TrialsNet: TRials supported by Smart Networks beyond 5G

Deliverable D3.1

Use Cases definition for Infrastructure, Transportation and Security & Safety (ITSS) domain

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List of Acronyms and Abbreviations

Acronym	Description
2D	Two Dimensional
3D	Three Dimensional
3GPP	3rd Generation Partnership Project
5G	Fifth generation of mobile communications
6G	Sixth generation of mobile communications
AAA	Authentication Authorization Accounting
ACS	Automatic Configuring Server
AI	Artificial Intelligence
AIA	Athens International Airport SA
AMF	Access and Mobility Management Function
AMS	Alarm Management Systems
AP	Access Points
API	Application Programming Interface
AR	Augmented Reality
AUSF	Authentication Server Function
AWS	Advanced Wireless Services
B5G	Beyond 5G mobile network
BMS	Building Management System
CCTV	Closed Circuit Television
CDF	Cumulative Distribution Function
CMX	Cisco Connected Mobile Experiences
CN	Core Network
CNIT	Consorzio Nazionale Interuniversitario per le Telecomunicazioni
CNN	Convolutional Neural Networks
COTO	Comune di Torino
CPE	Customer Premises Equipment
CPU	Central Processing Unit
CSS	Cascading Style Sheets
DAEM	Dimos Athinaion Epicheirisi Michanografisis
DL	Deep Learning
DL	Download Link
DT	Digital Twins
E2E	End-to-end
eMBB	Enhanced Mobile Broadband
ERC	Ericsson España SA
ETSI	European Telecommunications Standards Institute
EU	European Union
FDD	Frequency Division Duplexing
FOD	Foreign Object Damage
FOV	Field of View
GDPR	General Data Protection Regulation
GNSS	Global navigation satellite system
GPS	Global Positioning System
GPU	Graphics Processing unit
GUI	Graphical User Interface
HAL	Hardware Abstraction Layer
HD	High-Definition
HDSM	High-Definition Stream Management
HDTV	High-Definition Television
HEVCH	High Efficiency Video Coding
HMI	Human-Machine Interface
HTML	Hyper Text Markup Language
HTTPS	Hypertext Transfer Protocol Secure
HW	Hardware
IEEE	Institute of Electrical and Electronics Engineers
IMEC	Interuniversitair Micro-Electronica Centrum
IMU	Instruction Memory Unit
IoT	Internet of Things
IR	Infrared radiation
iSOC	Information Security Operations Center
ITSS	Infrastructure, Transportation and Security & Safety
KPI	Key Performance Indicator
KVI	Key Value Indicator
LCD	Liquid Crystal Display
LIDAR	Light Detection and Ranging
LTE	Long Term Evolution
MAC	Media Access Control Address
MDAF	Main Distribution Frame
MEC	Multi-access Edge Computing
MIMO	Multiple Input Multiple Output
ML	Machine Learning
MS	Milestone
NWDAF	Network Data Analytics Function
NMS	Network Monitoring System
NPN	Non-Public Network
NR	New Radio
NSA	Non-Standalone Architecture
NXW	Nextworks
OBU	On Board Unit
ONVIF	Open Network Video Interface Forum
O-RAN	Open Radio Access Network
ORO	Orange Romania SA
PNRR	National Recovery and Resilience Plan
PR	Probe Requests
PROS	Prosegur Compañía de Seguridad SA
PoE	Power over Ethernet
PTZ	Pan Tilt Zoom
REST	Representational State Transfer
RMS	Remote Management Station
RTSP	Real Time Streaming Protocol
QoE	Quality of Experience
QoS	Quality of Service
RAN	Radio Access Network

RIC	RAN Intelligent Controllers	*UDM*	Unified Data Management
ROS	Robot Operating System	*UE*	User Equipment
SA	Standalone Architecture	*UAG*	Unmanned Ground Vehicles
SDK	Software Development Kit	*UHD*	Ultra High Definition
SDN	Software Defined Networking	*UL*	Upload Link
SEAL	Screening External Access Link	*UPF*	User Plane Function
SIM	Subscriber Identity Module	*URLLC*	Ultra Reliable Low Latency Communications
SME	Small Medium Enterprise		
SMF	Session Management Function	*USB*	Universal Serial Bus
SMS	Short Message Service	*USRP*	Universal Software Radio Peripheral
SMTP	Simple Mail Transfer Protocol		
SNMP	Simple Network Management Protocol	*V2I*	Vehicle to Infrastructure
		V2V	Vehicle to Vehicle
SNS	Smart Networks and Services	*V2X*	Vehicle to Everything
SOC	Security Operations Center	*VAL*	Vertical Application Layer
srsRAN	Software Radio Systems RAN	*VM*	Virtual Machine
TCP/IP	Transmission Control Protocol/Internet Protocol	*VMS*	Video Management Systems
		VOC	Volatile Organic Compounds
TDD	Time Division Duplex	*VPN*	Virtual Private Network
TID	Telefonica Investigacion Y Desarrolo	*VR*	Virtual Reality
		VRU	Vulnerable Road User
TIM	Telecom Italia SPA	*WebRTC*	Web Real-Time Communication
TLT	Transfer Learning Toolkit	*WINGS*	WINGS ICT Solutions
TUIASI	Universitatea Tehnica Gheorghe Asachi Iasi	*WLC*	Wireless LAN Controller
		WP	Work Package
UC	Use Case	*XR*	Extended Reality

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Executive Summary

In the context of WP3 “Work Package 3”, this deliverable D3.1 describes the use cases design, requirements specification, and technologies (software and hardware identification) related to the Infrastructure, Transportation, Security & Safety (ITSS) domain. Each use case includes details on its definition, application design, devices and equipment, infrastructures in support of their implementation, trials description, preliminary technical requirements, and the time plan. WP3 is responsible for all the activities towards the implementation of the use cases (UCs) in the ITSS domain for all the TrialsNet clusters and will address the main objectives of i) trial a set of innovative 6G applications and ii) to introduce societal benefits in different areas, thanks to 6G applications as described in D1.1 “Management Handbook” [1].

A short summary for each use case is given below. As the Use Case 1 “Smart Crowd Monitoring” is performed in two sites, Madrid, and Iasi, it will be detailed in different sub-sections.

Use Case 1 “Smart Crowd Monitoring” (Madrid): This use case will be carried out in sports or spectacles venue in Madrid for the Spanish cluster. The high concentration of people and the social impact of these types of events make security a crucial issue in stadiums and sports facilities. To mitigate the security risks that occur during the sporting events with participation of a large number of people, the use case will be focused 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.

Use Case 1 “Smart Crowd Monitoring” (Iasi): This use case will be carried out in large public area in Iasi, for the Romanian cluster. The use case will focus on the use of B5G/6G applications to enable situation awareness to key end-users in the City of Iasi, by bringing disparate data streams into a common operational picture for real-time data-driven insights and actionable intelligence. The new platform will ingest available data from arrays of sensors and cameras deployed through the city, communicating over reliable B5G and Wi-Fi networks and output insights and actionable intelligence on public safety monitoring system. The use case will focus on outdoor public events by managing people counting, density, and dynamics of large numbers of persons (flow directions, spread, speed) and detecting special situations during normal traffic scenarios (e.g., presence of various objects such as cars, trucks, motorcycles, etc. in restricted access areas).

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 and 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 will analyze 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) will be used to provide on-site views of assets' blueprints and live communications with remote experts. In addition, Digital Twins (DT) of public construction sites will be created, allowing for validation of technical plans and real-time monitoring.

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 will enable real-time monitoring and remote control of vehicles, ensuring safer and more efficient operations. AI techniques will be used to analyze data from sensors and cameras, generating alerts and suggestions for improving operations. The integration of a Network Monitoring System (NMS) will enable continuous monitoring and automated mitigation of network anomalies.

Use Case 4 “Smart Traffic Management” (Iasi): This use case will be 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 will be monitored to create predictive models and suggest intersection rules adaptation to reduce congestion. Safety will be 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 will ingest available data from arrays of sensors and cameras deployed throughout the city, communicating over reliable B5G and Wi-Fi networks and output insights and actionable intelligence on traffic monitoring system.

Use Case 5 "Control Room in Metaverse" (Turin): The purpose of this use case is to employ Extended Reality (XR), Metaverse, Digital Twin and 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 situations of panic by contributing to improved decision-making and reduced intervention times in the event of an emergency on the side of emergency responders The target environment is the events area at Valentino Park.

Together with the other domains WPs (i.e., WP4 and WP5), WP3 will provide the requirements coming from the use cases definition to WP2 "Platforms & Network Solutions" to properly design the platforms and network solutions in support to their implementation. Interaction with WP6 "Validation & Dissemination" will also be performed for what concerns the validation activity related to KPIs and KVIs. Ethics implications will be considered in tight connection with WP8 "Ethics requirements" according 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].

It should be noted that the use cases defined in this deliverable might be further refined and integrated based on the activities progress (e.g., pre-trial phase, local infrastructure evolution, etc.) and the inputs coming from the other WPs.

1 Introduction

The WP3 of TrialsNet project focuses on conducting large-scale trials to implement a heterogenous and comprehensive set of innovative B5G/6G applications. The trials will be based on various technologies such as robots, metaverse, sensors and cameras, and covering the relevant domain of the urban ecosystems in Europe identified by Infrastructure, Transportation, Security & Safety.

This document represents the first deliverable for WP3, aiming to detail the use cases definition for ITSS domain. This deliverable D3.1 is considered as an initial document related to trials configuration, infrastructure and application and test cases execution that might be further refined or completed depending on their evolution and inputs from other WPs. The main documents sections of D3.1 are described in the following.

Section 2 provides an overview of the ITSS domain highlighting the benefits brought by SNS networks and trial clusters presentation.

Section 3 presents the use case definitions, implementation aspects such as application design, equipment and devices, infrastructure components and functionalities and trials description. A preliminary description of the use case trial is detailed in terms of both technical setup, test cases storyline and implementation steps, methodology and expected results.

Section 4 indicates technical requirements and evaluation methodology for each use. The technical requirements are reported (e.g**.,** throughput, latency, coverage, etc.) that the platforms and network solutions should fulfil (i.e**.,** input to WP2) to implement the use case. A description of the relevant Key Performance Indicators (KPIs) is presented and how these will be measured at the application level (e.g**.,** probes definition, statistic collectors, etc.). Preliminary qualitative aspects (towards Key Values Indicators- KVIs) of the use case are also identified and defined as part of the evaluation methodology.

Section 5 reports the time schedule for each use case by defining the milestones related to its use case implementation phases (i.e**.,** design, development, laboratory tests, on-field tests, and trials).

Finally, the Section 6 of conclusions, summarizes the main outcomes of the document, and reports the next steps related to WP3 activities.

2 Infrastructure, Transportation and Security & Safety (ITSS) domain overview

Infrastructure, Transportation and Security & Safety represents one of the relevant domains of the urban ecosystems in Europe in the context of TrialsNet activities. Targeting to improve the "liveability" of the urban environment in the ITSS domain, TrialsNet's use cases will also pursue the objective to i) understand where current networks are not sufficient to assure the performance needed by the use cases, and to ii) derive the new requirements for next generation mobile networks. TrialsNet will also treat the design of the objectives of sustainability and affordability of the deployed systems. ITSS development and improvements have the aim to decrease the negative effects (congestion, sprawl, pollution, inequality, etc.) of collapsing metropolises, as it is of utmost importance to ensure that cities are safe, affordable, and sustainable for all. Also, the uses cases will have positive impacts on Societal Values such us Trust, Resilience, Security, Sustainability, Trustworthiness, Automation, Service Availability.

2.1 SNS and B5G system benefits for ITSS domain

In the following some examples are reported on how SNS and future network technologies can bring benefits for Infrastructure, Transportation, and Security & Safety domain and that will be deployed as part of the large-scale trials performed by TrialsNet.

2.1.1 Infrastructure

Public infrastructures with their operations and services are being modernized and expanded and therefore require proactive assets management through transformative digital solutions and ecosystems. Several problems/damages related to the building and maintenance process are currently unsolved or uncontrolled due to the limited infrastructure management methods which can offer cost savings and automated decision-making. Proactive maintenance of infrastructure in public spaces is critical for the city's infrastructure and the coordination of its maintenance is a time and human-consuming task. Additionally, within the city, different agencies and departments must cooperate for these tasks, hence an innovative approach that will provide foreseen actions rather than ad-hoc is major added value. New SNS and B5G (towards 6G) systems will sustain the increase of the safety of the workers and reduction of required resources through proactive approaches by exploiting data coming from municipal vehicles, weather information, images, and video coming from security cameras and combining them with drone camera inspections.

2.1.2 Transportation

The growing size of cities and increasing population mobility have determined a rapid increase in the number of vehicles on the roads, which has resulted in many challenges for road traffic management authorities in relation to traffic congestion, accidents and air pollution. SNS and B5G (towards 6G) systems can provide the design, development and deployment of the envisioned tools that will validate the concept of intelligent traffic management and successfully support the B5G and 6G applications in large-scale environments by enabling a tight interaction between humans and the surrounding environments through the usage of IoT Sensors, Computer Vision (CV), LIDAR Enhanced Vision, On-Demand Intelligent and Autonomous Drones Surveillance and Cameras, within a robust, Zero-Touch Management capability of Edge resources.

2.1.3 Security & Safety

The high concentration of people in public areas, stadiums, sports facilities and concert areas and the social impact of these types of events make security a crucial issue for each city. In championships, where there may be a high level of rivalry between teams, there is a higher risk of violence and incidents. In most extreme cases, relevant international competitions may be subject to terrorist threats. Critical areas, such as the access to the facilities, corridors and stands must be controlled and monitored, as well as the game area itself to avoid incursions or throwing objects. Additionally, security and safety measures are needed within the tourist and cultural places in urban areas - outdoor and indoor. New SNS and B5G (towards 6G) systems can utilize cameras, sensors, XR, metaverse, and digital twin solutions to assist in prevention, management and simulation of emergency conditions for safety and security of people and operators.

2.2 TrialsNet clusters overview

Large-scale trials in the context of ITSS domain require the identification of the proper locations and sites where to perform the experimentations. In this section, the current sites that have been identified for the in-volved clusters are introduced.

2.2.1 Spanish cluster

Madrid, the capital of Spain located in the center of the country, has been named World Capital of Sport for 2022. It hosts countless major sporting events including high level competitions (football, basketball), with highest level teams in the world. Different sports venues in Madrid are being considered as locations for TrialsNet trials activities: basketball arenas such as Wizink Center or Magariños, tennis courts as La Caja Mágica, football stadiums as Bernabeu or Civitas Metropolitano and small to medium-sized venues. An arena such as Wizink Center is presented in Figure 1.

Figure 1. Wizink Center in Madrid (Source: Madrid Turismo).

2.2.2 Romanian cluster

Iasi is the second largest city in Romania by population and is the economic and cultural main city of the eastern region, Moldova. Iasi is also known for its cultural scene, being the home of famous concert halls and theatres. The Romanian cluster comprises two regions of interest to be covered: i) in Figure 2, the square in front of the Palace of Culture in city downtown area; public events (concerts, meetings) are hosted in this area providing a very good location for smart crowd monitoring (UC1) in public areas and the pedestrian area between the City Hall and the intersection with a major street situated nearby, Stefan cel Mare Boulevard; ii) in Figure 3, the Podu Roș Intersection Area providing relevant area for traffic comfort and safety use case (UC4). The intersection is one of the biggest in the city and brings problems related to congestion and traffic incidents. The Stefan cel Mare Boulevard area zone is a crowded one since several cultural and religious buildings are situated there, and therefore represents a good location for implementing UC1.

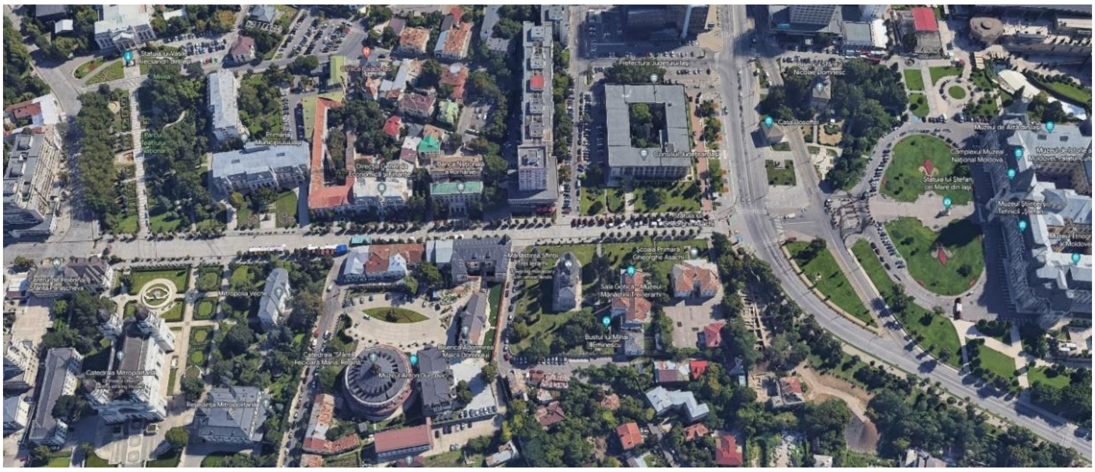

Figure 2. Square in front of the Palace of Culture in Iasi.

Figure 3. Podu Roș Intersection Area.

2.2.3 Greek cluster

Athens, the capital city of country, is a large cosmopolitan metropolis and central economic, financial, industrial, maritime, political, and cultural life in Greece. The UC2 and UC3 will be implemented in the Greek cluster that includes the Athens International Airport "Eleftherios Venizelos" (the "Airport") and the public infrastructures provided by DAEM.

The Airport (Figure 4, [65]) covers an area of approximately 16,000 km2 and has two runways in compliance with the International Civil Aviation Organization Aerodrome Reference Code "4E”. The Airport features a 168,000m2 main terminal building and a 34,000 m2 Satellite Terminal Building with a total of 24 Contact Bridges and 75 active remote aircraft parking positions. The Airport is certified for all known types of currently operating aircraft, including the Boeing 747- 8 and the Airbus A380. The APRON area, where aircraft are parked, loaded, unloaded, and serviced is a vital component of the airport's infrastructure. This location was chosen for its relevance to the project's goals and its potential to demonstrate innovative approaches to proactive maintenance and safety practices in a critical infrastructure setting.

Figure 4. Athens International Airport.

Two indicative areas of the Municipality of Athens (Figure 5, [66]) are also proposed as testbeds. These areas, Athens Trigono and the neighborhood and surroundings of the Athens City Hall, require advanced maintenance for assets such as existing municipal buildings, pavements, crossroads, and pedestrian routes. Athens Trigono is a low-traffic zone for vehicles in the center of Athens, where many traditional businesses are located, and it was recently redesigned to become more pedestrian-friendly. The Athens City Hall is located close by in Kotzia Square; a central place of historical and cultural significance and its surroundings often require fieldwork for improvements.

Figure 5. City of Athens.

2.2.4 Italian cluster

Turin is the city capital of the Piedmont region (North-West Italy) and one of the most important cities in Italy. The city administration deals with the management of territorial and municipal assets and of public services (civic, social, sport & leisure, commerce, etc.)

The Municipality of Turin is engaged in diversification and innovation activities to promote societal, cultural and market growth. Its goal is to encourage the ecological and technological transition towards the revitalization of the local territory and ecosystem of innovative startups in the areas of Smart Urban and Air Mobility, Industry 4.0 and, more generally speaking, smart-city oriented.

Within this framework, it is worthy of mention "Torino City Lab", an open innovation platform promoted by the City of Turin launching the initiative known as Turin House of Emerging Technologies "CTE NEXT". Within this framework, CTE NEXT offers top-notch conditions for accelerating start-ups and promoting technology transfer through:

- A multiservice infrastructure
- A set of free consultancy services from strategic industrial partners
- Fully equipped stress test areas city-wide.

Through the Green and Parks Division and Cultural Department, the Italian cluster has access to Valentino Park, key location of UC5 - "Control Room in Metaverse". In this context, the Digital Twin of the events area at Valentino Park will be made available along with engaging digital content to emergency responders for remote XR training and enhanced real-time visualization of behavioral anomalies/movement patterns. Critical for enhanced decision making and reduced intervention times in the event of an emergency. The location in which the trial is going to take place is represented in Figure 6.

Figure 6. Events area in Valentino Park, Turin.

3 Use case detailed description

3.1 UC1: Smart Crowd Monitoring (Madrid)

The "Smart Crowd Monitoring" use case is oriented to deploy several technology solutions that enable to ensure the security and safety of people at highly busy areas whether they are concentrated in one area or moving from one area to another. Highly crowded public sites such as concerts or sports facilities pose a challenge for the security companies operating on site. An important feature of the protection of public places is achieving the right balance between effective protection and people's individual and collective fundamental rights [31].

The primary goal of event security is not to respond to threats, but to prevent them from occurring. Proper security management in events requires a holistic and technologically advanced approach that PROS has called "hybrid security model" based on three fundamental pillars: people, technology, and data. Regarding the second pillar, the combination of AI, robotics, Virtual Reality (VR) and other technologies help to enhance the prevention capacity of the security companies, however, it also poses several challenges in terms of communications capabilities and cybersecurity risks.

B5G (towards 6G) technology is an ideal option for this scenario as it provides high speed of data traffic and ultra-low latency ensuring that commands and orders sent to robots can be received almost instantly, which is critical to ensure that robots respond in real-time. Additionally, B5G (towards 6G) technology can handle a large volume of data, ensuring fast and reliable communication.

3.1.1 Use case definition

Madrid site is a place hosting sportive competitions and/or spectacles. Main security risks that may occur at crowded public spaces are:

- **Risk of intrusion:** Unauthorized access of people to company facilities, premises, etc., with the aim of hindering, interrupting the activity or causing damage that makes it impossible to maintain its operability. Depending on the type of event, this risk may be more or less important. No one likes intruders at a party or a tournament since they are elements that may only have the intention of seeing their idols or causing a brawl.
- **Risks of disturbance of order**: One of the most important risks, since even the minor ones can become very conspicuous. A protest during a charity event or clashes between two fans during a game can create a very bad public image that must be avoided.
- **Risk of theft:** Taking property of others against the will of its owner without using any type of violence or intimidation. An event begins and ends long before the guests arrive and leave. The transport of supplies, audiovisual material, or assembly equipment may include the risk of theft of all this material, in addition to theft in the cloakroom or in any other areas of the event.
- **Risk of heist:** Appropriation for profit of another's property using violence or intimidation against the person.
- **Risk of vandalism:** Commission of physical damage to public furniture or private property indiscriminately or targeted.
- **Risk of attack**: The worst-case scenario is an attack during an event, which is a tragedy that needs to be prevented to assure protection of the guests. This category of risk is undoubtedly the most complex and difficult to deal with.
- **Sabotage and manipulation:** Damage or destruction that is done intentionally in a service, an installation, a process, etc., as a form of fight or protest against the organization that directs them or as a method to benefit a person or group that is contrary to said organization.
- **Other risks:** There are complicated situations that can be generated in a very trivial way. For instance, a power outage can cause inconvenience and lead to a chaotic evacuation.

In addition, social aspects are crucial in large events: alterations in individual and/or collective behavior can cause situations of high concentration and density of people that difficulties risk management in high traffic

events. The variables that with the greater probability deteriorate mass management are suggestibility, contagion emotional and imitation.
An adequate access control is crucial to prevent most of the above-mentioned risks. Security guards at the entrance will not only validate the entrance ticket to avoid fraud but prevent the entry of people carrying a weapon or with evident malicious intentions. On the other hand, it is in this area where disorganized flows of people can be found or with erratic trajectories that, if uncontrolled, can increase the complexity of the operation and reaction of the security patrol. For UC1 the focus will be on the access area for which two main zones can be differentiated:

- **Outside the entrance door** (Figure 7, blue area), where crowds can make it difficult to access the facility and may result in a chaotic coordination of the access control.
- **At the entry hall** (Figure 7, green area), where it is necessary to verify that the people who want to enter do not pose any risk. For example, it is necessary to check that they are not carrying prohibited objects or attempting to enter restricted areas.

Figure 7. UC1 Madrid Sport Venue Example.

By actively monitoring these areas, security guards can receive real time information of potential risk and react accordingly. In large events, the number of attendees crossing through the access gate is expected to be approximately 1000 people in 45 min. Each of them will travel through a control area for ticket validation and access to the entry hall, where they will stay (most likely for a short period of time) until they find their way to their locations.

The use of surveillance cameras and LIDARs together with artificial vision algorithms can be applied to support in the following tasks:

- **Crowd monitoring:** Surveillance cameras and LIDARs can be used to monitor the size and movement of crowds entering the event. This can help security personnel detect any unusual behaviour, such as groups of people trying to enter the event together, which may indicate potential security threats.
- **Detection of suspicious behaviour:** Surveillance cameras can help identify individuals who may be acting suspiciously, such as those attempting to conceal their identity or carrying bags or items that may be prohibited.
- **Tracking of suspects:** If an incident occurs at the event, surveillance cameras can help security personnel track the movements of suspects or individuals involved in the incident. This information can be used to apprehend suspects and prevent further incidents from occurring.
- **Deterrence:** The presence of surveillance cameras can act as a deterrent to potential security threats. Knowing that they are being monitored may deter individuals from attempting to bring prohibited items into the event or engaging in other illegal or disruptive behaviour.

- **Evidence collection:** If an incident occurs at the event, surveillance footage can be used as evidence in an investigation or legal proceeding. For this reason and according to law in force, the images are stored for a period of 30 days.

With a particular focus on UC1, video-analytics algorithms will be used to detect:

- Crowds prevent free access to the facility.
- Violent activity such as people fighting or riots.
- Vandalism
- Weapons
- Suspicious activities such as loitering, or person running.
- Abandoned bags.

As for the indoor area, fixed and robot-based cameras will send the video streams to the cloud where different AI algorithms will help to detect the above-mentioned risky situations. Moreover, two terrestrial robots will circulate around the environment facilitating vision through its onboard cameras. The high-level solution for the UC1 Madrid is presented in Figure 8.

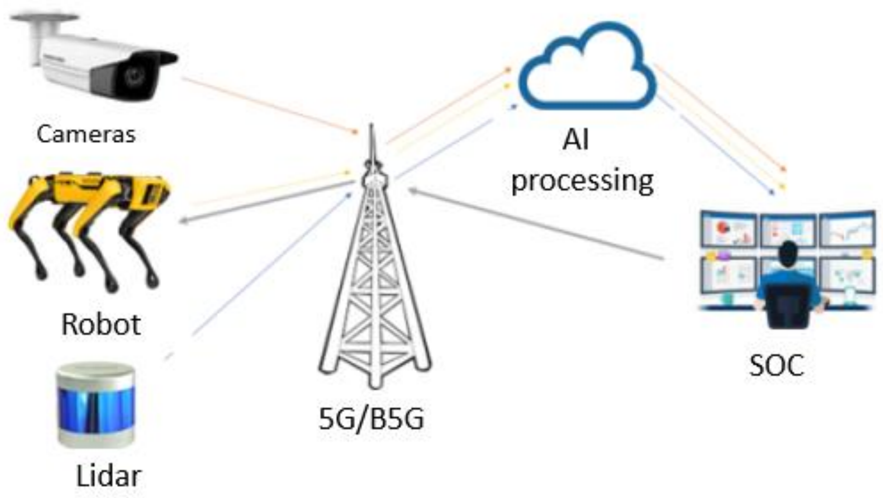

Figure 8. High level solution.

As for the outdoor area, to comply with GDPR legislation, no cameras will be present, and LIDARs will be installed instead. LIDARs cloud points will be processed by cloud-based software of spatial intelligence, enabling people crowd monitoring and tracking.

In the current solutions, the devices such as cameras, robot or LIDAR are wired towards a router that is connected to the Information Security Operations Center (iSOC) using the 802.11n IEEE standard protocol. Devices will use this connection to warn the security guard located in the iSOC in case of incidence, so he/she can implement the relevant protocols to solve the issue. The 802.11n protocol currently used has relevant limitations related to security and performance, so the need of a more secure and wireless connection is needed. Therefore, UC1 will use the most appropriate 5G/B5G wireless technology for the following reasons:

- **Security:** IPsec protocol is used to secure all the traffic from devices towards the iSOC, so the information and relevant protocols implemented to solve incidences are secure from a hacker attack.
- **Latency:** 5G is the only wireless communication that could achieve Ultra Reliable Low Latency Communications (URLLC). This 5G capability enhanced the reliability of the network and with extremely low latency could ensure the incidence are solved as fast as needed, for example in case the robot would be needed to be controlled from the iSOC to solve an incidence.
- **Throughput:** The enhanced Mobile Broadband (eMBB) that 5G would allow to transmit more information from the various devices to iSOC (uplink data) and the other way around, ensuring the avoid of the interference between devices as happen with the 802.11n protocol.

3.1.2 Implementation aspects

3.1.2.1 Application design

The diagram below (Figure 9) shows how the devices installed in the infrastructure are connected to the cloud systems and to the iSOC making possible the transmission and processing of information and alerts as well as the remote management of the devices.

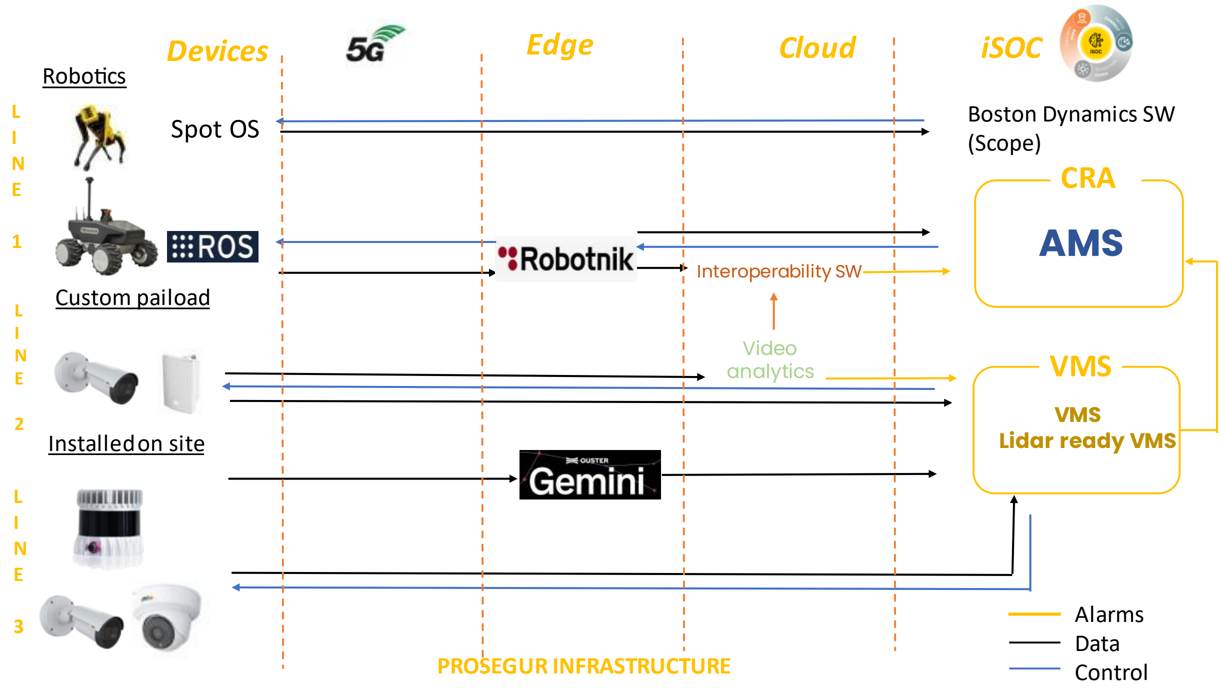

Figure 9. Application architecture.

There are three different types of components in this use case:

- The devices deployed at the facility (Figure 9, "Devices") and its control software (Figure 9, "Edge")
- The applications executing on PROS's cloud over Microsoft Azure (Figure 9 "Cloud").
- The different software running at the iSOC location (Figure 9, "iSOC").

The communication between the devices deployed at the facility towards its control Software (SW) deployed in the Edge will use the 5G network for the communication. 5G guarantees ultra-reliability, low latency and high-speed communication that ensure the data will reach the Edge in real-time and take advantage of wireless communication for all the devices.

In the following the three main "lines" (i.e., sets of devices) depicted in Figure 9 are described:

- **Line 1:** two robots' models will be used. The first is Yellow [33], a robot that will be teleoperated by a trained operator by Boston Dynamics software. The second robot, Kiiro, will move completely autonomously. This robot will send its status and malfunctions to its proprietary software (Robotnik-KMI). This software can generate alarms upon issue detection; when this occurs, the alarms are sent to the interoperability SW platform, owned, and administrated by PROS. The interoperability SW can convert any alert sent by IoT devices or AI algorithms into the language that can be processed by the Alarm Management Systems (AMS). The AMS is used for the operator at the iSOC. The operator will have access through an internet browser to the Human-Machine Interface (HMI) from which he will be able to telecommand the robot and/or program the routes.
- **Line 2:** the Robots have an onboard payload, this is, a backpack with the electronic components necessary for the security service. It includes cameras, intercom, computers for artificial intelligence, etc. The video and audio streams are sent to the iSOC VMS (Video Management System), so operators can see what is happening at any moment and can communicate through the intercom. In parallel, the video

stream is analyzed by video analytics behavioural analytics, which employ AI to automatically detect, analyse, and understand actions and events. Video analytics technology is based on deep neural networks capable of analysing and defining specific activities using video streams from conventional security cameras. When one of the incidents described in the previous section occurs, video analytics software sends an alarm to the interoperability SW. The interoperability SW is responsible for translating the alarm into the standard protocol used by AMS and sending to it. Then, the alert is received at the iSOC through AMS, and the operator can check the recording and/or life streaming through the VMS to video-verify if the received alarm corresponds to a real alert and therefore launch the required protocols. Using AI to identify risky situations enables the iSOC operator to monitor an increased number of cameras and to cover a bigger area.

- **Line 3:** the third type of component is the security infrastructure deployed on-site, that are basically cameras and LIDARs. Video from cameras is sent to a VMS directly as usual in this kind of business. LIDARs need software (Gemini) [35] to interpret the information generated before sending it to the VMS specific for this technology (LIDAR ready VMS). Gemini can manage alarms based on people and vehicles movement. It also enables 3D tracking of people and vehicles, in any weather or lighting conditions - including complete darkness. It works even for large-area sites and in real-time.

A brief description of the functions and features of each of the different employed SW (on edge, on cloud or at the iSOC servers) is given hereafter:

AMS is an advanced alarm management system that allows users to monitor and manage alarms from multiple locations in real-time. Some of the key features of the alarm management system include:

- **Customizable Alarm Rules:** AMS allows system users to create custom alarm rules based on specific criteria, such as motion detection, camera tampering, or door access. These rules can be customized for individual cameras or groups of cameras, allowing users to tailor the alarm system to their specific needs.
- **Real-Time Alarm Monitoring:** When an alarm is triggered, AMS provides real-time notifications to users via email, SMS, or mobile app. Users can also view live video footage from the affected cameras to quickly assess the situation and respond accordingly.
- **Alarm Reports and Analytics:** VMS includes reporting and analytics tools that allow users to track alarm activity over time. This data can be used to identify trends, improve response times, and optimize system performance.

By providing real-time monitoring and response capabilities, customizable rules, and advanced analytics, AMS helps users quickly identify and respond to potential security threats. AMS supports several protocols as for example HTTPS, TCP/IP, SNMP, SMTP and ONVIF.

VMS is a video management software platform. It is designed for managing large-scale video surveillance systems, and is widely used in businesses, organizations, and government agencies around the world. The platform consists of several components, including:

- **Management Server:** This is the core component of the VMS system and is responsible for managing and recording video footage from connected cameras and devices. The Management Server includes features such as video storage, user management and system configuration.
- **Recording Server:** The Recording Server is responsible for recording and storing video footage from cameras and devices. It can be installed on a separate server or on the same server as the Management Server.
- **Client Applications:** VMS offers several client applications, including the XProtect Smart Client and XProtect Web Client, which allow users to view live and recorded video, manage cameras and devices and configure system settings.

VMS supports a wide range of IP cameras and devices and can integrate with third-party software and hardware using standard protocols such as ONVIF, RTSP, and HTTP. The platform also includes advanced features such as video analytics, license plate recognition, and facial recognition, which can provide valuable insights for businesses and organizations.

Gemini software is a data processing software package specifically designed to work with the Ouster's 3D laser scanning sensors. The software is designed to process and visualize the data captured by the sensors, allowing users to create and manipulate 3D point clouds.

Some of the key features of Gemini may include:

- **Data Visualization:** Gemini provides users with a visual representation of the LIDAR data, allowing them to view and analyse the data in real-time.
- **Point Cloud Processing:** The software can process point cloud data generated by Ouster's LIDAR sensors, allowing users to extract meaningful information from the data.
- **Sensor Configuration:** Gemini can be used to configure Ouster's LIDAR sensors, adjusting settings such as field of view, scan rate and resolution.
- **User-Friendly Interface:** Gemini provides users with a user-friendly interface, making it easy to configure, visualize and analyse LIDAR data.

The Gemini software is designed to be user-friendly and is compatible with a variety of platforms and operating systems, making it accessible to a wide variety of users and applications.

LIDAR ready VMS is a management software based on IP video that allows users to manage and control IP security cameras on a network. It uses standard protocols such as ONVIF and RTSP to connect to security cameras and enables video recording, live viewing, recorded video playback and camera management.

- Video analysis functions such as motion detection, object detection, etc. These features enable users to automate surveillance and receive real-time alerts when important events are detected.
- Tools to manage the security and privacy of recorded data, such as video encryption, user and permission management and data retention policy configuration.
- Integration with other security systems such as access control systems and intrusion alarms.
- Open Platform that allows adding video analytics, access control, or other third-party devices to build a comprehensive security approach.

LIDAR ready VMS provides a scalable, user-friendly, and customizable video management platform that allows users to manage and protect their critical assets and resources by implementing a video surveillance system.

Robotnik software is responsible for Kiiro management and configuration. It supports the development, deployment, and management of robotics applications in a wide range of industries. Its focus is on compatibility with open-source software platforms such as ROS (Robot Operating System), a popular choice for developers and researchers in the robotics community. Robotnik software has two different applications:

- **Robotnik-ROS**: is a compound of software modules that include drivers, controllers and other tools that allows technicians and developers to work with Robotnik's hardware products, as well as with other ROS-compatible devices. This software runs on the top of ROS and allows the robot to navigate, execute tasks, and read its status. This software also interacts with Robotnik-HMI to send the information needed and receive the configurations of the robot.
- **Robotnik-HMI**: is a wrapper of Robotnik-ROS and allows final users (iSOC operators in our case) to configure and control remotely Kiiro as well as track the location and status of Kiiro in real-time, manage tasks, schedules, routes and other aspects of the robot. This software is a web APP and is installed in the on-board PC of robot. It is accessible by using a web browser and a VPN connection with the robot.

Robotnik software provides a range of features for remote operation, configuration, and status control of Kiiro making it a valuable tool in the iSOC for security operations.

Scout is responsible for Yellow management and configuration. It is a software platform developed by Boston Dynamics for managing their quadruped robot, Spot. Scout is designed to be an easy-to-use, web-based platform that enables users to operate and control Spot remotely, as well as program and customize its behavior. Some of the features of Scout may include:

- **Remote Control:** Scout allows users to remotely control Spot using a simple and intuitive interface, which includes joystick controls for movement and various functions.

- **Autonomous Operation:** Scout includes features for autonomous operation, such as the ability to program Spot to navigate pre-defined routes, detect and avoid obstacles and perform other tasks.
- **Customization:** Scout allows users to customize Spot's behavior and programming using a range of software development tools, including Python, ROS and other programming languages.
- **Data Management:** Scout provides tools for data management, including data visualization, storage, and analysis.
- **Collaboration:** Scout enables multiple users to work on the same Spot simultaneously, allowing for collaborative programming and operation.

Video analytics software is a video analytics platform that uses artificial intelligence and machine learning algorithms to detect and classify various activities in real-time. It can analyze video footage from multiple cameras, making it a powerful tool for security and surveillance. This software has developed several advanced machine learning algorithms for video analytics, including:

- **Behavior Recognition:** This algorithm uses deep learning techniques to detect and classify human behaviors, such as running, fighting, loitering and more. It can analyze multiple objects in the scene and provide a detailed report of each activity.
- **Action Recognition:** This algorithm uses Convolutional Neural Networks (CNN) to detect and classify specific actions, such as walking, jogging, or sitting. It can also recognize complex actions, such as carrying an object or using a tool.
- **Facial Recognition:** This algorithm uses deep learning techniques to recognize faces in real-time, even in challenging conditions such as low light or partial occlusion. It can also track individuals across multiple cameras, making it useful for security and surveillance applications.
- **Object Detection and Classification:** Video analytics has developed several algorithms for object detection and classification, including those for vehicles, bicycles, motorcycles, and other objects. These algorithms can detect and track objects in real-time and provide detailed information about their location, speed, and direction.
- **Anomaly Detection:** This algorithm uses unsupervised learning techniques to detect anomalies in video footage, such as unusual behavior or unexpected events. It can learn patterns of normal behavior over time and alert security personnel when anomalies occur.

Some of the key features of Video analytics software include:

- **Real-time detection and classification:** Video analytics can detect and classify various activities in real-time, including people, vehicles, and other objects. It can also detect specific actions such as running, fighting, and loitering.
- **Multiple camera support:** Video analytics can analyze video footage from multiple cameras simultaneously, making it a powerful tool for security and surveillance applications.
- **Customizable rules and alerts:** Video analytics allow users to set customizable rules and alerts for specific events or activities. For example, it can be configured to send an alert when a person enters a restricted area.
- **Advanced analytics and reporting:** Video analytics provide advanced analytics and reporting features that enable users to analyze data over time and identify trends or patterns in activity. This can help to improve security and operational efficiency.
- **Easy integration with existing systems:** Video analytics is designed to integrate seamlessly with existing security and surveillance systems, making it easy to add advanced video analytics capabilities to any system.

Interoperability SW middleware operates as a hub for all alarms generated by the different security systems and is responsible for their distribution to the tools and software used at the iSOC workstation. Its main functionality is the translation and homogenization of input alarms, adapting them to the appropriate format for each type of application. At present it allows to increase the number of received alarms and to adapt them to the new connectors according to the requirements derived from the evolution of the iSOC workstation. In addition, it allows communication with the corporate database to complete the alarm information and assist the security guard's role.

3.1.2.2 Equipment and devices

The equipment required to develop and test the system for this use case is composed of the list of the devices reported in the Table 1.

Table 1. Equipment and devices for UC1 (Madrid).

Equipment	Item	Description	Quantity
LIDAR 	LIDAR OS0 [36]	The Ouster OS0 LIDAR is a sensor that uses an array of Vertical Cavity Surface Emitting Lasers (VCSEL) to emit a series of light pulses in a 3D pattern. The sensor captures the reflected light using a high-speed photodiode array, which generates a point cloud of the environment in real time. The sensor has a horizontal Field of View (FOV) of 45 degrees and a vertical resolution of 32 channel operating at a wavelength of 905 nanometres (nm), providing a high-density point cloud with up to 8,192 points per frame. The LIDAR OS0 has a range accuracy of up to ±3 centimetres (cm) and a range resolution of 1 cm, making it very accurate in measuring distances. The sensor has a maximum range of 120 meters and can operate in a variety of lighting conditions, including bright sunlight and total darkness. The sensor is enclosed in a rugged IP67-rated aluminium housing, making it weatherproof and suitable for use in harsh environments. The OS0 LIDAR can operate in temperatures ranging from -10 to 50 degrees Celsius and has a power consumption of less than 10 watts, making it ideal for battery-powered applications.	1
LIDAR 	LIDAR OSDome [37]	The LIDAR OSDome in its dome version offers the features of the new evolution of the product allowing to increase the range of emission up to 100m and a frontal view of 180º. Both models of LIDAR devices allow creating a 3D cloud of evenly spaced points and pixel-aligned 2D camera images that are easily integrated into security solutions and generate alerts by processing the signals (distance, reflectivity).	1
PTZ camera 	AXIS Q6135-LE PTZ Network Camera [14]	The AXIS Q6135-LE is a high-speed Pan-Tilt-Zoom (PTZ) camera that offers Optimize IR up to 250 m as well as Lightfinder 2.0 [39] for clear, sharp overviews and excellent details in demanding light conditions. It is ideal for city surveillance in any unlit or low-light area – such as parks and alleys– eliminating the need for additional lighting. Thanks to the sharpdome design it allows you to see 20° above the horizon with the same sharp image quality as below. It offers 32x optical zoom, superior	1

		video and excellent details in HDTV 1080p resolution. Featuring Lightfinder 2.0 this camera captures low-light images with more saturated colours and sharper images of moving objects. Furthermore, speed dry ensures clarity in rainy weather and supports efficient cleaning.	
Bullet camera 	H5A Camera [40]	The H5A is a camera with adaptative Infrared IR that automatically adjusts IR beam width and exposure settings based on scene conditions to help maximize image quality. It has integrated IR illuminators that provide uniform illumination even in complete darkness. The High-Definition Stream Management (HDSM)™3 provides maximum image detail while minimizing bandwidth usage, helping to keep internet connectivity costs down. It includes High Efficiency Video Coding combines HEVC/H.265 video compression with HDSM. SmartCodec™ technology to substantially reduce storage and bandwidth requirements while maintaining exceptional image quality. Once mounted and aimed, the zoom level can be adjusted, and the image can be focused remotely. IP66/7 weather rating and Impact Kinetic (IK10) impact rating for vandal resistance.	1
Robots 	Yellow + Payload	Yellow is PROS's iconic four-legged robot used by the company in major events such as Mutua Madrid Open or Rock in Rio. It is based on the famous Spot robot from Boston Dynamics and adapted to offer security solutions. The robot has the ability to make autonomous security rounds, as well as to perform inspection tasks. The payload, designed by PROS, is based on the technologies the company already uses to protect its customers. It incorporates a fish-eye camera (AXIS M3068-P) security camera, two-way intercom, secure communications, and a Jetson Nano to execute AI algorithms for detecting risk situations. These situations include intrusion detection, fire detection and violence detection. Weight: 32 Kg Battery: Use 90 mins / Load 90-120 mins Payload max:14 Kg Main advantage of Yellow when compared with Kiiro is its capacity of ability to go up and down stairs. Its appearance is also more friendly for visitors.	1
	Kiiro + Payload	Kiiro is a robot co-created between PROS and the company Robotnik, based on its emblematic Summit-XL platform. The robot, designed to provide security solutions in the industrial and logistics field, can make rounds completely autonomously, as well	1

Robots 		as providing industrial inspection services. This robot, which has four wheels and a large battery capacity, shares a similar payload to Yellow: high-resolution PTZ security camera, two-way intercom, secure communications, and AI to detect risk situations. Weight: 65 Kg Battery: Use 8-10h/ Load 3-4h Payload max: 65Kg Main advantages of Kiiro vs Yellow are an increased autonomy and the possibility to program the routes on the map loaded in the software just by selecting a number of waypoints.	
5G CPE 	5G routers Askey RTL6305	5G Customer Premises Equipment (CPE) support the mm Wave and Sub 6GHz for 5G NR SA core network. Thank for Ethernet Cat 6 cable, the RTL6305 can provide Gigabit highspeed connections to connected devices for Internet access. Is targeted for the outdoor environment usage with IP67 weather rating of protection against temporary water submersion. 5G NR capabilities: • 3GPP Release 15 NSA and SA modes. • 5G NR Sub 6GHz: • TDD: n41, n77, n78, n79 • FDD: n1, n3, n7, n8, n20, n28 • 5G mmW: n257, n258 (8CC support) • LTE band: B1, B3, B5, B7, B8, B20, B28, B32, B38, B40, B41 • Support LTE 4x4 MIMO & 5G Sub 6GHz 4x4 MIMO; mmW 2x2 MIMO	6

3.1.3 Infrastructure components and functionalities

The network infrastructure to be deployed for this use case will be a 5G/B5G Ericsson Non-Public Network (NPN). All the devices shown in the Figure 9 that will be in the venue, will use only the Ericsson Non-Public Network, while the commercial devices will use the public network. A diagram of the infrastructure is depicted in Figure 10. The Ericsson 5G NPN infrastructure is a distributed 5G Stand-Alone (SA) network. The 5G SA architecture adopts the new concept of Service-Based interfaces. This means that the Network Functions (NFs) that include logic and functionality for processing signaling flows are not interconnected via point-to-point interfaces but instead exposing and making available services to the rest of NFs. Thus, there is a separation that broadens the range of possible locations in which the network elements can be located. The RAN and the User Plane Function (UPF) are installed at venue premises, while the rest of components of the 5G Core (5GC), the control plane components, are running at 5Tonic [42] (Leganés, Madrid). This model is interesting because verticals do not need to have their own full 5G deployed, making the service a lot more cost-efficient for them. With this solution, the 5G RAN equipment splits the user plane traffic and the control traffic. The use case traffic is directed via the UPF towards the vertical applications. In this way, the user plane traffic remains geographically close to the end user devices, keeping a very low latency. Complementarily, the control and management plans of the 5G equipment are done from a remote location in 5Tonic Virtual Private Network (VPN), as control traffic does not require as low latency and high-speed levels as the local user plane traffic.

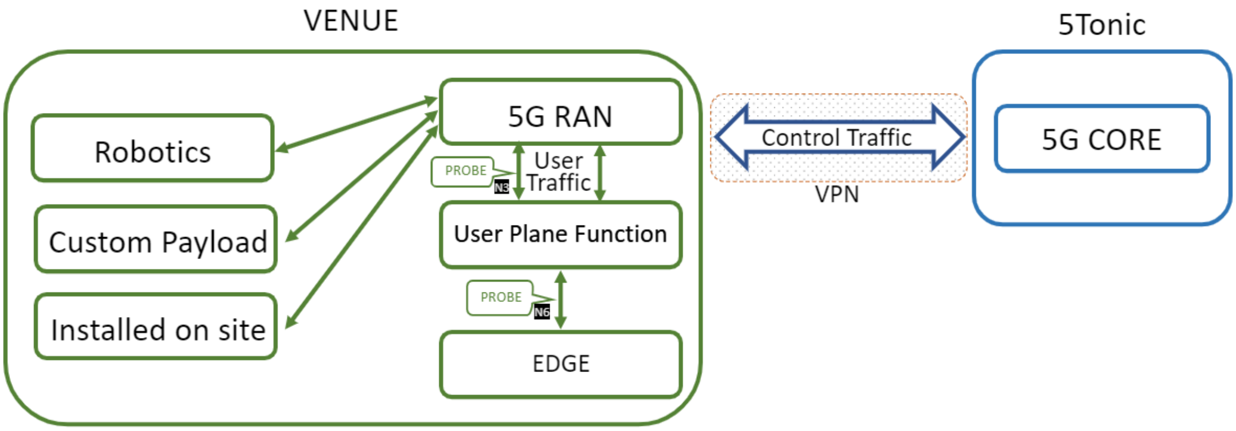

Figure 10. Infrastructure architecture.

Robotics, customized payload, and on-site installed elements, access the 5G network using 5G CPEs depending on the required technology (mid-band or mm Wave). To collect network metrics there are two software probes (N3 and N6 in Figure 10) to obtain the network measurements.

3.1.4 Trial description

The use case will be performed in a context of a large-scale event in a sports venue in which applications provide safety and security measures to protect the participants. The Ericsson 5G NPN infrastructure will be used for the trial. Initially, the participants of the UC will be actors from the participating partners and employees in their organizations. Table 2 and Table 3 describe the test cases related to the trial activity.

Trials will be performed in three progressive phases oriented to ensure a rapid and reliable deployment and operation at the demonstrative site. The three phases are described hereafter:

Phase 1: Lab Scale

- Set up of the server at Azure Cloud, deployment of software and configuration.
- iSOC position configuration with the installation of VMS, AMS, LIDAR ready VMS, Robotnik and Scout, and other software if required.
- Set up an Azure environment and tools necessary for Cloud services.
- Creation of a VPN network and configuration of the components involved.
- Deploy interoperability middleware software and configure it.
- Deploy Video analytics applications which are containerized with docker. Test alerts. Integrate via API with interoperability middleware.
- Set up and configuration of LIDAR ready VMS.
- Set up and configuration of Gemini Software on cloud. Test pre-alerts and alerts. Integration vía API of Gemini with LIDAR ready VMS.
- Integration in the interoperability middleware the technical signals of Kiiro.
- Test the teleoperation test from iSOC position using 5G network.
- Cybersecurity requirements analysis.

Phase 2: 5Tonic

- Set up of the hardware devices.
- Configuration of the B5G network
- Separate network KPIs measurement for the communications between devices and cloud and from cloud to iSOC and vice versa.
- Simulation of events for AI evaluation
- Usability analysis for the iSOC operator.

Phase 3: Demonstrative site

- Site analysis and selection of the cameras and LIDAR installation points.
- Deploy hardware devices and required cabled connections.
- Mapping of the area and configuration of the automatic routes of Kiiro.
- Configuration of the B5G network.
- Separate KPIs measurement for the communications between devices and cloud and from cloud to iSOC and vice versa.
- Evaluation of the precision and recall of the AI for both, fixed camera video streams and mobile cameras on the robots.
- Measurement of the transmission of the LIDAR data from device to cloud and from cloud to iSOC.
- Real time telecommand of one and two robots simultaneously.
- Evaluation of the video stream from cameras (both, onboard and fix) to iSOC.
- Usability analysis for the iSOC operator.
- Evaluation of network KPIs.

Table 2 and Table 3 describe the trials that will be performed for UC1 in Madrid.

Table 2. UC1 (Madrid) trial description through static infrastructure and artificial vision.

Trial ID / Name	**Trial 1.1 / Crowd monitoring through static infrastructure and artificial vision**	
Infrastructure / Venue	**5Tonic Lab and Real environment / Sport Cultural Event**	
Description	Deploy a number of technology solutions (cameras and lidars) to ensure the security and safety of people at highly crowded areas whether stationary or in motion. Image analysis through artificial vision algorithms will serve to automatically detect people counting, violent activity, vandalism, weapons, suspicious activity such as loitering and abandoned bags.	
Components and Configuration	Components	• CCTV (closed circuit television) and PTZ (pan,tilt and zoom) cameras. • LIDAR. • iSOC position (server, screens, and routers). • 5G communication infrastructure. • Probes to measure the network KPIs. • 5G connection to enable real-time data sharing and communication.
	Configuration	• Video streams to be sent to Azure for AI analysis. • Alerts from algorithms will be sent through the interoperability middleware to AMS. • LIDAR will send the points cloud to Gemini (on cloud) that will be sent to LIDAR ready VMS (iSOC). • Realtime video stream from fixed cameras will be sent to VMS. • 5G communication infrastructures. • Monitoring tool: probes will be installed in different parts of the network, to measure network KPIs.
Trial Procedure	Pre-conditions	• Video streams received on cloud for AI processing. • Video streams received at VMS in iSOC. • Pointcloud received at Gemini on cloud (Azure). • Alerts from video analytics received at AMS. • Alerts from Gemini received at LIDAR ready VMS.

		• For the live test VPN should be configured to reach the 5Tonic lab with the CORE equipment. • Probes should have access to the influx database in 5Tonic through the VPN. • Control functions should be configured through VPN. • Applications deployed in the Edge.
	Trial steps	• Deployment of devices and network. • Pre-test of the correct integration of the different platforms. • Network KPIs evaluation for the separate use of the different security systems (fix cameras, LIDARs). • AI KPIs evaluation under simulated and real conditions. • B5G network KPIs evaluation for simultaneous functioning of all the systems.
	Methodology	• Works for 5Tonic will last 1 month of which 1 week will be devoted to iterative KPIs measurements. • The real environmental demonstration will last 2 weeks, one before the event and one during the event. • Controlled and real environment tests will be carried out on a daily basis.
	Complementary measurements	• Technical staff on-site will be measuring the efficacy of the algorithms by simulating events and through the verification of the real events received on AMS. • Security guards will help to validate occupancy of the area in order to contrast it with people counting measurements carried out by algorithms. • As complementary measurements, Ericsson has developed a SW probes tool (a component that extracts KPIs from the end-user traffic with the granularity of flow for IP traffic) that are installed in different points of the network and would be used as complementary sources of measurements. For example, Ericsson has a probe installed in the User equipment (UE) and collects data related to the KPIs as latency, jitter, user data rate and send to a database. This information is later processed and used as complementary measurement.
	Calculation process	Computer vision and machine learning algorithms to process the images and detect damages, potential hazards, and other issues.
Expected Result	The platform is expected to detect damages and potential hazards in real-time, triggering alarms and sending alerts to the iSOC and remote experts for immediate action.	

Table 3. UC1 (Madrid) trial description through programmed or tele-controlled robots with AI.

Trial ID / Name	**Trial 1.2 / Crowd monitoring through programmed or tele-controlled robots with AI**	
Infrastructure / Venue	**5Tonic/ Real environment – Sport or Cultural Event**	
Description	Deploy two ground robots equipped with cameras and artificial vision for autonomous and remote-controlled security inspection rounds.	
Components and Configuration	Components	• Yellow. • Kiiro. • iSOC position (server, screens and routers).

		• 5G communication infrastructure. • Probes to measure the network KPIs. • 5Gconnection to enable real-time data sharing and communication.
	Configuration	• Technical signals of Kiiro to the interoperability middleware that will send alerts to AMS. • Video streams from onboard cameras to be sent to cloud for IA analysis. Alerts will be sent through the interoperability middleware to AMS. • Scout will be installed in the iSOC for the operation of Yellow. • The iSOC operator will manage Kiiro through Robotnik /software accessible via web browser. • 5G communications infrastructure. • Monitoring tool: probes will be installed in different parts of the network, to measure network KPIs.
Trial Procedure	Pre-conditions	• Technical signals received in AMS. • Correct installation of Scout in iSOC. • Mapping of the area and waypoints selection for automatic routing of Kiiro. • For the live test VPN should be configured to reach the 5Tonic lab with the CORE equipment. • Probes should have access to the influx database in 5Tonic through the VPN. • Control function should be configured through VPN. • Applications deployed in the Edge.
	Trial steps	• Deployment of devices and network. • Pre-test of the correct integration of the platforms. • Mapping and route configuration of robots. • Network KPIs evaluation for the separate use of robots. • 5G network KPIs evaluation for simultaneous functioning of all the systems.
	Methodology	• The set-up in 5Tonic will last 1 month of which 1 week will be dedicated to iterative KPIs measurements. • Real environment demonstration will last 2 weeks, one before the event and one during the event. Controlled and real environment tests will be carried out on daily basis.
	Complementary measurements	On-site technical staff will validate the precision of the robot when following pre-set routes and will identify connection failures between the robot and the iSOC.
	Calculation process	Computer vision and machine learning algorithms to process the images and detect damage and potential hazards.
Expected Result	The platform is expected to detect damages and potential hazards in real-time, triggering alarms and sending alerts to the iSOC and remote experts for immediate action. This will enable the remote control of the robots and faster reaction time.	

The trial description reported in Table 2 and Table 3 are intended to be complemented with the specific KPIs and KVIs definition and measurements reported in section 4.1.2.

3.2 UC1: Smart Crowd Monitoring (Iasi)

The use case will present the benefits offered by B5G (towards 6G) technologies for improving the protection of people in crowded public spaces. The information provided by the use case will help the authorities to better plan public events and to efficiently react in case abnormal situations occur.

3.2.1 Use case definition

The Smart Crowd Monitoring use case to be implemented in Iasi, Romania, is going to complement the similar type of application to be put into operation in Madrid. The telecommunications and processing infrastructure will take into consideration two distinct scenarios:

- Crowd characterization in terms of people counting, density, and dynamics of large numbers of persons (flow directions, spread, speed) during outdoor public events.
- Detecting special situations during normal traffic scenarios (e.g., presence of various objects such as cars, trucks, motorcycles, etc. in restricted access areas).

The relevant information will be gathered from ensembles of cameras and Wi-Fi access points. The efficiency of the two types of sensor data will be assessed both individually and following a sensor-fusion approach.

There are two regions of interest to be covered, namely the square in front of the Palace of Culture and the pedestrian zone between the City Hall and the intersection with a major street situated nearby (see Figure 2 and Figure 3 in Section 2.2.2). The former area has been chosen because it regularly hosts public events (concerts, meetings), while the latter is a rather crowded zone since several cultural and religious buildings are situated there.

As indicated in Figure 11 and Figure 12, several cameras will be installed on poles already available on the premises, along with Wi-Fi Access Points (AP’s). Video streams and information related to the number of Wi-Fi enabled devices present in the region under study will be sent (through the 5G communication infrastructure put in place by ORO) to a server located in the 5G Lab facility within the “Gheorghe Asachi” Technical University of Iasi. Specific (AI-oriented) algorithms will run on the server side, aiming at reliably estimating the number, density, and dynamics of large crowds, along with the identification of special events of interest (e.g., cars entering restricted access areas or people falling on the street). Analytics results provided by the algorithms will be transmitted to the relevant stakeholders and made visible through appropriate interfaces.

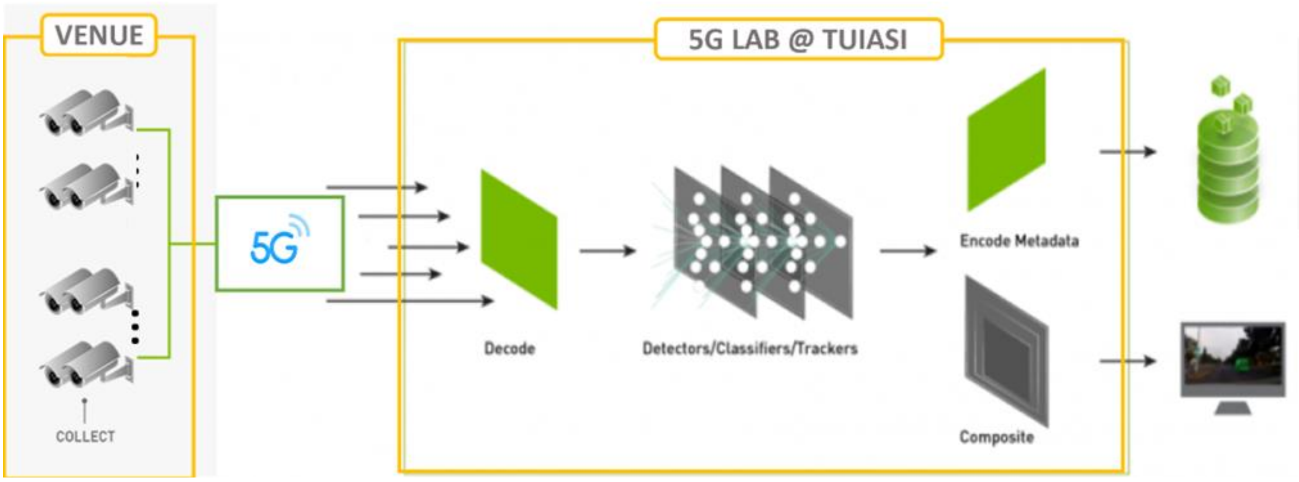

Figure 11. Block diagram of the smart crowd-monitoring use case in Iasi with cameras.

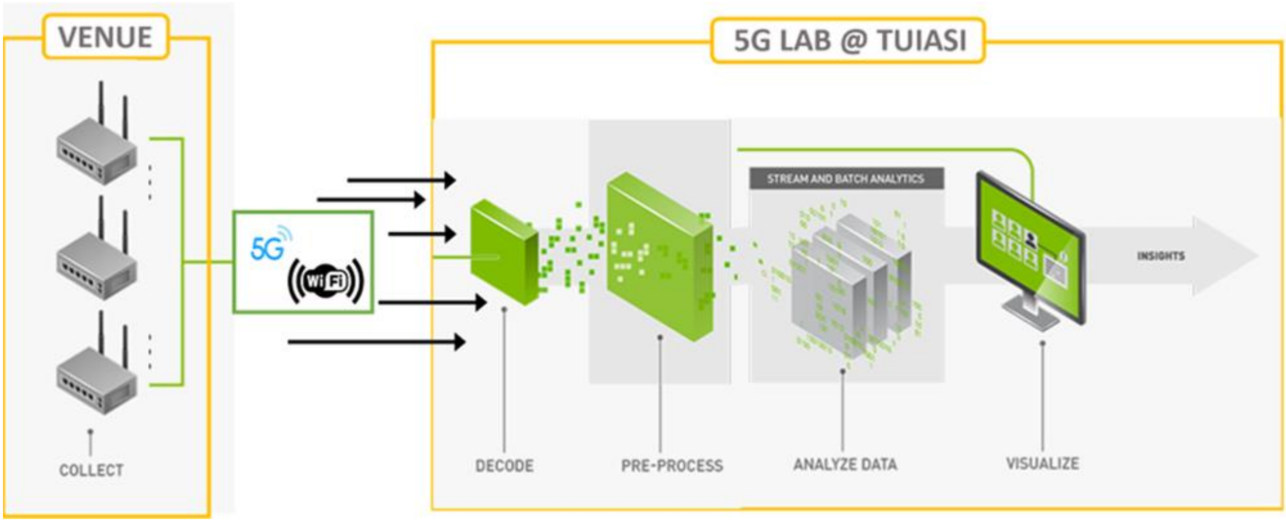

Figure 12. Block diagram of the smart crowd-monitoring use case in Iasi with Wi-Fi.

The added value provided by the TrialsNet project builds on the advantages of the 5G communication infrastructure in terms of increased number of connected sensors/terminals, fast and reliable transmission, slicing options, gathering various networks on a single platform. Evaluating key performance indicators will enable the identification of the current limits of the technology and provide useful insights for the standardization of the next B5G generations. KPI's include the uplink/downlink cell capacity, roundtrip latency between the device and the network, application-level latency, service reliability and availability. A special focus will be put on evaluating the trade-off between the flexibility of the architecture and its efficiency in terms of data transfer and control, latency, bandwidth, energy, and operational costs. The envisioned use cases are critical for real-time monitoring and analysis of the public infrastructure, and successful deployment of the proposed solutions may lead to faster response times and improved decision-making by city authorities.

3.2.2 Implementation aspects

3.2.2.1 Application design

The block diagram in Figure 13 represents a detailed description of the application design for implementing the crowd monitoring use-case in Iasi, Romania. The architecture of the 5G Lab in TUIASI is further detailed in the infrastructure section, in Figure 15.

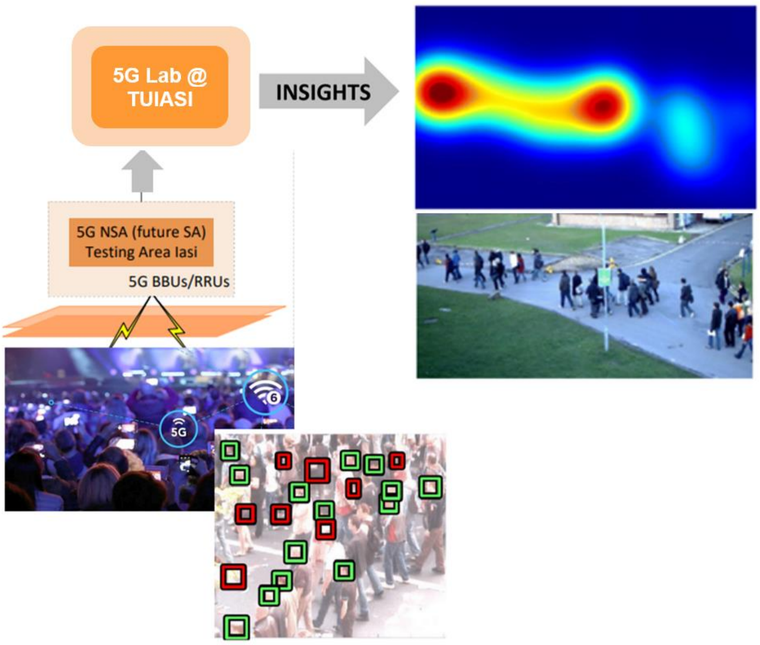

Figure 13. Block diagram of the proposed approach.

There are two distinct information processing flows that consider the specificities and constraints of the corresponding sensory input: i) the video feed from the (visible spectrum) cameras; ii) Wi-Fi access points.

The camera-based solution will consider the acquisition and transmission of video streams from the devices on place to a server installed in the "Gheorghe Asachi" Technical University of Iasi. The video stream will subsequently be the subject of video analytics algorithms aiming at providing statistical information to be further sent to interested third parties (city administration, 112 service, etc.). The video processing flow will be based on the (free) DeepStream SDK package provided by Nvidia [46] that integrates continuous acquisition, AI-based algorithms implementation, and decision-making.

According to the documentation on Nvidia's website [46], the DeepStream SDK is a streaming analytic toolkit to build AI-based applications for video and image understanding. The DeepStream SDK can help build optimized pipelines taking streaming video data as input and outputting insights using AI. It offers turnkey integration of models trained with the NVIDIA Transfer Learning Toolkit (TLT) [47]. The TLT is a Python-based AI toolkit for creating highly optimized and accurate AI apps using transfer learning and pretrained models. Along with creating accurate AI models, the TLT is also capable of optimizing models for inference to achieve the highest throughput for deployment.

The workflow using pretrained models is given in the Figure 14 below:

Figure 14. Processing workflow using TLT (from Nvidia documentation sites).

The documentation available on Nvidia's website clearly defines all the necessary steps to be followed to successfully use and deploy a broad range of already available pretrained models.

An end-to-end built-in configurable application from DeepStream SDK (deepstream-app) will be used to run specific AI models. The app enables the setup of the input source, output sinks, and the AI model (with the encryption key) to be used. There are generally two or more config files that are required to run deepstream-app: one is the top-level config file that sets parameters for the entire pipeline, and the others are config files for the inference step. The crowd monitoring test cases will consider Convolutional Neural Networks (CNN) to estimate the total count of people entering a specific access point (the entrance of the Iasi Mitropolitan Church).

The smart crowd monitoring use case UC1 in Iasi will be trialed in distinct areas targeting different outcomes, as follows:

- Estimation of the total count of people entering a specific access point, namely the entrance of the Iasi Mitropolitan Church.
- Reliable and fast identification of selected classes of objects (cars, trucks, motorcycles, etc.) entering in a restricted access area (the pedestrian one in front of the Palace of Culture).
- Estimation of the density and dynamics of large numbers of people present in the surveilled area (the Stefan cel Mare Boulevard) using information provided by the Wi-Fi access points (AP's) installed on the premises. The Wi-Fi solution was chosen as a complementary alternative to cameras, since they typically suffer from obstructions, adverse weather conditions, poor illuminations and are more prone to privacy concerns. According to the IEEE 802.11 standard, mobile devices emit data packets called Probe Requests (PR) to scan an area for existing networks. The temporal rate of such transmissions is an indicator of the number of devices present within a given region of interest, which in turn, using extrapolation formulas [48], will provide an estimation of the total number of people on the premises. The system will monitor the PR's using a non-cooperative approach (namely, without the need of performing an actual Wi-Fi connection between the smartphone and the nearest access point nor requiring the installation of a specific app). From a privacy preserving perspective such PR's contain a randomized Media Access Control (MAC) address that acts as a source address field, although this randomization procedure does not affect the counting result.

3.2.2.2 Equipment and devices

The equipment required to develop and test the system for this use case is composed of the list of the devices reported in Table 4. The number of devices may be adapted in the future following the results of the on-field site survey and design output.

Table 4. Equipment and devices for UC1 (Iasi).

Equipment	Item	Description	Quantity
Fix Camera (5G) 	Milesight MS-C8266-X4GPC [12]	The Milesight MS-C8266-X4GPC is a 5G SA/NSA surveillance camera that can record 4K footage. This camera will be used for 2K/4K video capturing in the area defined for the use-case. This video stream will be transmitted directly to an Edge-compute facility via the 5G SA/NSA network, this way eliminating the security risks involved with the transmission of sensitive data through publicly accessible switches.	1
Fix Camera  	AXIS Q6100-E Network Camera [13]	AXIS Q6100-E Network Camera features four 5 MP sensors with a total of 20 MP resolution both day and night and 360° overview for total situational awareness. Designed for operation with any AXIS Q61 or Q63 PTZ Network Camera, it captures high resolution overviews and details in one complete camera solution. It's ideal for city surveillance applications, for instance at street crossings or squares. When used with AXIS Q63-Series camera, an AXIS Camera Heater Power Supply is required. It includes directional audio detection which redirects the PTZ camera to the audio source whenever an audio incident is detected. Furthermore, it offers automatic PTZ tracking. When motion is detected in one of the four 5 MP sensors, the connected AXIS Q61 PTZ Network Camera will automatically track the object within the viewing area.	6
PTZ Camera 	AXIS Q6318-LE PTZ Network Camera [14]	AXIS Q6318-LE offers superior 4K UHD resolution for great detail. It features a ½" sensor to deliver clear, bright images and better handling of shadows even in challenging light conditions. And, with IR Illumination and D/N functionality, it's perfect for surveillance in pitch darkness. Featuring 31x optical zoom, a built-in laser, and quick-zoom functionality, AXIS Q6318-LE allows you to easily follow fast-moving objects. Plus, it offers laser focus for precise focus–every time. Furthermore, Zipstream with H.264 and H.265 significantly lowers bandwidth and storage requirements without compromising image quality.	2
	Nokia FastMile 5G14-B [15]	The Nokia FastMile 5G14-B is a 5G SA/NSA outdoor CPE that can connect simultaneously to multiple slices, with different IPs and different Package Data Unit (PDU) sessions, with a single	6

5G CPE 		SIM card specifically provisioned to support 2 or more DNN profiles. The CPE splits the traffic into separate VLANs and ends the connection into a switch that allows devices to access different slices. This Nokia CPE is also able to connect to a TR-069 Automatic Configuring Server (ACS), this way being able to transmit real-time metrics about the UL and DL traffic values for the connected slices and the radio signal parameters. The CPE will be configured to connect to both an eMBB slice and an URLLC slice. This way, the non-cellular cameras and the sensors will use the eMBB for data transmission, while the VRUs will be notified by the security system through the URLLC slice.	
Wi-Fi Access Points 	Cisco AIR-AP1572EAC-E-K9 [16]	The Cisco AIR-AP1572EAC-E-K9 is a Wi-Fi Access Point, providing 2.4 GHz and 5 Ghz outdoor Wi-Fi coverage in the outdoor Wi-Fi Hotspot at Pietonala Bd. Stefan cel Mare in Iasi. The outdoor AP supports the 802.11ac Wi-Fi standard, with data connection speeds up to 1.3 Gbps. This industrial-grade AP supports 4x4 multiple-input and multiple-output (MIMO) smart antenna technology and three spatial streams. It is waterproof with an IP-67 rating.	7
Wi-Fi Access Points 	Cisco AIR-AP1562E-E-K9 [17]	The Cisco AIR-AP1562E-E-K9 is a Wi-Fi Access Point, providing 2.4 GHz and 5 Ghz outdoor Wi-Fi coverage in the outdoor Wi-Fi Hotspot at Pietonala Bd. Stefan cel Mare in Iasi. Compared to the Cisco AIR-AP1572EAC-E-K9, it retains most of its characteristics, with the notable mentions that instead of 4 physical external antennas, this model supports just 2 physical antennas, a maximum speed of 867 Mbps and 2x2 MIMO with 2 spatial streams. It is also waterproof with an IP-67 rating. Due to its low profile and lower energy / PoE consumption it can be installed in certain places where the AIR-AP1572EAC-E-K9 cannot.	10
Wi-Fi Access Point Switches 	Cisco WS-C2960CX-8PC-L [18]	The Cisco WS-C2960CX-8PC-L is a member of the Cisco Catalyst 2960-CX series of switches. It is a compact, fan-less Gigabit Ethernet switch that provides enterprise-class Layer 2 switching for branch offices or remote sites. It also supports up to 1 Gbps Full-Duplex speeds and a PoE budget of 124W. The switches have been installed either in indoor locations (where permits were obtained) or outdoors in IP-67 rugged boxes.	6

3.2.3 Infrastructure components and functionalities

The use-case will be implemented based on a network infrastructure that covers both 5G and Wi-Fi connectivity. In the following chapters a high-level overview of the two networks will be provided, while the full details about the testbed implementation will be described in the first WP2 deliverable.

3.2.3.1 5G network infrastructure

The ORO 5G Labs, in both Bucharest and Iasi, will serve as the primary locations for hosting the infrastructure for this use-case and will be the desired places for testing and validation of the related applications. The Bucharest 5G Lab is located within the CAMPUS Research Center of the Polytechnic University from Bucharest (UPB) and currently implements a full 5G SA infrastructure, comprising 5G RAN, 3GPP Release 16 compliant Core Network (basic functionalities including Access and Mobility Management Function (AMF), Session Management Function (SMF), User Plane Function (UPF), Authentication Server Function-(AUSF) and Unified-Data-Management (UDM), Edge Computing and advanced SDN Network in the Datacenter. The Iasi 5G Lab is located within the Iasi Technical University (TUIASI) and currently hosts only 5G SA RAN components. In the next months it will be prepared so that it will have similar Edge-computing capabilities to the Bucharest laboratory and in the medium term the RAN will be extended so that the use-case area will be covered with 5G SA connectivity. The Edge-compute facility from the Iasi Datacenter will host two compute servers with virtualization capabilities, one equipped with a GPU for video processing, and a dedicated virtualized UPF that will help integrate the servers and Internet with the mobile network. The two facilities are interconnected through ORO's commercial transport network.

Initially the commercial 5G NSA network, integrated with the Iasi Edge-compute facility, will be used for piloting and testing of the developed solutions.

The testbed, represented in Figure 15, is capable to provide multi-slices implementations, with QoS/QoE guarantee in the concurrent services implementation, as eMBB (1500Mbps DL/200MBps UL) or URLLC (E2E one way delay <2.5 ms), this way being able to accommodate multiple types of applications with different requirements.

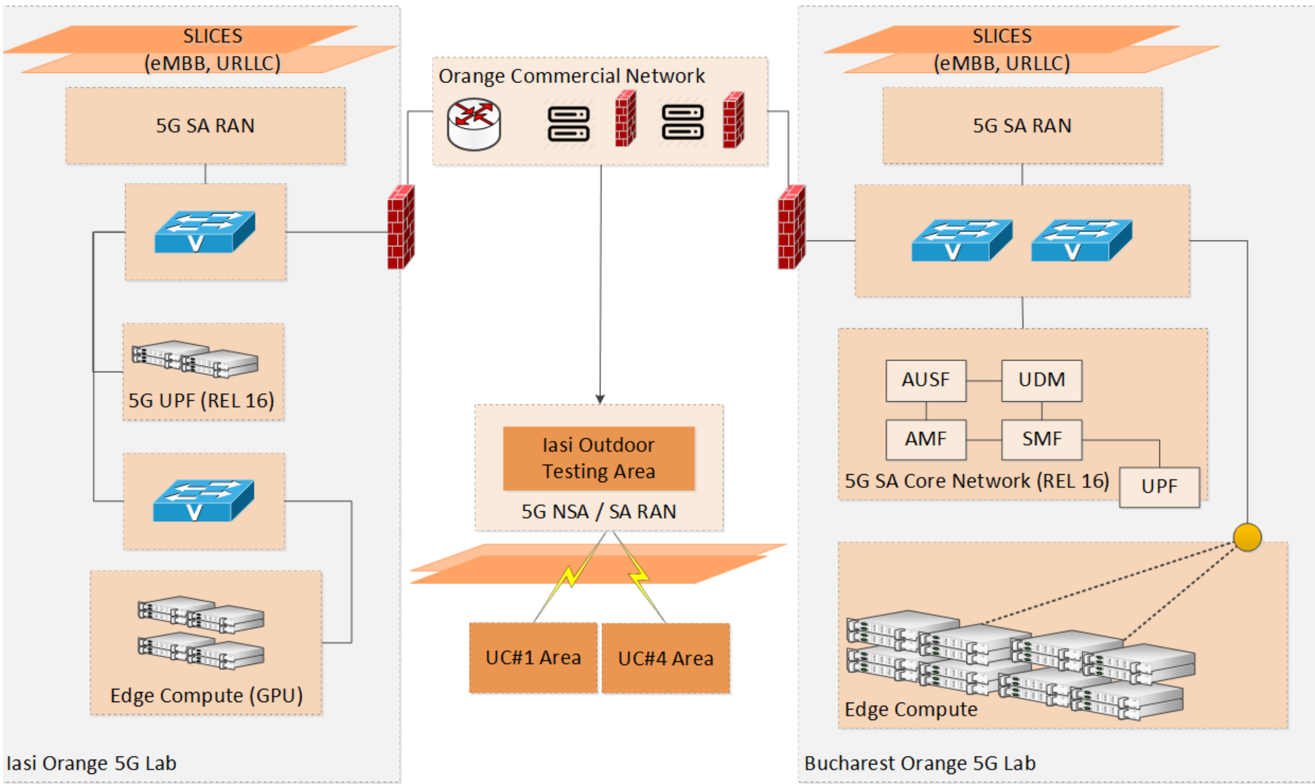

Figure 15. ORO 5G Labs architecture.

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3.2.3.2 Wi-Fi infrastructure

The current Wi-Fi network backbone is provided through an AP-WLC framework which includes centralized advanced Wi-Fi LAN management (WLCs), authentication (AAA), asset infrastructure management via a Network Management System provided by Cisco, Wi-Fi Presence and Location Analytics , Core Solutions (Seamless Wireless Access, Voice over Wi-Fi), in order to provide multiple Wi-Fi functionalities and features flexibility for clients and ORO internal users.

The diagram below (Figure 16) depicts the evolution of the ORO Wireless Network.

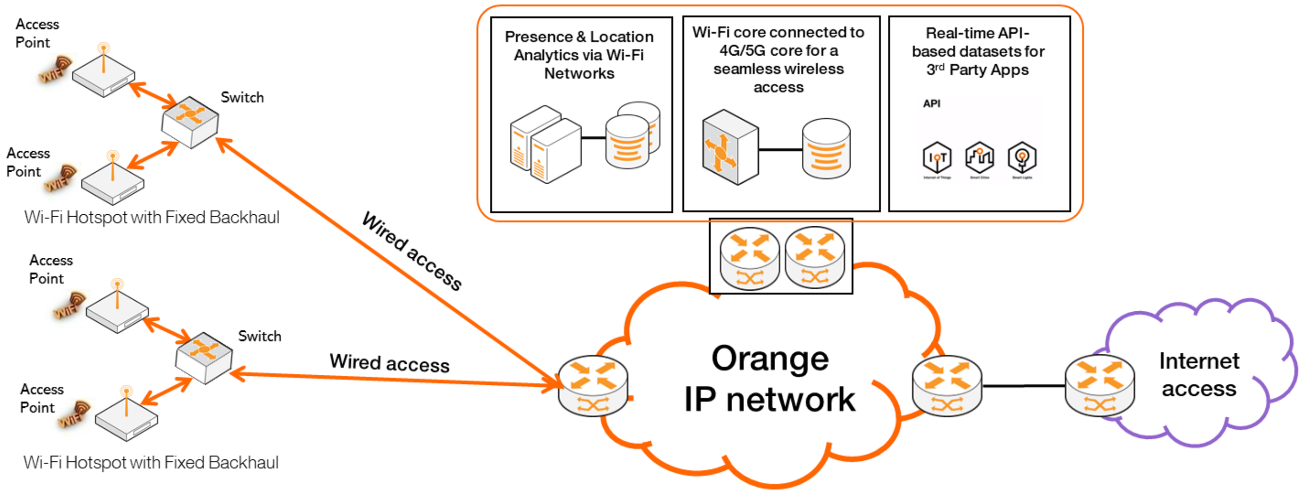

Figure 16. Orange Wireless Network Modules and Air Quality Sensors by Functions.

All APs function in a controller-based architecture. The connection of APs with the ORO backbone was made through a router. The APs were enrolled in a WLC located in ORO Datacenter. The WLC is enrolled in a Cisco Network Management System (used to configure and monitor multiple WLCs). All Wi-Fi hotspots are mapped to enable presence and location analytics.

Also, all the above-mentioned modules have Representational State Transfer (REST) based APIs which can be exposed to 3rd party dashboarding applications (such as Elk Stack Kibana dashboards) using the HTTP/HTTPS protocols.

3.2.4 Trial description

The use case will be performed in a context of a large-scale event in public area where applications provide safety and security measures to protect the participants. The crowd monitoring use case will consider surveillance, but only from a global (statistical) perspective, rather than on an individual basis. No personal data will be stored, sold, or transmitted to any other parties. The information to be extracted from the datasets under study will consider only statistical figures and facts, without any reference to individual data. The Table 5 and Table 6 below describe the trials that will be performed.

Table 5. UC1 (Iasi) trial description using Wi-Fi information.

Trial ID / Name	Trial 1.3 / Crowd monitoring using Wi-Fi information	
Infrastructure / Venue	**Indicated areas onto the Stefan cel Mare Boulevard + Iasi 5G Lab Data-center**	
Description	The application estimates the total count, density, and dynamics of crowds in surveyed areas using probe requests received by Wi-Fi access points.	
Components and Configuration	Components	• Wi-Fi AP's. • 5G communication infrastructure. • Algorithms estimating relevant statistical parameters. • Interface displaying relevant statistical parameters.

	Configuration	• APs installed on the premises. • 5G communications infrastructure. • Algorithms running on server side inside the Iasi 5G Lab Datacenter. • Graphic interface showing a dashboard of relevant statistical parameters.
Trial Procedure	Pre-conditions	Test signals from the Wi-Fi infrastructure to be sent to the server to verify the connectivity and estimate delays.
	Trial steps	• Probe requests sent to APs transmitted to the server side. • Compute relevant statistical indicators (number, temporal average, spatial distribution). • Dump computed parameters to ORO's backend server. • Transmit relevant information to third parties.
	Methodology	Monitoring frequency is 10-15 times per second.
	Complementary measurements	Ground truth data to be confirmed on the premises.
	Calculation process	The algorithms first compute the average number of (anonymized) probe requests received by every AP on predefined time intervals. A linear interpolation formula will provide the estimated number of subjects present on the surveyed area.
Expected Result	• It is expected that statistical indicators relative to the crowd computed using data provided by the Wi-Fi based approach would be realistic in terms of magnitude and fall within value ranges provided by human experts. • Evaluate performance indicators (uplink/downlink cell capacity, roundtrip latency between the device and the network, application-level latency, service reliability and availability) to be used for defining B5G requirements.	

Table 6. UC1 (Iasi) trial description using cameras.

Trial ID / Name	**Trial 1.4 / Crowd monitoring using cameras**	
Infrastructure / Venue	**Pedestrian areas within indicated locations (Stefan cel Mare Boulevard, Place in front of the Palace of Culture) + 5G Lab@TUIASI**	
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.	
Components and Configuration	Components	• Working RGB cameras. • GPU compute capability at the server side. • 5G communication infrastructure. • AI-based algorithms.
	Configuration	• GPU-enabled server. • Nvidia's TLT+DeepStream framework. • Object detection/classification/tracking/density estimation algorithms based on Convolutional Neural Networks (CNN).

Trial Procedure	Pre-conditions	Test signals from the cameras to be sent to the server to verify the connectivity and estimate delays.
	Trial steps	• Video stream received at the server side. • People counting/density estimation algorithms start. • Dump computed parameters to ORO's backend server. • Transmit relevant information to third parties. • Object detection/classification algorithm starts. • If decided that the detected object implies risks, then the object tracking algorithm starts. • An alarm signal is triggered and sent to ORO's backend server and further to the relevant authorities.
	Methodology	• The monitoring test is started and executed over a duration to be set by the user. The monitoring tool presents the following results: • Heat maps estimating the density of people in the region of interest. • Total count of people passing through access facility. • Each time an object from a predefined set (cars, trucks, bicycles, motorcycles) is detected within the area under surveillance a visual alarm is triggered. The monitoring tool presents the following results: • Number and type of detected objects of interest. • Number of alarms and time occurrence for detected objects.
	Complementary measurements	Ground truth data to be confirmed on the premises.
	Calculation process	• First detect the heads of the subjects, then smooth the corresponding regions to finally yield a heat map that would approximate the true people density. Density values within calibrated regions may be used to estimate the total persons count (to be compared against the ground truth data). • Detected objects entering a restricted access area to be confirmed by direct inspection on the premises.
Expected Result	• It is expected that statistical indicators relative to the crowd computed using data provided by cameras would be realistic in terms of magnitude and fall within value ranges provided by human experts. • Typical classes of objects such as cars, bicycles, motorcycles should be reliably detected and classified in real-time, with an accuracy rate exhibiting 90%. • Evaluate performance indicators (uplink/downlink cell capacity, roundtrip latency between the device and the network, application-level latency, service reliability and availability) to be used for defining B5G requirements.	

The trial description reported in Table 5 and Table 6 are intended to be complemented with the specific KPIs and KVIs definition and measurements reported in sections 4.1.2. and 4.2.2.

3.3 UC2: Proactive Public Infrastructure Assets Management

The Athens site is set to implement a cutting-Edge solution for Proactive Public Infrastructure Assets Management. This use case involves collecting data from various sources such as security cameras, drones, municipal vehicles, and weather information. The data will be processed using AI and Deep Learning (DL) mechanisms to provide relevant information about the condition of public infrastructure assets. Remotely controlled cobots will also be used to assist in necessary maintenance activities.

3.3.1 Use case definition

This case will be implemented in two areas within the Greek Cluster: the Athens International Airport and public infrastructure provided by DAEM in the Municipality of Athens. The solution will utilize data from various sources, such as municipal vehicles, weather information, security cameras drones and robots, to assess the structural health of buildings, pavements, and roads. The data collected will allow for more efficient and effective proactive management of public infrastructure assets, leading to cost savings and improved operations and services.

The use of Augmented Reality (AR) will allow construction workers to have an on-site view of buildings or other assets blueprints and receive live bidirectional communications with remote experts who can provide assistance and video instructions. Remotely controlled or unmanned vehicles will be used to reduce risk and accelerate the building process. AI techniques, such as Neural Networks (NN) and Deep Learning (DL), will be used to assess the state of public infrastructure assets, produce alerts and suggestions for city authorities, improve workers' safety, and schedule predictive maintenance. Digital Twins of public construction sites will be used to validate complicated technical plans without wasting physical resources. These Digital Twins will be accessed by VR headsets, allowing real-time monitoring of the construction site. The utilization of B5G can enable faster and more reliable data transfer, which is critical for real-time monitoring and analysis of public infrastructure assets. This can lead to faster response times and improved decision-making by city authorities.

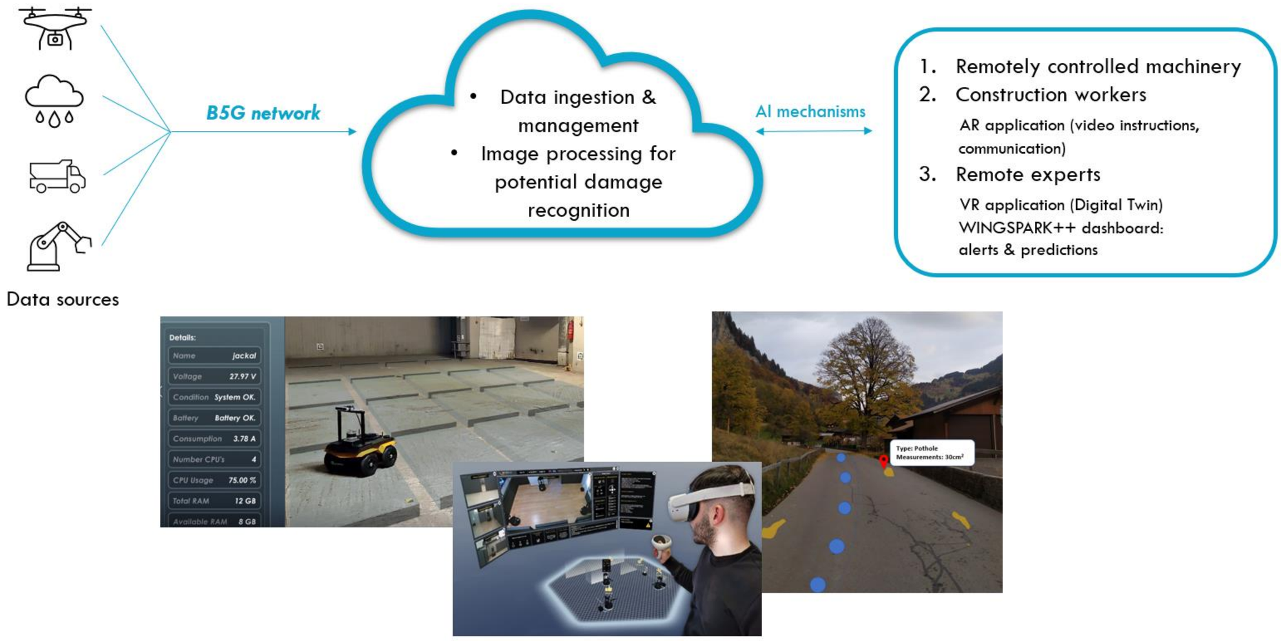

Figure 17. Proactive public infrastructure assets management.

3.3.2 Implementation aspects

3.3.2.1 Application design

The proposed application design depicted in Figure 17 involves the deployment of autonomous devices such as drones and robots for real-time monitoring of public infrastructure and critical assets. The devices capture images and other data, which are transmitted over 5G/B5G networks to a central platform for processing and analysis using AI techniques. The WINGSPARK++ [63] enables users to view and analyze the data collected by the devices. Users can access various features such as data visualization, anomaly detection, and predictive analytics. Additionally, there is a Digital Twin module that provides a detailed virtual representation of the airport and its infrastructure. This allows remote experts to assess any issues and plan repair processes. Finally, there is an AR application that allows users to interact with the construction site in a more immersive way. A high-level depiction of the application design is presented in Figure 18.

To implement the Proactive Public Infrastructure Assets Management use case, a multi-layered software architecture will be designed that consists of four main software modules:

- **Data Collection and Management Module:** This module will be responsible for collecting data from various sources, such as municipal vehicles, weather information, security cameras, drones, and robots. The data will be processed and stored in a centralized database for further analysis.
- **AI Analytics and Alerting Module:** This module will use AI techniques such as Neural Networks and Deep Learning to assess the state of public infrastructure assets, produce alerts and suggestions for city authorities, and schedule predictive maintenance. The AI models will be trained on historical data to accurately predict the future state of the assets. The module will also provide a real-time dashboard for monitoring the infrastructure's health.
- **AR Visualization and Communication Module:** This module will use AR and technologies to allow construction workers to have an on-site view of the assets' blueprints and receive live bidirectional communications with remote experts who can provide assistance and video instructions.
- **Digital Twin Simulation Module:** This module will be responsible for creating Digital Twins of public construction sites to validate complicated technical plans without wasting physical resources. The Digital Twins will be accessed by VR headsets, allowing real-time monitoring of the construction site.

Figure 18. High level depiction of the application design for UC2.

In the context of the proposed system, the GPS and cameras will feed the AI/ML algorithms for analysis and also send real time video streaming and positioning to the user applications that will be provided. The combination of GPS and camera data can provide rich contextual information that can be used to train AI algorithms for analyzing the environment. The GPS data provides location information, while the camera data captures visual information about the surrounding environment. To feed this data into AI algorithms, the first step would be to preprocess and synchronize the data. This involves aligning the timestamps of GPS and camera data, so that the corresponding location and visual information can be matched. The data can then be filtered and cleaned to remove any receiver noise such as multipath interference in GPS, as well as Gaussian blur or motion artifacts in the images. Once the data is preprocessed, AI algorithms can be used to analyze the environment. For example, computer vision techniques will be applied to the camera data to detect and classify objects in the environment. This information can be combined with GPS data to identify the location of each asset and track its condition over time. Deep learning algorithms can also be used to extract features from the data, such as texture, color, and shape, which can be used to classify and segment different types of infrastructure assets. For example, a deep learning algorithm can be trained to recognize cracks or to detect signs of wear and tear on infrastructure assets. The functionality described will be available at WINGSPARK++ where the system will trigger alerts depending on the severity of the problem found.

The insights derived from these analyses, such as the condition of the infrastructure assets, relevant predictions, and alerts, can then be used to inform maintenance and repair activities. For example, the data can be used to prioritize maintenance activities based on the condition and location of different infrastructure assets, or to schedule maintenance activities in advance based on predicted wear and tear. Additionally, remotely controlled cobots can be used to assist in necessary maintenance activities based on the insights derived from the data analysis.

3.3.2.2 Equipment and devices

The equipment required to develop and test the system for this use case is composed of the list of the devices reported in the Table 7. It should be noted that the list may be augmented as the implementation of the use cases progresses.

Clearpath Robotics like Jackal, Husky or even Warthog are Unmanned Ground Vehicles [70]/ UGVs are capable to navigate in outdoor areas with ease. Going from small to medium to large, these all-terrain unmanned ground vehicles can handle tough environments and be used in a wide variety of robotics applications. These robots have the capacity for a maximum payload of 20kgs for the small and up to almost 300kgs for lifting objects on top of them and even more in some cases when pulling different objects. These autonomous vehicles can move with a maximum speed of 10km/h for the slower robot to up to 18km/h.

In addition, the use of a custom-made quadcopter with PixHawk flight controller [67] and a Raspberry Pi [68] as a companion board will be investigated. Both the Jackal robot and the quadcopter can be used as auxiliary sensing devices e.g., for video streaming over an area of interest.

In this use case, the Ouster OS1 [69] which is a type of LIDAR sensor, can be mounted on a robot/autonomous vehicle to provide a real-time map of the surrounding environment. The LIDAR data can be used to help the robot navigate and avoid obstacles, such as walls, people, or other vehicles delivering a clean, dense data across its entire field of view for accurate perception and crisp mapping.

In addition to the robotic assets and LIDAR sensors, high resolution cameras will also be utilized. Intel RealSense Depth Cameras [70] are considered for this type of usage (Figure 19).

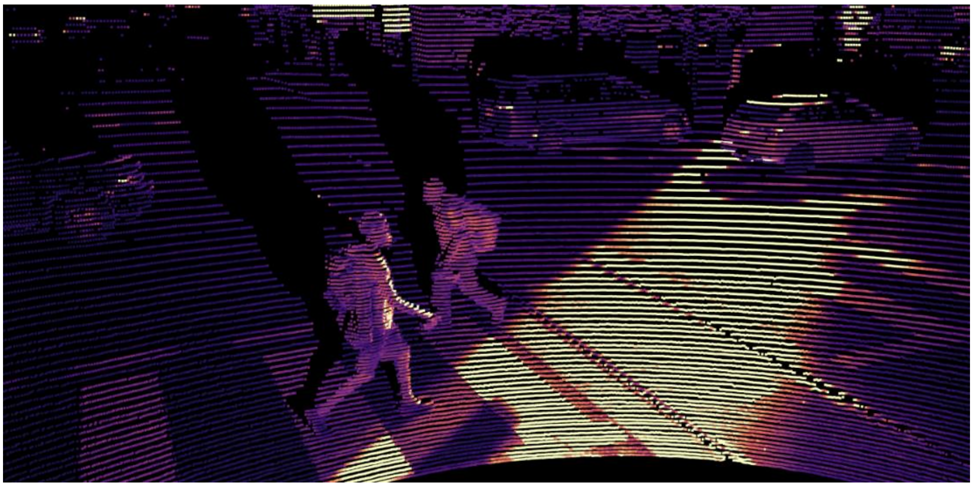

Figure 19. Mapping image from stereo camera.

Table 7. Equipment and devices for UC2.

Equipment	Item	Description	Quantity
 **Robot**	Clearpath Robotics Jackal Unmanned Ground Vehicle [72]	Clearpath Robotics Jackal Unmanned Ground Vehicle/UGV is a small, fast, entry-level field robotics research platform. It has an onboard computer, GPS, 3D LIDAR, camera and IMU fully integrated with ROS. Jackal's chassis is made entirely from welded aluminium and provides IP65 protection rated to operate from -20 Celsius or +45 Celsius. The high torque 4x4 drive train gives Jackal maximum traction, with enough onboard power available to traverse obstacles or unconsolidated terrain.	1
  **Drone**	Tarot Quadcopter Custom Drone + PixHawk controller [67]	A custom-made quadcopter with a PixHawk flight controller and carbon ultra-light weight body can be an excellent tool for aerial photography, mapping, and surveying applications. The PixHawk is a popular open-source autopilot system that provides advanced control algorithms for stabilization, navigation, and mission planning. The PixHawk flight controller provides stable and reliable flight performance, thanks to its advanced sensor fusion algorithms that combine data from multiple sensors, including accelerometers, gyroscopes, and magnetometers. This ensures that the quadcopter remains stable and responsive, even in challenging environments.	1
 **Computer**	Rasberry pi 4 [68]	The Raspberry Pi 4 is a powerful single-board computer that can be used for a wide range of applications, including drone technology. Its quad-core ARM Cortex-A72 CPU running at 1.5GHz, combined with its high RAM options, makes it a suitable choice for drone technology. With its small form factor, low power consumption, and various connectivity options, the Raspberry Pi 4 can be integrated into a drone's flight control system, providing real-time data processing, image and video capture, and even remote-control capabilities. Additionally, the Raspberry Pi 4's multimedia capabilities can be used to enhance a drone's camera and video streaming capabilities.	1
	Ouster OS1 [69]	Some of the sensors that will be used are the Ouster OS1 which is a type of LIDAR sensor used for 3D imaging applications. LIDAR stands for "light detection and ranging" and it uses lasers to generate a 3D map of the surrounding environment. The Ouster OS1 is designed for use in robotics and autonomous vehicles like the Jackal robot. The sensor has up to 128 laser beams that emit light in a 360-degree pattern, allowing it to capture a comprehensive image of the surrounding environment. It has a range of up to 200 meters and can generate up to 5.2 million points per second. In this robotic use case, the Ouster OS1 can be mounted on a robot/autonomous vehicle to provide a real-time	1

 **Sensors**		map of the surrounding environment. The LIDAR data can be used to help the robot navigate and avoid obstacles, such as walls, people, or other vehicles delivering a clean, dense data across its entire field of view for accurate perception and crisp mapping.	
 **Cameras**	Intel RealSense Depth Camera D455 [70]	Intel RealSense Depth Cameras will be integrated into the robots, to capture images of faults and other defects. By using these cameras, the robots will be able to more accurately and efficiently identify and address issues within the area. The high-resolution capabilities and depth sensing based on stereo camera array of these cameras will provide a level of detail and precision that would not be possible with traditional inspection methods. The cameras can capture full HD video to up to 10 meters combining depth information with a wide field of view making it the preferred solution for applications such as robotic navigation and object recognition even in low-light areas allowing robots to navigate spaces in dark environments.	1
 **GPS Devices**	Vision RTK 2	GPS devices will also be incorporated into the robotic assets to facilitate easy tracking of their location. This integration will enable the system to monitor and control the movement of the robots with greater accuracy and precision, avoiding potential hazards and obstacles. The selected GPS receivers use GNSS technology to provide location solutions that are 100 times more accurate (centimetre-level positioning) than traditional GNSS solutions. The combination of GPS and camera data will be used to train AI/ML algorithms for analysing the environment. This analysis will run on specific GPUs like the NVIDIA's GeForce RTX 3070 GPUs or newer for a better and faster analysis of the collected data. With tensor and cuda cores the system will be optimized for parallel computing or accelerated deep learning and AI workloads that this use case needs.	1

3.3.3 Infrastructure components and functionalities

The use case will be implemented using 5G network, WINGSPARK++ and a Configurable monitoring platform.

3.3.3.1 5G network infrastructure

To support the operation of advanced technologies, robots, drones, and other devices, a public 5G network will be used, leveraging its high-speed connectivity, low latency, and wide coverage. Specifically, the network will use Non-Standalone (NSA) architecture and operate at a frequency of 3.5 GHz. The allocated band for this network is 80-100 MHz, which will provide high-speed connectivity and low latency to support the data-intensive applications required by the use case. Future versions of the public network will also be used.

In addition, a WINGS owned, private network infrastructure will be utilised, to conduct testing activities, validation, and demonstration, prior to the deployment in the field. Figure 20 depicts the architecture in a high-level manner.

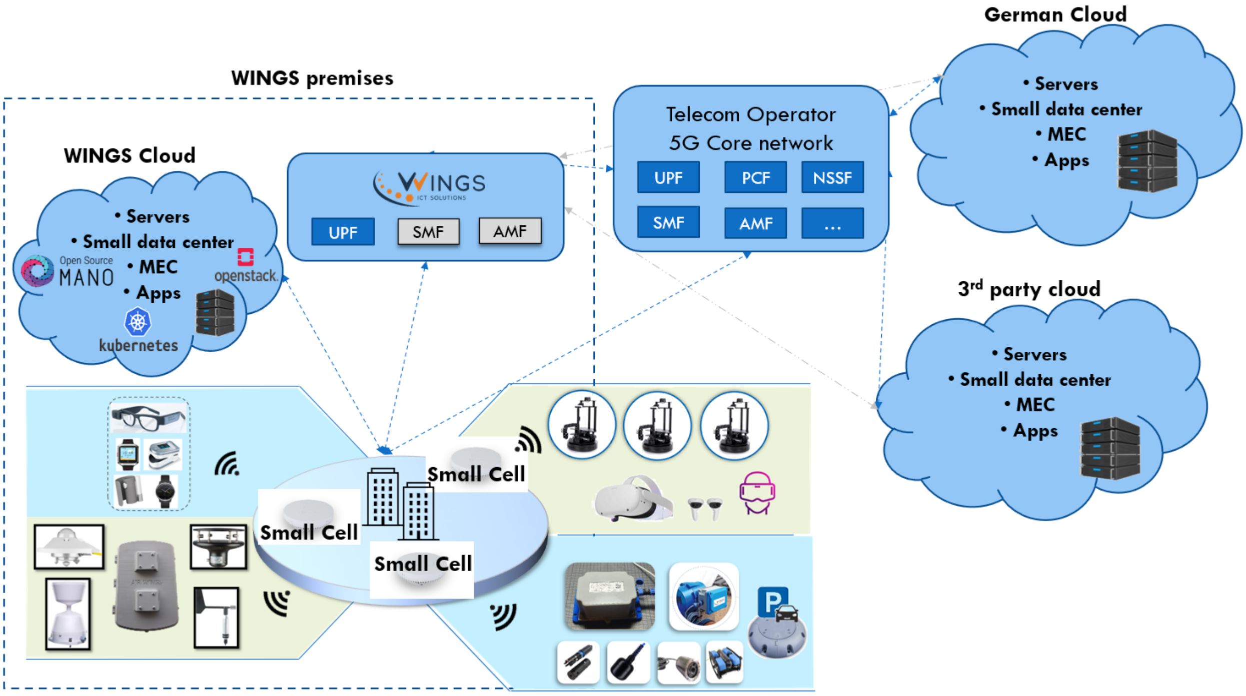

Figure 20. WINGS architecture for experiments.

The WINGS testbed provides end-to-end 5G/B5G functionality, along with extensive cloud and edge computing capabilities, leveraging the 3GPP (Release 16 and beyond) PNI-NPN with shared Control Plane (at a first phase) and isolated, SNPN, with all network functions (UP and CP) inside WINGS premises, isolated from the public network in the final phase. The site offers a range of 5G/B5G services and will be gradually evolved to 6G. It supports- various vertical domains, with WINGS providing the necessary hardware, software, and configurations to enable the testbed to handle these use cases. WINGS testbed serves as a testing ground for services, equipment, and new features before they are commercially released. Detailed description of the testbed will be provided in D2.1 “Preliminary design aspects for Platforms and Networks solutions”.

3.3.3.2 WINGSPARK++

WINGSPARK++ [63] is a fully integrated management system for transportation and infrastructure that provides solutions for various stakeholders such as public and private transport providers and infrastructure operators. WINGSPARK++ utilizes advanced monitoring, fault detection, performance optimization, security, and configuration capabilities in the areas of i) Infrastructure, ii) Parking, and iii) Stations.

The system WINGSPARK++ provides tools for structural health monitoring, traffic level predictions, and predictive maintenance for infrastructure like roads and bridges. By monitoring the structural health of infrastructure and analyzing traffic levels, WINGSPARK++ can help stakeholders make decisions about maintenance and long-term planning. Additionally, predictive maintenance tools allow for more efficient infrastructure management, reduced downtime and people safety.

In addition, WINGSPARK++ utilizes a range of devices, including the WINGS OBU (on-board unit), cameras, drones, sensors, and more, to collect and analyze data about transportation and mobility infrastructure, parking, and transportation hubs. These devices provide real-time information about traffic, congestion, and resource availability, helping stakeholders make informed decisions about infrastructure management and maintenance.

Finally, WINGSPARK++ also incorporates advanced IoT and AI mechanisms, including video analytics, predictive analytics, and optimization mechanisms, to improve transportation and mobility. With these tools, WINGSPARK++ can predict demand and availability, conduct slot allocations (bookings, enforcement), and derive policies for infrastructure and parking management. This allows for more efficient use of resources and improved overall transportation and mobility experiences.

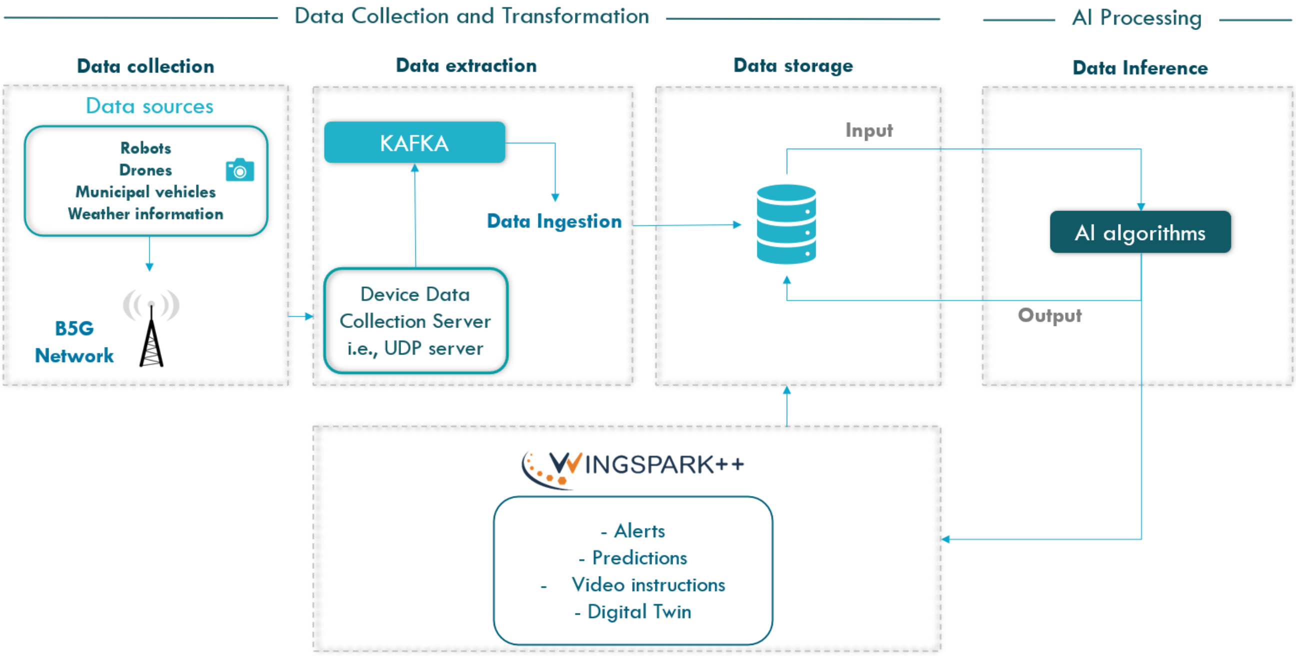

Figure 21. WINGSPARK++ architecture diagram.

In the scope of the 5G-TOURS [71] project WINGS extended its WINGSPARK++ platform to monitor in real-time the parking facility at Athens International Airport by leveraging on its 5G-enabled Smart Parking Occupancy sensors. This work also comprised a mobile app utilizing 3D graphics to assist users in finding and navigating to the airport spot leveraging on AI.

As part of the TrialsNet project, data collected from multiple sources will be transmitted through a 5G network using KAFKA, enabling further data extraction, and processing (Figure 21). The resulting data will be ingested into a highly scalable datastore, which will serve as input for AI processing. WINGSPARK++ will leverage advanced AI technologies to analyse data and provide insights, such as infrastructure faults. In addition, the platform will enhance its user interfaces with a dashboard that will provide insights and alerts to the remote experts. To further improve accessibility and convenience, mobile apps will also be developed, providing users with easy access to information and insights on the go.

3.3.3.3 Configurable Monitoring platform

WINGSPARK++, along with the set of sensors and network assets, will be supported by a platform capable to integrate several open-source software components, adopted as a baseline, which have been integrated together, extended, and can be customized to collect monitoring data generated from several data sources. It has been developed to be compliant with the Network Data Analytics Function (NWDAF) defined in the 3GPP management system.

Figure 22 depicts the software architecture of the Configurable Monitoring Platform. Considering the heterogeneity of the data sources, there is a Data Adaptation layer to provide a data normalization function, to expose the monitoring data according to a common format.

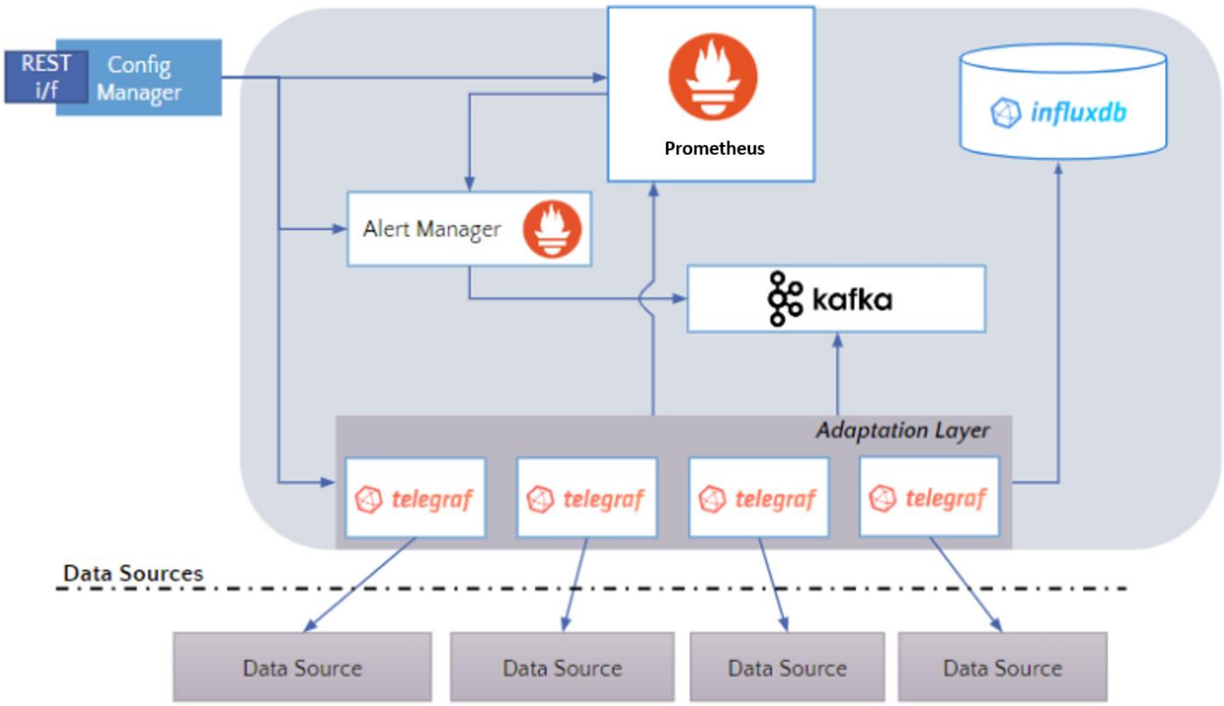

Figure 22. Architecture of the Configurable Monitoring Platform.

The core system is composed of a monitoring loop composed by a Prometheus instance for aggregating the data and, using the Alert Manager, for triggering alarms and events based on configurable conditions. A Kafka-based message bus is used to distribute data and events to the components of the system using a publish-subscribe message pattern. Data is also stored in a Data Lake implemented through an Influx DB database.

3.3.4 Trial description

The trials will include two different scenarios that will take place on two sites.

3.3.4.1 Athens International Airport

For the trials focused on infrastructure asset management in the Airport, the APRON area has been chosen as the ideal site as it is crucial to the operation of the airport. By conducting trials here, it will allow for a thorough evaluation of the effectiveness of new technology and methods to manage the infrastructure assets, including maintenance, and upgrades. The trials will be closely monitored by experts in the field, with the aim of improving the safety, efficiency, and overall management of the airport's critical infrastructure assets. The scenario for the trials is presented below:

- Shift starts at AIA and Airside Monitoring and Inspection personnel begins the routine inspection of the APRON.
- The Airside Monitoring and Inspection personnel deploy robots equipped with cameras to survey the airport's infrastructures and take pictures of the areas.
- The robot uses its sensors to detect damage to the ground (e.g., cracks, potholes), or other irregularities.
- The robot proceeds to monitor the condition and functionality of various airport infrastructure assets (e.g., lights and signs), to ensure their optimal operation.
- It also uses object detection to identify debris, litter, and potential hazards (e.g., birds) that could interfere with aircraft operations.
- Utilizing the collected data WINGSPARK++ uses AI techniques such as Neural Networks and Deep Learning to predict potential damages and hazards.
- Based on the assessment, WINGSPARK++ send alerts and suggestions to the airport authorities about the necessary repairs and actions.
- The remote experts access the Digital Twin of the APRON through VR headsets.

- The Digital Twin provides remote experts with a detailed view of the APRON, enabling them to identify damage, potential hazards, and other issues that require attention.
- The workers use AR to access infrastructure blueprints and receive live bidirectional communication from the remote experts. The AR provides workers with visual instructions, making it easier to carry out the necessary repairs and actions.
- The repair process is completed successfully, and the affected APRON area reported back to use.

The Table 8 provides a description of the testing that will be conducted at Athens International Airport.

Table 8. UC2 trial description in Athens International Airport.

Trial ID / Name	**Trial 2.1 / Public Infrastructure Assets Mangement**	
Infrastructure / Venue	**Athens International Airport**	
Description	This test case utilizes advanced technologies to efficiently inspect and monitor infrastructure, demonstrating the potential benefits of automation and AI in improving safety and operational efficiency.	
Components and Configuration	Components	• Robots. • Cameras. • Sensors. • AI software (analysis and prediction of potential damages and hazards). • Virtual Reality (VR) headsets (Digital Twin of the APRON). • Mobile devices. • Cloud-based storage for collected data and analysis results. • 5G internet connection to enable real-time data sharing and communication.
	Configuration	• The robots' cameras should be connected to the airport's small cells 5G network to enable real-time data collection and analysis. • The VR headsets should be configured to access the Digital Twin of the APRON through the small cells 5G network. • The AR devices should be configured to access infrastructure blueprints and receive live communication and instructions from remote experts over the network. • Monitoring tool should be installed on the devices, to measure latency and throughput.
Trial Procedure	Pre-conditions	• The devices should be fully charged and properly configured to connect to the small cells 5G network. • Before executing the test case, the robots should be deployed across the APRON and runways to survey the airport's infrastructure and collect data. • The test signals from the cameras and sensors should be sent to the AI platform to verify connectivity and ensure proper data collection and analysis.
	Trial steps	• The robots are deployed by the Airside Monitoring and Inspection personnel to survey the airport's infrastructures and take pictures of the areas.

		• The robots use their sensors to detect damages on the ground and other irregularities and monitor the condition and functionality of various airport infrastructure assets. • Object detection is used to identify debris, litter, and potential hazards that could interfere with aircraft operations. • WINGSPARK++ AI software analyses the collected data using Neural Networks and Deep Learning to predict potential damages and hazards. • Based on the assessment, WINGSPARK++ sends alerts and suggestions to the airport authorities about the necessary repairs and actions. • The relevant Technical Services department access the Digital Twin of the APRON through VR headsets to identify damages, potential hazards, and other issues that require attention and repair. • The Airside Monitoring and Inspection personnel use AR to access infrastructure blueprints and receive live bidirectional communication from the remote experts. • The AR system provides the Airside Monitoring and Inspection personnel with visual instructions, making it easier to carry out the necessary repairs and actions.
	Methodology	The monitoring tool shall perform iterations, and data shall be collected at the end of each testing session.
	Complementary measurements	Accuracy, specificity, and precision of AI mechanisms.
	Calculation process	Repeated tests will be performed to collect a large sample of KPI values and measurements. Different methods will be used (see also section 3.3.1). The average value will be compared to the target value set. The overall functionality of the system will be assessed to ensure that the system "behaves" as it should. Usability will be measured via questionnaires.
Expected Result	The platform is expected to detect damages and potential hazards in real-time, triggering alarms and sending alerts to the airport authorities and remote experts for immediate action.	

3.3.4.2 Public infrastructure provided by DAEM

For the City of Athens, the approach of proactive maintenance of public spaces is of the utmost importance since the city's infrastructure is in some areas outdated and the coordination of its maintenance is a time and human-consuming task. Adding up the safety of workers and reduction of required resources through proactive approaches further enhances this use case. Additionally, within the city different agencies and departments must cooperate in these tasks, hence an innovative approach that will provide foreseen actions rather than ad-hoc is major added value.

For TrialsNet use case two indicative areas of Athens are proposed as trial's locations where assets such as existing municipal buildings, pavements, crossroads, pedestrian routes require advanced maintenance. The proposed areas are Athens Trigono that is an area set as low traffic zone for vehicles in the center of Athens where many traditional businesses are located. The area was re-designed in recent years to become pedestrian-friendly. A map of Athens Trigono is depicted in Figure 23.

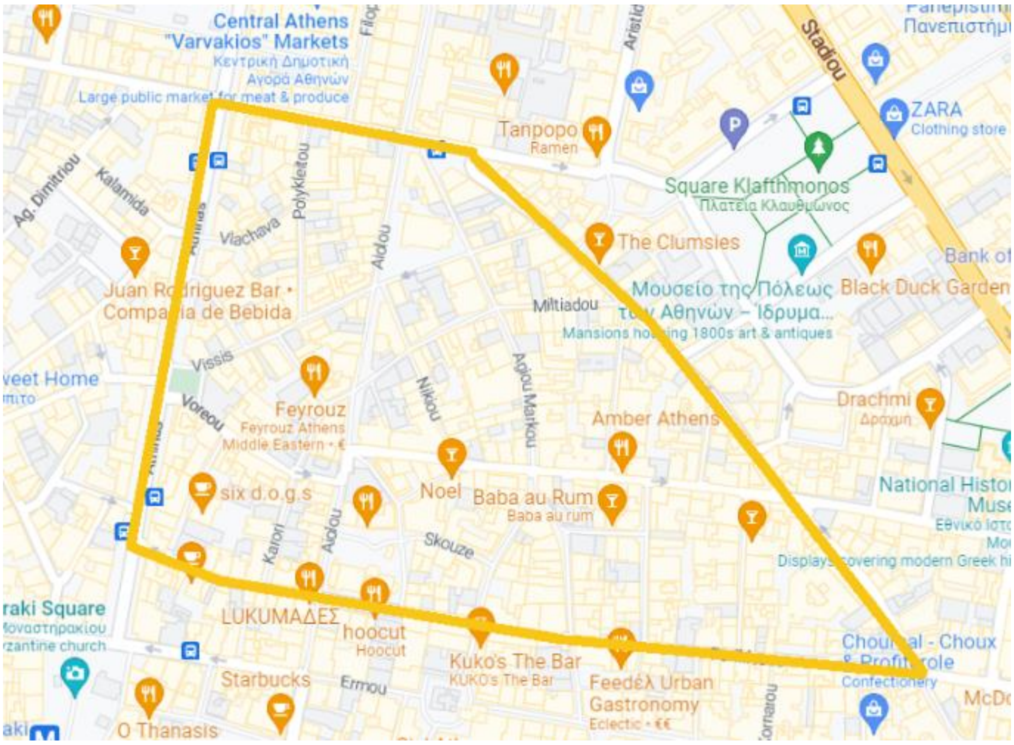

Figure 23. Athens Trigono.

The second area that is proposed is the neighbourhood and surroundings of the Athens City Hall. The City Hall is located close by Athens Trigono in the central place of Kotzia Square and it is a building of historical and cultural value. Its surroundings often have decays and require field work for improvements especially roads and pavements. The area is depicted in Figure 24.

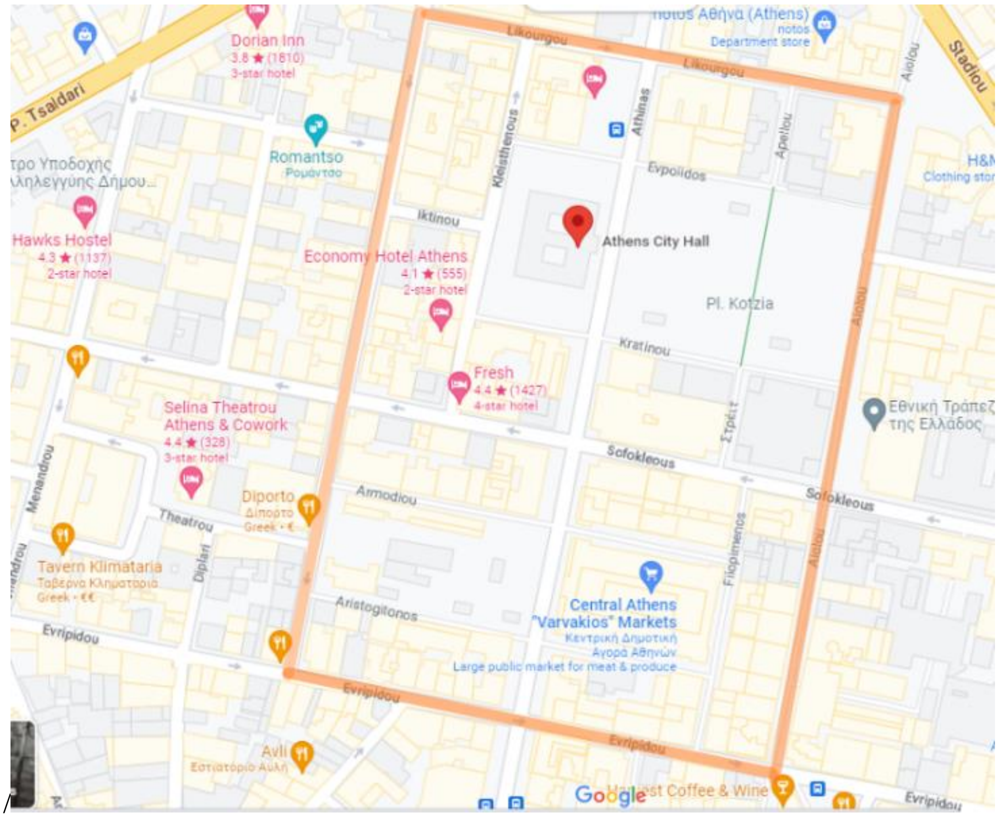

Figure 24. Athens City Hall.

The following scenario describes the trial storyline:

- Upon arriving at the site, the construction workers are tasked with monitoring the condition of the pavements, roads, and buildings by detecting potholes, Edge defects, simple cracks, web cracks, building wear, etc.
- Drones and robots, equipped with cameras, collect data on the condition of the roads, pavements, and buildings.
- Data is also collected from various sources such as municipal vehicles, weather information, security cameras to assess the state of the assets.
- The collected data is transmitted to WINGSPARK++ and analyzed by AI and DL algorithms to detect any potential hazards or damages.
- Based on the results of the assessment, WINGSPARK++ generates alerts and sends them to city authorities.
- The alerts provide recommendations on the actions that need to be taken to ensure the safety of the building, pavement etc., and the workers.
- The construction workers follow the instructions from the remote experts, utilizing unmanned machinery and vehicles such as cobots to assist with the necessary maintenance tasks.
- The remote experts monitor the building's condition in real-time through a Digital Twin of the construction site, which is accessible through VR headsets.
- The Digital Twin helps remote experts detect environmental hazards, machinery malfunctions, and schedule maintenance works for public assets in a predictive manner.
- After the construction workers finish the maintenance tasks and ensure that the building is safe for use.

Table 9 provides a description of the testing that will be conducted at public infrastructures provided by DAEM.

Table 9. UC2 trial description in Public Infrastructure.

Trial ID / Name	Trial 2.2 / Public Infrastructure Assets Mangement	
Infrastructure / Venue	**Public Infrastructure provided by DAEM**	
Description	This test case utilizes advanced technologies to efficiently inspect and monitor infrastructure, demonstrating the potential benefits of automation and AI in improving safety and operational efficiency.	
Components and Configuration	Components	• Robots. • Cameras. • Sensors. • AI software (analysis and prediction of potential damages and hazards). • Virtual Reality (VR) headsets (Digital Twin of the infrastructure). • Mobile devices. • Cloud-based storage for collected data and analysis results. • 5G internet connection to enable real-time data sharing and communication.
	Configuration	• The robots' cameras should be connected to the airport's small cells 5G network to enable real-time data collection and analysis. • The VR headsets should be configured to access the Digital Twin of the infrastructure_through the small cells 5G network. • The AR devices should be configured to access infrastructure blueprints and receive live communication

		and instructions from remote experts over the network. • Monitoring tool should be installed on the devices, to measure latency and throughput.
Trial Procedure	Pre-conditions	• The devices should be fully charged and properly configured to connect to the small cells 5G network. • Before executing the test case, the robots should be deployed and collect data. • The test signals from the cameras and sensors should be sent to the AI platform to verify connectivity and ensure proper data collection and analysis.
	Trial steps	• Drones and robots, equipped with cameras, collect data on the condition of the roads, pavements, and buildings. • Data is also collected from various sources such as municipal vehicles, weather information, security cameras to assess the state of the assets. • The collected data is transmitted to WINGSPARK++ and analyzed by AI and DL algorithms to detect any potential hazards or damages. • Based on the results of the assessment, WINGSPARK++ generates alerts and sends them to city authorities. • The alerts provide recommendations on the actions that need to be taken to ensure the safety of the building, pavement etc., and the workers. • The construction workers follow the instructions from the remote experts, utilizing unmanned machinery and vehicles such as cobots to assist with the necessary maintenance tasks. • The remote experts monitor the building's condition in real-time through a Digital Twin of the construction site, which is accessible through VR headsets. • The Digital Twin helps remote experts detect environmental hazards, machinery malfunctions, and schedule maintenance works for public assets in a predictive manner.
	Methodology	• The monitoring tool shall perform iterations, and data shall be collected at the end of each testing session. • Reports summarizing the following should be extracted: • Damages / hazards detected. • Latency / throughput of the AR, VR applications.
	Complementary measurements	Accuracy, specificity, and precision of AI mechanisms.
	Calculation process	Repeated tests will be performed to collect a large sample of KPI values and measurements. The average value will be compared to the target value set. The overall functionality of the system will be assessed to ensure that the system "behaves" as it should. Usability will be measured via questionnaires.

Expected Result	The platform is expected to detect damages and potential hazards in real-time, triggering alarms and sending alerts to the city authorities and remote experts for immediate action.

The trial description reported in Table 8 and Table 9 are intended to be complemented with the specific KPIs and KVIs definition and measurements reported in section 4.3.2.

3.4 UC3: Autonomous APRON

This use case aims to design, develop, and deploy tools for the implementation of an Autonomous APRON at the Athens International Airport, powered by B5G (towards 6G) technology. The goal is to optimize airport operations and increase efficiency while minimizing costs and improving sustainability.

3.4.1 Use case definition

The use case focuses on showcasing how autonomous and smart systems can perform typical ground handling operations at the APRON such as passenger handling, in-flight catering, aircraft fueling, potable water & aircraft toilet servicing, baggage and cargo handling, and Foreign Object Damage (FOD) prevention. This will be achieved using remotely controlled or unmanned vehicles, such as collaborative robots. The Digital Twins of the APRON will be accessed by VR headsets, enabling a real-time depiction of the physical world inside the virtual one. Digital Twins have a significant impact in optimizing the operations of the staff supervising APRON, ensuring safer and incident-free operations. Operators can intervene remotely and take control of vehicles in critical situations.

Data will be collected from vehicles in the airport APRON and robots using a variety of sensors, including LIDAR and GPS, as well as images and videos from security cameras. Advanced AI techniques will be employed to analyze the data, identify patterns, and make accurate predictions, allowing for continuous monitoring and analysis of airport operations. Based on these analyses, alerts and suggestions will be generated to improve operations and enhance overall airport efficiency.

The integration of a distributed monitoring system will enable the continuous monitoring of unmanned vehicles, collaborative robots, and relevant resources. This system can collect data across the Edge and far Edge resources, and traffic profiling will be conducted to detect network anomalies and predict/prevent failures and security breaches. Automated mitigation procedures will be applied to address any issues that arise (Figure 25).

The utilization of 5G technology is crucial to this use case, as it enables low-latency, high-speed communication necessary for real-time monitoring and control of unmanned vehicles and resources. This in turn leads to more efficient and safer airport operations, facilitated by the advanced technologies mentioned above. The high bandwidth and low latency of 5G technology enables faster and more reliable data transfer, resulting in more accurate predictions, better decision-making, and overall improvements in airport operations.

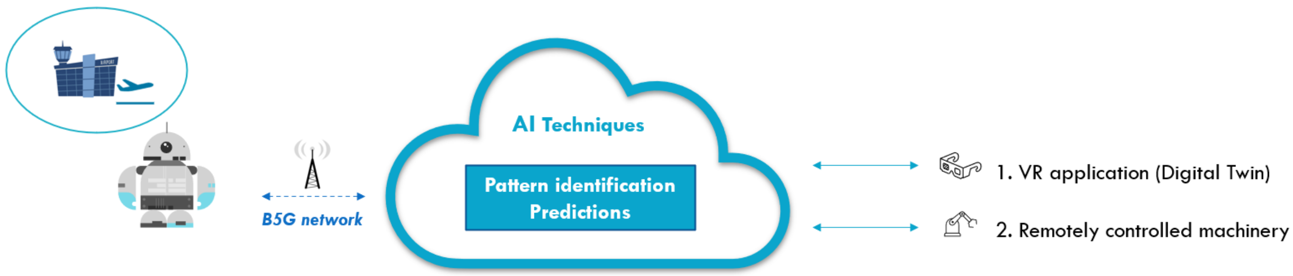

Figure 25. Use Case 3 high level architecture.

3.4.2 Implementation aspects

3.4.2.1 Application design

The design of the Autonomous APRON application will involve various components and functions that work together to enable the robot to navigate the airport apron independently (Figure 26). The navigation module will rely on the use of markers and beacons on the ground, as well as LIDAR sensors, to accurately track the robot's position as it moves along the APRON and that will be strategically placed throughout the APRON area to provide reference points for the robot to use in its navigation. The robot will follow predefined routes on the APRON that have been carefully mapped out in advance. These routes will consider factors such as the location of parked aircraft, the position of obstacles on the APRON, and the proximity of other airport infrastructure. The navigation module will use this information to calculate the optimal path for the robot to follow to reach its destination. Another crucial function of the application will be the robot control, which will ensure the robot follows the calculated path accurately. The control component will receive input from the navigation function and translate it into motor commands for the robot to execute. It will also monitor the robot's sensors to adjust its movement if necessary. Additionally, in case of emergencies, the airport personnel will be able to take control of the robot. The navigation/control module can reside either within the robot or in the cloud. Obstacle detection will be a critical component of the application, and the robot will use various sensors to detect obstacles and determine their distance and position relative to the robot. This function will work together with the control component to adjust the robot's movement to avoid obstacles.

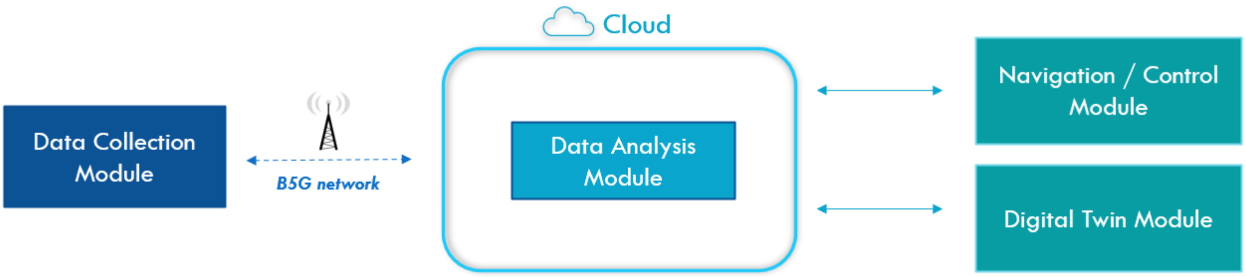

Figure 26. Application design for UC3.

The data collected from cameras and robots will be sent to the cloud for further analysis. In addition to the software modules mentioned, the autonomous APRON application design will also involve the creation of a Digital Twin of the airport APRON area (Figure 27). This Digital Twin will provide a virtual representation of the physical environment that the robot will operate in, and it will be updated in real-time, so the airport personnel will be able to monitor the robot's progress and receive alerts in case of any issues or emergencies.

Figure 27. Example of Digital Twin Application for Autonomous APRON.

In an airport setting, users may use various devices to monitor the Digital Twin of the environment and track everything that is happening on the APRON. Some devices that could be used by users include Desktop or Laptop computers that are often used by remote users to access the Digital Twin of the environment. Users can view a 3D model of the airport APRON and monitor various aspects of operations in real-time, view live streaming video from robotics cameras and view any information, events, or alerts that the system generates. Additionally, mobile devices such as tablets or smartphones with at least 5G capabilities will be utilized by users that are monitoring the area, allowing them to monitor airport operations from anywhere within the airport.

3.4.2.2 Equipment and devices

For the initial implementation of the use case, the Jackal unmanned ground vehicle will be utilized. Given the Robots capabilities, it will be able to perform a range of APRON operations, such as baggage transport and cargo, debris clearing, or other related tasks. Its agile mobility and advanced autonomous capabilities will allow it to navigate the APRON's terrain quickly and efficiently while ensuring the safety of nearby personnel. As the project progresses, the use of a robot capable of lifting larger payloads will be explored. This will enable the robot to perform more substantial tasks and increase overall operational efficiency.

The use of LIDAR sensors will also be explored as part of the project. LIDAR is a remote sensing method that uses laser light to measure distances and generate precise, high-resolution 3D maps of environments.

In the context of the use case, LIDAR sensors will be used to collect data on the APRON environment, such as the position and movement of vehicles and objects, and to generate real-time maps of the area. This data can then be used to help the autonomous vehicles navigate the APRON safely and efficiently, avoid obstacles, and interact with other vehicles and objects, allowing it to avoid collisions. LIDAR, GPS, and stereo cameras are commonly used in robotics for navigation, localization, and obstacle avoidance. In an airport environment, these technologies can help robots move in specific areas, follow lines, and avoid obstacles such as other robots, humans, and equipment.

As described in the application design, a Digital Twin application will be developed to represent the physical environment, such as the airport APRON. VR headset can be used to provide an immersive experience of the airport APRON (Figure 28). Users can navigate the Digital Twin of the environment in 3D and view live updates of airport operations and control or fix any problems that may arise.

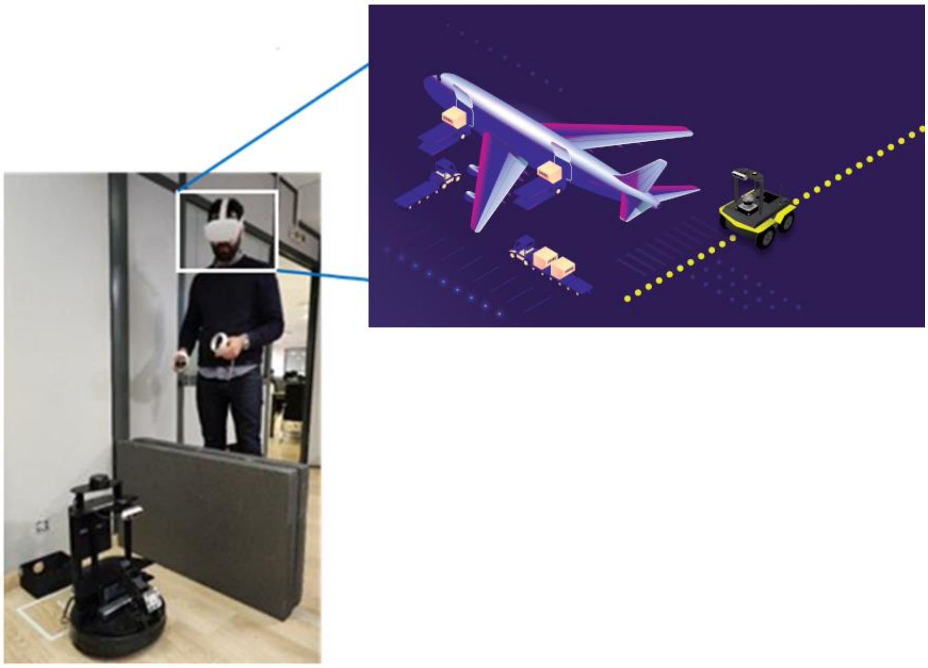

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Figure 28. Use of VR headset and Digital Twin view.

The equipment required to develop and test the system for this use case will be the Clearpath Robotics Jackal, Ouster OS1, Intel RealSense Depth Camera D455 and GPS device Vision RTK 2 already described in Table 7. In addition, the 5G cellular module described in Table 10 will be also used.

Table 10. Equipment and devices for UC3.

Equipment	Item	Description	Quantity
 **5G cellular module**	Quectel RM500Q-AE	For enabling wireless connectivity for the robots, the Quectel RM500Q-AE will be used. This module is a 5G cellular module designed for high-speed data transmission in various industrial applications. The module supports 5G networks, enabling high-speed data transmission with download speeds of up to 2.5 Gbps and upload speeds of up to 660 Mbps and other various cellular network standards, including 5G NR, LTE-A Pro, LTE-A, and WCDMA, allowing it to operate in different network environments. Additionally, the module features built-in GNSS (Global Navigation Satellite System) support, including GPS, GLONASS, BeiDou, and Galileo. This enables the module to provide accurate positioning and timing information. The Quectel RM500Q-AE is designed to withstand harsh environments, with a wide operating temperature range of -40°C to +85°C and high resistance to shock and vibration making it suitable for industrial applications, including smart transportation, industrial IoT and video surveillance, among others. The module can be integrated into the robots, providing reliable and high-speed connectivity / data transmission and accurate positioning information.	2

3.4.3 Infrastructure components and functionalities

The infrastructure for the airport APRON use case will utilize cutting-edge technologies to streamline typical ground operations. The implementation of remotely controlled or unmanned vehicles, such as collaborative robots, will be made possible using devices such as sensors and cameras. Data collected from these devices will be transmitted over a 5G network to the cloud for further processing and analysis (Figure 29).

The 5G network infrastructure utilised in this use case is the same as the one that will be used for UC2 (see section 3.3.3.1). As mentioned, a public 5G network will be used, leveraging its high-speed connectivity, low latency, and wide coverage. Specifically, the network will use Non-Standalone (NSA) architecture and operate at a frequency of 3.5 GHz. The allocated band for this network is 80-100 MHz, which will provide high-speed connectivity and low latency to support the data-intensive applications required by the use case. Future versions of the public network will also be used. In addition, a WINGS owned, private network infrastructure will be utilised, to conduct testing activities, validation, and demonstration, prior to the deployment in the field. Further details on the infrastructure and platforms that will be used for supporting this use case can be found in 3.3.3.1.

A distributed monitoring system will ensure the continuous monitoring of unmanned vehicles, collaborative robots, and relevant resources. Automated mitigation procedures will be applied to address any issues that arise, ensuring a safe and efficient use case deployment. The distributed monitoring system collects data from various application components potentially located at the far-edge/core resources to access and reason regarding the performance of the overall system in real-time. Such a system comprises several components and a central management platform for higher level decision or visualization purposes. As an outcome a complete view of achieved KPIs and KVIs will be provided.

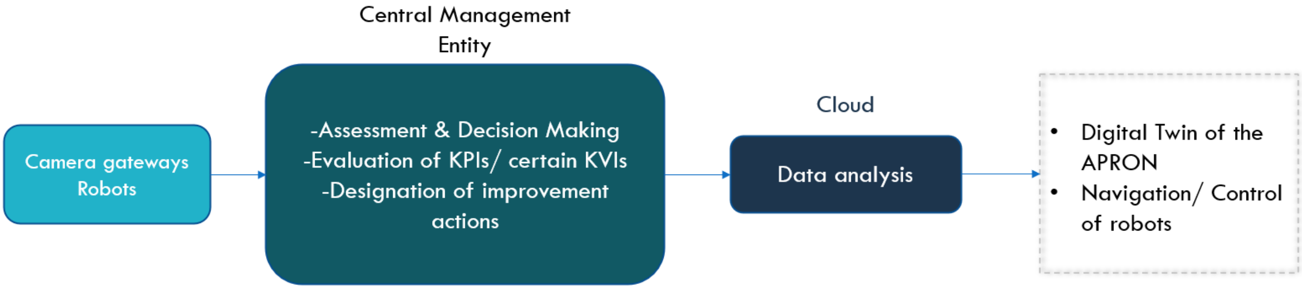


Figure 29. Data flow from robots & cameras to Digital Twin application.

3.4.4 Trial description

The selected location for the upcoming trials is the APRON area at Athens International Airport, where ground handling activities and services take place. By conducting the trials in this area, a thorough assessment of the effectiveness and safety of new technology and handling methods will be allowed. The Airside Monitoring and Inspection personnel will closely monitor the trials, ensuring the safety of all involved while gathering valuable information for future improvements (Figure 30).

Figure 30. APRON area of the Athens International Airport.

The scenario for the trials is presented below:

- The Airside Monitoring and Inspection personnel responsible for supervising the APRON operations use VR headsets to access the digital twin of the APRON.
- They can see a detailed depiction of the APRON in real-time, which is updated with data from the various unmanned vehicles and robots moving around the APRON.
- As the final boarding call is announced, some passengers are informed that their carry-on luggage exceeds the allowed dimensions and cannot be taken on board.
- The Ground Handler immediately sends the remotely controlled robot, which can transport luggage, to collect the oversized bags and transport them to the aircraft.
- The robot's position is tracked using markers and beacons on the ground, as it follows predefined routes on the APRON to navigate safely to the plane.
- The Ground Handler monitors the robot's movement from their control room to ensure that it reaches the aircraft without any issues.
- Thanks to this efficient use of technology, the robot can quickly and safely transport the oversized bags to the aircraft, saving valuable time for both the staff and the passengers.

The 11 provides a description of the testing that will be conducted at Athens International Airport.

Table 11. UC3 trial description.

Trial ID / Name	Test 3.1 / Autonomous APRON	
Infrastructure / Venue	**Athens International Airport**	
Description	The test case involves the use of technology to optimize the transport of oversized bags on an airport APRON. The purpose of the test case is to demonstrate how advanced technology such as unmanned vehicles, robots, and sensors can be used to improve typical ground handling operations by making the transport of oversized bags safer, more efficient, and more cost-effective.	
Components and Configuration	Components	• VR headsets. • Remotely controlled robots for luggage transportation. • Markers and beacons on the ground to track robot's position. • Sensors. • Digital twin of the APRON for real-time monitoring. • Monitoring software to track the movement of the robot. • 5G network.
	Configuration	• Integration of the various components, including the VR headsets, digital twin, robot, sensors, markers, and beacons, to enable the Ground Handler to remotely control the robot and monitor its movement from the control room. • Reliable and fast network connectivity to ensure real-time updates to the digital twin and enable the Ground Handler to remotely control the robot and monitor its movement without any delays or interruptions. • Automated systems for checking the size and dimensions of hand luggage at the gate to prevent passengers from carrying oversized bags onto the aircraft. • Trained personnel who can operate the VR headsets, control the robot, and monitor its movement from the control room to ensure that the test scenario is executed safely and efficiently.
Trial Procedure	Pre-conditions	• The VR headsets should be properly configured, calibrated, and functional. • The digital twin of the APRON should be up-to-date and accurately represent the current state of the APRON, including the locations and movements of all unmanned vehicles and robots. • The robot should be properly configured, charged, and equipped with sensors to detect potential obstacles in its path. • The markers and beacons on the ground should be properly configured, calibrated, and functional to accurately track the robot's position. • The automated system for checking the size and dimensions of hand luggage should be properly configured and functional to prevent passengers from carrying oversized bags onto the aircraft.

		• The personnel operating the VR headsets, controlling the robot, and monitoring its movement should be properly trained and familiar with the equipment, tools, and procedures involved in the test scenario.
	Trial steps	• The Airside Monitoring and Inspection personnel responsible for supervising the APRON operations use VR headsets to access the digital twin of the APRON. • They can see a detailed depiction of the APRON in real-time, which is updated with data from the various unmanned vehicles and robots moving around the APRON. • As the final boarding call is announced, some passengers are informed that their carry-on luggage exceeds the allowed dimensions and cannot be taken on board. • The Ground Handler immediately sends the remotely controlled robot, which can transport luggage, to collect the oversized bags and transport them to the aircraft. • The robot's position is tracked using markers and beacons on the ground, as it follows predefined routes on the APRON to navigate safely to the plane. • Additionally, the robot is equipped with sensors to detect any potential obstacles in its path, preventing collisions with other equipment or vehicles on the APRON. This ensures that the robot safely navigates to the plane without any incidents. • The Ground Handler monitors the robot's movement from their control room to ensure that it reaches the aircraft without any issues. • Thanks to this efficient use of technology, the robot can quickly and safely transport the oversized bags to the aircraft, saving valuable time for both the staff and the passengers.
	Methodology	• The acceptable value for monitoring time will depend on the distance between the gate and the aircraft, the speed of the robot, and the complexity of the APRON environment. • The monitoring frequency should be sufficient to ensure that the robot is moving safely and without any issues. The acceptable value for monitoring frequency will depend on the speed of the robot and the complexity of the APRON environment.
	Complementary measurements	• Average time taken by the remotely controlled robot to collect and transport oversized bags to the aircraft. • Number of successful vs. unsuccessful trips made by the robot. • Number of incidents of collision or near-miss events avoided by the robot.
	Calculation process	• To calculate the robot's route, distance and route optimization algorithms may be used to identify the most efficient path to the aircraft. This may involve calculating the distance between the robot and the aircraft,

		as well as considering any obstacles or hazards on the APRON. • To ensure that the digital twin reflects the actual state of the APRON, data must be collected and transported in real-time from various sources, such as unmanned vehicles, robots, sensors, and other monitoring devices. • Repeated tests will be performed to collect a large sample of KPI values and measurements. The average value will be compared to the target value set. The overall functionality of the system will be assessed to ensure that the system "behaves" as it should. Usability will be measured via questionnaires.
Expected Result	• The primary goal of the testcase is to transport oversized bags to the aircraft in a safe and efficient manner. • The use of distance and route optimization algorithms should result in a more efficient and direct path to the aircraft, reducing the time and resources required to transport the oversized bags. • The robot should be able to detect and avoid any potential obstacles or hazards on the APRON, ensuring that it navigates safely to the aircraft. • By using technology to optimize the transport of oversized bags, the Ground Handler should be able to save time and resources.	

The trial description reported in 11 is intended to be complemented with the specific KPIs and KVIs definition and measurements reported in Section 4.4.2.

3.5 UC4: Smart Traffic Management

The use case 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. The use case will provide methods to improve traffic management in a very crowded intersection in Iasi and to detect and prevent potentially dangerous situations.

3.5.1 Use case definition

The Smart Traffic Management use case to be implemented in Iasi, Romania involves the design, development, and deployment of the envisioned tools that will demonstrate the effectiveness of intelligent traffic management and successfully support the B5G/6G applications in large-scale environments by enabling a tight interaction between humans and the surrounding environments, through the usage of IoT Sensors, Computer Vision and Cameras, within a robust, Zero-Touch Management capability of Edge resources, as well as the large-scale deployment of B5G (towards 6G) networks to support the use case, provided the installation, configuration, and operation of state-of-the-art network components, to cover the areas in which the use case is to be demonstrated.

The Platform will ingest available data from arrays of Sensors and Cameras deployed through the city, communicating over reliable B5G and Wi-Fi networks and outputting insights and actionable intelligence on Traffic Monitoring. This use case will be deployed in the Podu Roș Intersection Area with a focus on traffic comfort and safety functions. From a comfort perspective, the traffic flow will be monitored to create predictive models and suggest intersection rules adaptation to reduce congestion. Safety will be increased especially by protecting Vulnerable Road Users (VRUs) by creating a traffic digital model, capable of identifying hazardous traffic situations. In addition to a real-time dynamic mobility digital model, an air quality heat map will be created by collecting data from the IoT sensors for Environmental Monitoring.

Deploying a large number of sensors and cameras increases the need for flexibility addressed by unwiring them and the need of high throughput due to the high-resolution video streams. The safety critical applications impose stringent reliability and latency requirements. The utilization of B5G can enable faster and reliable data transfer at higher rates, which is critical for real-time traffic monitoring for comfort and safety functions.

In addition to the data-driven models for designing smart traffic monitoring, two additional use case enablers will be extensively trialed, thereby measuring their impact on the service performance. The first one is zero-touch management, Edge resources and services and RAN optimizations, which will be tested and validated in trialing activities along with the use case-related scenarios with traffic management and enhancements for vulnerable road users. The second one is related to the framework for designing and developing vertical applications for 5G and beyond systems, i.e., Edge Network Applications (EdgeApps). The use case infrastructures are described in more detail in Sections 3.5.3.2 and 3.5.3.3 respectively. Concerning the zero-touch management, due to the optimization of wireless technologies will be validated with the help of enhanced rule-based or AI/ML-based mechanisms that will select suitable network slice based on the network performance (real-time and historical data) and traffic requirements imposed by use case applications running at the network Edge. The optimal selection and Edge computing resources will be tailored to application requirements so that the required levels of service quality are guaranteed at any time.

The Podu Ros intersection area and some details related to the poles where the cameras will be installed are presented in the following group of pictures (Figure 31).

Figure 31. Smart traffic management – Podu Ros intersection area.

3.5.2 Implementation aspects

3.5.2.1 Application design

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 pilot solution to enhance the traffic management is a traffic digital model as base for an interactive platform centred on end users, from conventional vehicles, connected vehicles, automated vehicles to vulnerable road users, e.g., pedestrians and cyclists. This can be achieved by using specific sensors (e.g., cameras) to observe, detect and classify the traffic participants and understand traffic situations via Artificial Intelligence – Deep Learning techniques. The challenge consists in the computational requirements of AI techniques for high data volume, but also in the need for URLLC communication as safety critical situations are addressed. To meet processing requirements, the AI algorithms are run on the Edge (MEC) for time-critical applications, and in the cloud for non-real-time services. The system architecture follows the same framework as described for UC1 (see section 3.2.2.1) of sensing and perceive, communicate, process, communicate, visualize and/ or signal (alarm).

The smart infrastructure senses the upcoming road users with the deployed sensors and short-range communication. A traffic digital model is built in the Edge based on the sensed data received via 5G. The system shares the processed information with the users in various ways, e.g., displayed within a monitoring and control centre or disseminated via 5G communication to the road users, together with signalling identified possible hazardous traffic situations.

Figure 32. Smart traffic management - application design.

The application design presented in Figure 32 will use and follow the principles of B5G/6G Network Edge Applications (EdgeApps), which are considered as building blocks of Edge application services that boost network performance with data-driven insights for enhancing situation awareness. EdgeApps are designed to be programmable, modular, and configurable, based on specific service requirements (e.g., URLLC for sending prioritized notifications to VRUs, or eMBB for collecting data from distributed sensors, such as cameras). Such design is abstracting the complexity of underlying 5G and Wi-Fi infrastructure, and it makes services suitable for resource-constrained Edge deployments, while at the same time making their interfaces open and programmable for connecting to i) users such as VRUs via different radio access technology (5G and Wi-Fi), and to ii) other EdgeApps to build complex vertical services for addressing city resilience.

Proper management and orchestration are necessary for vertical services to fully benefit from 5G technologies, such as network slicing and Edge computing, thereby achieving ultra-low latency (1-10 ms), high reliability (99,999%), and enhanced throughput (up to 20 Gbps). Their design needs to be tailored to particular use cases, considering vertical service-specific requirements towards 5G (service quality requirements such as latency, throughput, and reliability). By applying the cloud-native principles and programmability of service function chains to the design and development of vertical services in 5G ecosystems, EdgeApps are defined as a fundamental building block of the 5G-enhanced vertical service chains. Such EdgeApps could be deployed on top of the Edge and cloud 5G-enabled infrastructure and used for creating any complex 5G vertical service by abstracting the underlying 5G network complexity, bridging the knowledge gap between vertical stakeholders, network experts, and application developers. In the case of Smart Traffic Management use case, various EdgeApps will be designed and developed to create mechanisms for predictive models and suggestions of intersection rules to reduce congestion, as well as for creating environment models capable of predicting hazardous traffic situations, and heat maps based on collected data.

The framework for EdgeApps will be defined by leveraging the knowledge and experience from the H2020 VITAL-5G project [74] and going beyond that by extending the so-called Service Enabler Architecture Layer (SEAL) architecture from 3GPP Release 16 [74]. This framework is shown in Figure 33 and it is standardized as an effort to address an ever-increasing demand for vertical applications. Aiming to enable the operation of such applications in 5G and beyond systems and to cope with the proliferation of vertical industries, 3GPP is fostering innovation in the application layer, focusing on the standardization of vertical applications. Given such framework, the fundamental goal is to facilitate the development of vertical applications by enabling developers to completely focus on the core functionalities of their applications, i.e., Vertical Application Layer (VAL), and further leverage SEAL for the services that could help core ones integrate better with wireless network systems.

The functional architecture of this framework is shown in Figure 33, whereas the main components are:

- **VAL Client**, responsible for providing client functionalities specific to vertical applications, and the same time interacting with the VAL server and SEAL clients (e.g., VAL client could be a client running at the VRUs' devices to collect notifications/alarms/warnings on the intersections),

- **VAL Server**, providing a server functionality specific to vertical applications, thereby interacting with VAL client and SEAL servers (e.g., EdgeApp running at the network Edge, with proactive environment models and heat-maps that are used for enhancing awareness of VRUs in busy traffic environments),
- **SEAL Client**, as in case of **VAL**, provides client-side functionalities specific to SEAL service, and interacts with the VAL client and SEAL servers running at the Edge, and
- **SEAL Server**, responsible for providing server-side functionalities specific to SEAL service, while interacting with the SEAL clients and VAL servers.

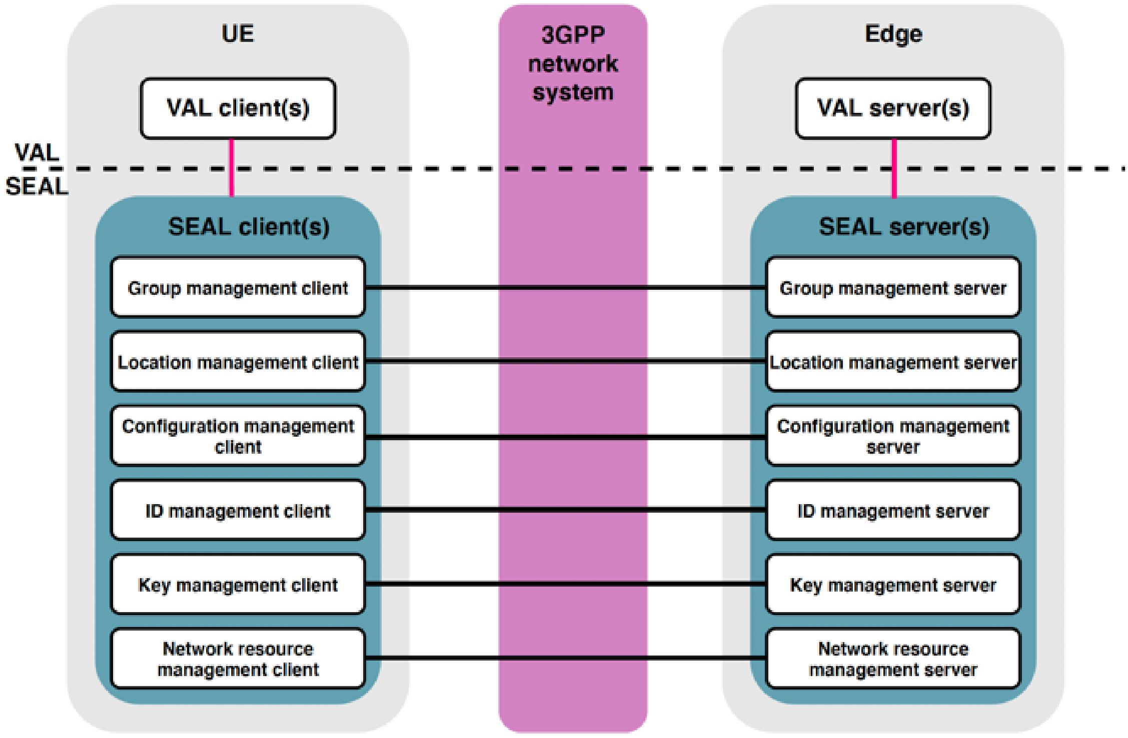


Figure 33. Service Enabler Architecture Layer Architecture.

Therefore, VAL clients and VAL servers provide vertical application-specific functionalities that will be specific for the use case logic in the case of smart traffic monitoring and enhanced awareness of VRUs, while the SEAL clients and SEAL servers will provide a common framework as a support for all vertical applications running at the same network Edge. However, such architecture of future vertical applications still does not consider any QoS requirements specific to the vertical, which is a complex task given that vertical users (all participants in mixed traffic environments) connect to different services in the backend. Thus, the goal of using this framework is to further adopt it and extend it with additional capabilities that will allow EdgeApps to be aware of the network and its performance, but also to connect with zero-touch management services that will enhance their operations based on application insights and requirements.

Keeping the design of applications in line with the framework described in this section facilitates the application of zero-touch management mechanisms, due to the simplicity and tight coupling with the 3GPP systems. Thus, UC4 applications are suitable candidates to be deployed as EdgeApps, and further details of coupling the above-described framework and corresponding applications from UC4 will be detailed in subsequent WP3 deliverables.

3.5.2.2 Equipment and devices

The equipment required to develop and test the system for this use case is composed of the list of the devices reported in the Table 12.

Table 12. Equipment and devices for UC4.

Equipment	Item	Description	Quantity
 **Camera**	Bullet Camera Mobotix Mx-BC1A-4-IR-D [11]	The Mobotix Mx-BC1A-4-IR-D is a PoE surveillance camera that can record 2K footage. These cameras will be used for video capturing in the area defined for the use-case and will help in defining the environment model of the "Podu Ros" intersection. This video stream will be transmitted directly to an Eedge-compute facility via the 5G SA/NSA network.	6
 **5G Router**	5G CPE Nokia FastMile 5G14-B [7]	The Nokia FastMile 5G14-B is a 5G SA/NSA outdoor CPE that is able to connect simultaneously to multiple slices, with different IPs and different PDU sessions, with a single SIM card specifically provisioned to support 2 or more DNN profiles. The CPE splits the traffic into separate VLANs and ends the connection into a switch that allows devices to access different slices. This Nokia CPE is also able to connect to a TR-069 Automatic Configuring Server (ACS), this way being able to transmit real-time metrics about the UL and DL traffic values for the connected slices and the radio signal parameters. The CPE will be configured to connect to both an eMBB slice and an URLLC slice. This way, the non-cellular cameras and the sensors will use the eMBB for data transmission, while the VRUs will be notified by the security system through the URLLC slice.	1
 **PoE Switch**	Aruba 2530 [12]	The Aruba 2530 is a PoE switch that has 8 Ethernet ports and is managed. It will power all the 6 cameras placed in the intersection, will aggregate the traffic from them and will connect them to the 5G network through the Nokia FastMile 5G14-B CPE.	1
 **Wi-Fi Air Quality Sensor**	URAD-Monitor A3 [13]	The uRADMonitor A3 is an air quality monitoring station that has sensors for Particulate Matter (PM2.5, PM1, PM10), Ozone, Formaldehyde, Carbon Dioxide, Volatile Organic Compounds (VOC), temperature, barometric pressure, air humidity and noise. The A3 devices that will be used are featured with Wi-Fi connectivity.	10
 **Wi-Fi Router**	Teltonika RUTX50 [14]	The Teltonika RUTX50 is an industrial-grade, feature-rich, professional rugged Dual SIM 5G LTE and Wi-Fi router, equipped with other interfaces such as: Ethernet, GNSS (GPS included), USB, micro-SIM, interfaces.	1

3.5.3 Infrastructure components and functionalities

3.5.3.1 Wi-Fi Infrastructure with Mobile Backhaul

The Wi-Fi infrastructure that will be used in the development of this use-case will be the same as for the UC1: Smart Crowd Monitoring for Iasi. This infrastructure is described in Section 3.1.3.

In addition to the existing Wi-Fi Infrastructure based on a fixed backhaul, as part of the Iasi Smart City assets, ORO has deployed Wi-Fi routers with 4G/5G capabilities, which provide Wi-Fi services in city buses while also acting as gateways for all other devices that are in the buses (e.g.: air sensors, ticketing machines). The Wi-Fi infrastructure high level architecture to be used in this use case is presented in Figure 34.

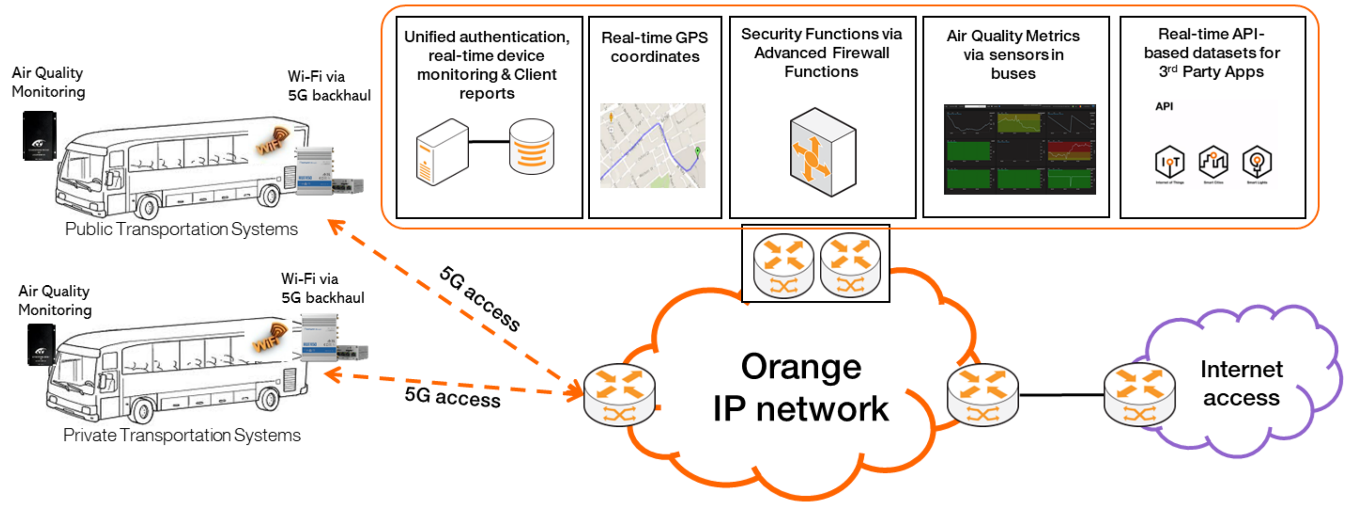


Figure 34. The high-level architecture of the Wi-Fi Infrastructure with Mobile (4G/5G) backhaul.

Furthermore, these routers can help measure, using the incorporated GPS module, the estimated speed of the bus in each timeframe and location, information that can be correlated with the air quality sensor information, while also offering some of the router parameters values (like download or upload data, router load, Mobile Network wireless signal) in an Open API data format in order to be consumed by 3rd party Smart City apps.

Also, as part of the Wi-Fi Mobile solution, security functions such as traffic filtering, application control, data inspection, intrusion prevention system implemented by default (can be removed).

As part of the Iasi Smart City project, a total of 10 uRadMonitor Air Sensors (Wi-Fi backhaul) have been installed on Iasi buses (connected to Wi-Fi Mobile Teltonika routers). These will provide air quality metrics such as PMT 2.5 (tiny particles or droplets in the air that are two- and one-half microns or less in width).

Concerning the network infrastructure enhancements that will be applied to UC4, zero-touch service management is an enabler that (i) enhances service operation by enabling an automated and efficient service life-cycle management (AI for network), and (ii) significantly improves resource usage efficiency at network Edges by adopting enhanced decision-making (rule-based and AI-based) mechanisms for management and orchestration, thereby dynamically reconfiguring Edge resource assignments and service function chains consisted of use case applications. The former, i.e., enhancing service operation by designing proactive management and orchestration mechanisms, targets to employ closed-loop orchestration that creates and manages service deployment in a fast and proactive way. The scope of the latter is two-fold:

- It aims to optimally configure the available wireless technologies (5G and Wi-Fi) based on the traffic requirements and the wireless environment. In that direction, the Wi-Fi access point will be integrated with the RAN Intelligent Controllers (RIC) under the O-RAN framework, enabling unified dynamic configuration of both radio access technologies, exploiting AI, ML and rule-based mechanisms. Moreover, the interworking and interoperability between 5G and Wi-Fi will be enhanced enabling traffic aggregation, load-balancing and increased reliability.
- It intends to configure the computing resources exploiting placement strategies based on the availability of the Edge computing assets. The configuration of both network and computing resources is based on

continuous proactive monitoring of the radio, Edge and core resources and functions. Therefore, the usage of available network and computing resources can be optimized ensuring QoS guarantees for city resilience and safety of vulnerable road users.

3.5.3.2 5G network infrastructure in Romania

The 5G infrastructure that will be used in the development of this use-case in Romania will be the same as for the UC1 Smart Crowd Monitoring for Iasi. This infrastructure is described in section 3.2.3.1.

3.5.3.3 Lab Infrastructure in Belgium

Initial development and testing of the zero-touch management of Edge resources and services, and RAN optimizations, as well as the framework for designing and developing vertical applications will be performed using the lab infrastructure of IMEC in Belgium. This infrastructure consists of the CityLab and Smart Highway testbeds in Antwerp, which combine several software (AI-enhanced) orchestration solutions, network, and service monitoring systems, 5G Network slice orchestration solutions, a framework for designing EdgeApps and framework for managing V2X communication technologies and services. Furthermore, the lab infrastructure includes O-RAN-based 5G testbed based on commercial and open-source/SDR solutions (OpenAirInterface, Software Radio Systems RAN-srsRAN, open5GS. Free5GC, Universal Software Radio Peripheral- USRP) and openWi-Fi equipment. Further details related to zero-touch management will be provided in the context of WP2.

3.5.4 Trial description

The use case will take place in a large intersection area, where the configuration of roads and traffic patterns creates significant complexity in managing traffic flow, leading to high levels of congestion. The end-users envisioned for Iași Resilient City are representatives of the Public Administration Vertical – Iași Municipality and the City Council, while the principal outcome of this use case is a Single-pane-of-glass Operational Platform, supporting decision-making and planning. The Table 13 describes the trial that will be performed.

Table 13. UC4 trial description.

Trial ID / Name	**Trial 4.1 / Smart Traffic Monitoring and Safety Application**	
Infrastructure / Venue	**Podu Roș intersection**	
Description	The test case framework is structured on three layers: 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 out of the digital traffic model to traffic participants with the aim of increasing safety of the VRUs and c) Incorporate and analyse information gathered from devices mounted on public transportation vehicles, e.g., connected Wi-Fi users within the tram/ bus and air quality data.	
Components and Configuration	Components	• Working with RGB cameras. • GPU compute capability at the server side. • 5G communication infrastructure. • AI-based algorithms. • Apps for data visualization and analytics.
	Configuration	• GPU-enabled server. • Nvidia's TLT+DeepStream framework. • Object detection/ classification/ localization/ tracking algorithms based on (CNN). • Application for data analytics and visualization at monitoring facility. • Application for safety enhancements of the VRUs deployed on 5G mobile devices.

Trial Procedure	Pre-conditions	• Test signals from the cameras to be sent to the Edge server to verify the connectivity and estimate delays. • Data from devices mounted on public transportation vehicles sent to the Edge server. • Computer vision (based on CNN) framework set-up. • Visualization and Safety apps installed.
	Trial steps	• Video stream received at the server side via ORO's 5G infrastructure. • Object detection and classification algorithms start. • Object localization algorithm starts. • Compute relevant traffic data analytics. • Detect safety risk / abnormal traffic situation. • Dump computed parameters to ORO's backend server. • Feed the data within the visualization application at the monitoring facility. • Transmit relevant information to safety app hosted on 5G connected devices. • Visualize the traffic situation and trigger potential risk/ abnormal situations on 5G connected devices. • Receive data from devices mounted on public transportation vehicles, e.g., connected Wi-Fi users within the tram/ bus and air quality data. • Embed data within the visualization app, e.g., public vehicle information (id, GPS location, number of passengers) within the digital traffic model and/ or the air quality heatmap overlaid to the traffic statistics.
	Methodology	• The monitoring test is started and executed over a duration to be set by the user. The monitoring tool presents the following results: • Digital traffic model of the surveyed area of the intersection. • Traffic related statistics (heatmap, number of objects per routes, etc). • Information collected from public transportation vehicles in the proximity of the intersection. • Air quality information. • The relevant information is sent also to traffic participants, accompanied by some safety risk/ abnormal traffic situations detected. The application hosted on mobile devices shall presents the following results: • Digital traffic model of the surveyed area of the intersection. • Specific alerts.
	Complementary measurements	Ground truth data gathered through direct observation to be confirmed on the premises.
	Calculation process	• First detect the objects within the received images by 2D bound boxes and classify each detected object. Then apply a transformation to estimate the location of each object on a map of the area surveyed. Repeat the process for every image frame received.

		• Compute traffic statistics based on the list of detected objects, their type and their location. Feed the visualization tool with this info. Use additional computing vision algorithms to detect safety risk / abnormal traffic situation. Send this information to mobile devices of interested traffic participants. Interpret, visualize, signal this information onto the mobile devices. In parallel, process data from devices mounted on public transportation vehicles, e.g., connected Wi-Fi users within the tram/ bus and air quality data, and include this into the visualization tool at the monitoring facility location.
Expected Result	• It is expected that the digital traffic model should fit the ground truth and that the statistical indicators relative to the traffic monitoring using data provided by cameras would be realistic in terms of magnitude and fall within value ranges provided by human experts. • Typical classes of objects such as cars, bicycles, motorcycles, pedestrians, trucks, trams/ busses should be reliably detected and classified in real-time, with an accuracy rate exhibiting 90%. • It is expected that new requirements for B5G will be identified.	

The trial description reported in Table 13 is intended to be complemented with the specific KPIs and KVIs definition and measurements reported in Section 4.5.2.

3.6 UC5: Control Room in Metaverse

The Control Room in Metaverse use case aims to demonstrate the performance, relevance and impact of 5G and B5G-enabled technologies, such as metaverse, XR, digital twinning and IoT solutions, in the context of a novel remote, environment-tailored, inter-agency XR training and real-time visualization of movement patterns/behavioral anomalies, resulting in improved management of large events (and potential situations of panic) through improved decision making and reduced intervention times.

3.6.1 Use case definition

The control room will be designed to ensure full scalability in terms of environments that can be uploaded, avatars that can be created, real-time data that can be integrated (and visualized in the form of analytics) as well as domains of application that can be covered, starting with the events area of Valentino Park (Figure 6) and a baseline training scenario for improved mission planning, protocol testing and real-time, in-platform communications.

As a result, the Control Room in Metaverse aims to deploy sensors and cameras for counting people while recreating by means of LIDAR scanning and 3D rendering the digital twin of Valentino Park (events area) which will be populated with engaging digital content. Thus, it enables local emergency responders (inter alia, police, civil protection, 112, 118 and firefighters) to undertake remote XR training and be able to visualize real-time movement patterns for enhanced situational awareness. A high-level description of the UC5 is depicted in Figure 35.

By already knowing elements such as the planimetry of the intervention area and the exact location of people, including those in need of urgent assistance (e.g., injured, wounded), emergency responders can save precious time and increase expediency. The control room will thus enable emergency responders to:

- Undertake immersive remote, environment-tailored, inter-agency XR training for mission planning, intervention protocol testing, real-time communications exchange, and mission debriefing.
- Access real-time analytics from sensors and cameras-detected data on movement patterns and behavioral anomalies. Analytics from in-loco sensors and cameras will be displayed directly in the metaverse application.

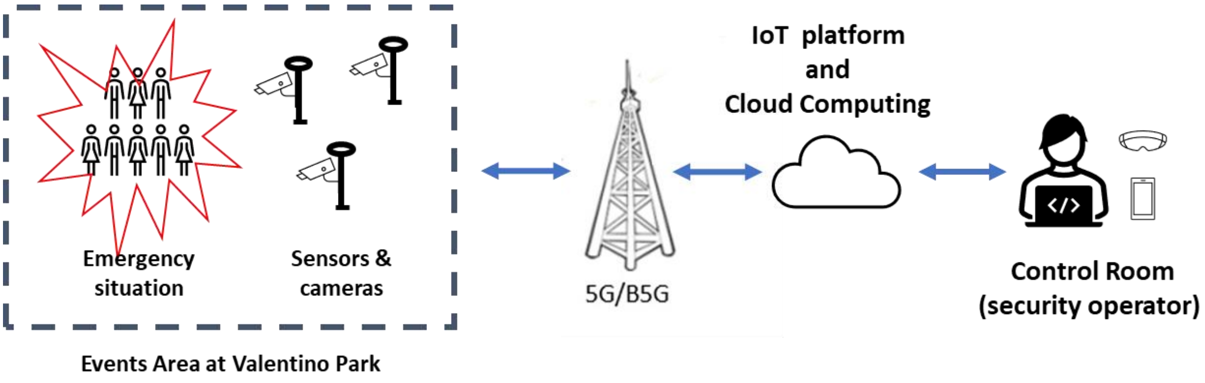


Figure 35. High-level description of UC5.

Based on the above, local emergency responders would be able to access the control room in metaverse in different ways that include:

- **Static scenario**: through a dedicated VR/XR headset or light viewer, (and accompanying relevant equipment/devices), located at the respective HQs (Headquarters) of engaged emergency responders, these may undergo the training at their convenience, without time or logistical constraints.
- **Mobile scenario**: through a dedicated VR/XR headset or light viewer (and accompanying relevant equipment/devices), first responders may see/frame the place and visualize real-time movement data as they are heading toward the location of the accident for reduced intervention times.

As an additional layer, the metaverse application will be complemented by in-loco field agents who can confirm and provide continuous information in the event of an anomaly/accident. As such, the deployed agent will be able to communicate and confirm in real-time what has occurred and has been captured by the sensors, thus complementing the information available to emergency responders (dynamic location) in the metaverse application. During the project life cycle, end-users may test the control room from "Consorzio per il Sistema Informativo" in Turin, which has a dedicated virtual room for VR/XR applications. The added value provided by the TrialsNet project builds on the advantages of the 5G communication infrastructure in terms of increased number of connected sensors/terminals and fast, reliable, and high-quality transmission of data.

3.6.2 Implementation aspects

3.6.2.1 Application design

In this section, the modules that will be employed to implement the control room in metaverse are outlined see Figure 36.

Client: The client-side code is primarily built on A-Frame [20], an open-source web framework for building virtual reality experiences. A-Frame is a powerful tool for creating 3D environments and objects, and it uses HTML-like syntax that is easy for web developers to understand. The A-Frame library includes support for physics, animations, and other 3D graphics capabilities. The open nature is an added value as it will enable post processing to easily scale the solution. The client communicates with the server using WebSocket [21] and WebRTC [22] protocols. WebSocket is a protocol that enables bi-directional communication between the client and server, allowing for real-time messaging and data exchange. WebRTC is a set of communication protocols that allow for peer-to-peer communication between clients, including video and audio streaming – making it very attractive for the purpose of the control room and tasks such as mission planning, protocol testing and mission debriefing.

Server: The server-side code in Node.js [23] that is a popular JavaScript runtime for building scalable web applications. Node.js allows for fast, efficient server-side code that can handle large numbers of concurrent connections. The server-side code is deployed on cloud platforms such as AWS [24] or Heroku [25]. As such, multiple agents will be able to connect at the same time, which is critical when testing inter-agency intervention protocols and simulating an emergency. The server-side code uses Redis and MongoDB to store user data and room information. Redis [26] is a fast, in-memory data store that is ideal for caching and other high-performance use cases. MongoDB [27] is a document-oriented NoSQL [28] database that is well-suited for storing large amounts of semi-structured data.

Modules: The application is built with a modular architecture that allows developers to create custom modules and add new features to the platform thus ensuring un-matched tailoring based on operational and training needs of first and emergency responders. Here are some of the core modules:

- **The Client-Side Rendering Engine Module:** This module is responsible for rendering the 3D environment and objects on the client side. It uses A-Frame and other libraries to provide a rich, immersive experience for users.
- **The Networking Module:** This module handles WebSocket and WebRTC communication between clients and servers. It manages messaging, signaling, and other low-level network functions.
- **The Audio Module:** This module provides spatial audio capabilities for Mozilla Hubs, allowing users to hear sounds coming from different directions in the virtual environment. It uses Web Audio API and other technologies to provide a realistic audio experience. This possibility becomes extremely valuable in the context of training for emergency and panic management by enabling trainees to experience the same sounds they would in a real-life situation (e.g., sirens), contributing to higher levels of immersion and engagement and so long-term retention of tested protocols.
- **The Avatar Module:** This module allows users to create and customize their own 3D avatars. It provides a variety of customization options, including clothing, hair, and facial features which can improve immersion and engagement levels with a spillover effect on retention and the possibility to easily distinguish field officers amongst each other's (e.g., police, 118, civil protection, fire fighters) and wounded.
- **The Room Module**: This module manages the creation and deletion of virtual chat rooms. It allows users to create private or public rooms, and it provides tools for managing permissions, access, and other settings.

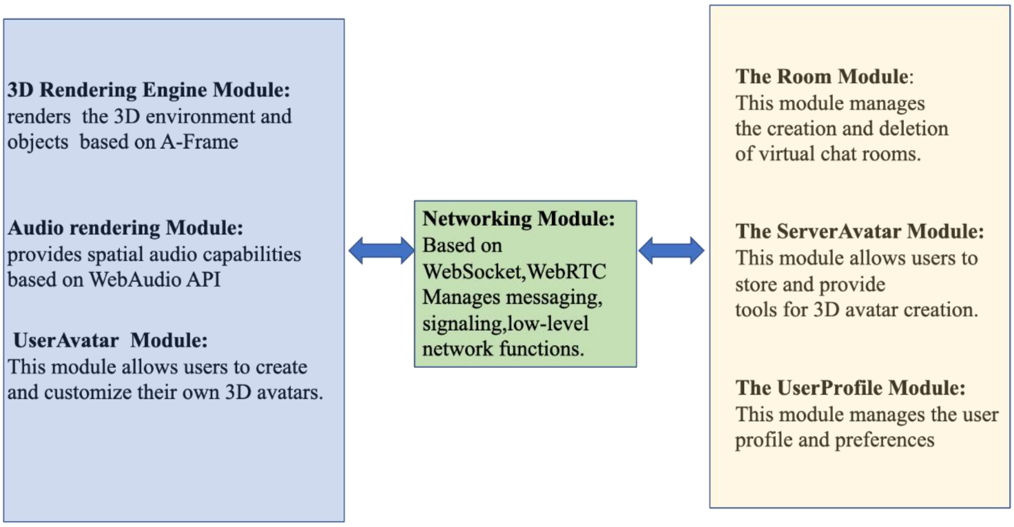


Figure 36. Simplified Application modules.

3.6.2.2 Equipment and devices

To increase the quality and spectrum of data that will be translated into actionable analytics within the metaverse application, offering emergency responders a real-time picture of movement patterns, different types of GDPR-compliant sensors and cameras (functioning according to a "people" counting algorithm) will be tested to reach maximum interoperability of data.

The testing will be performed in a controlled environment prior to deployment and enable the identification of the most performing sensors according to UC5 specific needs.

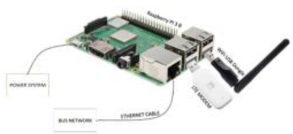
The type of equipment and devices reported in Table 14 were identified based on the following aspects:

- Remote, environment tailored, XR training and real-time visualization of behavioral anomalies/movement patterns.

- The need to fulfill GDPR-related constraints.
- The need to be able to recognize offenders through video analysis and access to cameras in the event of an illegal act. Integrating sensors and cameras generated data for outcome maximization.

Table 14. Equipment and devices for UC5.

Equipment	Item	Description	Quantity
 **Cameras**	5G solar-panel cameras [49]	5G Solar-powered cameras with lithium batteries, requiring non-power supply, with real-time video-imagery data transmission to a tablet and/or smartphone, including smart alerts. They are easily positioned, and/or (re)moved, operate under any lighting condition, and can be easily integrated within existing systems or with other IoT sensors for real-time detection of people and movement patterns.	4
 **Sensors**	Wi-Fi sniffer sensors (commercial version) [50]	Through specific algorithms enabled by machine learning, this sensor identifies and deletes the fake MAC address cloud generated by mobiles and tablets while generating a statistical counting from which it is possible to derive the presence and quantity of people in a given area. The adopted algorithms do not have the possibility of identifying the univocal and real MAC address of the device. Hence, aggregated data of statistical nature are transmitted to the mother platform from the IoT sensor, natively anonymously and in compliance with the GDPR. They reach an estimated average of 70-75% accuracy. All personal data is encrypted by hashing them at 256bit at the time of entry into databases.	10
 **Radar antennas**	mm Wave radar antennas [51]	With an accuracy of 98%, millimetre-wave (mm Wave) sensors use electromagnetic waves with short wavelengths. Using receivers, the radar system can intercept waves reflected from objects along the path, and then derive data such as the object's distance from the radar, along with its speed and orientation. Millimetre-wave radars transmit signals with a wavelength in the order of millimetre. This is considered a short wavelength in the electromagnetic spectrum and is one of the advantages of this technology. In fact, this makes it possible to reduce the size of certain components such as the antennas used to process the signal. Another advantage of the short wavelength is its high accuracy. A millimetre-wave system operating at 76-81 GHz (with a wavelength of 4mm), can detect movements that are smaller than a fraction of a millimetre.	2
	Wi-Fi sniffer sensors (experimental) [52]	Custom, open-source Wi-Fi sniffer counting the number of nearby mobile devices, based on the “probe-request” messages sent periodically by the devices. The main novelty in the proposed	1

 **Wi-Fi sniffer sensors**		architecture lies in the de-randomization approach, which is based on state-of-the-art ML algorithms and integrated with real-time information coming from local data and sensors. In terms of hardware implementation, the system will be based on a low-cost Raspberry PI platform, with on-board 802.11n Wi-Fi, Bluetooth and Ethernet connections.	
 **Cameras**	Ground LIDAR Faro Focus S350 [53]	The HDR camera captures detailed images by providing natural colour overlay with the scanned data. Up to 2 million points per second for long-range scanning: • Range: 350 m • Accuracy: 1 mm • Field of view 360° x 300° • Coloration 165 MPX HDR 5x • IP 54	1
  **VR equipment**	META QUEST II 256 GB [54]	Avanced all-in-one VR with a visor and controller only (smartphone app required). Alternatively, connect to a gaming computer to access Rift titles with the Link cable (Meta account for use needed). Six Degrees of Freedom (6DoF) technology enables the visor to track head and body movements and then translates them into VR with realistic accuracy. No external sensors are required. A new thumb rest adds stability when needed. Soft strap provides lightness and comfort for increased realism. OPTICAL DETAILS • Fast-switching LCD display • Resolution of 1832x1920 per eye • Support for 60, 72 and 90 Hz refresh rate • Compatibility with glasses	10-12
  **5G Mobile Equipment**	5G MOBILE/ SIM [55]	• SAMSUNG GALAXY A32 5G • SAMSUNG Galaxy S20 FE 5G These will be used to: • To provide 5G connectivity to enable on the move visualization of relevant information during the dynamic location scenario option – see trail description for more information. • To identify the location of people that will play the part of injured or wounded during the testing phase.	10-12

3.6.3 Infrastructure components and functionalities

In the following section, the two main platforms that will be used to implement the use case control room in metaverse are presented. These are Mozilla hubs for the implementation of the metaverse component, and Symphony, for the management of IoT devices and transmission of analytics directly into the control room in metaverse which will both be deployed in the Cloud.

3.6.3.1 Mozilla Hubs (XR Platform)

Mozilla Hubs [15] is a browser-based virtual reality platform that allows users to create and interact with 3D spaces using just their web browser, without the need for any specialized software or hardware.

In Mozilla Hubs, users can create their own virtual spaces, or "rooms", which can be customized with 3D objects, images, and videos. These rooms can be shared with other users, who can join and interact with each other in real-time, using avatars to represent themselves. Users can also communicate with each other through voice chat or text chat, making it a social experience. Figure 37 shows an example of Mozilla Hubs' main screen, which is user friendly both for users and developers.

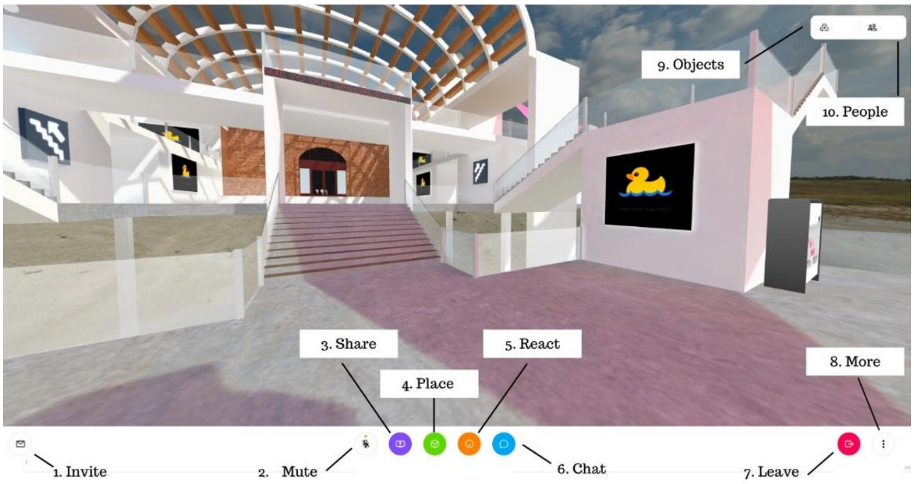


Figure 37. Example of Mozilla Hubs client rendering.

To run, Mozilla Hubs requires the employment of a web browser that supports WebVR, such as Firefox or Chrome, and a device with a keyboard and mouse, or a virtual reality headset. The platform is free to use, and there are no limits on the number of users or rooms one can create.

Mozilla Hubs is built on top of WebVR, a web-based technology that allows developers to create virtual reality experiences using standard web technologies like HTML, CSS, and JavaScript. This means that Mozilla Hubs can be accessed from any device with a web browser that supports WebVR, including desktop computers, laptops, smartphones, and virtual reality headsets like the Oculus Quest and HTC Vive.

Mozilla Hubs also includes a variety of tools for creating and customizing virtual spaces. Users can import 3D models from external sources like Sketchfab [16] Google Poly [17] or create their own custom 3D models using tools like Blender [18] or Tilt Brush [19]. These 3D models can be placed and arranged within the virtual space using simple drag-and-drop controls.

In addition to 3D models, users can also add other types of content to their virtual spaces, such as images, videos, and audio files. For example, a virtual art gallery might feature 3D sculptures alongside video installations and ambient music. Mozilla Hubs also supports a variety of lighting and sound options, which can be used to create immersive and engaging virtual environments.

Finally, it's worth noting that Mozilla Hubs is an open-source platform, which means that anyone can contribute to its development. This has led to the creation of a vibrant community of developers and designers who are working to improve and expand the capabilities of the platform.

Given the extreme flexibility and scalability by design granted by its open nature, user-friendly interface, and possibility to support real-time, multi-player collaboration through voice chat or text chat amongst avatars in the same room, with no capacity limits, Mozilla Hubs was deemed the most suitable platform to implement the control room in metaverse.

It is planned to customize Mozilla Hubs according to the needs of first and emergency responders when it comes to mission planning and intervention protocol testing, let alone for real time visualization of data analytics. As such, the following will play a pivotal role:

- **3D models and environments**: Custom-made 3D models of the events area of Valentino Park, expected to be scanned by the end of May 2023 and which will represent the main environment for UC5, will be made available. With the support of LIDAR scanning technology, the targeted area inside the park will be promptly reproduced in 3D and then fed to the XR platform for virtual rendering.
- **Multiplayer experiences**: Users can visualize the events area of Valentino Park as if they were there, allowing for a variety of virtual tasks including mission planning, mission debriefing and intervention protocol testing, let alone visualization of real-time movement patterns of individuals located inside the target area. To enable optimal management of a situation of panic it is imperative to recreate a training experience and scenario that encompasses avatars of first responders (multi-agency) and potential victims (wounded, injured).
- **Accessibility features**: Hubs can be customized with accessibility features such as text-to-speech and closed captioning to enable effective, real-time, in-platform communication flow between first responders and facilitate decision making.
- **Personalization**: Users can create avatars and customize their appearance, creating a more personalized and immersive experience that is as close as possible to a real-life situation. As such, the avatar of a fire fighter, police officer or civil protection agent rather than 118 employees can be easily made ensuring a high degree of fidelity with a real-life emergency management scenario. As a minimum, 10 to 12 avatars are needed of which 8-10 for first responders and 1-2 injured.

3.6.3.2 Symphony (IoT Platform)

Symphony is a full-featured IoT platform and BMS characterized by a modular architecture (Figure 38), which enables smooth and unified interaction with a variety of hardware devices, IoT sensors, or actuators. Access control, technical system monitoring, automation, energy management, and other uses can all benefit from the integration of a range of services for notifications, event management, analytics, and automatic reactions that Symphony offers internally. This makes Symphony the perfect platform to implement the control room in metaverse as it will enable efficient, sustainable, and smart management as well as integration of relevant IoT equipment and metaverse applications for the real-time visualization of analytics related to movement patterns and behavioral anomalies. Below is an overly simplified depiction of the symphony's IoT platform system architecture.

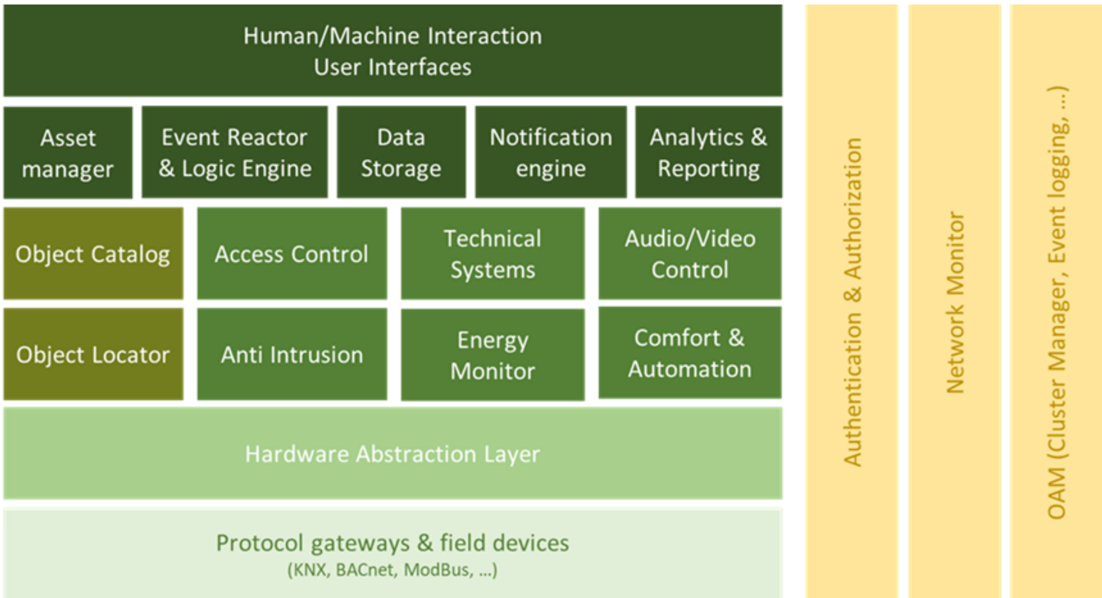


Figure 38. Symphony high-level architecture.

At its southbound, Symphony implements the Hardware Abstraction Layer (HAL). The HAL incorporates protocol-specific plugins to allow connection to field-deployed devices and heterogeneous protocol gateways. The "plain objects" notion, which refers to generic items expressed in a single format, is used to transform the "low level" data that was collected from the field. These objects are then subjected to additional processing based on device-specific information models to produce "objects with semantics," which serve as "meaningful" inputs for the data elaboration applications.

The Symphony Visualization Application provides system operators with a web-based graphical user interface (GUI). The GUI can be completely customized, allowing users to choose the type of data to be displayed on dashboards, as well as the filters that will be used and the graphs' layout. The Visualization Application can be utilized as a local dashboard to expedite the review of the data that was initially gathered from the sensors.

Symphony also provides a GUI for system configuration, such as for adding new SBI plugins and turning on the data gathering from additional data sources. REST APIs provide the foundation for communication between the GUI and the system backend. Below is a visual sample of dashboard for data visualization.

Aggregation, rate restriction, sub-sampling, variable data preservation policies, and synchronization across numerous instances deployed in Edge and cloud contexts are all provided by the Symphony Data Storage. Large amounts of data can be handled using Symphony Data Storage, which also offers high availability and eliminates single points of failure. Internally, it supports different databases as backends, including PostgreSQL, Apache Cassandra, and Elastic Search. Moreover, it is integrated with a Grafana-based dashboard for data visualization as shown below (Figure 39).

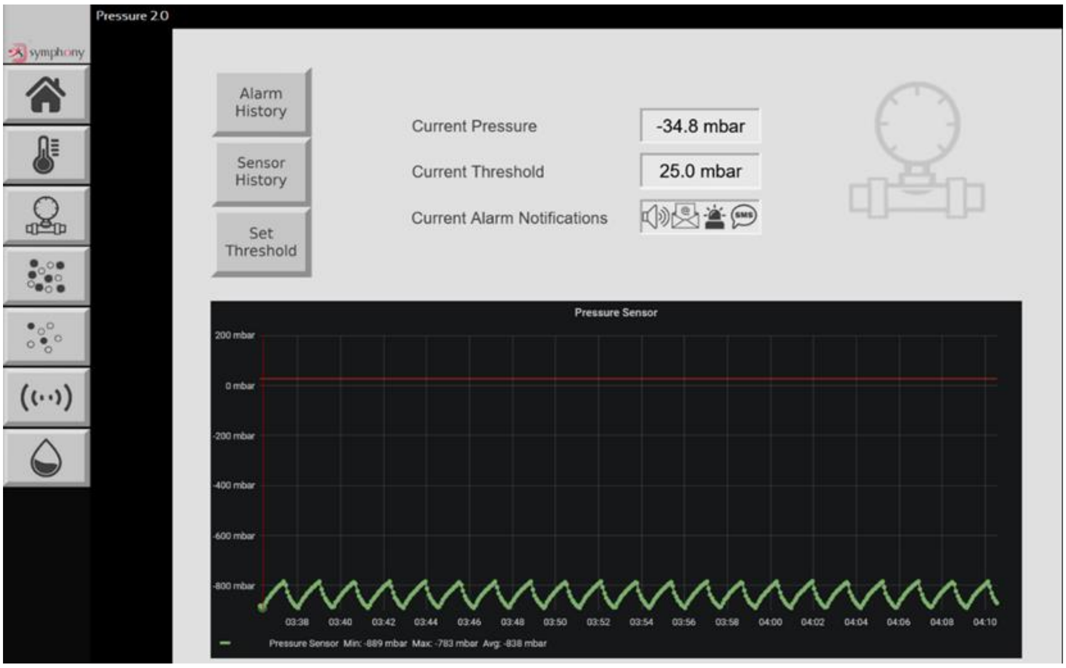


Figure 39. Symphony dashboard.

3.6.3.3 5G network infrastructure

The 5G connectivity for the use case implementation will be provided by the commercial network deployed by TIM (details will be reported in the deliverable D2.1 “Preliminary design aspects for Platforms and Networks solutions”). Preliminary on-field measurements were recently performed in one of the target areas, namely the one hosting public, cultural and recreational events, where the use case is likely to be implemented (see Figure 40). The measurements aimed at checking both coverage and performances (i.e., downlink and uplink throughputs, E2E latency) of the 5G network and will be used as baseline targets towards the identification of technical requirements in section 4.6.1. Further measurements and tests with devices will be performed during the development phase of the use case. The tests were only performed in one of the two potential candidate areas since Borgo Medioevale is already known to be covered by 5G.

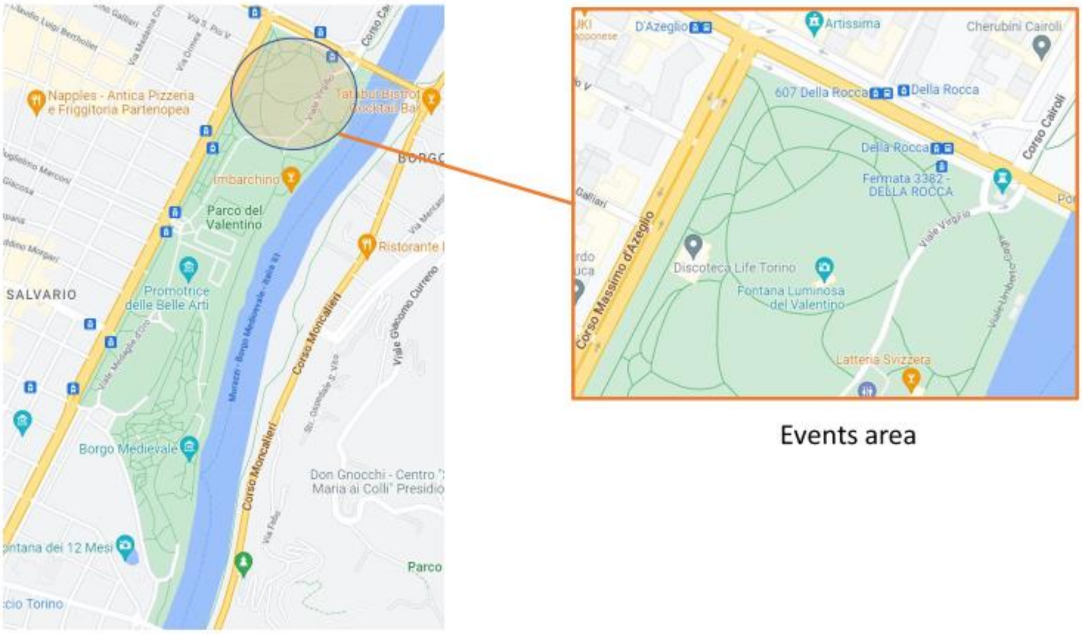


Figure 40. Events area covered by TIM commercial network.

3.6.4 Trial description

The objective is to design, implement, deploy, test and evaluate various technologies including XR, metaverse, massive twinning, IoT and environment-tailored and inter-agency XR training and real-time monitoring of behavioral anomalies. The goal is to enable optimal management of situations of panic and provide a real-life virtual environment for mission planning and protocol testing, live communications, and mission debriefing, amongst others. In Table 15 a description of UC5 trial is reported.

Table 15. UC5 trial description.

Trial ID / Name	Trial 5.1 / Control Room in Metaverse	
Infrastructure / Venue	**Valentino Park (Events Area)**	
Description	UC5 overarching goal is to employ metaverse, XR, digital twinning and IoT technologies to plan, implement, test and assess the performance/ relevance/impact of XR inter-agency training and monitoring of movement patterns for enhanced emergency and panic management during large events – improving decision making and reducing intervention times. The main building blocks include the scanning of the target environment (Valentino Park), the deployment of different sensors and cameras for data collection, data transmission and communication with the Symphony platform for the visualisation of analytics directly in the chosen metaverse application, Mozilla Hub.	
Components and Configuration	Components	• Wi-Fi sniffer sensors. • 5G solar-panel cameras. • Ground LIDAR. • VR Headsets. • Mobile devices and 5G sim cards. • IoT platform Symphony. • XR platform Mozilla Hub.
	Configuration	• Mozilla Hubs and Symphony IoT platform up and running.

		• Sensors and cameras need to be connected and configured to the IoT platform through a mobile network interface and to Mozilla Hubs • VR headset and mobile devices connected to 5G network, Mozilla Hubs and Symphony IoT platform.
Trial Procedure	Pre-conditions	• Verify with the appropriate offices the location of the testing area within Valentino Park. • Verify 5G coverage in Valentino Park upon IoT equipment deployment. • Site inspection. • Engagement of end users and collection/ refinement of strategic and operational requirements (local emergency responders) • Testing of sensors and subsequent selection. • Instalment of sensors within agreed area. • 3D mapping of site. • Rendering and content creation • Identification/procurement of mobiles, sim cards and additional VR headsets. • Connection/pairing and configuration of relevant equipment with XR platform (VR headset/mobiles/IoT platform). • Identification of location for controlled demo to ensure correct functioning of all components. • Deployment/configuration of relevant equipment to perform demo.
	Trial steps	• Network coverage and performance check. • Activation and connection of equipment and XR platform to enter the dedicated metaverse. • Log in and avatar selection. • Selection of Training module and testing of in-platform opportunities and features. • Debriefing and evaluation. • Assessment/analysis of feedback. • Action plan for feedback integration and follow-up test (refinement) - the testing will be performed multiple times and a diverse set of end-users engaged.
	Methodology	A survey inclusive of primary and secondary KVIs will be subjected to the users to gather their feedback.
	Complementary measurements	• A secondary list of metrics/KPIs useful to interpret the values of the target metric/KPI. Getting these measurements is not mandatory for the test case. • Complementary KVIs – to this date we could only produce a list of complementary KVIs, as opposed to a list of KPIs which will be provided at a later stage of the task's implementation. • Degree of realism. • Degree of freedom of movement. • Degree of ease of use. • Presence/absence of motion sickness.

		• Maximum exposure time before feeling overwhelmed or sick. • Accuracy of movement-related analytics. • Degree of appreciation for data visualization. • Degree of usefulness. • Degree of overall appreciation.
	Calculation process	Participants will be asked to fill in a questionnaire/survey with the possibility to integrate dedicated feedback on how the metaverse experience could be improved.
Expected Result	• More than 80% of participants find the control room in metaverse as enriching and useful experience. • More than 85% of all targets are met. • Sensors/cameras are functioning and integrated with Symphony platform. • Analytics are shown with an accuracy equal or above to 90% • When/where targets are not met, the appropriate actions are taken to improve the outcome through additional phases of refinement and testing.	

The trial description reported in Table 15 is intended to be complemented with the specific KPIs and KVIs definition and measurements reported in Section 4.6.2.

4 Technical requirements and evaluation methodology

This section provides the initial technical requirements and the evaluation methodologies that will be addressed by each use case. Each technical requirement can be reassessed (or new ones defined) based on the tests that will be performed in laboratory and/or on-field contexts, in different cycles, according to the TrialsNet's methodology defined in D1.1 "Management handbook" [30]. Due to the different design and implementation of the use cases, specific technical requirements and evaluation methodologies are defined.

4.1 UC1: Smart Crowd Monitoring (Madrid)

4.1.1 Preliminary technical requirements

In this use case robotics devices, LIDARs and video cameras, with cellular-5G connectivity are used. The technical requirements refer mainly to the performance and quality of the link between the devices and the 5G network are described in Table 16.

Table 16. Preliminary technical requirements for UC1 (Madrid).

Device Type	Requirements	Target
Robotics	Maximum latency	300 ms
Robotics	Maximum number of packages lost:	0.5%
Robotics	Throughput mín (up and down):	10 Mbps
Robotics	Throughput recommended	20 Mbps
Robotics	Number of users connected to the robot	Max. 4 users. 1 remote operator, 1 Viewer/Remote Operator backup, 1 Security technician, 1 Operator intercom.
Robotics	Cybersecurity	VPN tunnel is required (ideal VPN IPSec)
LIDARS	Maximum latency	10 ms
LIDARS	Throughput recommended (up and down)	250 Mbps
Fix cameras	Throughput mín	20 Mbps

4.1.2 KPIs/KVIs definition and measurement

Trials will be performed at three progressive levels oriented to ensure a rapid and reliable deployment and operation at the demonstrative site. The three phases and the test procedure used to measure the KPIs and KVIs reported in Table 17 and Table 18 are described in the section 3.1.4.

The KPIs in Table 17 or this use case are aimed at achieving optimal performance with the current technology available or to set a benchmark for future network advancements.

Table 17. KPIs of UC1 (Madrid).

KPI name	Description/KPI definition	KPI target
Network KPIs		
Downlink throughput per user	The downlink throughput per user refers to the amount of data (number of bits contained in the service data units delivered to Layer 3) that can be transferred from the network to a device over a certain period of time. This KPI is calculated with 5% percentile of the CDF (cumulative distribution function) of the downlink throughput during that specific period of time.	200-500 Mbps
Uplink throughput per user	Refers to the amount of data (number of bits contained in the service data units delivered to Layer 3) that can be transferred from a device to the network over a certain period of time. This KPI is calculated with 5% percentile of the CDF of the uplink throughput during that specific period of time.	20-100 Mbps
Downlink cell capacity	The maximum amount of data (number of bits contained in the service data units delivered to Layer 3) that can be transferred from the network to all devices in a specific cell (a geographic area covered by a single cell) over a certain period of time. This KPI is calculated with 5% percentile of the CDF of the downlink throughput during that specific period of time.	1.5 Gbps
Uplink cell capacity	Is the maximum amount of data (number of bits contained in the service data units delivered to Layer 3) that can be transferred from all devices in a specific cell to the network over a certain period of time. This KPI is calculated with 5% percentile of the CDF of the uplink throughput during that specific period of time.	150 Mbps
Application-level latency	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. It is a measure of the delay that the device experiences when interacting with an application. This KPI is calculated as the duration between the transmission of a small data packet from the device with the successful reception in the application connected to the UPF and located in the Edge computing and the response back time.	<100ms
Reliability	The KPI network Reliability measures the probability of transmitting an amount of layer 2 packets within the required maximum time. The maximum time is the time to deliver an amount of data packet from user equipment to the application located in the EDGE. (This measurement considers the protocol layer 2 SDU).	99%
Coverage	Geographic area where a network signal can be received and used by a device	99%
Service availability	This KPI refers to the percentage of time the E2E system is fully operational, this being defined as the ratio of uptime over the total time (uptime plus downtime). This KPI measures with an ICMP packet between the User equipment (UE) and the application located in the EDGE. If the ICMP packet reaches the destination successfully within an estimated time the availability is OK, if not the availability is NOK (Not OK).	99%

AI KPIs		
Accuracy	Proportion of correct predictions made by the algorithm. It can be measured as the number of correct predictions divided by the total number of predictions made.	>85%
Precision	Precision measures how often the algorithm is correct when it predicts a positive outcome. It can be measured as the number of true positives divided by the sum of true positives and false positives.	>90%
Recall	Measures how often the algorithm correctly predicts a positive outcome out of all the actual positive outcomes. It can be measured as the number of true positives divided by the sum of true positives and false negatives.	>90%
F1 score:	The F1 score is the harmonic mean of precision and recall and is often used as a single metric to evaluate the overall performance of an algorithm. It can be calculated as 2*(precision*recall)/(precision+recall).	>0,9

KVIs in Table 18 for this use-case are defined to report the satisfaction level of the trial involved entities (Security Company Operators and Clients) regarding important societal values for the future networks and applications.

Table 18. KVIs of UC1 (Madrid).

KVI name	Description/KVI definition	KVI target
Trust	Reported confidence in the digital devices, systems, and services used in the use-case development and operation.	>90% of the operators expressing positive evaluation regarding the robustness of the devices, the trustworthiness of the used AI algorithms, the E2E privacy of the system.
Resilience	Reported confidence in the reliability of the devices, network and over-the-top developed services and applications	>90% of the operators expressing positive evaluation regarding the reliability of the devices, network, developed applications and services.
Security	Reported perceived security of the digital devices, systems, and services used in the use-case development and operation.	>90% of the operators expressing positive evaluation regarding the secureness of the devices and of the E2E system.

4.2 UC1: Smart Crowd Monitoring (Iasi)

4.2.1 Preliminary technical requirements

For this use case two types of video cameras will be deployed: one fixed - for general crowd observation, and one mobile – able to focus on a certain small area of interest. A maximum of 4 fixed cameras and one mobile (PTZ) camera will be installed on a pole. These will be linked to the Edge computing and monitoring facility via a 5G CPE. Therefore, the technical requirements (Table 19) refer to the cameras, the performance and quality of the link between the CPE and the 5G network, and with the extension to the Edge-compute facility from the Iasi 5G Lab Datacenter, through the deployed RAN and local UPF. In addition, for crowd density estimation

Wi-Fi access points will be deployed across the area of interest, to be connected to the backbone infrastructure too.

Table 19. Preliminary technical requirements for UC1 (Iasi).

Device Type	Requirements	Target
PTZ Camera	Maximum RTSP latency	250 ms
PTZ Camera	Generated throughput min (1080p streaming)	5 Mbps
PTZ Camera	Generated throughput recommended (4K streaming)	10 Mbps
PTZ Camera	Minimum camera IR range	30 m
Fixed Camera	Average generated throughput (1080p streaming)	7 Mbps
Fixed Camera	Maximum RTSP latency	250 ms
Fixed Camera	Recommended no. of FPS	15 FPS
Fixed Camera	Minimum camera IR range	30 m
Fixed Camera	Horizontal recommended angle	> 90o
5G CPE	SNR	> 15dB
5G CPE	RSRP	> -90dBm
5G CPE	Monitoring	TR-069 Compatibility
5G CPE	Minimum Up-link throughput to be supported	> 50 Mbps (min 10 Mbps + 4x7 Mbps)
5G Network	Camera to Server link one-way latency	< 25 ms
5G Network	Recommended throughput per link	> 50 Mbps
AI Server	Processing capabilities for AI algo & application for 8 streams of 15fps of Full-HD images and 2 streams of 15fps of 4K images	< 100 ms
Wi-Fi AP	Wi-Fi Presence Analytics Maximum Simultaneous Users	1000
Wi-Fi AP	Wi-Fi Minimum RSSI	-75 dBm
Wi-Fi AP	Wi-Fi Minimum SNR	18 dB
Air Sensor	Air Sensor to Wi-Fi Router Minimum RSSI	-80 dBm

4.2.2 KPIs/KVIs definition and measurement

The KPIs in Table 20 for this use case are aimed at achieving optimal performance with the current technology available or to set a benchmark for future network advancements. The KPIs and KVIs reported in Table 20 and Table 21 are evaluated based on testing procedure described in section 3.2.4.

Table 20. KPIs of UC1 (Iasi).

KPI name	Description/KPI definition	KPI target
Downlink cell capacity	The maximum downlink throughput that can be achieved by the cell when multiple devices are connected to it.	1.5 Gbps
Uplink cell capacity	The maximum uplink throughput that can be achieved by the cell when multiple devices are connected to it.	150 Mbps

Application-level latency	The delay between the time the application receives the data from the network and the time is returns a computed result.	< 100ms
Uplink cell capacity	The minimum uplink throughput that must be achieved for the use case link at 2k resolution.	> 50 Mbps
E2E latency	Roundtrip latency between the device and the network.	< 50ms
Service reliability	Period of time for which the mobile service maintains the performance standards defined above (downlink/uplink capacity, E2E latency)	99%
Service availability	Period of time for which the mobile service is available for the users.	99%

The cell capacity will be measured by running simultaneous iPerf sessions, for both uplink and downlink traffic, between 2-3 5G devices connected to the network and a server placed in the Edge-compute facility. The E2E latency will be measured by running ping probes between the 5G devices and a server from the Edge-compute facility. The application-level latency refers, in this use-case, to the processing time related to crowd-monitoring related tasks and will be measured at the software level. The service reliability and availability will be measured by specific functions inside the CN and RAN and will be reported to demand when needed.

KVIs in Table 21 for this use-case are defined to report the satisfaction level of the trial involved entities (consortium partners, applications end-users, open-call SMEs etc.) regarding important societal values for the future networks and applications.

Table 21. KVIs of UC1 (Iasi).

KVI name	Description/KVI definition	KVI target
Trust	Reported confidence in the digital devices, systems, and services used in the use-case development and operation.	>90% of operators from the municipality expressing positive evaluation regarding the robustness of the devices, the trustworthiness of the used AI algorithms, the E2E privacy of the system (to be reviewed in WP6).
Resilience	Reported confidence in the reliability of the devices, network and over-the-top developed services and applications	>90% of operators from the municipality expressing positive evaluation regarding the reliability of the devices, network, developed applications and services (to be reviewed in WP6)
Security	Reported perceived security of the digital devices, systems, and services used in the use-case development and operation.	>90% of operators from the municipality expressing positive evaluation regarding the secureness of the devices and of the E2E system (to be reviewed in WP6).

4.3 UC2: Proactive Public Infrastructure Assets Management

4.3.1 Preliminary technical requirements

In this use case, the deployment of robotics devices, sensors, drones, and video cameras with cellular-5G connectivity is planned. The technical requirements (Table 22) refer mainly to the performance and quality of the link between the devices and the 5G network.

Table 22. Preliminary technical requirements for UC2.

Device Type	Requirements	Target
Robotics	Maximum latency	100 ms
Robotics	Maximum number of packages lost:	0.5%
Robotics	Throughput mín .(up and down):	10 Mbps & 50Mbps
Robotics	Throughput recommended (up and down)	30Mbps & 150 Mbps
Mobile Devices	Throughput recommended (up and down) of tablets/smartphones	10Mbps & 100Mbps
Robotics	Cybersecurity	VPN tunnel is required (ideal VPN IPSec)
Robotic Mobility	Speed at which a robot can move while maintaining a stable network connection	At least 2m/s
Robotic Energy Efficiency	The amount of energy required to transmit data, analyse data, and move of robots, measured in time	At least 6hours continuously
Cameras	Throughput minimum	1.5 Mbps

4.3.2 KPIs/KVIs definition and measurement

The KPIs in Table 23 for this use case are aimed at achieving optimal performance with the current technology available or to set a benchmark for future network advancements. Throughput measurements will be collected via probes, iPerf and Ookla. Latency measurements will be collected at the application layer by adding timestamps to requests between functional entities/service components of the overall application. Then the difference in time will be calculated between the request from one entity (e.g., client) and the response from the other entity (e.g., server). Additional measurements will also be collected e.g., with the use of iPerf. Location accuracy will be measured as the difference between the position to which a device (e.g., robot) is directed and the actual position where it ends up and the difference between the position of a device estimated by the overall system and the actual position. Service reliability will be measured by measuring the packet loss rate at the application layer (packets that arrive delayed or erroneous are considered as lost packets). Service reliability will be calculated based on packet loss and RTT latency measurements. The KPIs and KVIs reported in Table 23 and Table 24 are evaluated based on testing procedure described in section 3.3.4

Table 23. KPIs of UC2.

KPI Name	Description/KPI definition	KPI target
Downlink throughput per device	The amount of data that can be transmitted over the network in a certain amount of time	50Mbps (min), 150Mbps (recommended)
Uplink throughput per device	The amount of data that can be transmitted over the network in a certain amount of time	10Mbps (min), 30Mbps (recommended)
App latency (glass to glass)	Delay between the image captured by the camera and it showed in the screen of the user device	800 msec

Location accuracy	Accuracy in the positioning of the device	5 meters
Latency	Round-trip time for successful delivery of a packet from transmitter (e.g., device) to receiver (e.g., dashboard) plus the time it takes to send the response back	10-100 ms
Service availability	Capability of transmitting a given amount of traffic within a predetermined time duration with high success probability (calculated based on packet loss)	99.999%
Service reliability	Success probability of transmitting a layer 2/3 packet within a maximum latency required by the targeted service (ITU-R M.2410)	99.999%

KVIs in Table 24 for this use-case are defined to report the satisfaction level of the trial involved entities (consortium partners, applications end-users, open-call SMEs etc.) regarding important societal values for the future networks and applications.

Table 24. KVIs of UC2.

KVI name	Description/KVI definition	KVI target
Sustainability	Reported confidence in sustainable digital devices, systems, and services used in the use-case development and operation.	>60-70% of the users expressing positive evaluation regarding the sustainability of the devices, network, developed applications and services.
Trust	Reported confidence in the digital devices, systems, and services used in the use-case development and operation.	>60-70% of the users expressing positive evaluation regarding the robustness of the devices, the trustworthiness of the used AI algorithms, the E2E privacy of the system.
Resilience	Reported confidence in the reliability of the devices, network and over-the-top developed services and applications.	>60-70% of the users expressing positive evaluation regarding the reliability of the devices, network, developed applications and services.
Security	Reported perceived security of the digital devices, systems, and services used in the use-case development and operation.	>60-70% of the users expressing positive evaluation regarding the secureness of the devices and of the E2E system.

4.4 UC3: Autonomous APRON

4.4.1 Preliminary technical requirements

In this use case, the deployment of robotics devices, sensors, video cameras, and GPS devices with cellular-5G connectivity is planned. The technical requirements (Table 25) refer mainly to the performance and quality of the link between the devices and the 5G network.

Table 25. Preliminary technical requirements of UC3.

Device Type	Requirements	Target
Robotics	Maximum latency	100 ms

Robotics	Maximum number of packages lost:	0.5%
Robotics	Throughput mín .(up and down):	10 Mbps & 50Mbps
Robotics	Throughput recommended (up and down)	30Mbps & 150 Mbps
Mobile Devices	Throughput recommended (up and down) of tablets/smartphones	10Mbps & 100Mbps
Robotics	Cybersecurity	VPN tunnel is required (ideal VPN IPSec)
Robotic Mobility	Speed at which a service robot can move while maintaining a stable network connection	At least 2m/s
Robotic Energy Efficiency	The amount of energy required to transmit data, analyse data, and move of the service robots, measured in time	At least 6hours continuously
Cameras	Throughput minimum	1.5 Mbps

4.4.2 KPIs/KVIs definition and measurement

The KPIs in Table 26 for this use case are aimed at achieving optimal performance with the current technology available or to set a benchmark for future network advancements. The KPIs will be measured in the same way described in section 4.3.2.

Table 26. KPIs of UC3.

KPI name	Description/KPI definition	KPI target
Downlink throughput per device	The amount of data that can be transmitted over the network in a certain amount of time	50Mbps (min), 150Mbps (recommended)
Uplink throughput per device	The amount of data that can be transmitted over the network in a certain amount of time	10Mbps (min), 30Mbps (recommended)
App latency (glass to glass)	Delay between the image captured by the camera and it showed in the screen of the user device	800 msec
Location accuracy	Accuracy in the positioning of the device	5 meters
Latency	Round-trip time for successful delivery of a packet from transmitter (e.g., device) to receiver (e.g., dashboard) plus the time it takes to send the response back.	10-100 ms
Service availability	Capability of transmitting a given amount of traffic within a predetermined time duration with high success probability (calculated based on packet loss)	99.999%
Service reliability	Success probability of transmitting a layer 2/3 packet within a maximum latency required by the targeted service (ITU-R M.2410)	99.999%

KVIs in Table 27 for this use-case are defined to report the satisfaction level of the trial involved entities (consortium partners, applications end-users, open-call SMEs etc.) regarding important societal values for the future networks and applications.

Table 27. KVIs of UC3.

KVI name	Description/KVI definition	KVI target
Trust	Reported confidence in the digital devices, systems, and services used in the use-case development and operation.	>60-70% of the users expressing positive evaluation regarding the robustness of the devices, the trust-worthiness of the used AI algo-rithms, the E2E privacy of the sys-tem.
Resilience	Reported confidence in the reliability of the devices, network and over-the-top developed services and applications.	>60-70% of the users expressing positive evaluation regarding the reliability of the devices, network, developed applications and ser-vices.
Security	Reported perceived security of the digital de-vices, systems, and services used in the use-case development and operation.	>60-70% of the users expressing positive evaluation regarding the secureness of the devices and of the E2E system.

4.5 UC4: Smart Traffic Management

4.5.1 Preliminary technical requirements

In this use case, 6 video cameras without cellular connectivity will be connected to the commercial/private 5G SA network via one (or maximum two) 5G SA/NSA enabled outdoor CPE. Therefore, the technical require-ments presented in Table 28 refer to the cameras, to the performance and quality of the link between the CPE and the 5G network, and with the extension to the Edge-computer facility that will be deployed in TUIASI. The data is analyzed to generate insights that can be used to optimize traffic flow, reduce congestion, and increase safety. The perception functions from the device local sensors processing to the result at the cooperative per-ception level may present a significant latency time of several hundred milliseconds. According to ETSI [29], in this kind of use cases the maximum end-to-end latency time allowed should be less than 300 ms. In addition, the Wi-Fi access points deployed within the public transportation vehicles and connected to the backbone infra-structure could be exploited.

Table 28. Preliminary technical requirements for UC4.

Device Type	Requirements	Target
Camera	Average generated throughput at the resolution recom-mended by the application design (1280x720)	2 Mbps
Camera	Throughput generated at a streaming resolution of 2K	7 Mbps
Camera	Maximum recommended RTSP latency	200 ms
Camera	Minimum no. of FPS recommended by the application de-sign	15 FPS
Camera	Minimum camera IR range	30 m
Camera	Horizontal recommended angle	>90o
5G CPE	SNR	>15 dB
5G CPE	RSRP	>-90 dBm
5G CPE	Monitoring	TR-069 Compatibil-ity

5G CPE	Minimum Up-link throughput to be supported	6 x 2 Mbps
5G Network	Camera to Server link latency	10-15 ms
5G Network	Recommended throughput per link	6 x 7 Mbps
AI Server	Processing capabilities for AI algo & application for 6 streams of 15fps of 2K images	< 50 ms
LoRaWAN Air Quality Sensor	SNR	>10dB
LoRaWAN Air Quality Sensor	RSSI	>-110dBm
Wi-Fi AP	Wi-Fi Minimum RSSI	-75 dBm
Wi-Fi AP	Wi-Fi Minimum SNR	18 dB
Air Sensor	Air Sensor to Wi-Fi Router Minimum RSSI	-80 dBm

4.5.2 KPIs/KVIs definition and measurement

The KPIs in Table 29 for this use case are aimed at achieving optimal performance with the current technology available or to set a benchmark for future network advancements. The KPIs and KVIs reported in Table 29 and Table 30 are evaluated based on testing procedure described in Section 3.5.4.

Table 29. KPIs of UC4.

KPI name	Description/KPI definition	KPI target
Downlink cell capacity	The maximum downlink throughput that can be achieved by the cell when multiple devices are connected to it.	1.5 Gbps
Uplink cell capacity	The maximum uplink throughput that can be achieved by the cell when multiple devices are connected to it.	150 Mbps
Uplink cell capacity	The minimum uplink throughput that has to be achieved for the use case link at app recommended resolution.	6 x 2 Mbps
Uplink cell capacity	The minimum uplink throughput that has to be achieved for the use case link at 2k resolution.	6 x 7 Mbps
Application-level latency	The delay between the time the application receives the data from the network and the time is returns a computed result.	<50ms
E2E latency	Roundtrip latency between the device and the network.	<15ms
Service reliability	Period of time for which the mobile service maintains the performance standards defined above (downlink/uplink capacity, E2E latency).	99%
Service availability	Period of time for which the mobile service is available for the users.	99%

The cell capacity will be measured by running simultaneous iPerf sessions, for both uplink and downlink traffic, between 2-3 5G devices connected to the network and a server placed in the Edge-compute facility. The E2E latency will be measured by running ping probes between the 5G devices and a server from the Edge-compute facility. The application-level latency refers, in this use-case, to the processing time related to crowd-monitoring related tasks and will be measured at the software level. The service reliability and availability will be measured by specific functions inside the CN and RAN and will be reported to demand when needed.

In addition, during the trialing activities, the scenarios will be defined to test the impact of proactive AI-enhanced management and orchestration mechanisms on the service performance, finding the relationship between

Key Performance Indicators (KPIs) such as service deployment/scaling time (management and orchestration KPI) with service reliability and downtime (service KPIs), which is extremely important for ensuring safety of vulnerable road users in busy traffic environments like Podu Roș Intersection Area.

KVIs in Table 30 for this use-case are defined to report the satisfaction level of the trial involved entities (consortium partners, applications end-users, open-call SMEs etc.) regarding important societal values for the future networks and applications.

Table 30. KVIs of UC4.

KVI name	Description/KVI definition	KVI target
Trust	Reported confidence in the digital devices, systems, and services used in the use-case development and operation.	>90% of the operators from the municipality expressing positive evaluation regarding the robustness of the devices, the trustworthiness of the used AI algorithms, the E2E privacy of the system.
Resilience	Reported confidence in the reliability of the devices, network and over-the-top developed services and applications.	>90% of the operators from the municipality expressing positive evaluation regarding the reliability of the devices, network, developed applications and services.
Security	Reported perceived security of the digital devices, systems, and services used in the use-case development and operation.	>90% of the operators from the municipality expressing positive evaluation regarding the secureness of the devices and of the E2E system.

4.6 UC5: Control Room in Metaverse

4.6.1 Preliminary technical requirements

In this use case, sensors, and cameras with cellular-5G connectivity will be deployed. The technical requirements presented in Table 31 refer mainly to the performance and quality of the link between the devices and the 5G network.

The technical requirements of sensors and cameras will be derived during the testing phase in a controlled environment prior to their deployment at the target location. Following the identification of their technical requirements and of the exact number of devices that will be deployed, these will be used to derive the IoT platform Symphony's throughput as well as the overall network requirements.

Wi-Fi sensors process locally the probe-request traffic (mainly for privacy reasons) and output a summary with the counter of people and some additional metadata every T seconds. Thus, T can be seen as the reactivity time of the monitoring system and can be tuned based on the targeted application. The actual throughput of the traffic generated by the Wi-Fi sensors is equal to the size (in bit) of each summary message divided by T. So, the throughput can be tuned based on the required reactivity. E.g., for T equal to 1 second, the throughput can be estimated as few kbps for each sensor. Regarding the latency, the dynamics of people mobility occurs at a time scale (seconds, minutes) much larger than 5G network delays, thus it does not impose any constraint on the network QoS requirements.

The Table 31 provides rough estimates on the target performance needed to roll out the testing – it is worth mentioning that the numbers will be subjected to revision and refinement.

Table 31. Preliminary technical requirements for UC5.

Device Type	Requirements	Target
Metaverse Application	Maximum latency	100 ms
Metaverse Application	Maximum packet loss probability	0.5%
Metaverse Application	Throughput (up and down)	10Mbps
Metaverse Application	Throughput recommended (downlink)	40+ Mbps
Metaverse Application	Number of users active in the metaverse	10-12
IoT Platform)	E2E Latency (Data collection and Visualization)	< 300ms
IoT Platform	Data visualization loss	< 1%

4.6.2 KPIs/KVIs definition and measurement

KPIs in Table 32 for this use case are defined now as aspirational values, trying to get the best with the available technology and, if it's not affordable now, to define a target for future network evolutions. The KPIs and KVIs reported in Table 32 and Table 33 are evaluated based on testing procedure described in section 3.6.4.

Table 32. KPIs of UC5.

KPI name	Description/KPI definition	KPI target
Downlink throughput per user	Sustained throughput in a file transfer of a user.	20Mbps (min), 100Mbps (recommended)
Uplink throughput per user	Sustained throughput in a file transfer of a user.	20Mbps (min), 100Mbps (recommended)
Downlink throughput per application	Sustained throughput for the aggregation of users in the venue.	10.12 users @ min 20Mbps up to 100Mbps
Latency	Round-trip time for successful delivery of a packet from transmitter (e.g., device) to receiver (e.g., dashboard) plus the time it takes to send the response back.	< 100 msec

Use case KVIs are defined as the percentage of visitors expressing a positive evaluation (scores 1 to 3 on a 6 points scale) on the accessibility, user experience, edutainment experience and social connection enabled by the technology during the trial. Both on-site and at-home visitors will be involved in the evaluation.

Where it applies, KVIs in Table 33 will be also assessed as a measure of the improvement of the visitor experience with the proposed technology, compared to standard (not technologically enhanced) visits.

Table 33. KVIs of UC5.

KVI name	Description/KVI definition	KVI target
Accessibility	Perceived acceptability, ease of use and comfort of the experience,	70% of operators expressing positive evaluation (to be reviewed n WP6).

User experience	Perceived usefulness of the experience,	70% of end-operators expressing positive evaluation (to be reviewed in WP6).
Training	Perceived usefulness in enhancing training experience,	70% of trainees expressing positive evaluation (to be reviewed n WP6).
Social connection	Perceived quality of social interactions, social connectedness and sense of community	70% of operators expressing positive evaluation (to be reviewed n WP6).

KVIs will be measured by *ad hoc* questionnaires with responses on a 6-point Likert scale [56] Percentages of users expressing positive evaluation on each KVI will be assessed. If feasible, *Happy or not* devices [57] will also be used to measure general satisfaction of users in the trial site.

5 Implementation time plan

This section defines the time plan related to the implementation of the use cases. The Table 34 summarizes the overall WP3 time plan in terms of the milestones that are defined for each use case in the following sub-sections.

Table 34. Overall WP3 time plan for use cases implementation.

	2023				2024				2025			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
UC1		MS1		MS2					MS3		MS4	
UC1		MS1	MS2					MS3			MS4	
UC2		MS1		MS2				MS3			MS4	
UC3		MS1		MS2				MS3			MS4	
UC4		MS1	MS2					MS3			MS4	
UC5		MS1		MS2			MS3				MS4	

5.1 UC1 Smart Crowd Monitoring (Madrid)

Table 35 reports the time plan of UC1 in Madrid.

Table 35. Time plan for UC1 (Madrid).

<table>
<tr><th>Activities</th><th>Description</th><th>Use Case Milestone</th><th>Time plan</th></tr>
<tr><td>UC definition</td><td>A pre-trial phase to lay the foundations of the activities and the definition of UC</td><td>MS1</td><td>Q2 2023</td></tr>
<tr><td>Devices</td><td>HW acquisition of end devices (cameras, LIDAR and software licenses)</td><td rowspan="3">MS2</td><td rowspan="3">Q4 2023</td></tr>
<tr><td>Infrastructure design</td><td>Design infrastructure for 5Tonic site</td></tr>
<tr><td>Device lab testing</td><td>Set-up and lab testing of HW and end devices</td></tr>
<tr><td>Infrastructure deployment</td><td>Deployment and set-up of infrastructure at 5Tonic</td><td rowspan="6">MS3</td><td>Q2 2024</td></tr>
<tr><td>KPI collection and analysis</td><td>KPI collection and analysis for performance evaluation at 5Tonic</td><td>Q3 2024</td></tr>
<tr><td>Infrastructure design</td><td>Design infrastructure for Madrid site</td><td rowspan="3">Q4 2024</td></tr>
<tr><td>Infrastructure deployment</td><td>Deployment and set-up of network infrastructure for Madrid site</td></tr>
<tr><td>Devices integration</td><td>Integration of HW and end devices into network infrastructure</td></tr>
<tr><td>Initial demonstration</td><td>Initial UCs demonstrations</td><td>Q1 2025</td></tr>
<tr><td>Test Cases execution</td><td>Uses case test cases scenario deployment</td><td>MS4</td><td>Q3 2025</td></tr>
</table>

KPI and KVI collection	KPI and KVI collection		

The milestones of UC1 in Madrid are:

- **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 to 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.

5.2 UC1: Smart Crowd Monitoring (Iasi)

Table 36 reports the time plan of UC1 in Iasi.

Table 36. Time plan for UC1 (Iasi).

Activities	Description	Use Case Milestone	Time plan
UC definition	A pre-trial phase to lay the foundations of the activities and the definition of UC	MS1	Q2 2023
Infrastructure design	Design infrastructure for Iasi site	MS2	Q2 2023
Devices acquisition and lab testing	HW acquisition for lab testing, build the lab setup and test the concept		Q3 2023
Infrastructure acquisition and deployment	Acquisition, deployment and setup of infrastructure for Iasi site	MS3	Q4 2024
System integration	Integration of HW/SW and end devices into the 5G network infrastructure		
Initial demonstration	Initial UC demonstrations		
Test Cases execution	UC test cases scenario deployment	MS4	Q3 2025
KPI and KVI collection	KPI and KVI collection		

The milestones of UC1 in Iasi are:

- **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.

5.3 UC2: Proactive Public Infrastructure Assets Management

Table 37 reports the time plan of UC2.

Table 37. Time plan for UC2.

Activities	Description	Use Case Milestone	Time plan
UC definition	A pre-trial phase to lay the foundations of the activities and the definition of UC	MS1	Q2 2023
Devices	HW acquisition of end devices (headset, telepresence system)	MS2	Q4 2023
Infrastructure and application design	Design infrastructure and applications for Athens site		
Device lab testing	Set-up and lab testing of HW and end devices		
Infrastructure deployment	Deployment and set-up of network infrastructure for Athens site	MS3	Q3 2024
Devices integration	Integration of HW and end devices into network infrastructure		
Initial demonstration	Initial UCs demonstrations		Q4 2024
Test Cases execution	Uses case test cases scenario deployment	MS4	Q3 2025
KPI and KVI collection	KPI and KVI collection		

The milestones of UC2 are:

- **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.

5.4 UC3: Autonomous APRON

Table 38 reports the time plan of UC3.

Table 38. Time plan for UC3.

Activities	Description	Use Case Milestone	Time plan
UC definition	A pre-trial phase to lay the foundations of the activities and the definition of UC	MS1	Q2 2023
Devices	HW acquisition of end devices (headset, telepresence system)	MS2	Q4 2023
Infrastructure and application design	Design infrastructure and applications for Athens site		
Device lab testing	Set-up and lab testing of HW and end devices		
Infrastructure deployment	Deployment and set-up of network infrastructure for Athens site	MS3	Q3 2024
Devices integration	Integration of HW and end devices into network infrastructure		
Initial demonstration	Initial UCs demonstrations		Q4 2024
Test Cases execution	Uses case test cases scenario deployment	MS4	Q3 2025
KPI and KVI collection	KPI and KVI collection		

The milestones of UC3 are:

- **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.

5.5 UC4: Smart Traffic Management

Table 39 reports the time plan of UC4.

Table 39. Time plan for UC4.

Activities	Description	Use Case Milestone	Time plan
UC definition	A pre-trial phase to lay the foundations of the activities and the definition of UC	MS1	Q2 2023

Infrastructure design	Design the system architecture to include the sensors within a network infrastructure for the Iasi site	MS2	Q2 2023
Integration testing and acquisition of the needed HW	HW acquisition for initial integration testing, building the lab set-up and lab testing of the system		Q3 2023
Infrastructure deployment	Deployment and set-up of HW infrastructure for Iasi site	MS3	Q3 2024
System integration	Integration and configuration of the SW modules and algorithms		
Initial demonstration	Initial UCs demonstrations		Q4 2024
Test Cases execution	Uses case test cases scenario deployment	MS4	Q3 2025
KPI and KVI collection	KPI and KVI collection		

The milestones of UC4 are:

- **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 to 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.

5.6 UC5: Control Room in Metaverse

Table 40 reports the time plan of UC5.

Table 40. Time plan for UC5.

Facility Activities	Description	Use Case Milestone	Time plan
UC definition	A pre-trial phase to lay the foundations of the activities and the definition of UC	MS1	Q2 2023
Devices	HW acquisition of end devices	MS2	Q4 2023
Infrastructure design	Design of technological infrastructure needed to roll out the demo testing and pilot		
Modules design	Population of Mozilla Hubs with content and training modules and development of an analytics visualization feature		
Infrastructure deployment and set up	Deployment and set-up of network infrastructure for Turin	MS3	Q3 2024
Devices integration	Integration of HW and end devices into network infrastructure		

Devices, application, and network lab testing	Set up and activation of HW and SW components with 2 successful demo testing prior to the execution of the real pilot		
Test Cases execution	1st pilot testing in real life conditions	MS4	Q3 2025
KPI and KVI collection	KPI and KVI collection		

The milestones of UC5 are:

- **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 to 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** (Q3 2025): This milestone involves the execution of control and experimental sessions of the trial.

6 Conclusions

This deliverable defined the use cases that will be implemented by TrialsNet in the context of the Infrastructure, Transportation and Security & Safety (ITSS) domain and the related specific requirements, as they are provided by the relevant verticals and application developers. This document builds on those requirements and the initial architecture blueprint for each of the trial sites, providing a high-level overview of the trials to be conducted in Madrid, Iasi, Athens, and Turin.

In addition to their definition, the document provides an overview of the application design, infrastructure components and functionalities, preliminary technical requirements, and evaluation method, planning and experimentation procedures for each of the use case. An initial time plan and main milestones per use case towards the completion of the trials planning has been defined, pointing out the various activities to be carried out for each use case progress and the associated tests of the B5G (towards 6G) technologies. Each use case could be refined (e.g., in terms of their implementation aspects) during the project lifetime and integrated based on the activity progress.

The deliverable aims to provide insights into the network requirements for supporting deployment of applications and that will add input to the platform and network solutions that will be designed and deployed in the context of WP2. In addition, for each use the most relevant KPIs and KVIs have been identified and that will be served as input towards WP6 together with the measurements that will be performed during the trial phase.

This deliverable is the first step towards the implementation of the use case which preliminary results will be captured in the second deliverable D3.2 "First results of Use cases implementation for ITSS domain". One of the main goals of the trials activities that will be carried out will be to understand where current networks are not sufficient to assure the performance needed by the use cases and based on that, to derive the new requirements for next generation mobile networks.

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