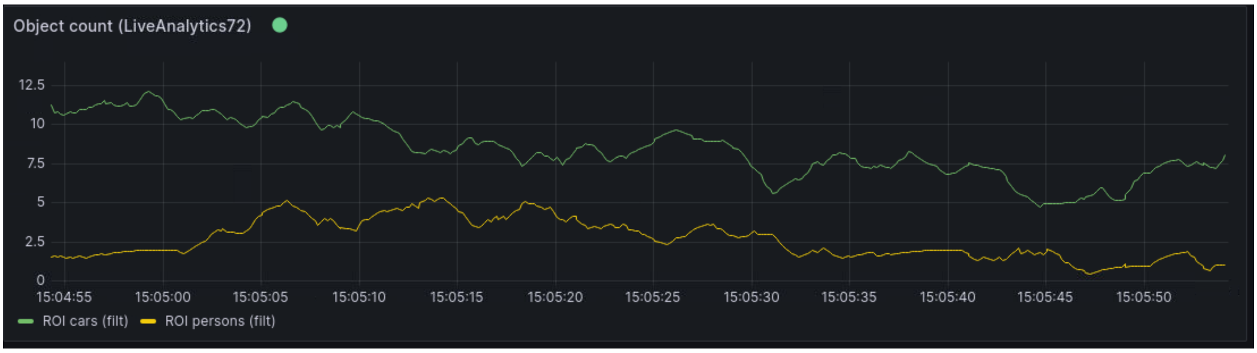

Figure 79. Sensing traffic participants in areas of interest.

Car flow estimation

The demo aims to estimate and display the trajectory of vehicles crossing through the intersection of Podu Roș in Iași. Like the Field01_01 test, the video feed from each camera separately is used and considers only the objects in a predefined region of interest.

The application is similar to Field_01 tests, based on the YOLO v7 neural network model detecting the objects of interest in each frame. The coordinates of each detection centroid are then converted to GPS coordinates using a similar extrinsic calibration procedure as in Field01_01 test. The GPS coordinates are published on the Kafka server, from which they are read and displayed in the visual dashboard.

A screenshot of the dashboard showing the trajectories of detected vehicles, in the form of a heatmap, is shown in Figure 80. The analysis and display are in real-time, at the FPS value of the video feed (25 fps), with no significant delays.

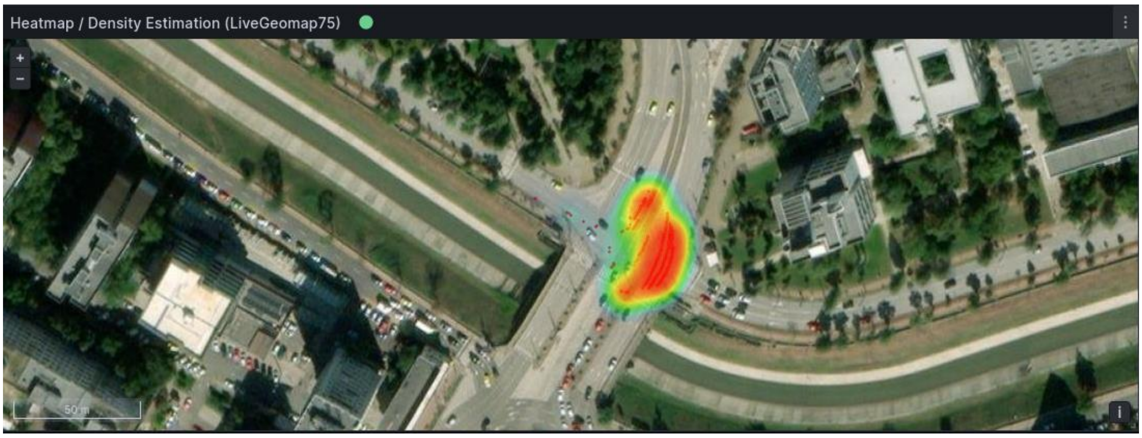

Figure 80. UC4 demo car flow estimation.

Car detection in forbidden areas

This demo is similar to UC1 Field01_03. The objective is to detect when a car is inside a predefined forbidden area and trigger a visible alert on the video. The video feeds are from the Podu Roș intersection.

A screenshot of the dashboard showing a visual alert when a car is detected inside the forbidden area is displayed in Figure 81. The analysis and display are in real-time, at the FPS value of the video feed (25 fps), with no significant delays.

Figure 81. UC4 demo car detection in forbidden areas.

Dissemination activities were carried out in several events organized in collaboration with TUIASI and ORO in 2023 and beginning of 2024. During these events, UC4 implementation details and demos results were presented. Figure 82 shows an image from the dissemination film made together with the Iasi City Hall.

Figure 82. UC4 dissemination activities with worldwide Orange 5G Lab representatives.

3.5.2 Remarks and next steps

From application point of view, the tests show that the same architecture and application software also used in UC1 can be used successfully for UC4 too, albeit the video cameras for UC4 have different capabilities than those of UC1. In addition, the tests in UC4 used live video feeds from several days, under different lighting and weather conditions (nighttime, snowy roads), in order to evaluate the robustness of the object detection models. With snowy roads, little to no change was observed in detection accuracy, whereas during nighttime the detection accuracy was lower especially for far away objects but remained satisfactory for the region of interest.

Several future tests are being considered for the next stages. The performance of object detection in scenarios with a significant degree of partial occlusions of vehicles, as during jams or peak traffic hours, needs to be evaluated. More extensive tests are also needed for atmospheric conditions, e.g. rain or foggy weather, as well as lighting conditions, as for example when there is a great contrast between shady and bright sunny spots during summer.

A further test concerned the potentially risky scenario where pedestrians are detected among vehicles at the same time, as for example when cars are advancing on pedestrian crossings during red light. These situations cannot be detected using fixed exclusion zones, since both pedestrians and vehicles can legitimately be detected over crossings at some time, but not simultaneously. In the software application, the aim is to compute and report the individual delays introduced by each component in the video processing pipeline, to evaluate the system's total reaction time.

For the 5G network evaluation, the conclusion is that the tests performed under the first iteration of field trials for UC4 were not in-line with the expectations due to poor availability of the 5G network coverage in the area and significant radio interferences posed by the metallic box that was surrounding the traffic aggregation 5G CPE. These issues will be solved during the first half of 2024 with the addition of a high-gain external antenna for the CPE and the coverage improvements that ORO will conduct in the UC4 area.

Regarding the next steps that should be performed on the network side, as previously mentioned in relation to UC1, the upgrade to outdoor 5G SA is expected to be performed at the end of 2024, while all the edge-compute related prerequisites (local UPF and computing servers' installation in Iasi) are to be finalized in June 2024. The integration of the UC4 application in the deployed 5G edge-compute ecosystem will happen in the fall, just in time for the second round of field tests that should be performed in October 2024. These advancements will lead to a new wave of tests for uplink/downlink throughput, E2E network latency, edge-computing latency and application-level latency because of the critical nature of the use case. KVIs assessment will also be provided in the next WP3 deliverable D3.3.

3.6 UC5: Control Room in Metaverse

3.6.1 Trial 5.1 - Control Room in Metaverse

The trials for UC5 focus on checking the integration of the system developed for the safety and security agents of the Turin municipality and the connection between the different equipment and devices. The first measurement of the KPI in terms of bitrate and latency are also presented. The first test was done on the Streaming Video Camera in the lab using the commercial 5G network of TIM.

3.6.1.1 Laboratory tests

The tests have been performed in Crossmedia Europe (CROSEU)'s laboratory in Turin. The main characteristics of the 5G network are listed in Table 42 while Table 43 provides the summary of the test.

Table 42. Test setup description for Trial 5.1.

Test setup parameters	Test setup ID: Lab01
Radio access technology	5G NR Rel-15
Network type	Commercial
Standalone / Non-Standalone	NSA
Cell Power	N/A

Frequency band	n78
Bandwidth per component carrier	80 MHz
Sub-carrier spacing	30 kHz
MIMO	massive MIMO (mMIMO)
Duplex mode	TDD
Device type	Streaming video-camera
Device number	1
Device speed	0 km/h
Slice Configuration	None
Background / simulated traffic	commercial

Table 43. Test summary for Trial 5.1.

Test summary	
Trial ID	5.1
Test setup ID	Lab01
Facility/Site	CROSEU lab
Objective	To check the KPIs of a video camera streaming and other devices connected to the system.
Description	The video camera streaming has been tested with different parameters to assess the load per camera in addition to a web browser simulating Mozilla Hubs.
Executed by	Marco Mazzaglia and Andrea Basso
Components involved	Streaming Video Camera
Targeted KPIs	KPI#01 (Downlink throughput per user) KPI#02 (Uplink throughput per user)
Measurement tools	Wireshark [45]
Ethics requirements implementation	There are no ethical implications as the tests have been conducted in a controlled laboratory environment, and all test operators are members of the project consortium. However, for the upcoming field tests and trials, ethical considerations and privacy concerns will be prioritized. To this end, all participants will sign a release form explicitly outlining their consent and understanding of the privacy and ethical aspects involved. This proactive approach underscores the commitment to upholding ethical standards and respecting the rights of all involved parties.
Involvement of beta-users	N/A

The streaming video camera setup involved a Hikvision camera connected via Wi-Fi to a 5G router and a PC with a web browser simulating HUBS. A tablet playing video content with high motion has been placed (see Figure 83). The following tests have been performed in the lab.

Figure 83. Video used for testing.

Transport Protocol

The camera supports multiple protocols, including HTTP, RTSP, SRTP, and WebSockets. For the transport protocol, WebSockets over port 7681 and Hypertext Transfer Protocol Secure (HTTPS) were selected to ensure compatibility with HUBS. This choice facilitates smooth and secure video transmission. WebSockets offer real-time, bidirectional communication, making them suitable for streaming applications. The use of HTTPS ensures secure data transfer, crucial for protecting sensitive video content during transmission. The combination of these protocols enhances both performance and security in the streaming setup.

Video Codec and parameters

The camera supports H.264 and H.265 codecs. For optimal performance, H.264 Main Profile was chosen. The Main Profile is suitable for high-quality video, and its compatibility with a wide range of devices makes it a practical choice. The decision to focus on H.264 over H.265 has been driven by the balance between compression efficiency and device compatibility. The following parameters have been also selected (see Figure 84):

- **Resolution**: Full HD (1920x1080) in progressive format
- **I-frame Interval**: 50 frames, essential for reducing latency and ensuring efficient compression
- **Rate Control**: Variable Bitrate (VBR), chosen for its adaptability to varying complexity of video scenes

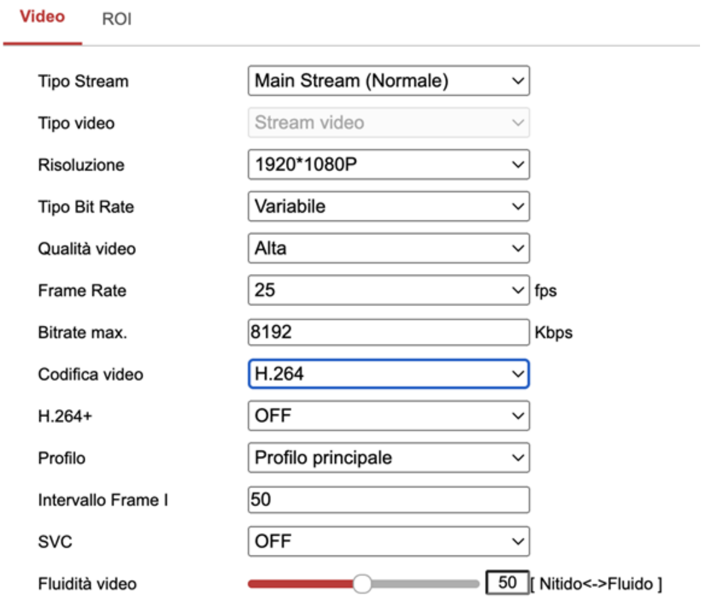

Figure 84. Video parameters.

Network protocol analysis

Wireshark Capture Setup. To delve deeper into the network performance, two packet captures were conducted using Wireshark software on the receiving end at frame rates of 15fps and 25fps, respectively, to assess the trade-off between smoothness and bandwidth consumption. 10,000 packets were captured, each with a Maximum Transmission Unit (MTU) of 1452 bytes. This comprehensive capture provides a detailed insight into the video transmission and its impact on the network.

Packet Analysis. Wireshark was utilized to analyze the captured packets. The focus was on filtering out the video stream related to the WebSocket communication from the overall network traffic. This detailed analysis allows for a granular examination of the WebSocket protocol behavior, ensuring that it meets the desired performance criteria.

Validation

Codec Efficiency. The packet captures offer an opportunity to validate the efficiency of the chosen H.264 Main Profile Codec. By examining the packet contents, it becomes possible to assess the compression ratios achieved by the codec, ensuring that it strikes a balance between video quality and bandwidth consumption.

I-frame Interval and Rate Control. The captured packets also enable a closer look at the I-frame interval and rate control settings. The consistency and distribution of I-frames within the stream can be evaluated, providing insights into the codec's ability to adapt to dynamic scenes and maintain a consistent video quality.

Frame Rate Impact. Analyzing the packet captures at different frame rates (15fps and 25fps) allows for an assessment of the impact on bandwidth consumption (see Figure 85). This examination ensures that the selected frame rates align with the desired streaming quality and network capacity.

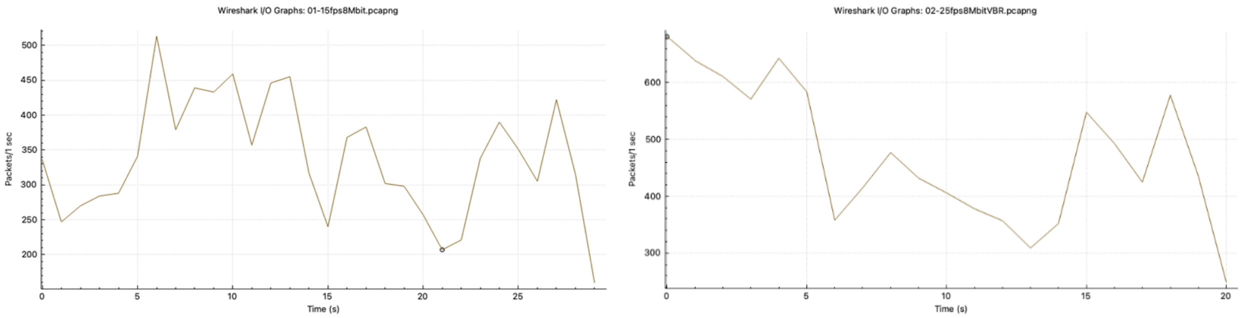

Figure 85. Wireshark results for 15 fps (left) and 25 fps (right).

Estimated Bitrate for Client Devices. Based on the conducted tests and the selected video codec settings, the estimated bitrate for each client device, considering two video streams, is calculated as follows:

Video Streams Bitrate: 16 Mb/s (Variable Bitrate - VBR).

In addition to the video streams, it is essential to consider the bitrate consumed by HUBS, estimated to be around 2 Mb/s.

Total Estimated Bitrate per Client Device: 16Mb/s (2 Video Streams) + 2Mb/s (HUBS) = 18Mb/s.

This estimation takes into account both the variable bitrate of the video streams and the additional bandwidth required for HUBS operation. It is crucial for clients to ensure their network capabilities can support this estimated bitrate for a seamless streaming experience.

In Table 44 measurements result of the test are reported.

Table 44. Test cases results for Trial 5.1.

Test case ID	Test requirement	Measurement result	Validation
5.1_Lab01_01	KPI#01, KPI#02: depend on event size (number of video cameras and security agents onsite)	KPI#01: 24Mbps KPI#02: 4Mbps	The bitrate and round-trip delay for one client are below the network specs for small to medium events, but not sufficient for medium to large events requiring more on-site cameras and agents.

3.6.1.2 Tests on field

So far, the tests have only been conducted in the laboratory of CROSEU at the OGR Tech, the incubator at the Officine Grandi Riparazioni in Turin. The commencement of the field tests is planned in early spring.

3.6.1.3 Early demo

The demo of the Metaverse Control Room has been developed and presented to the stakeholders' group, composed of representatives of Firefighters, Emergency Services, Ambulances, and Civil Protection during the second meeting of the Design Thinking + that was held in Turin on 5 February 2024 (see Figure 86).

Figure 86. Stakeholders involved in the second meeting of Design Thinking+.

Screenshots of the MCR and its primary window are presented in Figure 87 and Figure 88. This window presents various types of information, prominently featuring images and videos uploaded by security agents, a Google Map indicating the precise location of the accident, data sourced from sensors, and video feeds from cameras installed on-site.

Figure 87. Main room of the MCR.

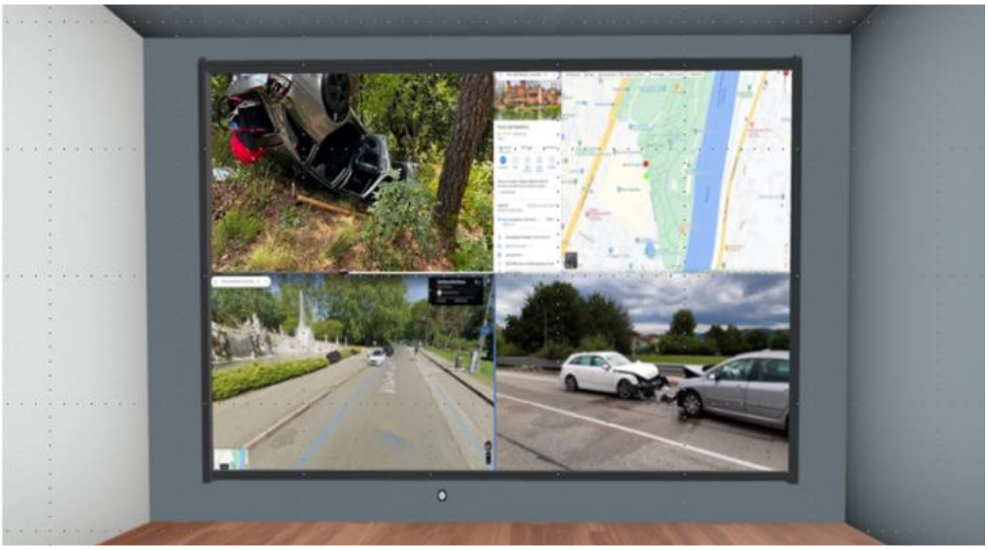

Figure 88. Main window of the MCR on Mozilla Hubs.

To facilitate interaction among the various security entities, three private rooms have been established adjacent to the MCR (see Figure 89). Within these rooms, avatars representing each security body can engage in private discussions with two or more agents. Additionally, an alternative option allows them to convene in a designated area within the MCR without disrupting other avatars in the room. While some minor challenges were initially encountered in segregating the audio streams of avatars in the main room, these issues have since been successfully addressed by the programming team as described below. The meeting with the safety and security forces confirmed their interest in the product and encouraged the programming team to continue the development as planned.

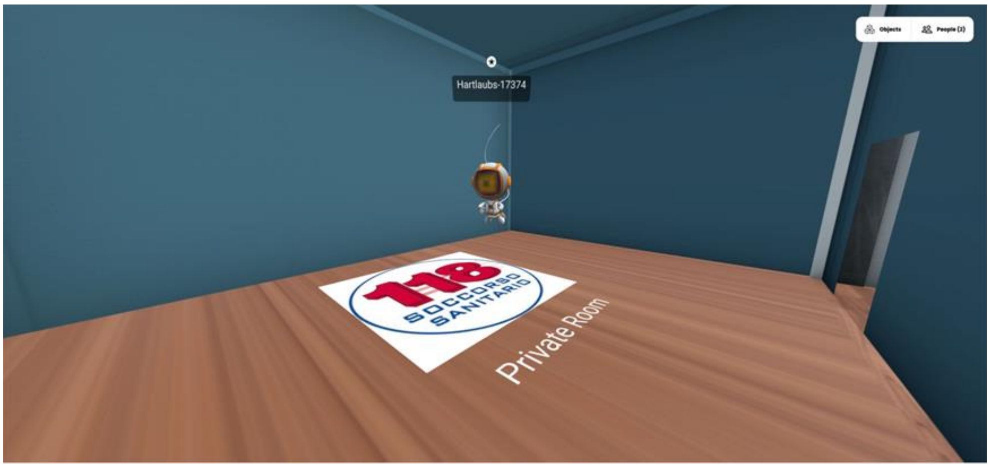

Figure 89. Private room of the MCR on Mozilla Hub.

3.6.2 Remarks and next steps

Security agents are usually given SIM cards which have priority access on other users. This implies that the 5G network could support a maximum of 25 connected agents and two video cameras, which should be sufficient in events of medium size. However, for large events where at least 6 critical spots should be monitored with video cameras, the network would support a maximum of 10 agents, which would likely not be sufficient to provide access for all the security and safety agents present onsite. This would justify the need for a more performant connectivity as compared to the 5G commercial network currently available, regarding both the downlink from the servers integrated in the video cameras and drones, and uplinks from the agent devices. Given the linearity of the use case and the reliance on these measurements, the plan is to perform field tests with the two available streaming video cameras, plus possibly one drone, and with the presence of 10-12 users, as was foreseen in D3.1. Extrapolation of the measurement will be used to identify the limits beyond which the existing 5G network's capability will not be sufficient. In case priority SIM cards are not available, then network saturation would most probably be reached given the high number of connected users attending an event. The other KPIs that will be measured during the trials are the aggregated downlink (KPI#03) and uplink (KPI#04), as well as the service reliability (KPI#15), which is crucial for this use case. The list of KVIs to assess during the trials has been drafted and agreed upon by the participants in the second meeting of the Design Thinking+ process.

4 Implementation plan updates

This section reports about the progress update for each use case with reference to the Implementation time plan included in D3.1. Milestones review and issues management are presented for each use case with the aim to track the project activities and apply mitigation measures, if needed.

4.1 UC1: Smart Crowd Monitoring (Madrid)

The milestones of UC1 in Madrid are recalled hereafter:

- **MS1** (Q2 2023): This milestone includes the definition of the trial, user needs and technical needs. The aim is to obtain a specific description of all the activities/tasks of UC1 Madrid.
- **MS2** (Q4 2023): This milestone involves the design of technical tools needed for Madrid. The main aim is the design of the network infrastructure. The hardware and technical tools of telepresence system will be acquired, set-up and tested.
- **MS3** (Q1 2025): This milestone involves the development, set-up and integration of network infrastructure and devices.
- **MS4** (Q3 2025): This milestone involves the execution of control and experimental sessions of the trial.

The activities for UC1 in Madrid are progressing overall as planned. 5G infrastructure, application and devices are available and under planned upgrades in order to perform the next final tests. Some delays, only related to the procurement of some licenses (Isentry and Gemini) was overcome by using free trial licenses.The process of finalizing purchase conditions is ongoing.

4.2 UC1: Smart Crowd Monitoring (Iasi)

The milestones of UC1 in Iasi are recalled hereafter:

- **MS1** (Q2 2023): This milestone involves the definition of the user needs, technical requirements, and trials design for the activities/tasks related to the implementation of UC1 use case at Iasi site.
- **MS2** (Q3 2023): This milestone involves the design of the technical setup needed to implement UC1 in Iasi site. It aims at configuring the infrastructure (sensing, communicating, processing, acting) and identifying the hardware/software tools to be used.
- **MS3** (Q4 2024): This milestone involves the acquisition, setup, and integration of HW/SW modules to enable first demo apps.
- **MS4** (Q3 2025): This milestone involves the execution of control and experimental sessions of the trial.

MS1 and MS2 are finalized as planned. 5G infrastructure, application and devices are available. The first set of tests have been performed on the field during October 2023 large event in Iasi and during December 2023 on the pedestrian street used for Christmas events. Upgrades are planned in order to perform the next tests for 5G infrastructure upgrades, including NSA in 2025. Final application development and final tests and KPI and KVI evaluation will be covered in MS4.

4.3 UC2: Proactive Public Infrastructure Assets Management

The milestones of UC2 are recalled hereafter:

- **MS1** (Q2 2023): This milestone involves the definition of the trial, user needs and technical needs. The aim is to obtain a specific description of all the activities/tasks of UC2 Athens.
- **MS2** (Q4 2023): This milestone involves the design of technical tools needed to UC2. The main aim is the design of the network infrastructure. The hardware and technical tools of telepresence system will be acquired, set-up and tested.

- **MS3** (Q4 2024): This milestone involves the development, set-up and integration of network infrastructure and devices.
- **MS4** (Q3 2025): This milestone involves the execution of control and experimental sessions of the trial.

Activities for UC2 are ongoing as scheduled, no major issues for UC2 have been identified up to the time of writing this report. 5G infrastructure, application and devices are available, initial integration of IP cameras to the WINGSPARK Plus platform as well as of the road damage detection model were achieved in this period. Preliminary testing also took place in lab settings, while the first round of on field trials are planned for the next period according to UC2 time plan.

4.4 UC3: Autonomous APRON

The milestones of UC3 are recalled hereafter:

- **MS1** (Q2 2023): This milestone involves the definition of the trial, user needs and technical needs. The aim is to obtain a specific description of all the activities/tasks of UC3 Athens.
- **MS2** (Q4 2023): This milestone involves the design of technical tools needed to UC3. The main aim is the design of the network infrastructure. The hardware and technical tools of telepresence system will be acquired, set-up and tested.
- **MS3** (Q4 2024): This milestone involves the development, set-up and integration of network infrastructure and devices.
- **MS4** (Q3 2025): This milestone involves the execution of control and experimental sessions of the trial.

Activities for UC3 are progressing as planned, no major issues for UC3 have been identified up to the time of writing this report. 5G infrastructure, application and devices are available, initial integration of the Jackal to the WINGSChariot platform were achieved in this period. Preliminary testing also took place in lab settings, while the first round of on field trials are planned for the next period according to UC3 timeplan.

4.5 UC4: Smart Traffic Management

The milestones of UC4 are recalled hereafter:

- **MS1** (Q2 2023): This milestone involves the definition of the trial, user needs and technical needs. The aim is to obtain a specific description of all the activities/tasks of UC4 Iasi.
- **MS2** (Q3 2023): This milestone involves the design of technical tools needed for UC4. The main aim is the design of the infrastructure architecture (sensing, communicating, processing, acting). The hardware elements will be acquired, set up and tested. The SW modules will be integrated within the system too.
- **MS3** (Q4 2024): This milestone involves the development, acquisition, set-up and integration of HW and SW modules to enable first demo apps.
- **MS4** (Q3 2025): This milestone involves the execution of control and experimental sessions of the trial.

MS1 and MS2 are finalized as planned. The first field tests as part of MS3 have been performed during October-December 2023. Cameras are installed on the intersection poles and connected to the 5G CPE. As the 5G coverage is poor in the intersection testing area, some updates will be implemented for the following tests, such as the addition of an external 5G antenna for 5G CPE. 5G infrastructure upgrades, including NSA in 2025, as well as final application development and final tests and KPI and KVI evaluation will be covered in MS4.

4.6 UC5: Control Room in Metaverse

The revised milestones of UC5 are recalled hereafter:

- **MS1** (Q2 2023): This milestone involves the definition of the trial, user needs and technical needs. The aim is to obtain a specific description of all the activities/tasks of UC5.

- **MS2** (Q4 2023): This milestone involves the design of technical tools needed for UC5. The main aim is the design of the network infrastructure. The hardware and technical tools of telepresence system will be acquired, set-up and tested.
- **MS3** (Q3 2024): This milestone involves the development, set-up and integration of network infrastructure and devices.
- **MS4** (Q4 2024): This milestone involves the execution of control and experimental sessions of the trial.

MS1, i.e., laying the foundation and definition of UC5, has been completed and the second meeting of the Design Thinking + with the identified users was held in February 2024. The Milestone MS2 has also been successfully completed. As described, the MCR was developed and populated, including an embedded screen with maps, graphs, photos or videos that can be uploaded from remote. Regarding the hardware, in December 2023, COTO has received 20 headsets (16 Meta Quest 2 and 4 Meta and two 5G tablets) that will be used in the trials of the UCs in Turin. Further tablets will be ordered by CROSEU in 2024 as required. The servers of PoliTO have been upgraded and tested, and in January 2024 the application software was migrated. The video camera has been tested but a new model is expected in the first half of 2024. System integration has been achieved. The last milestone, MS4, was rescheduled to the 4th quarter of 2024 to allow for more time for potential final improvements and adjustments.

The development of UC5 progressed well, considering also that some activities required more time and effort than initially expected. However, their impact on the project has been marginal and the activities are ongoing as planned. The only noteworthy variation with respect to the original plan was to replace in the MCR the captured 3D scans of the “Area Eventi” of Valentino Park with the relevant positioning on Google Maps. This not only avoids operations slowdown due to very large data processing and the risks for distraction from more crucial emergency data, but it also enables the use of the application in areas where 3D scans are not available.

5 Conclusions

This report outlines the use cases currently being implemented by TrialsNet within the ITSS domain, highlighting first solutions integration and test results. The document delves into the final application design, infrastructure components, functionalities, and initial KPI measurements for each use case at the trial sites in Greece, Italy, Romania, and Spain. Additionally, the report offers a comprehensive review of the initial time plan and key milestones for each use case as they progress towards trial completion.

Following the first tests presented in this deliverable, the main conclusions and the next steps to be considered for the final tests included in the last deliverable D3.3 are described below for each use case:

Use Case 1 "Smart Crowd Monitoring" (Madrid): Preliminary lab tests showcased that the 5G network can support the operation of one robot while it offers adequate latency for video stream only if compression is applied. Moreover, the use of LiDARs is challenging for the network as 250 Mbps is required in the uplink. The next steps will involve the optimization of the 5G network, to test jitter and latency values and improved throughput. Simultaneous use of two robots, two LiDARs and two cameras will be tested to further stress the B5G network and identify the latency and uplink throughput limits.

Use Case 1 "Smart Crowd Monitoring" (Iasi): First field tests demonstrated the main capabilities of the application, validating its overall architecture and functionalities. For the 5G network measurements, the conclusion is that the tests performed were in line with the expectations, i.e., the 5G NSA commercial setup working fine in case of not congested network but failed to deliver the expected performance during huge event (100.000s of people). Further tests will be performed at the end of 2024 based on 5G SA and B5G solutions aiming at the E2E latency and user experienced data rate measurements.

Use Case 2 "Public Infrastructure Assets Management" (Athens): The software application has been tested to validate its architecture and main functionalities, including video analysis, streaming, real-time processing, and video re-streaming. Application algorithm precision KPIs have been measured with a positive outcome. For the 5G network, streaming and re-streaming measurements have been done focusing on the E2E latency. The required latency was achieved, but it is expected that in real environments the 5G network will be stressed enough and network latency performances challenged. As next steps, further devices will be integrated, such as AGVs and drones, and field tests and KPIs measurements will be performed at DAEM and AIA.

Use Case 3 "Autonomous APRON" (Athens): The robot autonomy has been tested showcasing that the robot's operational autonomy is impacted due to the high energy demands of the onboard computational processes with the need to offload computational tasks from the robot to the cloud or edge computing platforms. In this context, the E2E latency measurements showcased that the 5G network offers improved latency with respect to Wi-Fi, with less variability, but still not as low or consistent as might be desired for critical applications. Next steps will include enhancements of the robotic platform's capabilities as well as on field measurements as AIA.

Use Case 4 "Smart Traffic Management" (Iasi): The test results were not in-line with the expectations due to poor availability of the 5G network coverage in the area and significant radio interferences posed by the metallic box of the traffic aggregation 5G CPE. The radio environment will be updated during the first half of 2024 with the addition of a high-gain external antenna for the CPE and the coverage improvements. The integration of the UC4 application in the deployed 5G edge-compute ecosystem is planned end of 2024, when the second round of field tests and KPIs measurements will be performed in October 2024.

Use Case 5 "Control Room in Metaverse" (Turin): First tests were performed mainly to validate the functionalities of the system and assess the network load provided by a video camera with different configurations. The main conclusion is that the throughput and E2E latency for one client are supported by the network but is expected to not be sufficient for medium to large events requiring more on-site cameras and agents. In the next period, tests with increasing video stream's data rates will be conducted to identify any bottlenecks or areas of optimization. Both network and application KPIs will be also collected to evaluate the system's performance.

The preliminary KPIs results presented in this deliverable will serve as basis to refine and optimize the platform and network solutions developed in the context of WP2 according to the TrialsNet framework defined on D2.1 [46], such as the deployment of new releases of the network functions and the use of different radio bands, the possible integration of some network innovations introduced by the project and the improvement of the applications which, in some cases, could also entail the integration of new components coming from the Open Call.

Interaction with WP6 will also be performed for what concerns the validation activity related to the preliminary KPIs results obtained and presented in this deliverable.

It is noteworthy that beyond implementing the defined use cases, a significant objective of the related trial activities is to identify current network technology limits. This effort aims to define new requirements for future evolutions and gauge user satisfaction with the developed applications. Evaluations of these aspects, measured in terms of KPIs and KVIs, are anticipated to be conducted during the trial phase and its results to be reported in the final deliverable D3.3 in September 2025.

Acknowledgment

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Annex A

D6.1 [36] defined a harmonized list of KPIs to be adopted by all the use cases in order to have a common terminology shared at the project level. In the context of the test activities, and later to the trial phase, it is necessary to have also an efficient way to refer to each KPI in a unique and immediate manner. Therefore, for each KPI, a proper ID has been defined according to the following Table 45.

Table 45. Harmonised KPIs from D6.1 [36] and related IDs.

KPI Name	KPI ID	KPI Definition	KPI Category
Downlink throughput per user	01	Sustained throughput experienced from a user to receive data	Capacity
Uplink throughput per user	02	Sustained throughput experienced from a user to send data	Capacity
Downlink aggregate throughput	03	Sustained throughput, aggregated on multiple users, to receive data in the considered application	Capacity
Uplink aggregate throughput	04	Sustained throughput, aggregated on multiple users, to send data in the considered application	Capacity
Downlink throughput per device	05	Sustained throughput at device level to receive data	Capacity
Uplink throughput per device	06	Sustained throughput at device level to send data	Capacity
Coverage	07	Geographic area where a network signal can be received and used by a device	Capacity
Application round-trip latency	08	Amount of time it takes for the application to receive a response or output after sending a request or input to a server or network.	Latency
Application one-way latency	09	Amount of time it takes at application level from the source to the destination application	Latency
Accuracy	10	Proportion of correct predictions made by the algorithm.	Compute

Precision	11	How often the algorithm is correct when it predicts a positive outcome.	Compute
Recall	12	How often the algorithm correctly predicts a positive outcome out of all the actual positive outcomes.	Compute
F1 score	13	Harmonic mean of precision	Compute
Communication reliability	14	Success probability of transmitting a layer 2/3 packet within a maximum latency required by the targeted service (ITU-R M.2410)	Availability and Reliability
Service reliability	15	Period for which the service satisfies the required performance constraints (downlink/uplink capacity, E2E latency)	Availability and Reliability
Communication availability	16	Capability of transmitting a given amount of traffic within a predetermined time duration with high success probability	Availability and Reliability
Service availability	17	Ratio between the amount of time during which a specific component of the use case (application, server, network function, etc.) is responding to the received requests, and the total amount of time that the component has been deployed.	Availability and Reliability
Location accuracy	18	Accuracy in the positioning of the device obtained through the 5G network	Localization