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# Deliverable D5.2

# First results of Use Cases implementation for CTE domain

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# List of Acronyms and Abbreviations

| Acronym | Description |
|---|---|
| *3GPP* | 3rd Generation Partnership Project |
| *5G* | Fifth generation of mobile communications |
| *B5G* | Beyond 5G mobile network |
| *5GNR* | 5G New Radio |
| *AAS* | Advanced Antenna System |
| *AGVs* | Automated Guided Vehicles |
| *AI* | Artificial Intelligence |
| *AIA* | Athens International Airport |
| *AIA DPO* | Athens International Airport Data Protection Office |
| *AIR* | Antenna Integrated Radio |
| *API* | Application Programming Interface |
| *AR* | Augmented Reality |
| *BW* | Bandwidth |
| *CMS* | Content Management System |
| *COTO* | Comune di Torino |
| *CPE* | Customer Premise Equipment |
| *CPF* | Control Plane Function |
| *CPU* | Central Processing Unit |
| *CROSEU* | Crossmedia Europe |
| *CTE* | Culture, Tourism and Entertainment |
| *DC* | Data Center |
| *DL* | Downlink |
| *DHCP* | Dynamic Host Configuration Protocol |
| *ERC* | Ericsson España S.A. |
| *FDD* | Frequency-division duplexing |
| *FPS* | Frames per second |
| *GAM* | Galleria d'Arte Moderna |
| *GDPR* | General Data Protection Regulation |
| *GPS* | Global Positioning System |
| *GPU* | Graphics Processing Unit |
| *IoU* | Intersection over union |
| *KPI* | Key Performance Indicator |
| *KVI* | Key Value Indicator |
| *LCD* | Liquid Crystal Display |
| *LTS* | Long Term Support |
| *MBPS* | Megabits per second |
| *MMw* | Millimeter Wave |
| *MECR* | Metaverse Extra Content Room |
| *mMIMO* | Massive Multiple-input Multiple-output |
| *MOT* | Multi-object tracking |
| *MP* | Megapixel |
| *MQTT* | Message Queuing Telemetry Transport |
| *ms* | Millisecond |
| *MS* | Milestone |
| *MTU* | Maximum Transmission Unit |
| *MVC* | Model-view-controller |
| *NPC* | Non-playable characters |
| *NSA* | Non-Standalone |
| *NR-DC* | New Radio – Dual Connectivity |
| *OAM* | Operation Administration Maintenance |
| *OTT* | Over the top |
| *PLS-SEM* | Partial Least Squares Structural Equation Model |
| *PoC* | Proof of concept |
| *POLITO* | Politecnico di Torino |
| *QoS* | Quality of Service |
| *QR* | Quick Response (code) |
| *RAM* | Random Access Memory |
| *RAN* | Radio Access Network |
| *SA* | Standalone |
| *SDK* | Software Development Kit |
| *SIM* | Subscriber Identity Module |
| *TDD* | Time Division Duplex |
| *TID* | Telefonica Innovación Digital |
| *TIM* | Telecom Italia Mobile S.p.A. |
| *TOS* | Terminal Operations Supervisors |
| *UC* | Use Case |
| *UC3M* | Universidad Carlos III de Madrid |
| *UL* | Uplink |
| *UPF* | User Plane Function |
| *VFX* | Virtual Effects |
| *VM* | Virtual Machine |
| *VR* | Virtual Reality |
| *WebGL* | Web Graphics Library |
| *WP* | Work Package |
| *XR* | Extended Reality |
| *YBVR* | Yerba Buena VR Europe S.L. |

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# Executive Summary

This public deliverable presents the initial results achieved within the framework of WP5, specifically focusing on Culture, Tourism, and Entertainment (CTE) use cases. This marks a significant step toward realizing the primary objective of the TrialsNet project, which aims to deliver compelling use cases contributing to the enhancement of urban liveability across various domains. The content of this deliverable is based on the use cases defined in the first WP5 deliverable D5.1 [1].

The preliminary results presented in this deliverable are based on the first platform and network solutions that have been deployed in the context of WP2 activties and that are based on the use cases requirements defined in D5.1 [1]. In addition, the results reported in this document adopt the harmonised framwork defined in WP6 for what concern the Key Performance Indicators (KPIs) and Key Value Indicators (KVIs) terminology as well as the Data Management Plan adopted by the project. Finally, it has to be highlighted that ethics implications are continuously considered in tight connection with the guidances elaborated in the context of WP8 “Ethics requirements”.

A short summary for each use case is given below (as the Use Case 13 “Extended XR Museum Experience” is performed in two sites, Turin and Athens, it will be detailed in different sub-sections).

**Use Case 10 “Immersive Fan Engagement” (Madrid):** This use case is based on the YBVR fan engagement service, which so far has been designed using fiber connections for the necessary links between cameras, production computers and the streaming distribution platform in the cloud. The goal of this use case is to explore the capabilities and limitations of the current 5G implementation for the immersive video streaming workflow, and to determine where it is possible to replace fiber with 5G connectivity to gain flexibility and versatility in venue deployments. This document presents the initial 5G network test (named as pre-test) description, development and results to evaluate the current cellular network's capabilities for this purpose. This pre-test was carried out in December 2023 at 5Tonic research laboratory, registering a first set of KPIs results, also a first survey with beta-users was carried out to measure the KVIs assigned for UC10.

**Use Case 11 “Service robots for enhanced passengers´ experience” (Athens)**: The aim of this use case is to create a connected airport ecosystem utilizing Artificial Intelligence (AI) algorithms and data from diverse sources to optimize passenger flows and improve the overall experience. This deliverable document details the final application design of the use case, the implementation activities that took place during this period as well as some preliminary tests that were performed in order to validate the solution as a whole. The reported tests confirmed the application´s´capabilities in video analysis, streaming, real-time post-processing, and restreaming. The WINGSPARK++ software efficiently managed multiple IP cameras, detecting congestion. The human detection model that was developed in the context of this use case is modular and supports integration of both pretrained and custom object detection models, with potential for further expansion. In the next period an new model will be trained and tested using input from thermal cameras rather than optical ones.

**Use Case 12 “City Parks in Metaverse” (Turin):** This use case seeks to showcase the capabilities of B5G/6G technologies in enhancing the visitor experience at cultural and public heritage sites, with a focus on edutainment and gamification. The experiment involves engaging users in an Augmented Reality (AR) and Virtual Reality (VR) fantasy game accessible via mobile phones or tablets (for the AR game) and VR headsets (for the VR game). The narrative and design of the whole game has been completed along with the development of the first two AR steps of the game, and the graphic features of the various characters. A team of four players with a tablet is tasked with acquiring a series of virtual artefacts (keys) by solving different challenges in four cultural-historical spots c of the Valentino Park. The AR functionalities are enabled via GPS coordinates. Once all artefacts are found, the game continues in a combat against an evil wizard utilizing VR headsets. The scenario, characters and artefacts of this step have been developed. The ultimate reward is a virtual exploration with a VR headset of a nearby fortress that is currently closed for renovation, which was developed by a previous project.

**Use Case 13: “Extended XR Museum Experience” (Turin):** This use case aims to enhance the appeal of four museums by developing immersive experiences also accessible through Turin's main tourist portal [2]. Simultaneously, it tests the capabilities of the public 5G network for seamless high-throughput data transfer of videos, images, and sound. Specifically, for the Galleria d'Arte Moderna (GAM) and Palazzo Madama, two iconic paintings, Fortunato Depero's "Plowing" at GAM and Giovanni Pannini's "View of Rivoli Castle", were selected to anchor the experimentation. These experiences, sharing a common structure, unfold in three parts. The initial segment is a pre-show utilizing video and sound to captivate visitors and pique their curiosity. In the second part, users employ a phone or tablet in AR to delve into the artwork, uncovering details, stories, or anecdotes. The final part, facilitated by VR headsets connected to the metaverse, enables visitors to explore the broader context around the paintings, viewing artworks of the same artist, movement, or relevant images and videos. A at the current project stage, while the narrative of the two experiences have been finalised, only the AR part and the VR background for the Castello di Rivoli have been completed. For the Museo Pietro Micca and Museo del Risorgimento, two immersive VR experiences previously developed are being enhanced together with the museums, to enable visitors to enrich the onsite visit with more engaging and immersive experiences and increase visitors' appreciation of the museums, while testing the performances of the local 5G network.

**Use Case 13 "Extended XR Museum Experience" (Athens):** The aim of this use case is to develop Virtual and Augmented Reality (AR/VR) digital applications aimed at showcasing the content and historical significance of various cultural sites, thereby enhancing the visitor experience and providing access to those unable to physically visit these locations. Two prominent tourist attractions have been selected for this project. The first attraction is the Parthenon temple, situated within the ancient Acropolis of Athens, dating back to the 5th century B.C. Users will have the opportunity to engage with this iconic site either through a Mobile Augmented Reality application or a Virtual Reality application compatible with VR headsets. The second attraction is the Corinth Canal, a relatively modern engineering marvel that holds significant commercial and economic importance in the history of Greece. The Corinth Canal is featured within the digital museum and Augmented Reality tour app. Both applications are designed with dynamic content updating capabilities, ensuring that users have access to the latest information and features. Leveraging a public 5G network, users can seamlessly access the most recent versions of content within each application, enhancing their overall experience and understanding of these historic sites.In this deliverable the final application design has been reported for both the applications as well as preliminary tests that were performed using the 5G experimental network at WINGS labs.

The results presented in this deliverable are based on the preliminary test activities performed in laboratory and/or on field contexts which will evolve into the trials phase based on the final applications implementation of the use cases and the network deployments. The results will be presented in the last WP5 deliverable D5.3 scheduled for September 2025.

# 1 Introduction

This document serves as the second deliverable of WP5, aiming to provide a comprehensive overview of the initial results from the implementation of use cases in the Culture, Tourism, and Entertainment (CTE) domain in terms of preliminary test of the applications in both laboratory and on-field environments, including the measurement of the related KPIs. The collected results will be used to further progress towards the final implementation of the uses cases that will be trialled in large-scale or experimental 5G and beyond networks deployments, supported by specific network innovation functionalities, optimized operations, and the value assessment of the provided solutions by the end-users. The main sections of D5.2 are outlined in the following.

Section 2 offers an overview of each use case, focusing on the final application design in terms of architecture, modules, functionalities, and interfaces. It elaborates on the activities carried out by each UC, such as GUI development, algorithm's implementation/integration, metaverse environment development, and content production.

Section 3 provides detailed information related to the trials, reporting on tests conducted in the laboratory or on field. It includes insights into early demos considered as "stable tests" that have been disseminated through videos, papers, events, etc. The test section comprises a description of the test setup, test summary outlining objectives, descriptions, measured KPIs, remarks (general outcomes of the test activity, including any preliminary expectations towards 6G requirements, if applicable), and next steps.

Section 4 reports the time schedule for each use case implementation and offers a review of the milestones presented in the previous deliverable D5.1 [1].

Finally, Section 5 summarizes the key findings of the document and outlines the next steps related to WP5 activities.

# 2 Use Cases implementation status

This section compiles a detailed overview of each use case development activity performed so far in the context of WP5. It delves into a thorough examination of the finalized application design, a culmination achieved through analysis of outcomes derived from preliminary tests.

## 2.1 UC10: Immersive Fan Engagement

The following sections outline the advancement in the development of UC10, providing a short recap of the use case description and describing its final application design.

### 2.1.1 Use Case recap

UC10 explores 5G and beyond 5G (B5G) limits supporting immersive fan applications already deployed by YBVR using fixed network infrastructure. YBVR has defined two different scenarios to test the 5G network. The first scenario is in-venue with mobile smartphones, where the user is receiving multi-screen information on the mobile smartphone showing the different TV feeds and choosing the preferred feed at any time (see Figure 1). This scenario requires low latency, a precise geolocation of the device and an optimized downlink to serve the video feed to a huge number of smartphones in a venue. The second scenario is at-home where users can enter into the event anywhere through mobile devices and VR headsets thanks to the cameras positioned on the courtside of the match, providing a seamless viewing perspective.


**Figure 1. Smartphone view of the in-venue experience.**

### 2.1.2 Final application design

In-venue scenario is based on a YBVR patented production solution for low latency streaming. It presents live streaming at 8K and multi-camera that users can select from multiple camera feeds, including 360/180 degree-camera and 2D broadcast with zero buffering and pinch to zoom feature as seen in Figure 2.

At-home scenario amplifies the remote viewing experience. The user enjoys an immersive experience from home, with immersive video (360 and 180-degrees) and multi-screen TV feeds included. The user experience is to be teleported to the venue to enjoy the match "virtually" from the front row of the arena. and users can view the event anytime (recorded) or live through their mobile devices and/or VR headsets. Users are immersed in the courtside during sports or concert events, that features instant camera change, high-quality video up to 8K (60FPS) and multidevice usage. Subsequently gives users the option to replay the scene in different views. This tailored viewing experience provides users with a personalized and immersive entertainment journey as seen in Figure 3. This scenario doesn't involve low latency since users can view the event anytime (recorded) or live through their mibile devices and/or VR headsets, but is more demanding on uplink bandwidth to contribute with huge video streams. A 360 camera rig (with 4 180-degrees cameras) is shown in Figure 4.

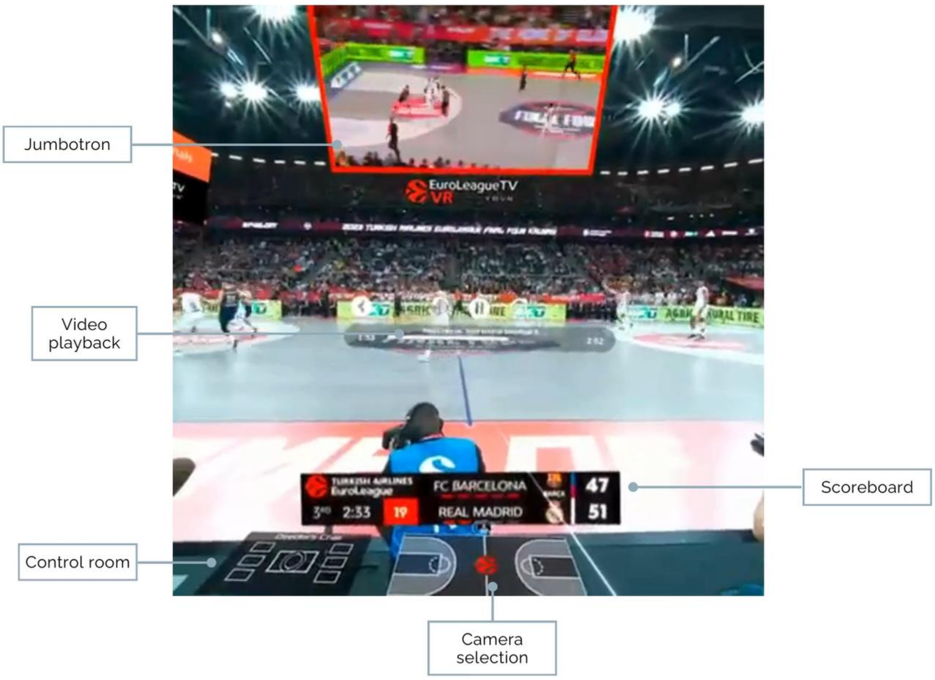


**Figure 2. VR viewer´s perspective.**

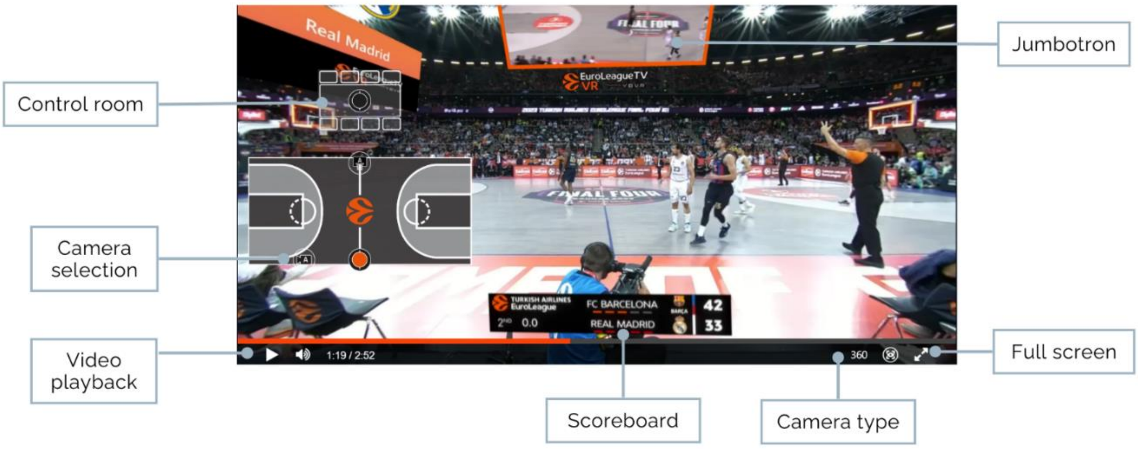


**Figure 3. Web and mobile viewer´s perspective.**


**Figure 4. 360-degrees camera rig.**

The design of the final application requires YBVR to adapt the existing YBVR solution for the two scenarios described above for whichYBVR has developed and has commercially released the Fan Immersive Application:

- **YB-Arena**: a real-time solution for audiences located in the venue, for mobile smartphones, like the in-venue scenario of this project.
- **YB-One**: an immersive OTT solution with VR for huge audiences, that features at-home scenario of this project.

These solutions are defined and deployed using fixed connections (mainly fiber/ethernet connections). The challenge is to move some links or segments of the communications architecture to 5G supported connections.

In order to progress towards the optimal design, candidate links to be moved from fiber to 5G radio link have been identified (as explained in D5.1 [1]) and tested. These links are numbered in the following Figure 5 and Figure 6.

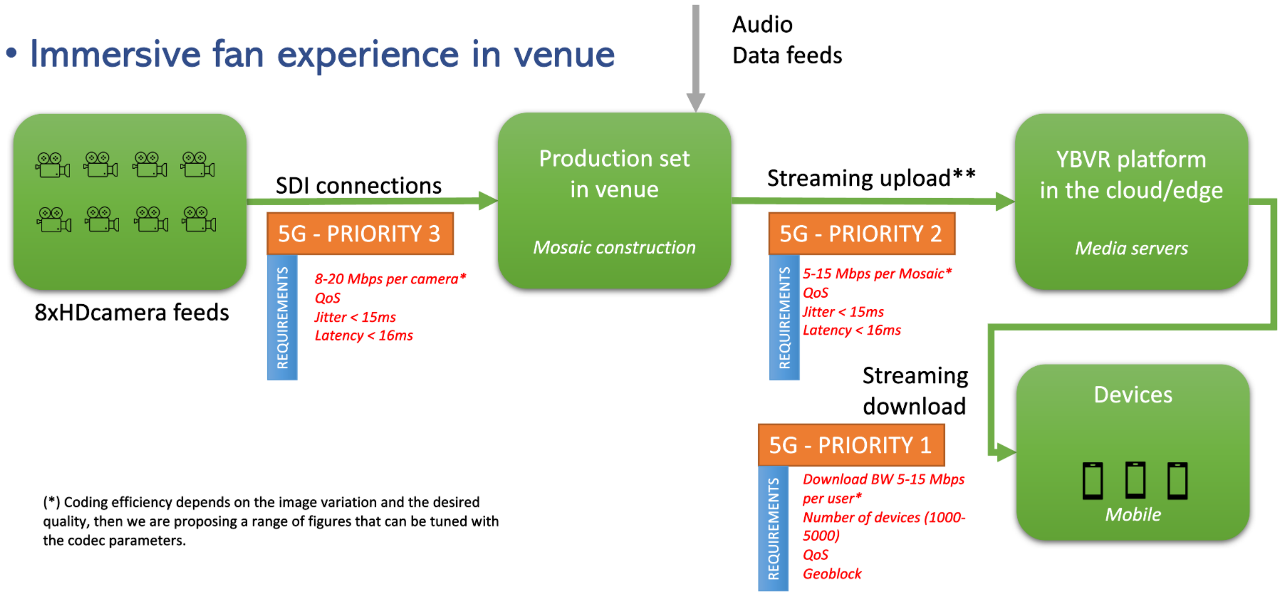


**Figure 5. In venue experience diagram.**

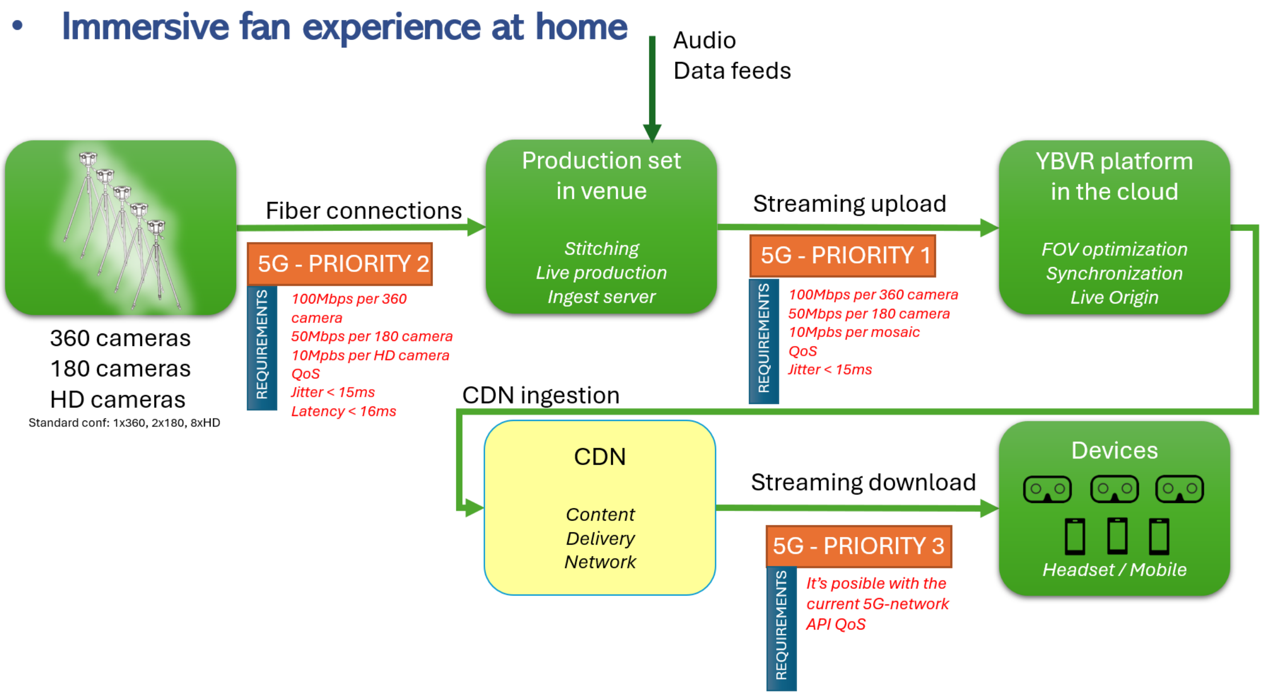


**Figure 6. At home experience diagram.**

The goal of the different tests is to check out if the 5G network is prepared to comply with the link requirements or, if not possible, to define the requirements for further evolutions (B5G or 6G). The final design will therefore depend on the feasibility check of the different links described above. Fiber or 5G can be decided as the appropriate technology to implement those segments. 5G will be selected, if possible, due to the easiness for deploying the different links.

To define the best design for the final application, the following three testing phases have been defined:

- **Pre-test**: Testing the 5G network today available with Ericsson (3GPP Rel-16) [3] in 5Tonic lab in Madrid. These tests are being carried out and are explained in the following sections.
- **Pre-trial**: Checking out the new features with new 5G features and frequencies (3GPP Rel-17) [4]. This test has been planned for May 2024, depending on the availability of millimetric compliant devices.
- **Trial**: Experience of both scenarios in a real basketball match. This trial has been planned for October 2024.

### 2.1.3 Development activities

The applications described in the previous section are commercial solutions provided by YBVR developed for a fiber-link scenario. According to the scope of the use case no further development has been required. Only testing activities have been performed which results are reported in section 3.1.1.

## 2.2 UC11: Service Robots and Enhanced Passengers´ Experience

The progress in the development of UC11 is described in the following sections including a recap of the use case description, the final design of the application and a description of the main development steps.

### 2.2.1 Use Case recap

UC11 aims to create a connected airport ecosystem utilizing AI algorithms and data from diverse sources to optimize passenger flows and improve the overall experience. 5G/B5G networks will facilitate the deployment of smart service robots for inspecting passenger flows and providing relevant information and services. The integration of AI-powered algorithms and data from cameras and sensors will enhance the efficiency of the passenger check-in process, reducing waiting times and queues. Real-time analysis of data, including historical information and B5G technology capabilities, will allow the system to detect anomalies and alert Terminal Operations Supervisors (TOS) for immediate intervention.

The AI-enabled robots will assist TOS in preventing congestion at check-in counters by providing personalized information to passengers. These robots will contribute to balancing demand for check-in counters, optimizing waiting times, and enhancing overall passenger service and experience. Furthermore, the smart service robots will offer additional services such as guiding passengers to boarding gates, personalized retail offers, and inspections for infrastructure issues.

### 2.2.2 Final application design

The application design of this use case involves various software modules and functionalities. Initially, optical cameras were planned to be installed at AIA, but due to GDPR concerns raised from the AIA DPO, it was decided to leverage on thermal cameras instead (by utilising thermal cameras, passenger physical characteristics are not recorded). Thermal cameras will be strategically placed at the airport to capture live video feeds from areas experiencing increased traffic and congestion. This data will be transmitted via the selected streaming protocol to the WINGSPARK++ platform, where the video feeds undergo processing utilizing AI algorithms for the detection of large crowds and congestion (Figure 7).

Simultaneously, any location data, etc., from the robots deployed at the airport terminal will be also transmitted to the WINGSPARK++ platform via the Message Queuing Telemetry Transport (MQTT) protocol for continuous connection with the server. Time-series data is stored in an Influx database, while a PostgreSQL database is utilized for storing the overall dataset. Subsequently, the data is transferred to user interfaces via APIs.

User applications receive real-time data through APIs. Specifically, a user interface (UI) has been developed to allow the TOS to receive real-time notifications and overview of camera placement areas. In cases of large crowds and congestion, notifications appear on the admin's dashboard for immediate intervention. Additionally, data from the robot, such as its position and feed from the integrated camera, is also sent to the dashboard. The WINGSPARK++ platform structure and modules utilized for UC11 are detailed below.

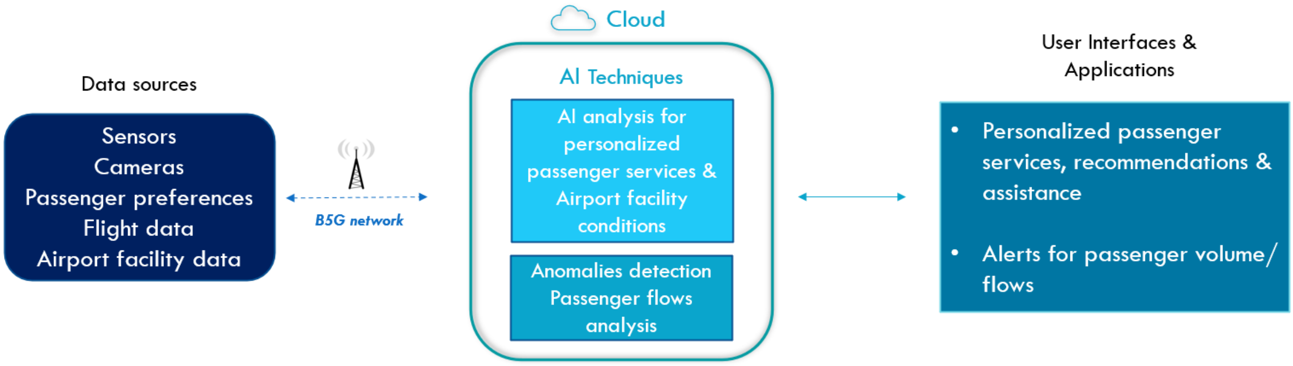


**Figure 7. UC11 high level view.**

The application can be broken down into the following main components (Figure 8):

- **Data input**: Any hardware such as Sensors, Robots, Drones, Cameras that communicates with the Data Processing layer. These devices are registered on the system with their details so that necessary information can be accessed by various parts of the system. Each of the devices can have one or more components (i.e. Sensors, Cameras) to collect further data.
- **Data Ingestion and Processing**: This part of the system is responsible for managing data streams from devices, processing it, and doing the necessary functionality for the various use cases. It receives the data from a device, either from an MQTT broker or a live camera/video feed, that, for example, in the case of a live camera feed that can be on a remote device or an IP camera. Depending on the type of device, different technologies are used to handle the frames, i.e. in the case of the camera being installed on a device each frame is sent to a remote server via ZMQ to handle further processing. For each different use case the data is processed accordingly, for example it could be passed directly on the datastore or passed through intelligence module for further processing and detections.
- **Intelligence Module Integration**: Depending on the use case a specific intelligence module is activated to process the video feed (frames from a camera) and make any necessary detections and calculations. For example, for human detection in the context of UC11, it monitors crowd congestion and flow in crowded areas, while tracking also the flows in order to be able to perform a second level of analysis to produce multiple statistics that give a representative picture of the crowd concentration and flow. Depending on the crowd concentration detected, the system is responsible for initiating any notifications required to indicate the issues on a dashboard. All communication with the main system is done through a remote REST API.
- **Streaming and Restreaming**: The restreaming module is responsible for receiving each processed frame and restreaming the frames via a restreaming media server. The restreaming media server is responsible for restreaming the videos in most of the streaming protocols, such as Real-Time Streaming Protocol (RTSP), Hypertext Transfer Protocol (HTTP) Live Streaming (HLS), Web Real-Time Communication (WebRTC) and more. Depending on the needs a specific streaming protocol can be activated.
- **APIs and Datastore modules**: Data generated from devices are stored in a timeseries database (InfluxDB) for further processing if needed and for future analytics. Any other information needed are stored in PostgresDB and are managed by the management server accessible via a RESTful API which is responsible for authentication/authorization, dashboard APIs, device configuration management and possibly other needed functionality.
- **Dashboard**: The dashboard is the management dashboard and is responsible for managing and presenting data generated by the devices, showing devices camera streams (if available), warnings and notifications and any analytics generated over time. Further features are added depending on the use cases.

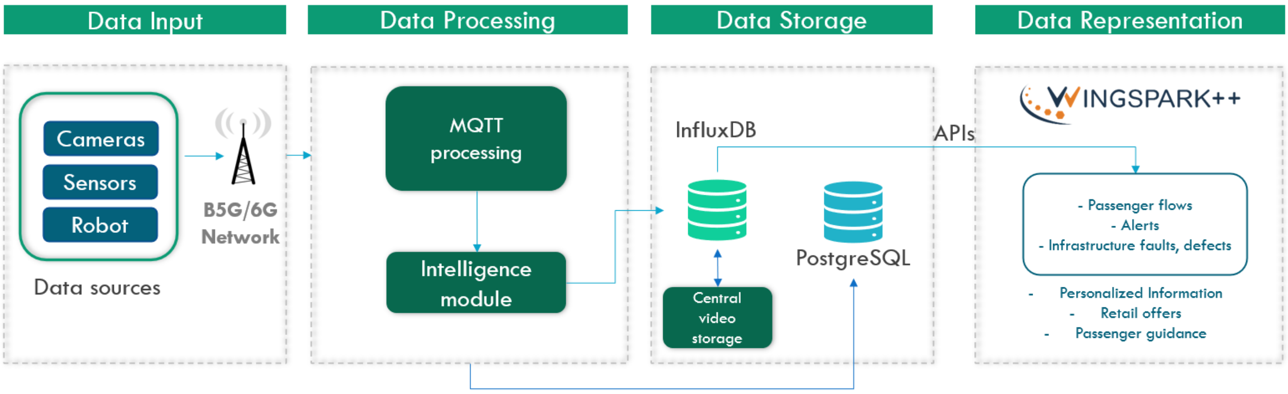


**Figure 8. UC11 final application design.**

### 2.2.3 Development activities

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

**WINGSPARK++ Platform**

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

**Development Operations (DevOps)**

Development of each component as a dockerised services and further deployment tools for ease of deployment of the services using latest technologies such as docker and docker compose inside a Virtual Machine (VM) that was provisioned via Ansible [5]. There are various deployment strategies such as dev, staging and production for different computer environment requirements.

**Robot**

Regarding the development activities on the service robot, progress has been made at both the software and hardware levels. On the hardware side, the foundational structure of the service robot has been completed, incorporating mechanical and electronic components (see Figure 9). The utilized sensors and components include:

- RPLIDAR-A2M12 [6]
- Realsense 435i [7]
- Interbotix px100 arms [8]
- Kobuki YMR-K01-W1 [9]
- Intel NUC i3 8gb [10]
- Quectel RMU500 5G modem [11]
- Verbatim PMT-14 touch screen [12]

An important feature studied is autonomous robot navigation combined with obstacle avoidance, allowing the robot to move autonomously within the airport facilities.

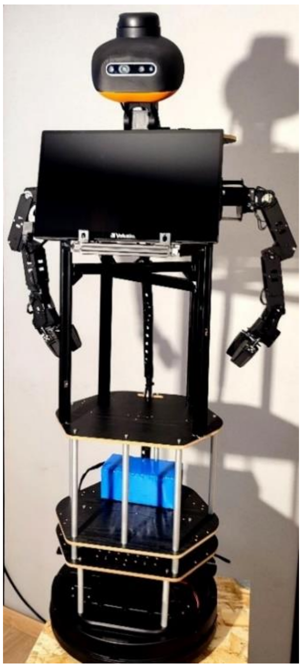

**Figure 9. UC11 service robot.**

Table 1 shows the status of development of the components of UC11 along with the plan for the next period.

**Table 1. Status for UC11 software development activities.**

| Software development activity / feature | Implementation status |
|---|---|
| **Main video analysis pipeline** | Done |
| **Containerized application services** | Done |
| **Streaming and Restreaming module** | Ongoing – Target Q3 2024 |
| **Authentication and Authorization** | Done |
| **Data Ingestion and Processing** | Done |
| **Datastore setup** | Done |
| **Rest APIs device configuration management** | Done |
| **Device Management – Admin Dashboard** | Ongoing – Target Q4 2024 |
| **Support for additional devices** | Planned for Q4 2024 |
| **Integration of additional detection models** | Ongoing - Target Q4 2024 |
| **Establish a deployment procedure** | Ongoing - Target Q4 2024 |
| **Visualization dashboard** | Ongoing – Target Q4 2024 |

## 2.3 UC12: City Parks in Metaverse

The progress in the development of UC12 is described in the following sections including a recap of the use case description, the final design of the application and a description of the main development activities.

### 2.3.1 Use Case recap

This use case revolves around an engaging fantasy game designed for teams of players, set against the backdrop of the Parco del Valentino, one of Italy's most popular parks (see Figure 10). Tailored for young adults, friends, and families, the game unfolds across various cultural points of interest within the park, incorporating stages that leverage AR, VR, and the metaverse. The game is characterized by its gameplay, flexibility, modularity making it adaptable to any city park. This innovative gaming experience is not only entertaining but also serves to promote cultural awareness and leverage cutting-edge technology in a public setting.

The primary objectives of this use case are as follows:

- **Promoting cultural access**: Utilizing gamification to encourage exploration and interaction with cultural points within the Parco del Valentino.
- **Encouraging exploration**: Stimulating a deeper connection with the park's monuments by fostering walking and exploration.
- **Stress 5G network**: Emphasizing the capabilities of the public 5G network by evaluating throughput and latency during the course of the game.


**Figure 10. 3D view of the Parco del Valentino in Turin (Google Earth).**

### 2.3.2 Final application design

The final application design derives from the outcomes of the Design Thinking+ session in May 2023. Multiple teams of four participants are invited to engage in an AR game, where each team member is equipped with a 5G-enabled phone or tablet. The objective of the game is to locate virtual keys hidden across various cultural sites within Valentino Park. Teams can uncover these keys by responding to quests or demonstrating their skills through various challenges. The game incorporates GPS positioning and people counting sensors to enhance the overall experience. Upon successfully finding all the keys, the team proceeds to a designated area, specifically the Talent Garden in Fondazione Agnelli situated right across the park. Here, the team is presented with a QR code, transporting them into a VR metaverse environment established on TIM’s experimental platform. Within this virtual realm, the final part of the game unfolds, requiring a collaborative effort of all four team members to overcome the last challenge. Additionally, external players can join the metaverse. The reward for the winning team is a virtual exploration of the Rocca of the Borgo Medievale which will be closed to the public from January 2024 until the end of 2026. The game in AR is entered via a QR code, while the different AR features appearing on the device screen are activated through geo-localisation when the player gets in the proximity of each cultural site. The final application design is outlined in Figure 11.

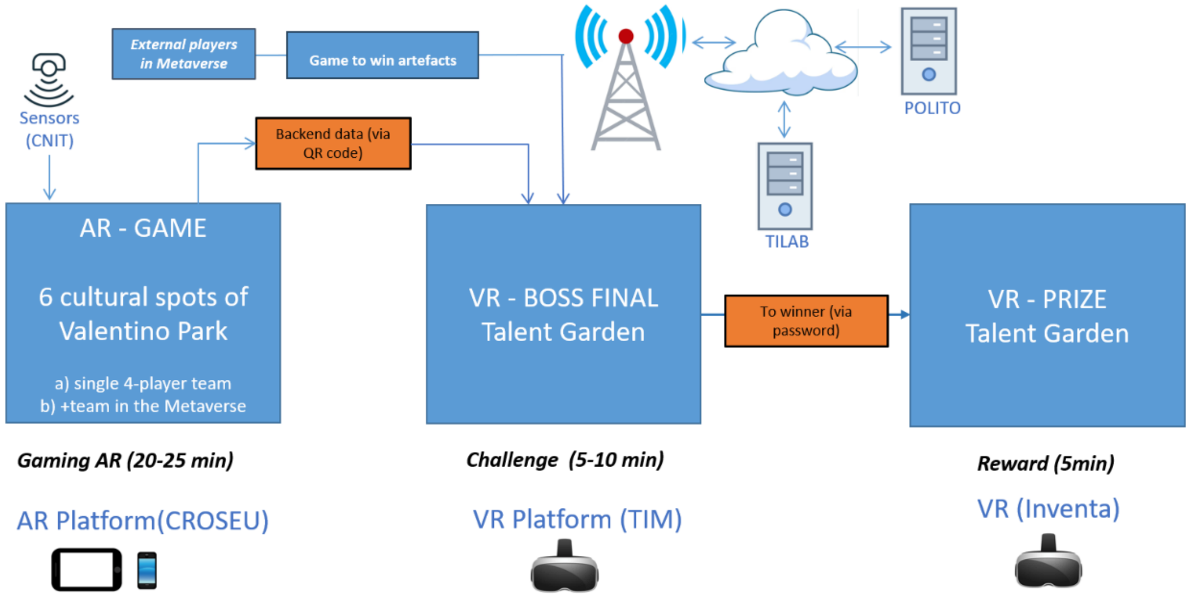


**Figure 11. Final application design of UC12.**

The initial phase of the game involves utilizing a web AR app through tablets or smartphones connected to the 5G network for a two-team competition. The AR app operates on the servers of Politecnico of Torino. Additionally, the game offers the option to include another remote group. A key aspect of the AR game relies on data from people-counting sensors, which is used in one of one of the six steps of the game. By solving the game challenges, the players acquire a certain number of artefacts to participate in the VR phase in metaverse.

Moving on to the second phase, the teams engage in a VR combat session against a computer-based opponent (Boss), determined by their performance in the AR game. The transfer from the AR to the VR phase is facilitated through a QR code. The VR App is hosted in TIM's premises, connected via the 5G network. The outcomes of the data determine the winning team's access to the third phase, a virtual tour of Rocca Medievale developed by Links Foundation as part of the Inventa project [13].

### 2.3.3 Development activities

The development of game components is described in detail in the following sections.

**Storyboard**
The narrative of the whole game was drafted based on the suggestions from the Design Thinking+ exercise in May 2023. As a first step, the partner COTO provided a list of 13 points of cultural interest in the Valentino Park. In order to limit the duration of the experience, it was decided to choose six of them (see Figure 12) - among them, the famous Fontana dei Dodici Mesi. In each spot, the players must pass different tests. Physical inspection of the selected spots and measurement of the distance between them has been performed to estimate the whole duration of the game. The chosen path in the park is depicted in the map in Figure 13, which also indicates the average walking time between two subsequent spots. This has implied several iterations with the software development team and various versions of the narrative that had been submitted. The final version was handed in the month of November 2023 which constitutes the basis for the software development phase.

| FASE | LUOGO | DESCRIZIONE | SIMBOLO | |
|---|---|---|---|---|
| 1 START | Fontana 12 Mesi | | | |
| 2 PRIMA TAPPA | Giardino Roccioso - Panchina degli Innamorati | Pendente della TERRA | | |
| 3 SECONDA TAPPA | Porta del Borgo Medievale | Scudo del FUOCO | | |
| 4 TERZA TAPPA | Società Canottieri Cerea | Ampolla dell'ACQUA | | |
| 5 QUARTA TAPPA | Castello del Valentino | Scettro dell'ARIA | | |
| 6 ARRIVO | Talent Garden | Combattimento finale in VR | | |

**Figure 12. Six spots of the Valentino Park for the AR game.**

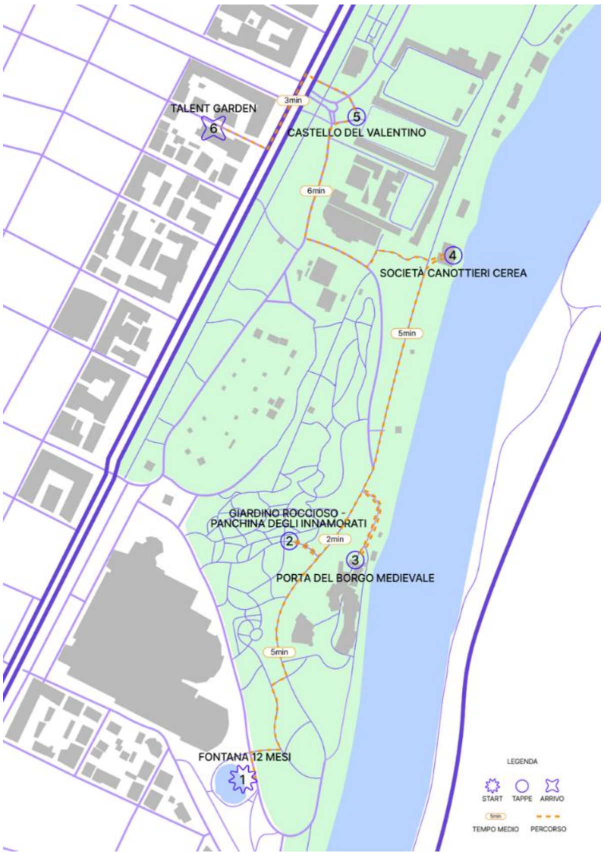


**Figure 13. Map of the 6 selected spots in the Valentino Park.**

**Augmented Reality**

Initial research was imperative to identify the tools and technologies essential for the project. The investigation focused on modules such as Augmented Reality (AR), QR code reading, multiplayer management, networking, and narrative tools. In the realm of AR technologies, particular attention was given to available software and libraries compatible with a web context, such as AR.js [14] and other WebGL [15]-compatible APIs. Specific coding efforts were dedicated to integrating AR functionality into the WebGL application, encompassing marker detection, 3D rendering, and interaction with AR elements. A thorough functionality test was subsequently conducted to ensure the software operated as intended, with a focus on tracking accuracy and smooth rendering. Additionally, optimization measures were implemented to prevent AR integration from compromising overall speed and responsiveness.

A comprehensive system was devised for dialogue management between players, emphasizing the architecture of the dialogue system. Assets for the dialogue system, including backgrounds, characters, text boxes, and graphical elements, were created. Integration of the dialogue system with the overarching narrative and gameplay mechanics of the WebGL application was ensured. The user interface was crafted to evoke a medieval cartoon style, incorporating consistent colours, fonts, and images. Clear and intuitive screens were designed for easy navigation, user progress tracking, and interaction with challenges. The user flow, from startup to challenge completion, was meticulously developed, with a focus on optimizing layout and touch controls for seamless mobile device usability.

The graphic design component was pivotal, involving the creation of characters central to the story. Information and inspiration for each character were gathered, exploring cultural, historical, and artistic elements influencing their design. Preliminary drafts and sketches were created for each character, considering various postures, expressions, and costume details, ensuring alignment with the overall story vision. Noteworthy characters, such as the “Hero”, the "Evil Wizard," the "Spirit of the 12 Months," and the "Guiding Statue," were crafted with distinct features reflecting their roles and backgrounds.

Figure 14 shows a screenshot of the device when a player arrives at the 2$^{nd}$ step of the game “la panchina degli innamorati (the lovers’ bench)” where he/she is confronted with the challenge to find several acorns to feed the squirrels. In exchange the squirrels will drop an artefact that the player will use to fight the evil wizard in the VR part of the game.


**Figure 14. First AR game of the “scoiattoli”.**

**Virtual Reality**

The final challenge (i.e., the part conducted in VR) represents the Hero's (e.g. the player) encounter with the Evil Wizard (the computer-animated Boss) that defends the Castle and combat. The Wizard will be holding an “Arcane Stick”, the main source of his power (see Figure 15 for first implementation of the Wizard).

**Figure 15. First implementation of the Evil Wizard.**

After a brief dialogue of confrontation, the Wizard will attack the Hero (i.e. the Heroes’ team of max 4 players), and using the Arcane Stick, it will begin to generate evil spells that, if successful, will take life points away from the Heroes. Those Heroes who succeed in the combat gain access to the final prize, i.e. a 3D VR visit of the Castle (Rocca Medievale in VR).

To develop this VR part of the game TIM will use the TIM XR Streaming Platform, already described in D5.1 [1]. It will be developed in Unity (2022.3 LTS version) using multi-player functionalities offered by Photon Networking [16] and it will then allow the 4 Heroes to search for or join the multi-player session game and interact each other and with the Evil Wizard for the final combat.

**Figure 16. Lobby and avatars waiting for the battle.**

Every player that comes from the previous AR part of the game could join the battle either alone or together with other players (max 4 players). Fighting the Evil Wizard in multi-player mode increases the chance of defeating it. Every player will join a "lobby" (a virtual room waiting for the real game to begin, see Figure 16) and enter the code he/she got from the previous AR part. This unique code represents the achievements of the player that he/she got from the AR part (whether it won a particular item or not). Each player will be represented in the game through an Avatar that can be chosen from among some predefined avatars. The app uses Ready Player Me platform [17] avatars. Moreover, VFX Graph - Visual Effect Graph Unity package [18] will be used to create all the visual effects representing attacking rays of the Evil Wizard (see Figure 17 for sample attack visual effect) and player defenses in the game.

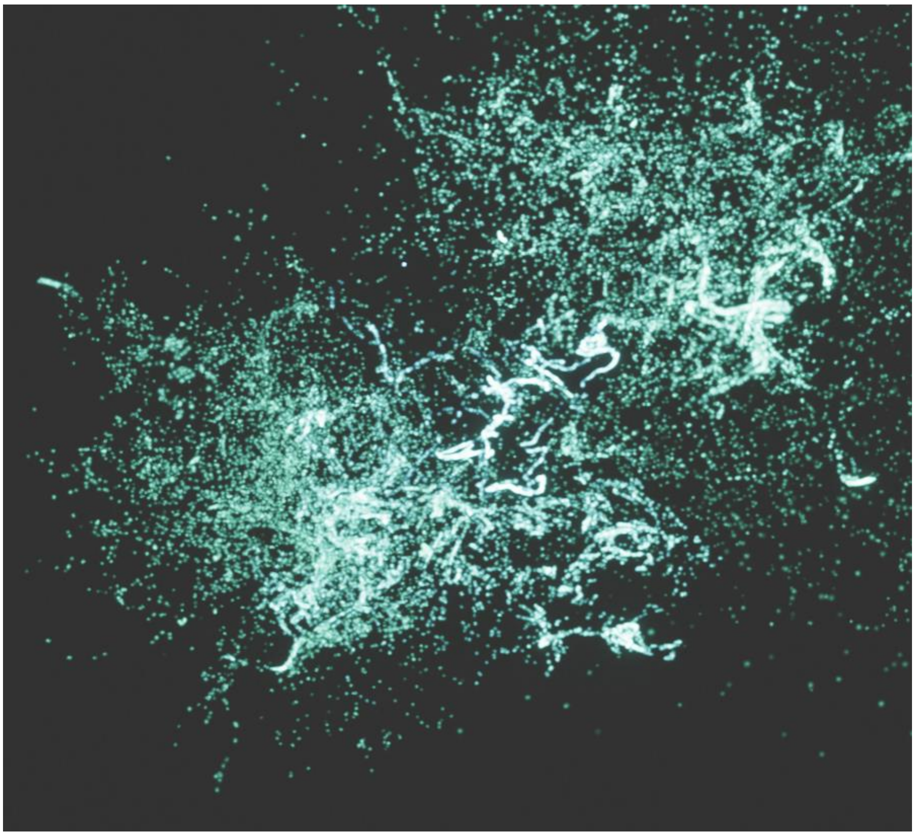

**Figure 17. Sample attack visual effect of the game.**

The navigation system of the platform will allow players to move their avatars through the virtual space of the game, interact with objects, other avatars and the wizard.

After leaving the "lobby" (the first player has the ability to start the real game after waiting for all other players to join), the real fight against the Evil Wizard begins. The Evil Wizard launches 4 different attacks to all the players, and the players must react accordingly to the current attack. The more together and with the right tool, the more effective is the defense. If the players are still "alive" after those first four attacks, the Evil Wizard proceeds with the final definitive attack. If all the players reach and steal the "Arcane Stick" to the Evil Wizard before this attack, the game ends with a victory and the twelve statues of the Fontana dei 12 mesi come to life and celebrate the players' win. The players will get a code to access the final prize.

**Devices**

Further to a tender procedure, COTO has awarded the company Impersive a contract to rent devices for the whole duration of the project along with users' support during the trials. The following services were procured in December and it will support the three use cases in Turin UC12 and UC13:

- **Operational Rental of VR viewers**: Supply 20 viewers among (16 Quest 2 [19] + 4 Quest 3 [20] complete with controller, charger and cable for charging.
- **Tablet Operational Rental**: Provision of up to 2 iPad 10.9 (10 gen) tablets with WiFi+5G connectivity (sim not included) chargers and charging cables [21]

- **VR Content Adaptation and Supply**: Stitching Mistika VR custom 8000x8000 VR 360 POV 3D (stereoscopic) [22]
- **Distribution Support**: Custom app player installation with gaze control for enjoyment of VR video content made by Impersive [23]. Support for content update, Phone/videocall technical support for assistance on visors and tablets. On-site technician presence to support use of visors.

Additional devices, in particular a high-end PC, a laptop, 7 5G tablets, and 2 Meta Quest 3 are being procured by Crossmedia Europe (CROSEU) for all trials in Turin. For the VR part, each player must be equipped with a VR headset (provided by COTO/Impersive) that will be connected via WiFi to a corresponding 5G smartphone (using tethering mode) equipped with a SIM (both smartphone and SIMs provided by TIM).

## 2.4 UC13: Extended XR museum experience (Turin)

The upcoming sections detail the advancement of UC13, encompassing a summary of the use case description, the final application design, and an account of the primary developmental milestones achieved.

### 2.4.1 Use Case recap

The primary objective of UC13 at the Turin site is to craft augmented/virtual reality experiences tailored for enjoyment across four municipal museums. This initiative partly builds upon the groundwork laid in previous European Union (EU) projects, particularly 5G-TOURS. The envisioned use case aims to deliver an immersive reality experience around four significant Turin museums: Palazzo Madama, Galleria d’Arte Moderna (GAM), Museo Pietro Micca, and Museo del Rinascimento (see Figure 18).

AR/XR devices will serve as the gateway for visitors to engage with exhibits, offering them the opportunity to explore high-resolution images, watch videos, read detailed content descriptions, and listen to captivating stories that pique their curiosity. The accessibility of content will be optimized for consumption on XR headsets or through mobile devices and tablets tailoring the experience based on the exhibition area, target audience, and the desired level of complexity/immersiveness.

The objectives of the UC13 are the following:

- Explore via Game thinking strategies enhanced access to museums
- Evaluate effectiveness of a new AR+VR and metaverse experience
- Explit the 5G network, in particular for throughput and latency performances

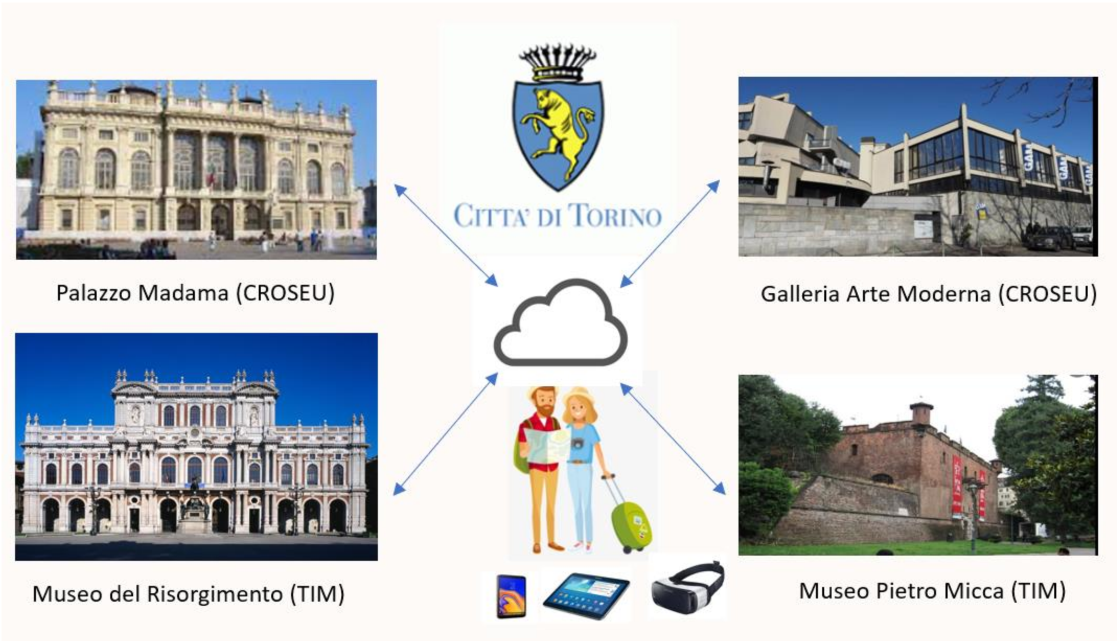


**Figure 18. Turin museums addressed in UC13.**

In the implementation phase, partner CROSEU is developing applications for Palazzo Madama and GAM, while the partner TIM is directing its efforts toward the Museo del Risorgimento and Museo Pietro Micca. This collaborative effort underscores the commitment to enhance the museum-going experience through cutting-edge technology, seamlessly blending cultural heritage with the possibilities offered by augmented and virtual reality. In the following sections, details on the application design and development activites for the diffent components are provided.

### 2.4.2 Final application design

**GAM and Palazzo Madama**

The final application consists of a monographic immersive experience on an iconic artwork in each museum. The experience articulates in three subsequent steps:

- **Pre-show**: A group of visitors enter a dedicated room in the museum where a short video explains the content of the experience that they are going to see in such a way to stimulate their curiosity.
- **Augmented Reality experience**: This step is conceived as to analyse the artwork in "depth". The visitors move to the room where the artwork is located. They are invited via QR code to open an AR application for the exploration of the artwork. Enhanced information/experience will be provided such as audio, video, expansion of details and 3D representation. The AR application is web based so the visitor will not be required to download a specific app. This is developed with the Vuforia software in a Unity engine, with an export based on WebGL.
- **Virtual Reality experience**: This step is conceived as to increase the "breadth" of the experience related to the artwork. The user after the AR experience can continue in a semantically coherent fashion the tour by moving to a room allocated for the metaverse together with friends/ other visitors or people remotely connected, the Virtual Museum Room aka as Metaverse Extra Content Room (MECR). In MECR, art will be presented that is in other museums but is closely related to the current exhibition. The metaverse software Mozilla Hubs is being used in the development of the VR part of the experience, which is open source, user friendly and with good graphic resolution.

The final application design of the system in the three blocks of the experience is presented in Figure 19. In total, the duration of the experience will be about 25 minutes, excluding the time to move from one room to another. The devices that will be used are smartphone, tablets, and VR headsets. The experience could be further customised by sending user's data and preferences across the three blocks. However, this function will only be developed for a potential commercial version, as it is irrelevant for the trials.

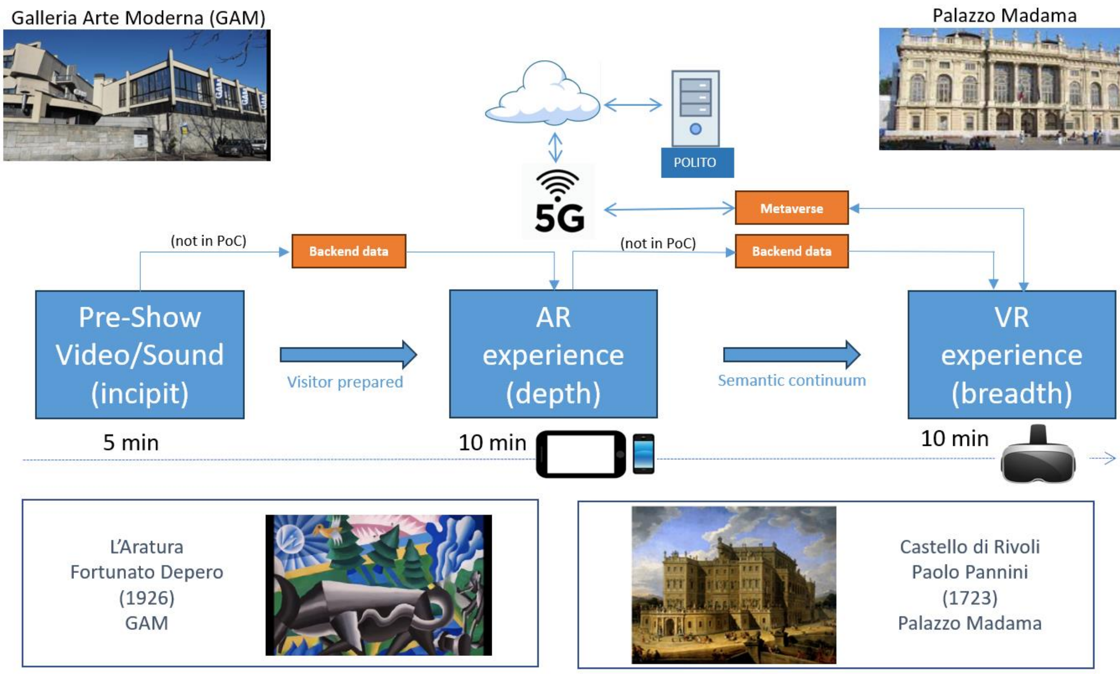


**Figure 19. Final Architecture application design of UC13.**

**Museo Petro Micca and Museo del Risorgimento**

Both Museo Pietro Micca and Museo del Risorgimento are interested in new way to engage visitors on-site with immersive and interactive VR experiences. TIM with representatives of both museums is developing two applications for VR headsets to allow visitors to explore the virtual reconstruction of some real spaces, enriching and deepening their visit by interacting with space and 3D objects related to the historical context of museums.

For Museo Pietro Micca TIM presented to the museum representatives a VR experience that takes place within 3D reconstruction of the underground tunnels (see Figure 20) where it is possible to engage visitors through a virtual guide. This guide, presented either through an avatar or a virtual narrator voice, narrates the history of various spaces and objects within the scene to provide an immersive experience for them. The starting point is the scale model of the Citadel of Turin, a pentagonal Savoy fortress located along the ancient Turin city walls where are displayed the ten different spots available where the tourists can be teleported by the virtual guide to explore the underground tunnels. Next, the user will be teleported to the entrance of underground tunnels where Pietro Micca, realizing the sudden arrival of the enemy, sent away a fellow soldier who was with him and activated the explosive to blow up the stairs. The user can see both an animation that will reconstruct the old walls of the Citadel and how the tunnels were before the explosion.

**Figure 20. VR Scenes of the Museo Pietro Micca.**

For Museo del Risorgimento, three different experiences were designed by TIM that will be submitted for review, verification of alignment with their interest and final experience. The VR experience proposals, that relate to the 3D reconstruction of the Chamber of Deputies, Figure 21, first seat of the Italian Parliament, are:

- **Virtual guide**: within the Chamber of Deputies, it is possible to engage visitors through a virtual guide. This guide, presented either through a virtual avatar or a virtual narrator voice, narrates the history of the various objects and characters within the scene to provide an immersive experience for the visitor.
- **Treasure hunt game**: the concept involves creating a treasure hunt using items found in the scene. Initially, the items are arranged on the table, and when the game begins, they disappear. Players must then move around inside the Chamber of Deputies to discover the hidden objects. The treasure hunt can be conducted using clues or by exploring the scene.
- **“Guess Who” game**: the concept is to reimagine one of the most popular board games, where each player must deduce a secret character by asking questions about their physical characteristics and receiving «YES» or «NOT» answers. In this version, a secret character can be randomly selected from the members of the Chamber of Deputies and the player has to guess the identity by posing relevant questions. The queries may revolve around physical characteristic or historical events. Following each response, the player can eliminate certain characters from the scene by clicking on them.

**Figure 21. VR Scenes of the Museo Risorgimento.**

**Devices**
For the experiences at GAM and Palazzo Madama, the same devices listed for UC12 will be used, since the trials will occur at different times.

For Museo Risorgimento and Museo Pietro Micca VR experiences, it is planned to have one station for each museum. Each station will be equipped with a High-End (NVIDIA GPU RTX 4090 [24]) Notebook, a CPE WiFi/5G with SIM for VR headset connection, and a LCD monitor to cast the VR headset experience all provided by TIM). In addition, Quest 2 and Quest 3 VR headsets are supported by both museums' experiences (provided by COTO/Impersive).

### 2.4.3 Development activities

In the following, the development activities performed so far for the 4 museus are reported.

**GAM**
At GAM, which experience is based on "The Ploughing" painting, it is important to make the visitor perceive movement, speed, noise as it was in the spirit of the Futurists so as to, on one hand, create an active participation of the user in acquiring the cultural part and, on the other hand, to have his or her point of view with respect to the work.

As discussed in the museum visit on the 19th of October 2023, a first phase of preparation of the visitor (pre-show) is thought of, which serves to immerse him/her in the spirit of the work through a sensory experience (entering the represented field, with background noises, sounds, vocal and textual descriptions) that also serves to familiarize him/her with the subsequent AR and VR phases.

In the AR part, in front of the painting, the Ploughing has been divided into a kind of puzzle, with reconstruction of the elements of the work in 3D, animations, text, and sound effects that recall the futurist manifesto. The visitor focuses on the geometric aspects, can recompose the work. Each time a piece of the puzzle is recomposed, an information or comment pops up. Figure 22 depicts a first implementation of the puzzle game.

**Figure 22. Puzlze game based on the "The Ploughing" painting at GAM.**

Finally, the visitors enter the final room where the VR experience will take place. The visitor enters the environment of the painting: it is 1926, the social and industrial perspective is explored, the focus is on the futurist manifesto, the shapes that compose and decompose to give idea of mechanics, speed, movement, even though the visitor does not actually move much. The GAM has another work from the 1800s (located in the warehouse) that reproduces ploughing in a classical way, and that will be used in the VR experience, as well as other futurist works that link to Depero's work.

The development has required several steps, in order to develop the narrative (to be edited according to the selected content), the 3D reconstruction of the artwork's elements, videos of the animations and files for the sound design.

**Palazzo Madama**

A similar 3 phases approach has been adopted also for the application of Palazzo Madama based on "The View of Castello di Rivoli" painting.

During this first phase - pre-show - the users, from their own device or from a device they will be given, will be able to access a Webapp, through a QR code that they will find in the pre-show reception area. The Webapp initial interface will allow the user, by means of an activation button, to start a short video (1'30"/2'00) that will introduce them to the contents and the operating modes of the experience.

Once the introductory video has been watched, the user will move in front of the painting for the second part of the experience in AR. A visit to Palazzo Madama revealed problems with lighting inside the room (which cannot be solved before the trial) and light reflections on the artwork, which makes it difficult to use devices pointing at details of the work to generate an AR experience. The proposed solution is to reproduce the image in very high resolution on the device used (tablet/smartphone) by dividing it into 6 navigable panes where the visitor can point and explore in AR elements of the work. In AR, one can illustrate the life of the castle, the history of the period, the characters in the painting, and the history of the painting.

Figure 23 contains an example of the AR App for the Castello di Rivoli showing a screenshot of the tablet used by the visitor. On the screen the painting is divided into six windows, each of which includes several details. By pressing on the detail, the App opens us a short explanation of the detail.

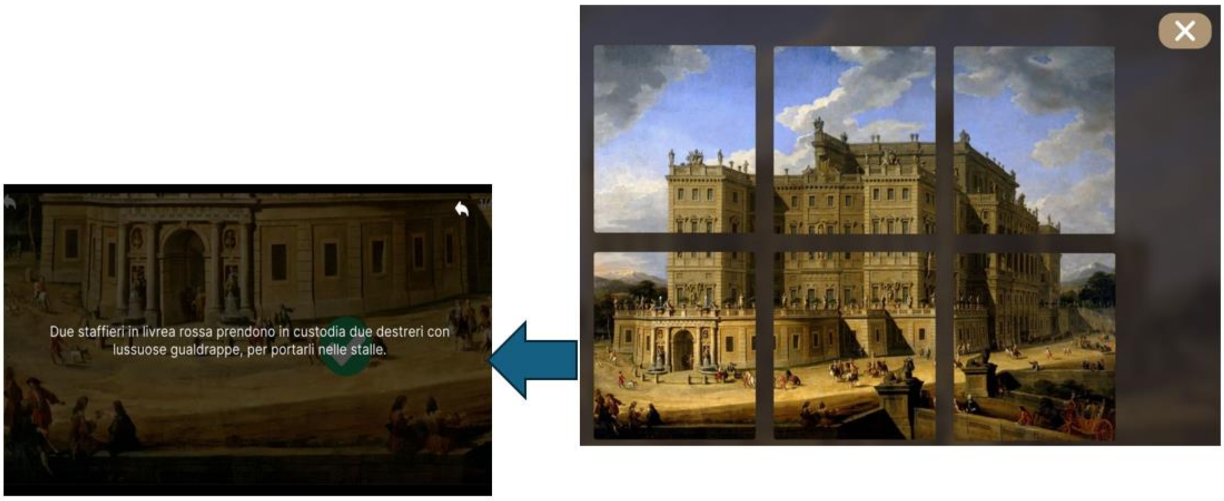


**Figure 23. Example of AR screenshot of the Castello di Rivoli.**

In the VR experience, the visitors enter a room (see Figure 24) where other views of the castle from the drawings and other paintings are reproduced, with a game mechanic that involves exploration through a guided path that stimulates the visitor to search. Content related to the current architecture of the castle would also be added. In the case of the Rivoli Castle, the 4 exterior views (paintings that are in other museums, in addition to or as an alternative to the drawings that are in the Palazzo Madama collection) need to be reproduced for the VR experience. In addition, Palazzo Madama has a video of the residences projected by Iuvarra and digital images of the Castle as it is today made by COTO with a drone.

**Figure 24. VR App of the Castello di Rivoli: corridor and main room.**

The development activities have so far focused on the narrative and the development of the AR and VR apps for the Castello di Rivoli. The main reasons were to present the game and its functionalities to the participants in the second meeting of the Design Thinking+ process which took place in Turin on 5/2/2024. Given the unanimous positive response from the participants, the development teams will proceed in the following months with the development of the AR and VR parts for the Ploughing, as well as with the pre-show for both museums.

**Museo Pietro Micca and Museo del Risorgimento**

In 2017 TIM developed two vertical apps for both museums based on the Unreal Engine 4.21 [25], a custom multiplayer solution (developed internally), and using the avatars provided by Oculus SDK [26]. In order to use the TIM eXtended Reality Platform described in D5.1 [1], two main developments have been carried out:

- Porting of all 3D Models from Unreal Engine 4.21 to Unity 2022.3 LTS (current game engine for the TIM XR Platform), including mesh, textures and materials.
- Integration of the new TIM XR Platform package to recreate the original app interactions but using Ready Player Me Avatars [17] instead of Oculus and multiplayer user communication based on Photon Engine Fusion v1 [27] and Photon Voice [28] instead of custom multiplayer solution.

In the next months the development will continue until summer 2024 with a view to performing the tests and trials in the 4th quarter of this year. For the GAM and Palazzo Madama, the narrative, the AR step of phase of VR phase of Castello di Rivoli has been completed while the development is still underway for the Ploughing. For the Museo Pietro Micca e Museo del Risorgimento, the next step will be the creation of two VR to implement what has been decided together with the respective museums.

## 2.5 UC13: Extended XR museum experience (Athens)

The progress in the development of UC13 is described in the following sections, including a recap of the use case description, the final design of the application, and a summary of the main development activites.

### 2.5.1 Use Case recap

As part of the TrialsNet project, WINGS has developed an AR application that serves as a digital museum guide and a VR application, offering interactive experiences and providing additional access to a wealth of information. The applications include information about archaeological sites, exhibits, and an insightful perspective on the evolution and history, aiming to enhance the visitor's experience and expand knowledge. The applications cover various subjects and areas of interest, such as the Acropolis [29], the Parthenon, and the Corinth Canal [30] It allows visitors to explore and learn more about exhibits and sightseeing areas, engaging and immersively.

The applications allow users access to various information and audiovisual material but also interact with 3D models of sites and exhibits, historical insights and maps, 360° panoramic images, and educational games. All these are done by exploiting AR technologies for plane detection, target image recognition, and touchscreen gestures. Additionally, VR technology allows users to explore and travel around 3D spaces and environments but also communicate and interact with each other via multiplayer capabilities, offering a more realistic and immersive experience.

### 2.5.2 Final application design

This section explores the essential infrastructure components and functionalities that form the backbone of WINGS system. Developed on Ubuntu 22.04 [31], the setup includes PostgreSQL [32] for robust data management, Apache2 [33] for web server capabilities, Grafana [34] or advanced analytics and visualization, and Node.js [35] to support Unity applications. This architecture is optimized for seamless operations over a 5G network, ensuring high-speed and reliable connectivity for Unity applications.

As described in the scheme depicted in Figure 25, the application architecture consists of three basic components:

- **Cloud Server**: A file system is accessible with native Unity Web Requests. Certain types of databases support digital content, such as texts, images, videos, and sound clips. Unity Asset Bundles contain 3D models, textures, and scenes and are requested by the applications with requests directly to the file system server.
- **End-User Level**: The front end of the applications fetches the updated content, and depending on the case of communication, there were different types of requests (e.g., GET, POST, etc.).
- **Analytics**: The application gather data metrics to monitor specific KPIs. The analytics run while the applications communicate with the server through an exposed API that was constructed with Node.js. The analytics are sent with JSON format containing timestamps for proper analysis. Then, the information is stored in a database and visualized in the Grafana environment. The timestamps, the primary component of this level, are the database used for the metrics storage (PostgreSQL) and the visualization tool that presents the results of the data analysis (Grafana).

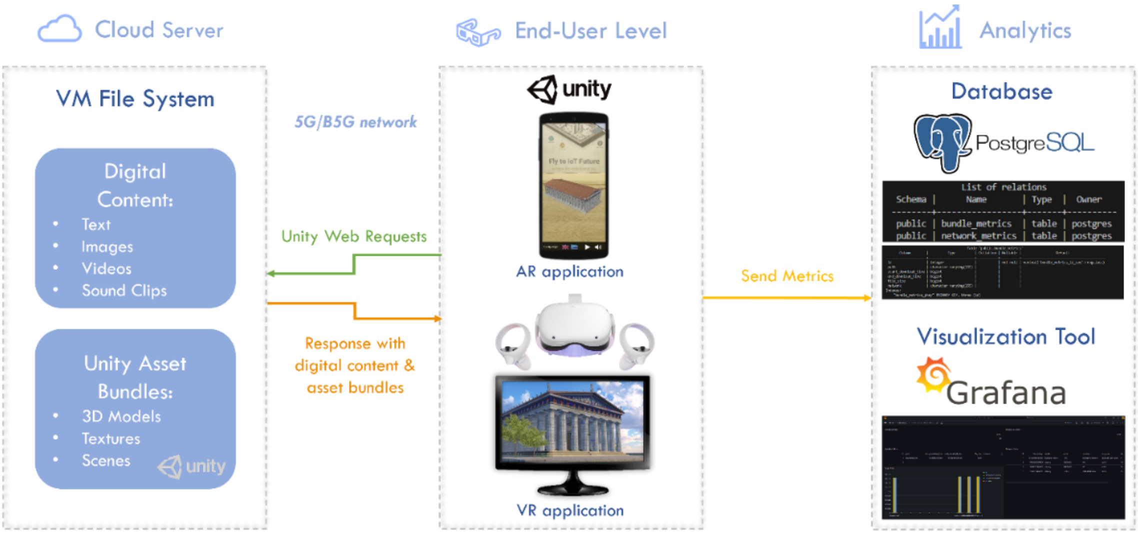


**Figure 25. High-level scheme of UC13.**

The **AR Parthenon** application consists of a user-friendly interface. It utilizes plane detection technology to spawn an Asset Bundle, which includes a 3D model of the Parthenon on any flat surface. A touchscreen provides resizing capabilities to scale up or down the 3D object in space and change, rotate, and adjust the model's position. The 3D model also includes interactable annotations in various positions to help users explore and discover the Parthenon's architecture and components through text and audiovisual description in two languages, English and Greek, created by an AI text-to-speech generator.

The **VR Parthenon application** offers users an immersive time travel to the ancient Acropolis, focusing on the famous Parthenon. The users begin their journey in a 3D archaeological museum room where they can select to explore a variety of renowned historic sites. Once inside the Parthenon's 3D environment, users transport themselves on the Acropolis as it stood centuries ago. They have the chance to wander through the space and discover interactable points and annotations strategically placed throughout the building. These points provide in-depth information about the Parthenon's rich history, intricate architecture, and significant components. To enhance the exploration, detailed text descriptions and audio clips are available in English and Greek, ensuring a comprehensive understanding. This scene is efficiently managed as an asset bundle, dynamically loaded on demand when users choose to enter. This approach optimizes performance and minimizes the initial download size of the application, allowing for a seamless and efficient user experience. Additionally, the application offers a multiplayer mode that enables visitors to communicate and interact with each other while connecting to the same room, inthis case, the Parthenon area.

As aforementioned, the application was expanded to cover additional areas of interest, including the **Corinth Canal**, to offer an immersive and insightful perspective of the history of the iconic waterway through interactive experiences. This includes:

- **Augmented Reality Tour Guide**: a guided AR tour that exploits image recognition, more specifically QR code detection technology, that can be used in the interior environment of a museum. Visitors can track QR codes located in various places inside a building using their mobile device camera to access exhibit insights. The content and data, text descriptions, images, and audio clips are stored and retrieved from a database and accessed through API requests.
- **Virtual Museum Tour**: the users, using mobile devices and VR headset, enter a 3D virtual space representing the Corinth Canal Museum, where they can navigate and interact with the 3D exhibits. They can explore artifacts and displays in a dynamic environment, which allows them to interact with history and the museum's content. Similarly to the AR Tour Guide, the content is dynamically displayed through API requests, and the data are stored and retrieved from the same database. The VR application also offers 360 panoramic images of the surrounding area and landscape to enhance users' connection with the historic landmark.
- **Quiz game**: an educational game with multiple choice questions for the enrichment of knowledge on various subjects concerning the Corinth Canal. The entire content of the chapters, questions, and answers is dynamically updated in the selected language through a central database and dynamically displayed through API requests. This feature enriches the game's future with additional learning material.

### 2.5.3 Development activities

The leading technologies of the AR/VR applications' development and implementation are summarized below:

**3D modelling and texturing**
This activity has been performed using Autodesk 3DS Max [36][37]. The architectural 3D model of the Parthenon was created based on the way it looked when it was first constructed which representation is based on historical sources and architectural sketches (Figure 26).

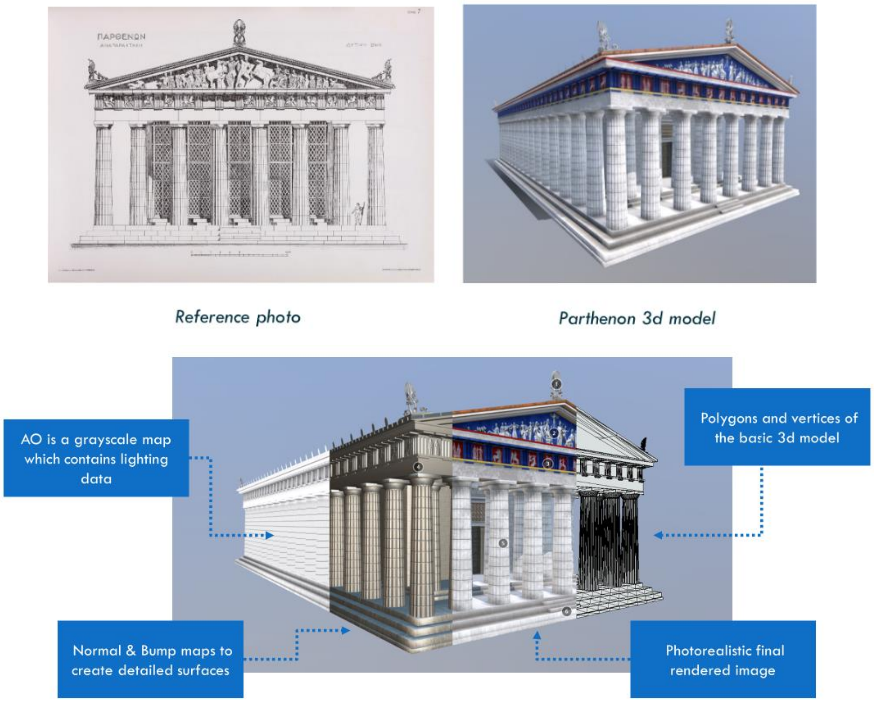


**Figure 26. Modelling procedure of the Parthenon.**

Additionally, the representation of the Corinth Canal Museum has been created based on architectural building plans and photographic material from a physical visit (Figure 27). Authentic exhibits are represented by 3D scanned objects that are displayed in the museum (Figure 28).

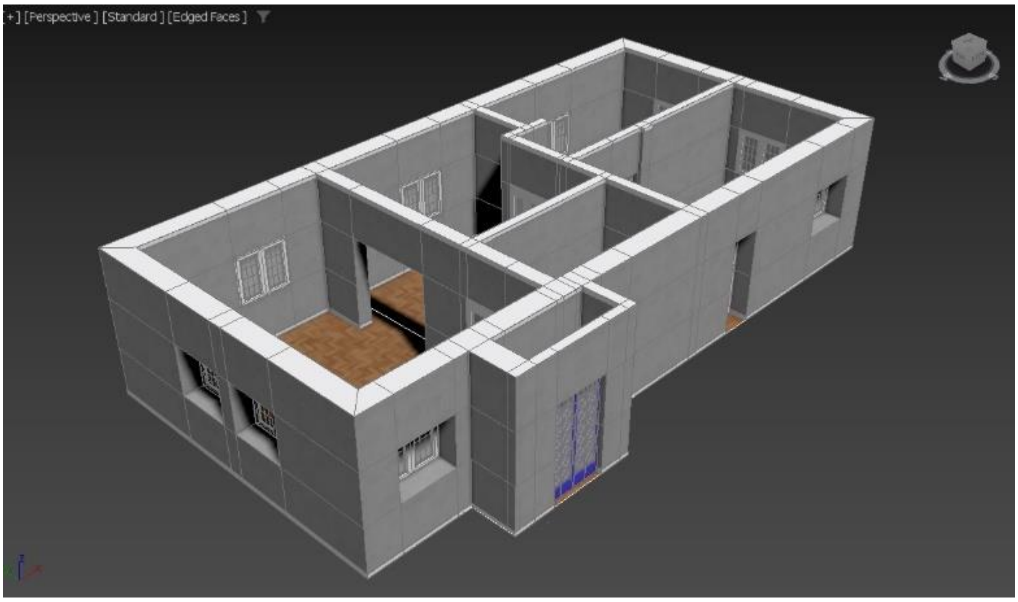


**Figure 27. Corinth Canal Museum 3D model.**

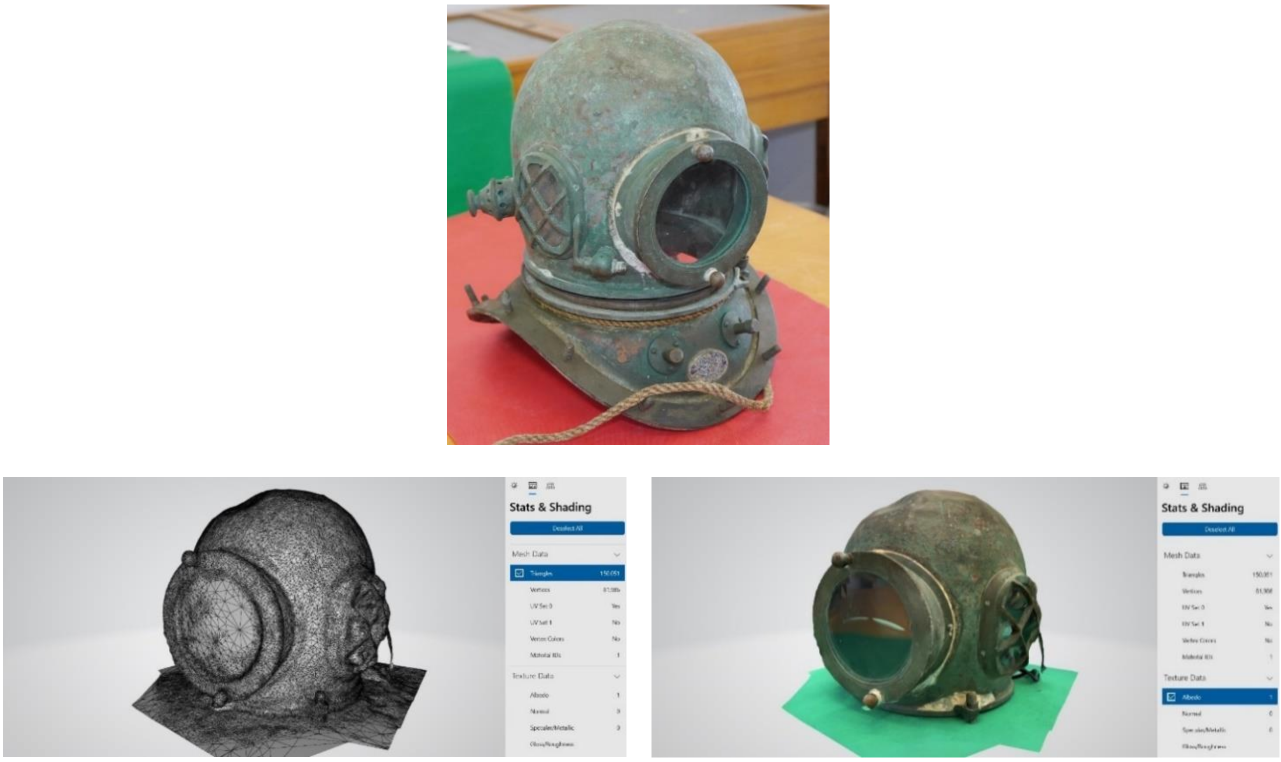


**Figure 28. Example of 3D scanned object, including the mesh and textures.**

### AR/VR development

Unity's AR Foundation [37] framework was used for the development of the AR features, specifically plane detection, and image tracking to detect and track surfaces and 2D images. QR Foundation [38] plugin was used for the QR recognition. This module uses computer vision algorithms to analyze the images captured by the camera module and identify objects and patterns within them. It then matches these objects and patterns with a pre-existing database of images to provide additional information about the objects.


**Figure 29. Example of Corinth Canal Museum exhibit.**

### Multiplayer platform

The Normcore Unity [39] plugin was used for the development and implementation of this feature. It is a networking plugin and hosting service created by Normal [40] that offers room servers to create multiplayer applications. It provides a component named Realtime, which bridges the scene to Normcore's datastore. Normcore is built on a client-server model and keeps the state of all clients in a room synchronized so they feel immersed in the experience by interacting with each other in the same space. This high-quality multiplayer networking plugin for Unity includes state syncing, physics syncing, voice chat, persistence, fast serialization with versioning, delta compression, flow control, and an intuitive API to create and sync custom components. Normcore provides rooms that are used to separate groups of players. Players who join the same room name are automatically connected to the same room. Also, all states are synchronized using the room's data store. Normcore also uses an MVC (Model, View, Controller) based architecture to help establish a clear separation of concerns for what handles the networking code. The data store holds a collection of RealtimeModel objects, ensuring client synchronization. In this case, the players' position, their name, which they can set and change from the main menu, and their colour, which is a random, unique colour that is assigned to each player who enters the scene, are all synchronized and viewed by all players who join. Players can also mute or unmute the voice chat. In Unity, each GameObject represents the visual state of the app. The View and the Realtime component scripts act as the controller.

Using the aforementioned plugins we developed an initial version of the multiplayer platform, which is to be tested in the trials.

### Mobile Content Management System

A mobile Content Management System (CMS) [41] that includes all the types of data an application may need. The developers and the editors can have access to the database and update the content of an application. The CMS is developed to store the following data types:

- Asset Bundles
- Scene Asset Bundles
- Texts
- Images
- Videos
- 360º Videos
- 3D Models

This system combines file storage and analytics for the application's content within an efficient system that manages bidirectional communication between the applications and a centralized system. Moreover, using a virtual machine (VM) has multiple purposes. It is employed to handle the requests for asset bundles within the Unity framework, ensuring seamless integration and efficient management of resources. Each type of content is stored efficiently in the database, guaranteeing swift and organized retrieval.

This system has beed developed in order to be able to store all the assets and file types that are needed for the application.

### Asset Bundles and VM Handling

Asset bundles have proven to be an effective solution to ensure consistent and up-to-date content in a museum application. Dynamically fetching Asset Bundles and Asset Bundle Scenes (called 'bundles' henceforth) enables users to access the most current content. These bundles can be created to target various platforms, such as Android and Oculus Quest. All the files are stored on a server alongside other necessary data, with the server serving as a centralized system responsible for managing application data. These bundles, created in the Unity Editor, are content packages. They typically include assets like textures, models, materials, cameras, scenes, and more. It's important to note that bundles cannot contain scripts. In terms of communication between a Unity app and the file system server where the bundles are stored, Apache 2.0 was used. A virtual machine (VM) is set up to handle requests for asset bundles. The application back-end flow consists of three parts:

- **Content Requests**: The AR/VR application updates its content by sending requests to the server.
- **Server Directories**: Bundles are made available upon request through server directories.
- **Exposed API**: Various APIs facilitate direct communication with the database, allowing for data retrieval or registration. These APIs expose custom database components that have been pre-configured.

The objective is to create a centralized system that is flexible and easy to maintain. The database structures are designed to be simple. This approach greatly supports content editing by individuals without extensive experience in back-end systems.

All the assets described above and more specifically the 3D models are exported from unity as asset bundles and then uploaded to the Mobile Content Management System described above in order to be able to be loaded on demand on the end users applications through the API mentioned above.

Below is Table 2 which shows the status of development for the UC13, along with the plan for the next period.

**Table 2. Status for UC13 software development activities.**

| Software development activity / feature | Implementation status |
|---|---|
| **Acropolis AR application** | Done |
| **Acropolis VR application** | Done |
| **Corinth Canal AR application** | Ongoing – Target Q4 2024 |
| **Corinth Canal VR application** | Ongoing – Target Q4 2024 |
| **Data Fetching and Processing** | Done |
| **Local VM supported server** | Done |
| **Public VM supported server** | Ongoing – Target Q4 2024 |
| **Devices Configuration** | Done |
| **Multiplayer Application** | Done |
| **Testing and Validation of the Applications** | Ongoing - Target Q4 2024 |
| **Local Network Metrics** | Done |
| **Public Network Metrics** | Ongoing – Target Q4 2024 |

# 3 First integration and test activities

This section provides an overview of the activities conducted and the challenges encountered during the integration and testing phases of the use cases developed in WP5. The measurement of KPIs has adopted the harmonized terminology elaborated in the context of WP6 and reported in Annex A of this document in which KPI IDs are defined. Furthermore, the dataset collection process, including the results of measurements, has been conducted in accordance with the guidelines established in the Data Management Plan defined by the project.

## 3.1 UC10: Immersive Fan Engagement

### 3.1.1 Trial 10.1 – Immersive Fan Engagement

The tests defined in the previous deliverable D5.1 [1] have been planned in three steps. Firstly, a pre-test involved assessing the 5G capabilities within the existing infrastructure at 5Tonic in 2023 based on 3GPP Rel-16 (see Figure 30). The previously scheduled deployment was October 2023, but ultimately carried out in December 2023. These tests are detailed in this document. The second step, a pre-trial is scheduled to be conducted before June 2024, involving the laboratory network upgrade to 3GPP Rel-17 as soon as the compliant terminals will be available. The third and final step will occur at the selected venue, deploying a fully equipped use case with real users.


**Figure 30. UC10 Pre-test in 5Tonic lab.**

#### 3.1.1.1 Laboratory tests

Tests set up required to include some laboratory elements in the network environment connecting the Use Case equipment. A Linux application has been developed to obtain the KPIs of the traffic sent to the 5G network. The probe runs as a service on a Linux Mini-PC, which sends the measurements obtained to an influxdb database that will later be used to generate the graphs of the different KPIs obtained during the execution of the tests. Figure 31 shows the elements described below. The probes can measure the KPIs of downlink throughput, uplink throughput and Round Trip Time (RTT) latency.

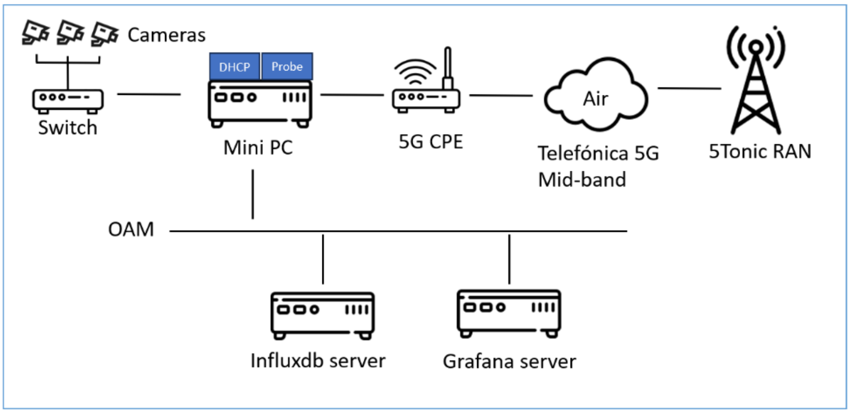


**Figure 31. 5Tonic probe setup.**

The Table 3 describes the radio network parameters that have been configured to perform the tests.

**Table 3. Radio Network configuration.**

| Test setup parameters | Test setup ID: Lab01 |
|---|---|
| **Radio access technology** | 5G NR Standalone |
| **Network type** | Experimental |
| **Standalone / Non-Standalone** | Standalone |
| **Cell Power** | 1W |
| **Frequency band** | n78 |
| **Bandwidth per component carrier** | 100 MHz |
| **Sub-carrier spacing** | 30 kHz |
| **MIMO** | 1x1<br>(best KPI result 4x4) |
| **Duplex mode** | TDD<br>(pattern: DDDSUDDSUU) |

As defined in section 2.1, the objective of these tests was to validate the links or segments of the communication architecture that can be transitioned from fibre support to 5G-based connectivity. Table 4 compiles the high-level requirements of the links to be tested for various scenarios.

**Table 4. Links to be tested in the 5G lab for Trial 10.1.**

| Link | Direction | Delay | Bandwidth | Jitter |
|---|---|---|---|---|
| **1** | Uplink | Low | Up to 100Mpbs | < 1/30 sg |
| **2** | Uplink | Low | Up to 100Mpbs | < 1/30 sg |
| **3** | Downlink | Low | Up to 12Mbps per user | < 1/30 sg |
| **4** | Uplink | Not a requirement | Up to 300Mbps | < 1/60 sg |
| **5** | Uplink | Not a requirement | Up to 300Mbps | < 1/60 sg |
| **6** | Downlink | Not a requirement | Up to 25Mbps per user | < 1/60 sg |

The following Table 5 summarizes the test carried out for Trial 10.1.

**Table 5. Test summary for Trial 10.1.**

| Test summary | |
|---|---|
| **Trial ID** | 10.1 |
| **Test setup ID** | Lab01 |
| **Facility/Site** | 5Tonic |
| **Objective** | Test the current 5G network capabilities to comply with UC10 requirements |
| **Description** | 6 links types has been defined and emulated in the lab |
| **Executed by** | YBVR and Ericsson |
| **Components involved** | 5Tonic Lab & Network, YBVR immersive fan solution |
| **Targeted KPIs** | KPI#03 (Downlink aggregate throughput)<br>KPI#04 (Uplink aggregate throughput)<br>KPI#09 (Application one way latency) |
| **Measurement tools** | Ericsson probes |
| **Ethics requirements implementation** | Faces of participants as beta users has been blurred in the videos captured for dissemination propose |
| **Involvement of beta-users** | Survey to meter KVIs has been probed with beta users to check the consistency of the indicator calculation method |

Elements in Figure 32 represent the deployment in 5Tonic lab in Madrid by Ericsson and YBVR to characterize the 5G network uplink and downlink traffic performance in the current 3GPP release. Tests were carried out on December 11$^{th}$ and 12$^{th}$, 2023. Ericsson provided the 5G network and the tests were conducted in the RAN coverage area called X3 room with the 5GC CP in the data center (DC). The current 5G RAN equipment is configured in mid-band (n78 - 3.5 GHz) and Standalone technology, where LTE is not required as an anchor and the Core supports both control and user plane (CP/UP). The software installed on the RAN and Core components is 3GPP Rel-16 compliant.

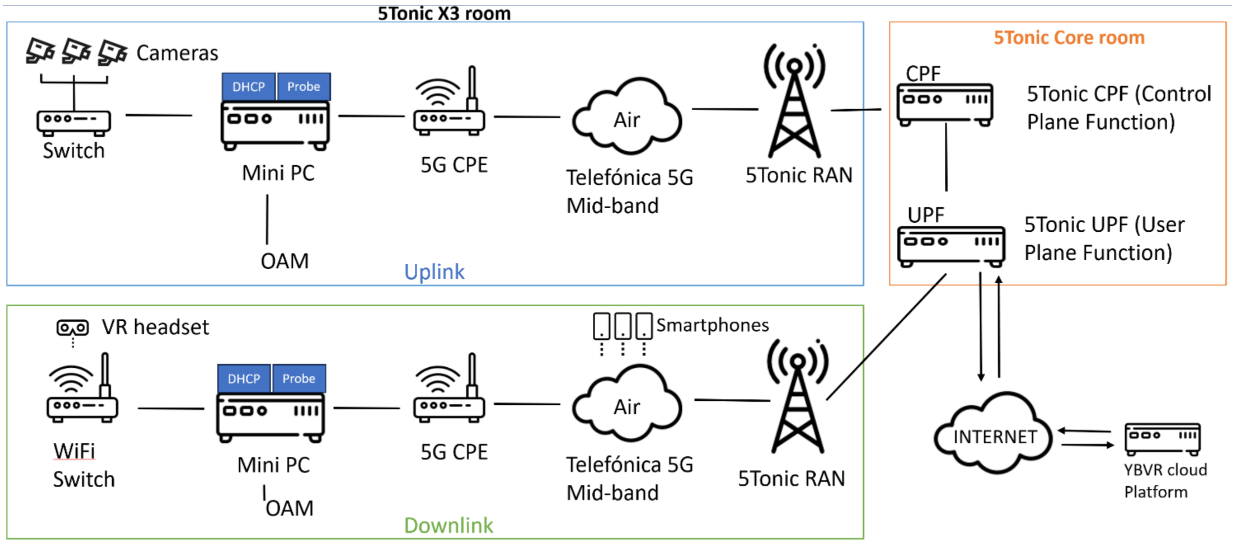


**Figure 32. 5Tonic lab testing setup.**

In uplink, YBVR transmitted a video signal through a switch connected to the Mini PC. This Mini PC is connected to the 5G CPE using an ethernet cable, and it includes a probe to measure DL throughput, UL throughput, and latency. The probe sends the measurements to an influxdb database located in 5Tonic DC using the

Operation Administration Mainte-nance (OAM) interface to avoid disturbing 5G traffic. The result is shown in Grafana tool [34].

In downlink, VR headset and smartphones receive the video according to the same network configuration described for uplink. VR headsets were connected via Wi-Fi, while smartphones via 5G network. For the VR headsets traffic passes through the probe on the Mini PC where DL throughput, UL throughput, and latency can be measured. Traffic from smartphones can be measured directly in the RAN in terms of DL throughput and UL throughput. The RAN KPIs are stored in the same influx database and shown in Grafana tool.

YBVR deployed 2 cameras Panasonic BGH1 with 180 degrees lens, 1 Insta360 Pro 2, and 4 PCs with different functions (1 to create multiscreen mosaics, 2 to capture and produce the 180 degrees streams, 1 to stitch the 360 video and host the ingest server for streaming). Also, 1 Meta Quest 2 was deployed with the YBVR App (player). Finally, the YBVR App for Android was installed and tested in two 5G smartphones provided by Ericsson.

**Link 1 and link 2 test**

Both links shared similar requirements, leading to their joint testing. The configuration involved the contribution of 8 mosaics of the Control Room experience (8xHD). This setup requires a low-delay connectivity for optimal user experience on the app, with an uplink requirement of approximately 80 Mbps constant bitrate (less than 100Mbps). The video source feed was locally ingested on the YBVR Ingest server on the production side and then connected to the 5G switch for uplink to the YBVR cloud infrastructure. The initial lab trial required an uplink bandwidth from the YBVR Ingest production server around 80 Mbps (continuous traffic). During this first test, uplink traffic problems were detected, having network drops when reaching around 25-30 Mbps on the uplink side. From the YBVR Ingest server point of view, the network traffic was dropping all the time and was not able to complete the ingest properly impacting on the user experience on the app (video playback issues). On the uplink network side, both the production and 5G network exhibit drops on the network due to the low uplink bandwidth available, as illustrated in Figure 33.

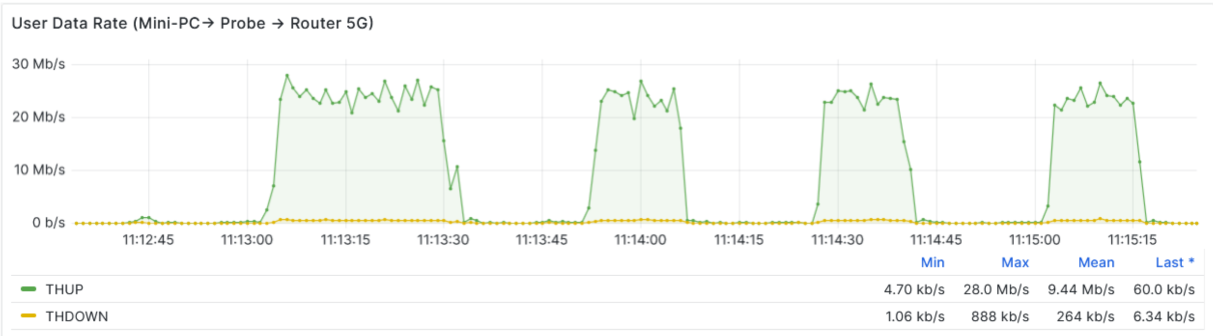


**Figure 33. Uplink throughput for link1 and link2 (80Mbps feed).**

Same tests were reiterated by decreasing the uplink bandwidth on the YBVR Ingest production server (although not an ideal solution) to assess the jitter and latency values. As expected, reducing the uplink bandwidth yields better results for jitter and latency on the probe. The following values reflect a reduction from 80 Mbps on the uplink to 50 Mbps, where despite the persistence of traffic drops impacting the video user experience, the jitter and latency values are improved, as depicted in Figure 34.


**Figure 34. Uplink throughput for link1 and link2 (50Mbps feed).**

Regarding jitter, the values shown on the 5G probes are high compared with the expected and required values by the use case, as shown by the figures in Table 6.

**Table 6. KPIs for 50 Mbps uplink feed.**

| KPI | Max | Mean |
|---|---|---|
| **Data rate** | 42.7 Mbps | 35.34 Mbps |
| **Latency** | 336 ms | 184 ms |
| **Jitter** | 980 ms | 55.5 ms |

The setup was also tested to measure the downlink using an uplink bandwidth around 18-20 Mbps (Figure 35). With this setup, no more traffic drops were detected on the uplink side and the downlink could also be tested with some concurrent devices.

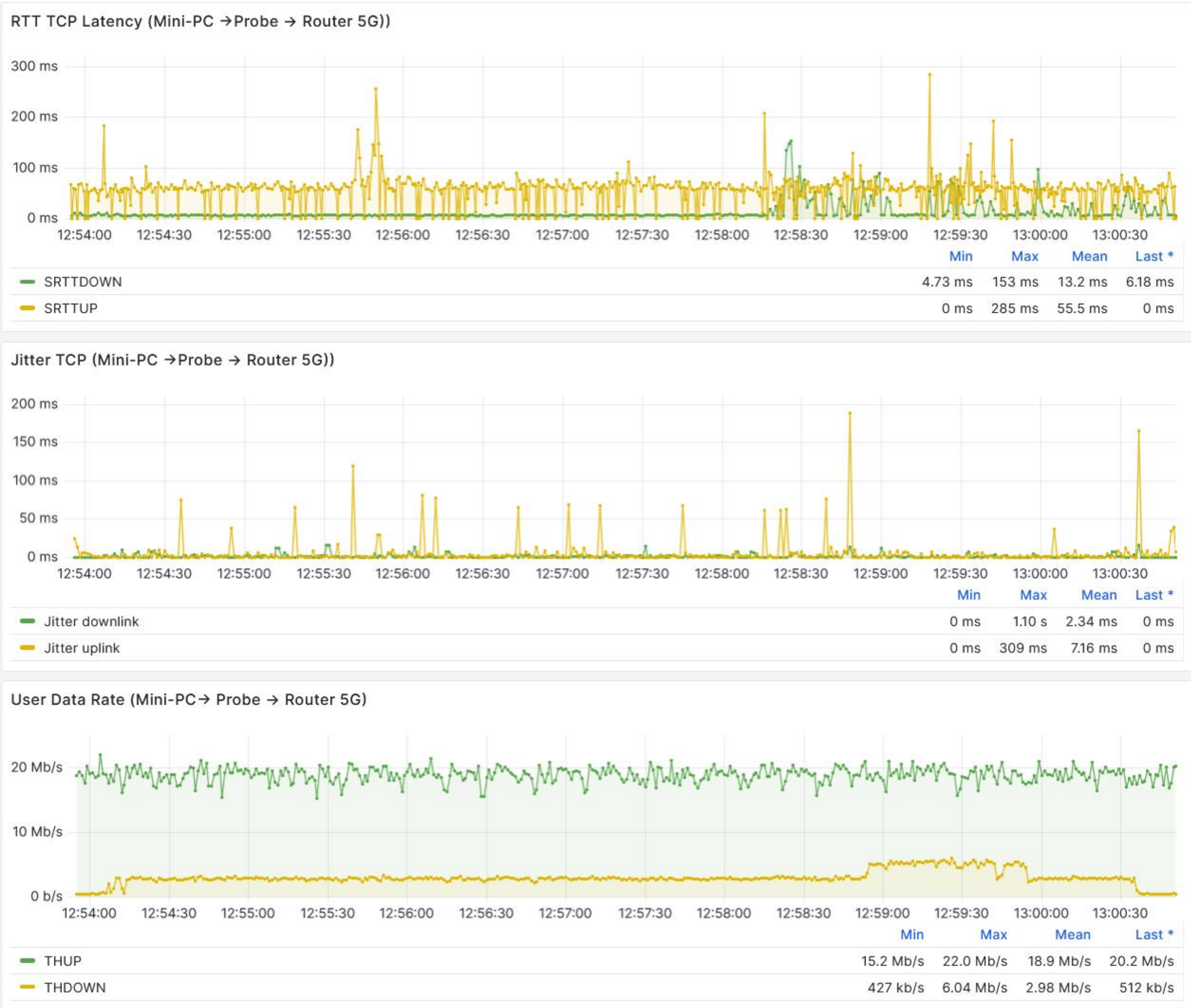


**Figure 35. Uplink throughput for link1 and link2 (20Mbps feed).**

In this test, the mean of latency and jitter are reduced dramatically Table 7 although maximum values are yet to be reduced in future setups.

**Table 7. KPIs for 20Mbps uplink feed.**

| KPI | Max | Mean |
|---|---|---|
| **Data rate** | 22 Mbps | 18.8 Mbps |
| **Latency** | 153 ms | 13.1 ms |
| **Jitter** | 1100 ms | 2.32 ms |

**Link 3 test**

5G downlink was also tested with the YBVR application playing back the content ingested on the production side (used in link 1 and 2 testing) using the last configuration described above. Simultaneous devices were used for reproducing the video content.

The uplink bandwidth remains stable due to the contribution of 8 mosaics, while downlink bandwidth fluctuates depending on the number of devices simultaneously downloading one of these mosaics. The graphs depicting the data rate are presented below (Figure 36).

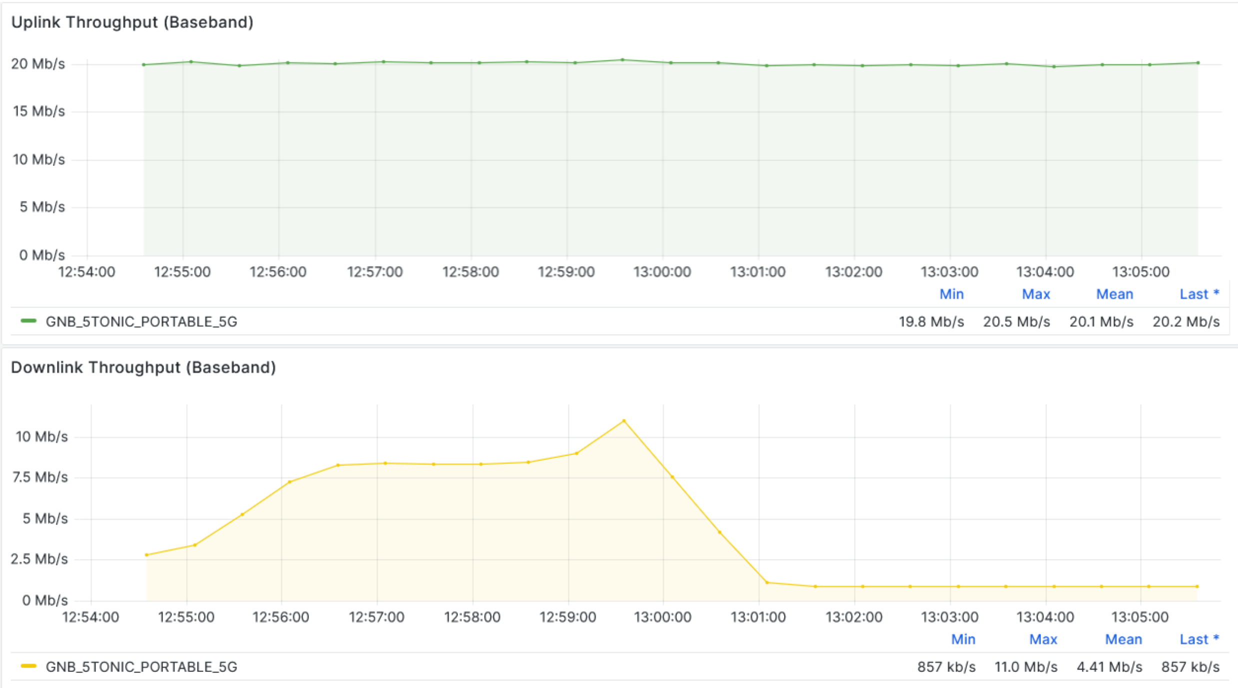


**Figure 36. Uplink and downlink throughputs for link3.**

From the application point of view, the latency edge to edge (namely glass-to-glass) was also tested with a clock added on the video feed on the input side (Figure 37). The computer is showing the video contribution (camera edge), while the smartphones are showing the player playback (user edge). The difference between both numbers shows the glass-to-glass latency (lightly less or more than 1 second).

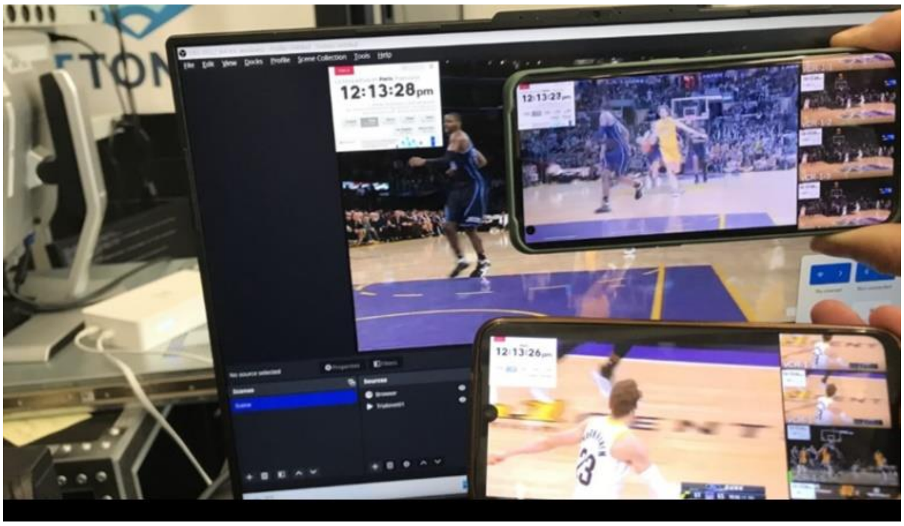


**Figure 37. Glass to glass latency.**

**Link 4 and link 5 test**

Due to the results obtained in links 1 and 2, acquiring additional bandwidth proved to be an unattainable challenge. The limitations detected on those links were far from meeting the requirements for more demanding KPIs related to bandwidth and jitter.

**Link 6 test**

Test of link 6 is very similar to link 3, but it involves an increase in bandwidth per user and the use of a VR device. To assess this setup, an immersive video contribution (180 degrees) was carried out, evaluating the downlink bandwidth with various devices requesting video traffic. The initial graphics depicts measurements on the probe on the uplink side, using the same 18-20 Mbps configuration on the YBVR production system (Figure 38).

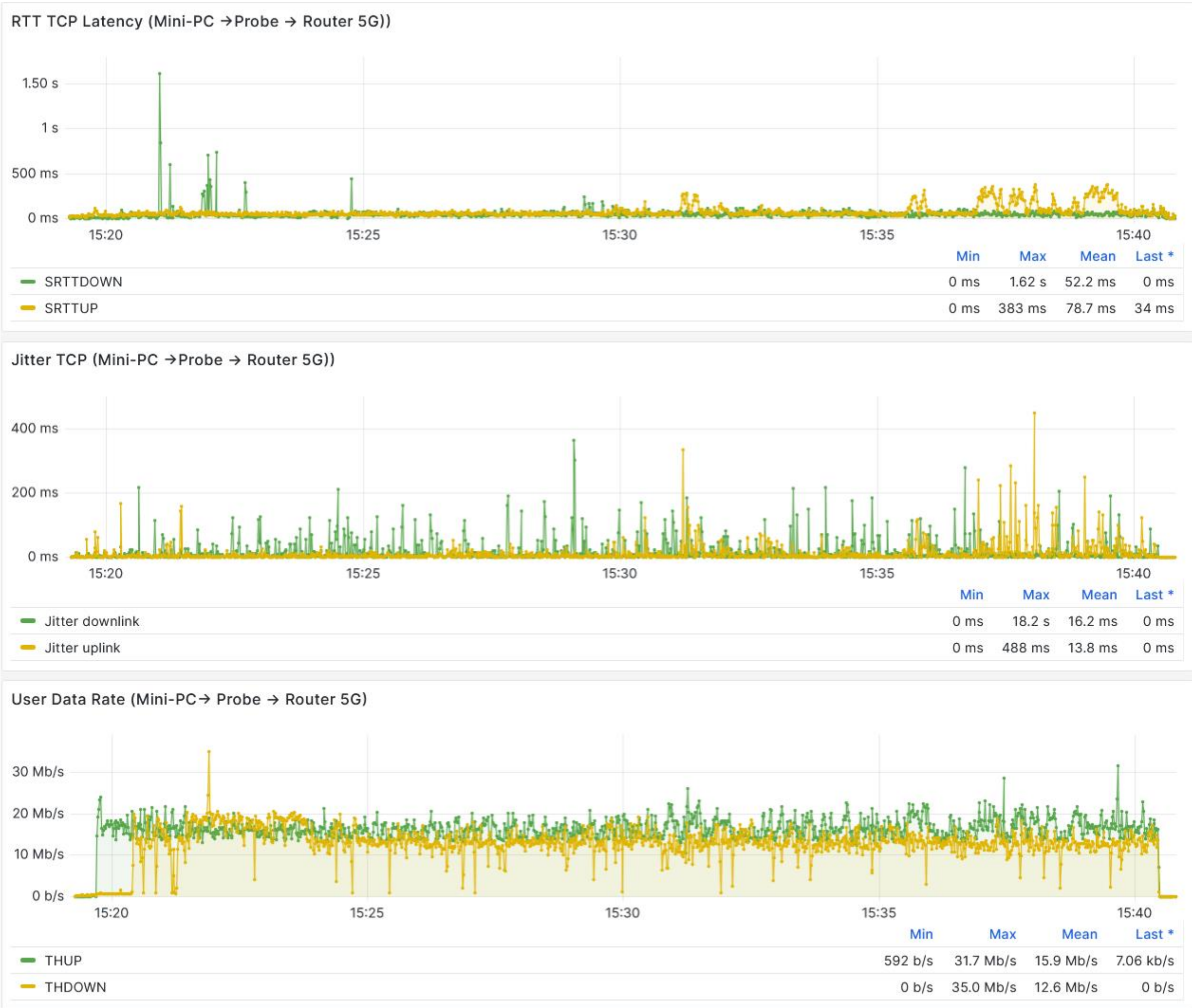


**Figure 38. Uplink: link6 for 20Mbps feed.**

The second graphic shows the downlink throughput for different simultaneous devices requesting same video traffic (Figure 39).

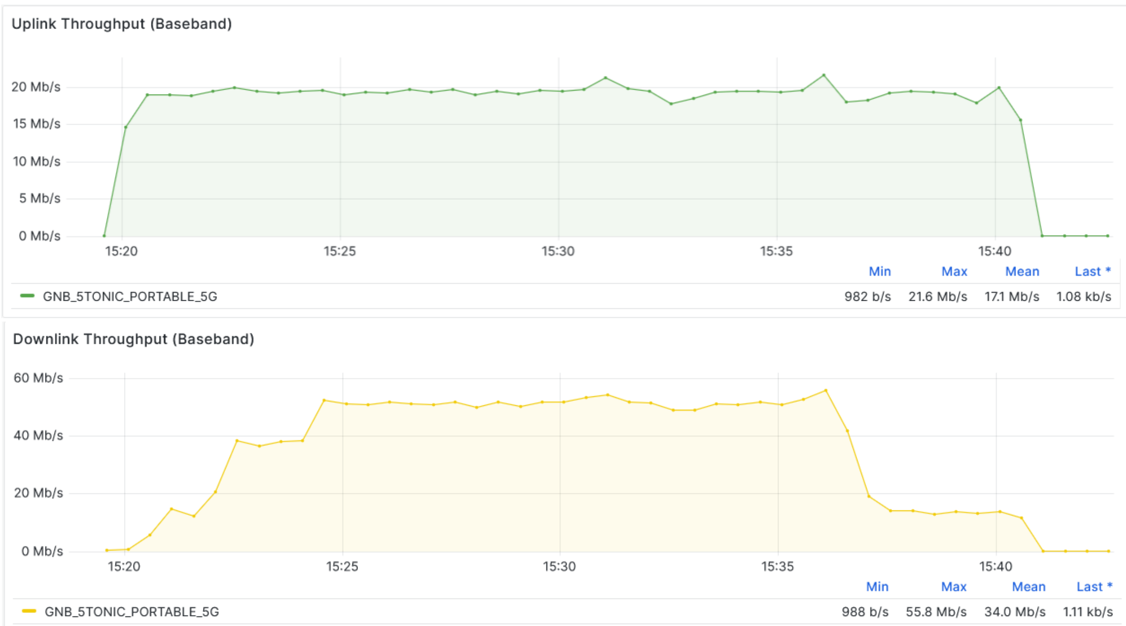


**Figure 39. Downlink: link6.**

Only throughput per user was measured in this pre-test. Furthermore, latency and jitter were collected as additional information. Also, glass-to-glass latency is metered when possible. In terms of measured KPIs, Table 8 details the requirements and results of the tests.

**Table 8. Test cases results for Trial 10.1.**

| Test case ID | Test requirement | Measurement result | Validation |
|---|---|---|---|
| **10.1_Lab01_01** | KPI#04: 100 Mbps | KPI#04: 22 Mbps | Not complied |
| **10.1_Lab01_02** | KPI#04: 100 Mbps | KPI#04: 22 Mbps | Not complied |
| **10.1_Lab01_03** | KPI#03: 12 Mbps | KPI#03: 12 Mbps | Complied (limited by the uplink) |
| **10.1_Lab01_04** | KPI#04: 300 Mbps | KPI#04: 22 Mbps | Not complied |
| **10.1_Lab01_05** | KPI#04: 300 Mbps | KPI#04: 22 Mbps | Not complied |
| **10.1_Lab01_06** | KPI#03: 25 Mbps | KPI#03: 22 Mbps | Complied (limited by the uplink) |

#### 3.1.1.2 Tests on field

As previously reported, tests on field will be performed in the last quarter of 2024.

#### 3.1.1.3 Early demo

Taking advantage of the pre-test activity in 5Tonic, a methodology for calculating KVI in this Use Case was also tested. A pre-test analysis with Universidad Carlos III students was conducted on 11-12th of December 2023, at the 5Tonic laboratory, in Leganes, Madrid (see Figure 40). This is to carry out a qualitative analysis to measure the initial reaction of viewers while viewing the Euroleague basketball final four 360º immersive video streaming, produced by YBVR. This test was executed on a standard WiFi network at 5Tonic, without using B5G technology.


**Figure 40. UC3M students participating in test case scenarios A & B.**

The users took part on two different scenarios to view the sportsmatch, Scenario A, using VR headsets and Scenario B, using mobile application connected to standard WiFi network.

The participants started with Scenario B, in which viewers were using their own mobile phones to download the application of YBVR Euroleague TV VR application [42] available in both Android and iOS and finishing with Scenario A, using a VR headset. Participants were shown a video with instructions how to navigate the app and the VR headsets, and they were given time to execute these scenarios. Following the test, a QR code linked to an online survey using Qualtrics, Net Promoters Score [43], was displayed so that the users can respond (see Figure 41).


**Figure 41. UC10 pre-test banners.**

The Table 9 reports the KVIs results for the pre-test. A detailed description of the methodology, the questions provided in the survey, and the KVIs analysis and validation related to this pre-test activity will be reported in the deliverable D6.2 “Second report on validation and dissemination activities” that will be released in November 2024.

**Table 9. UC10 KVI pre-test result.**

| KVI name | Description/KVI definition | Value |
|---|---|---|
| **User experience In-venue and at-home** | Perceived easiness, enjoyment, and emotional quality of the experience in the venue | 67% positive effect on user experience |
| **Acceptability** | Perceived acceptability, ease of use and comfort of the experience | 77% positive effect on how users accept this technology |

### 3.1.2 Remarks and next steps

The main conclusion drawn from YBVR is that current 5G uplink network provides bandwidth values that fall short of the requirements for live video transmission in both Immersive Fan Experiences (in venue and at home use cases). Tests conducted involved limiting the uplink bandwidth to 18-20 Mbps, whereas the typical bandwidth needed for the described setup in the immersive Fan Experience in-venue use case scenario is approximately 80Mbps. The “At home” use case scenario was not tested, given that the uplink bandwidth requirements for this use case surpass those of the “In venue” use case.

In addition to the bandwidth findings, latency values were deemed acceptable even when the uplink bandwidth were reduced, demonstrating positive results in testing 5G downlink capabilities. From the downlink perspective, certain measures will be focused on in the upcoming steps, including device concurrency, geolocation, etc., particularly for the “in venue” use case.

It is important to emphasize how the jitter can degrade video quality more than other types of content. Video codecs are based on incremental changes, where a key frame is sent to the player to establish a starting point, then only the incremental changes between frames are transmitted to reconstruct the new frame based on the previous one and the last changes. 30 frames per second means a new frame every 1/30 seconds (33.33ms). 60 frames per second video have to transmit a new frame every 1/60 seconds (16.67 ms). A jitter greater than this number means that frames can arrive disordered and this impacts on decoding of this frame and the rest of frames until a new key frame arrival. Then, this parameter is important to follow up and to be considered a new KPI in this use case.

Concerning the next steps, the network setup will be reviewed or upgraded and new tests to measure latency and jitter will be performed on the new millimetric waves spectrum. In particular, the new 5G high-band frequency (B258, 24.25-27.5 GHz) will be integrated in the gNodeB adding three new sectors with the advanced antenna system (AAS) radio AIR5322. This AIR is designed for outdoor use, intended for pole, wall or rooftop mounting. Each sector will be configured with 800Mhz bandwidth, and they will provide higher throughput and lower latency. Finally, current 5G CPEs are NR-DC capable, supporting 5G mmW spectrum when 5G midband coverage is available. The new configuration will require a new CPE working in 5G SA mmW.

## 3.2 UC11: Service Robots for Enhanced Passengers´ Experience

UC11 development and testing carried out so far is described in the following paragraphs.

### 3.2.1 Trial 11.1 – Enhanced airport experience

This use case involves the experimental validation and development of prototypes of the envisioned services supported by IP cameras and B5G/6G that will improve the enhanced passengers' experience in the airports. For the purposes of the trial, thermal cameras are installed in order to monitor the flow of passengers in certain areas of the airport's terminal and also identify potential areas of congestion.

#### 3.2.1.1 Laboratory tests

**Analytics component**

The analytics component of the WINGSPARK++ platform that is utilised for UC11 aims to monitor crowd congestion and flow in crowded areas. For this purpose, after receiving the video source as input, object detection is performed to identify humans. Then a tracking algorithm is applied to the detections to assign a unique ID to each detected human. After the tracking results are gathered for a time window, a second level of analysis is performed to produce multiple statistics that give a representative picture of the crowd concentration and flow. Below, the data used was analysed, its structure, the models constructed as well as the results obtained so far. The following Table 10 summarizes the test carried out for Trial 11.1.

**Table 10. Test summary for Trial 11.1 (analytics component).**

| Test summary | |
|---|---|
| **Trial ID** | 11.1 |
| **Test setup ID** | Lab01 |
| **Facility/Site** | Athens – WINGS Lab |
| **Objective** | Testing Performance of the Analytics module for Crowd concentration Detection using IP cameras |
| **Description** | Testing of the model using the CrowdHuman dataset |
| **Executed by** | WINGS |
| **Components involved** | Analytics |
| **Targeted KPIs** | KPI#11 (Precision)<br>KPI#12 (Recall)<br>KPI#13 (F1-Score) |
| **Measurement tools** | - |
| **Ethics requirements implementation** | The tests have so far been performed only in the lab without involving users. In the future, a questionnaire will be submitted to participants for assessing KVI, along a release form regarding possible privacy and ethical concern. |
| **Involvement of beta-users** | N/A |

The main components used to perform this test are:

- **Dataset**: The object detection model is based on CrowdHuman Dataset [44]. The CrowdHuman dataset is large, rich-annotated and contains high diversity. It contains 19.370 crowded images. There is a total of 470K human instances from train and validation subsets and 23 persons per image, with various kinds of occlusions in the dataset. Each human instance is annotated with a head bounding-box, human visible-region bounding-box and human full-body bounding-box. The dataset has been passed through the augmentation procedure. From each image of the train and validation set, it produced 10 more images by zooming, rotating, brightening, warming the original images to train the model in various environmental conditions. Thus, the dataset finally consists of a total of 176.294 images and their corresponding label files. The used labels of the annotated data are "Person" and "Head".
- **Object Detection**: An object detection model based on the YOLOv8 architecture [45] has been constructed. This model can detect multiple objects in a single image. The analysis of a video/stream is, therefore, performed frame-by-frame. The frame is given as an input to the model and the detections are the output of the model. For the purpose of UC11, class "Person" is only detected. The detections of the image are then passed to the tracking algorithm. Figure 42 reports an example of the outpout provided by the human detactoin model.

**Figure 42. Output of the human detection model.**

- **Tracking Algorithm**: For this task, ByteTrack Multi-object tracking (MOT) algorithm [46] is used. This algorithm aims at estimating bounding boxes and identities of objects in videos by associating almost every detection box instead of only high-scoring frames, which is the main method applied by other algorithms. The tracking results contain the objects' IDs, classes, detection confidence levels, coordinates of the bounding boxes as well as some video info like frame ID and frame rate.
- **Post Processing Analysis**: Having the IDs, the coordinates, the frame IDs, and the time interval between the frames, the total number of people, their trajectories, and their instantaneous speeds (measured in pixels/sec) are calculated. The number of different trajectories (after filtering "noise" trajectories) equals to the total number of people in the video. The peoples' speeds are then transformed to km/h by applying some factors that correlate with the size of the object and the angle of the camera. The average speed is calculated, as well as the average flow, which reflects the total number of people crossing the monitored area per minute. Finally, the average delay time is calculated, which is the queue waiting time for which a person remains almost still (person's speed is under 1 km/h).

A test set was retained to evaluate the detection model. For this procedure, interference was performed on the test dataset (1,934 images) using a confidence level of 0.5. Then, the results were compared with the ground truths using an Intersection over Union (IoU) threshold of 0.5. A summary of the results is detailed below (Table 11). Precision is the number of positive predictions that are actually positive, Recall is the number of positive predictions made out of all positive ground truths while the F1-score is the harmonic mean of Precision and Recall.

**Table 11. UC11 human detection results.**

| Metric | Results |
|---|---|
| **For the whole dataset** | |
| Total number of ground truth positives (all bounding boxes) | 85860 |
| True Positives | 45288 |
| False Positives | 8502 |
| Precision | 0.8419 |
| Recall | 0.5274 |
| F1-score | 0.6485 |
| **For class "Person"** | |
| Total number of ground truth positives for class 0 | 42930 |
| True Positives | 22499 |
| False Positives | 4654 |
| Precision | 0.8286 |
| Recall | 0.5240 |
| F1-score | 0.6420 |

In terms of KPIs, Table 12 details the requirements and results of the tests.

**Table 12. Test cases results for Trial 11.1 (analytics component).**

| Test case ID | Test requirement | Measurement result | Validation |
|---|---|---|---|
| **11.1_Lab01_01** | KPI#11: 0.80 | KPI#11: 0.8419 | Complied |
| | KPI#12: 0.60 | KPI#12: 0.5274 | Not Complied |
| | KPI#13: 0.68 | KPI#13: 0.6485 | Not Complied |
| **11.1_Lab01_02** | KPI#11: 0.80 | KPI#11: 0.8286 | Complied |
| | KPI#12: 0.60 | KPI#12: 0.5240 | Not Complied |
| | KPI#13: 0.68 | KPI#13: 0.6420 | Not Complied |

**Restreaming component**

The purpose was to test the optimal configurations of the camera first to properly measure the KPIs mentioned in D3.1 [1]. However, additional measurements were taken to estimate the optimal configurations for a streaming camera without or with a model enabled, i.e., restreaming with detections or just restreaming the camera feed. The set up that will be applied once the tests involve also the 5G network is given in Table 13.

**Table 13. Test setup parameters for Trial 11.1 (restreamng component).**

| Test setup parameters | Test setup ID: Lab02 |
|---|---|
| **Radio access technology** | 5G NR |
| **Network type** | Commercial |
| **Standalone / Non-Standalone** | NSA |
| **Cell Power** | N/A |

| | |
|---|---|
| **Frequency band** | n78 |
| **Bandwidth per component carrier** | - |
| **Sub-carrier spacing** | - |
| **MIMO** | - |
| **Duplex mode** | - |
| **Device number** | 1 |
| **Device speed** | 0 km/h |
| **Slice Configuration** | None |

The following Table 1414 summarizes the test carried out for Trial 11.1.

**Table 14. Test summary for Trial 11.1 (restreamng component).**

| **Test summary** | |
|---|---|
| **Trial ID** | 11.1 |
| **Test setup ID** | Lab02 |
| **Facility/Site** | Athens – WINGS Lab |
| **Objective** | Testing Performance of the Streaming and Restreaming module for Crowd concentration Detection using IP cameras |
| **Description** | Testing the Streaming & Restreaming latencies from the cameras |
| **Executed by** | WINGS |
| **Components involved** | Streaming & Restreaming |
| **Targeted KPIs** | KPI#08 (App round-trip latency)<br>KPI#15 (Service Reliability)<br>KPI#17 (Service Availability) |
| **Measurement tools** | Windows Task Manager, iPerf |
| **Ethics requirements implementation** | The tests have so far been performed only in the lab without involving users. In the future, a questionnaire will be submitted to participants for assessing KVI, along a release form regarding possible privacy and ethical concern. |
| **Involvement of beta-users** | N/A |

Based on some initial tests that we performed, it was observed that the restreaming function when based on CPU was lacking in performance. As such, we decided to perform the testing using a GPU server additionally. The two systems configurations are depicted in Table 15 below.

**Table 15. UC11 system configurations.**

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

Initially, the performance of the integration was tested with CPU VMs, but Computer Vision (CV) models based on the literature provide better results when tested on GPU, and thus it was decided to perform the same experiments on a GPU server in order to find the optimal configurations on both. To this extent, testing the smoothness and responsiveness of the live restreaming from a source IP Camera through the WINGS Frame-Whisper module was initiated (Figure 43). The FrameWhisper processed frame by frame and restreamed the frames on the media server to identify whether the simplest integrationwould have caused any issues. Based on this first testing, different option were researched to identify the optimal camera configuration. As following step, tests was performed with and without the detection model which demanded high CPU/GPU usage for processing of each one of the frames in order to generate the detections. Then, for each different camera configuration, perceived performance was tested and usability of the total restreaming process under different configurations and utilized specific metrics to identify any limitations. Figure 44 describes the aforementioned testing procedure. The different parameters and values utilized for testing are presented in Table 16.

.

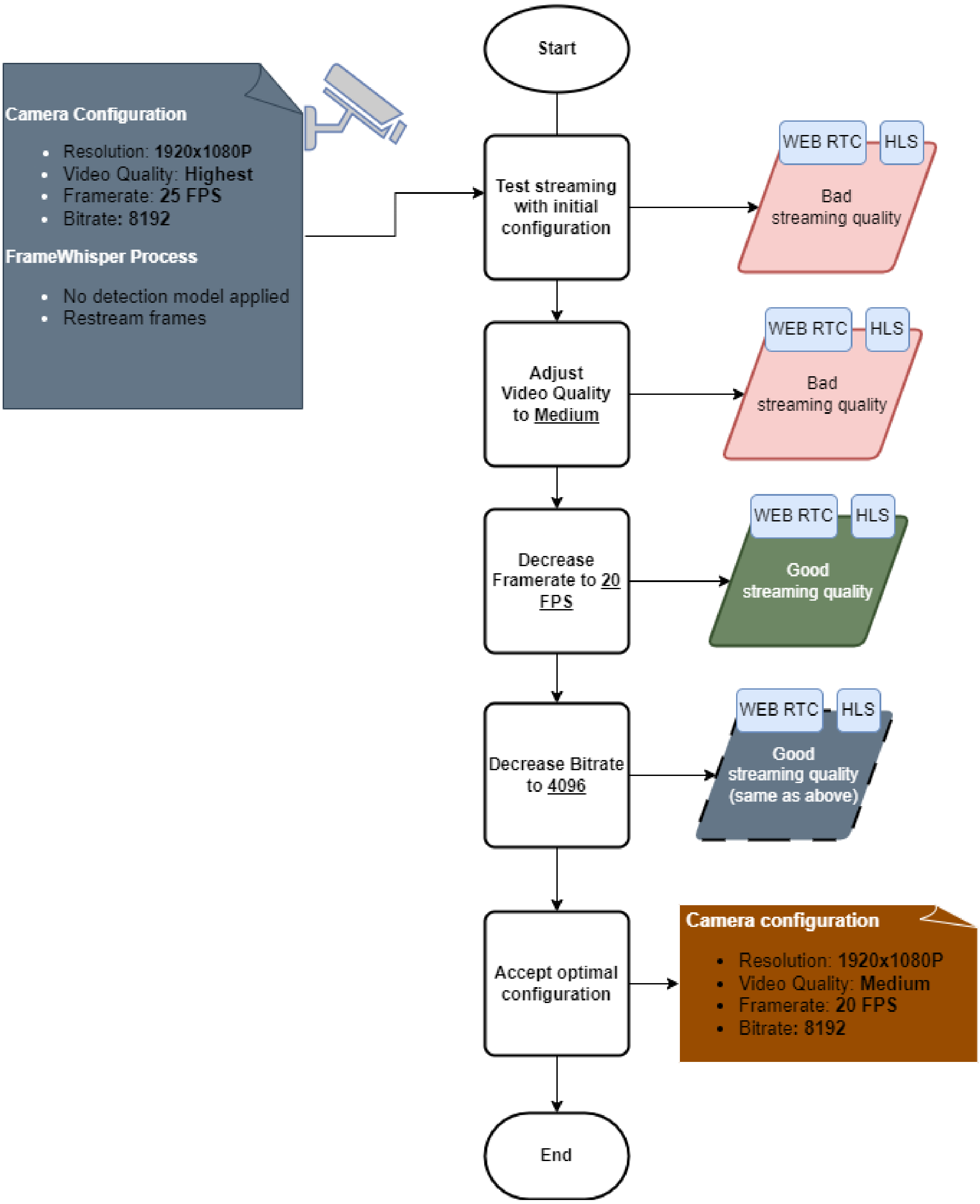


**Figure 43. Streaming and restreaming testing procedure (one camera and Framewhisper module).**

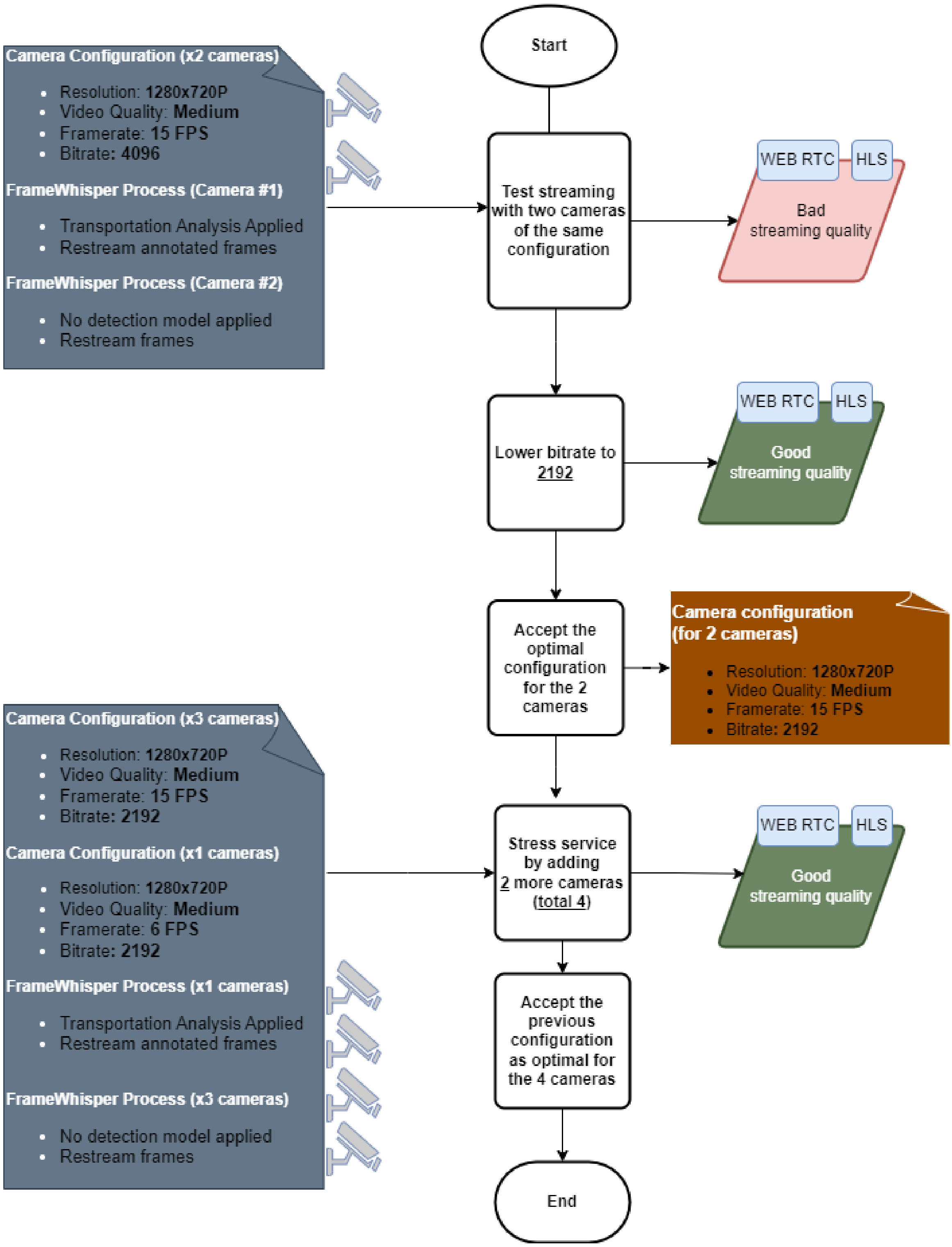


**Figure 44. Streaming and restreaming testing procedure (multiple cameras and analytics model enabled).**

**Table 16. UC11 parameters and values utilised for testing.**

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

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

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

Based on the preliminary tests, some camera configurations were unusable and as such did not perform any further testing with intelligence analysis module enabled. Furthermore, for each of these different settings was also tested both restreaming protocols (HLS and WebRTC), which are widely supported. The 'Test #' denotes the internal numbering for the conducted tests. Only the best results are reported here for reasons of brevity.

**Table 17. UC11 configurations used for testing.**

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

| | | |
|---|---|---|
| **7** | **17** | **Protocol:** HLS/Web RTC**, Batch size:** 6000**, Resolution:** 1280x720**, Video Quality:** Medium**, Frame Rate:** 15**, Max bitrate:** 2192**, Video Encoding:** H.264**, No. of Cameras:** 4**, Time Window:** 5min**, Intelligence Model analysis:** Disabled |
| **8** | **20** | **Protocol:** HLS/Web RTC**, Batch size:** 6000**, Resolution:** 704x576**, Video Quality:** Medium**, Frame Rate:** 10**, Max bitrate:** 2192**, Video Encoding:** H.264**, No. of Cameras:** 2**, Time Window:** 5min**, Intelligence Model analysis:** Enabled |
| **9** | **22** | **Protocol:** HLS/Web RTC**, Batch size:** 6000**, Resolution:** 704x576**, Video Quality:** Medium**, Frame Rate:** 6**, Max bitrate:** 2192**, Video Encoding:** H.264**, No. of Cameras:** 3**, Time Window:** 5min**, Intelligence Model analysis:** Enabled |

Based on the configurations detailed above the metrics presented below were collected:

- Inference time per frame (Intelligence model analysis)
- Post Processing time (Intelligence model post processing)
- Intelligence Model Analysis Total Time (without post processing)
- Intelligence Model Analysis Total Time (with post processing)
- Estimated the possibly max FPS a camera can use
- Latency (Jitter)
- Service Availability
- Service Reliability

The results obtained for each of the configurations are presented in Table 18.

**Table 18. UC11 lab test results.**

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

In terms of KPIs, Table 19 details the requirements and results of the tests.

**Table 19. Test cases results for Trial 11.1 (restreaming component).**

| Test case ID | Conf. No. | Test requirement | Measurement result | Validation |
|---|---|---|---|---|
| **11.1_Lab02_01** | 1 | KPI#08: 800ms | KPI#08: 517ms | Comply |
| **11.1_Lab02_02** | 1 | KPI#15: 99.99% | KPI#15: 99.99% | Comply |
| **11.1_Lab02_03** | 1 | KPI#17: 99.99% | KPI#17: 99.95% | Not comply |

#### 3.2.1.2 Tests on field

Test on field related to Trial 11.1 are planned in the next months.

#### 3.2.1.3 Early demo

Preliminary tests were performed using actual feeds provided by cameras installed at WINGS labs. The tests validated the set up of the solution, confirmed stable video feed and saving the actual records on the storage servers both at WINGS premises and AWS deployment.

Early demos are available as videos showcasing the camera feeds, the human detection model output as well as the capabilities of the streaming and the restreaming modules developed in the scope of the UC. Initial KPIs were measured and reported in section 3.2.1 both for the human detection model as well as for the streaming and re-streaming module both for the deployment at WINGS and also at the AWS deployment.

The figures below present the outputs of the streaming and re-streaming modules of the WINGSPARK Plus platform as well as other features available in the platform to support UC11. Figure 45 depicts an indicative view on the WINGSPARK Plus dashboard showing the output of the model using the restreaming module, providing the estination of the people calculated as well as alerts indicating congested. Figure 46 shows the calculated statistics regarding actual and predicted waiting times based on the human detection model's output. Finally, Figure 47 depicts the congested area detected by the model in a map.

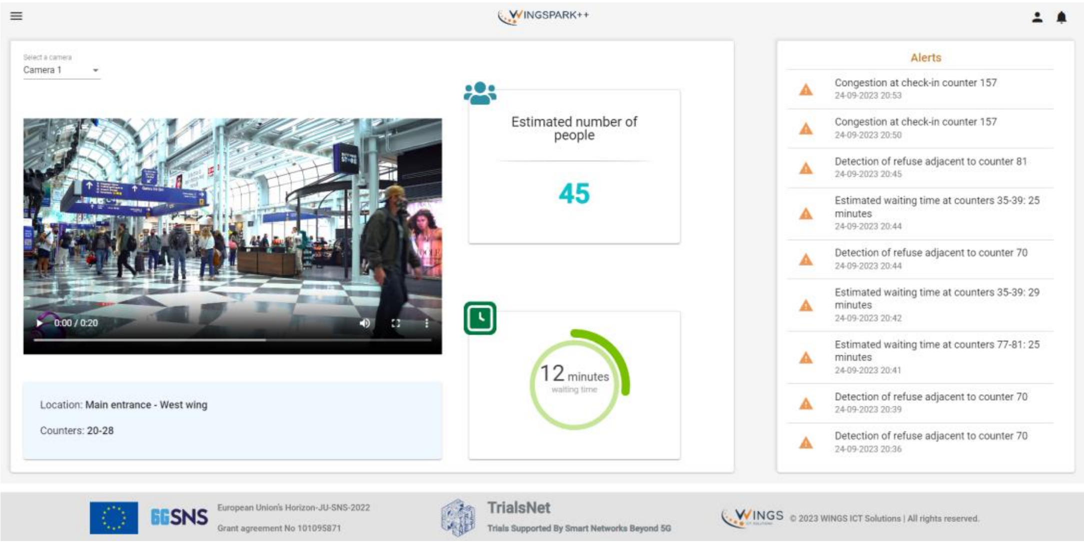


**Figure 45. WINGSPARK++ dashboard performing crowd concentration estimation in real-time.**


**Figure 46. Calculated statistics regarding actual and predicted wating times.**


**Figure 47. Map on the congested area.**

### 3.2.2 Remarks and next steps

In conclusion, the tests were successful in demonstrating the main capabilities of the application software developed. They validate the overall architecture of the application, showing it is capable of video analysis, streaming, real-time processing, restreaming of the video with the human detection model output and visualization of the basic analytics data. The software is capable of handling multiple IP cameras as well as other devices (Automated Guided Vehicles - AGVs) in parallel, detecting congestion in certain areas. The video analysis pipeline can integrate both pretrained object detection models available in the literature but also custom models; the tests that was performed used both a pre-trained model as well as a custom one, but the system can be extended to support more.

As for the next steps, the plan is to start the trialling at AIA as soon as the thermal cameras will be installed. Due to the change of the types of cameras to be used (see details for the reasons of change in section 2.2.2) there is a slight delay, but the platform development and testing with the thermal cameras progressed at WINGS labs in order to be ready to start the field trials when the cameras have been deployed at AIA. The focus will also be on the further development of the visualization dashboard and its integration with the back-end. Finally, additional KPIs will be measured. Furthermore, a new analytics model for human detection is planned to be built that will fulfil the above task through thermal cameras. Having the thermal cameras, a custom dataset is going to be collected and annotated. Then the training procedure will hopefully produce an even more accurate detection model.

## 3.3 UC12: City Parks in Metaverse

The first trial for UC12 was on checking the load on the 5G network of the most critical component, that is the VR part of the game, which foresee 4 players at a time in the same room. The AR part of the game does not involve a high throughput since it is only needed to charge the assets on a device. Also, the final prize of the game, i.e., a virtual visit of the Rocca Medievale, is operated only by one player at a time. Furthermore, with respect to the load to the network, these steps are independent from each other and take place at different locations and cells.

### 3.3.1 Trial 12.1 – City Parks in Metaverse

The tests have been performed in TIM's laboratory in Turin without access to the local 5G network. In particular, the test addressed the VR part of the game developed by TIM, since the impact of the AR part on the 5G network is negligible.

#### 3.3.1.1 Laboratory tests

The initial measurements have been done on TIM's experimental platform that will be used for the VR part of the game. The components of the tests were a VR Headset (Meta Quest 2), a workstation with NVIDIA RTX 2080 Super GPU, a Huawei B525 Access Point for Headset WiFi access and a Gigabit Ethernet connection. This test did not involve a connection to the 5G network and aimed to define the baseline performances. Both downlink and uplink throughputs have been measured. The Ethernet traffic between VR streaming app and the headset has been recorded through Wireshark app running on Workstation, to double check the results from the Windows Task Manager. The test summary for Trial 12.1 is described in Table 20.

**Table 20. Test summary for Trial 12.1.**

| Test summary | |
|---|---|
| **Trial ID** | 12.1 |
| **Test setup ID** | Local_01 |
| **Facility/Site** | TIM Labs Turin |
| **Objective** | Testing UC12 (VR part) KPIs |
| **Description** | The tests are used as a reference for the real application that will be developed. Maximum bandwidth measured for each user with application under test are the same expected in real final test environment |
| **Executed by** | Filippo Della Betta |
| **Components involved** | Workstation with NVIDIA GPU RTX2080 Super, Test Application running on this workstation, Meta Quest 2 VR headset with custom Android app to received video and send VR headset and controllers movement to the app running on the workstation |
| **Targeted KPIs** | KPI#01 (Downlink throughput per user)<br>KPI#02 (Uplink throughput per user)<br>KPI#03 (Downlink aggregate throughput)<br>KPI#04 (Uplink aggregate throughput) |
| **Measurement tools** | Wireshark, Windows Task Manager |
| **Ethics requirements implementation** | The tests have so far been performed only in the lab without involving users. In the future, a questionnaire will be submitted to participants for assessing KVI, along a release form regarding possible privacy and ethical concern. Access for disabled layers is also being addressed. |
| **Involvement of beta-users** | N/A |

In Figure 48 the test setup for VR part is described. The workstation hosts a test app (made by Unity with TIM XR Streaming platform integration) with same characteristic of the one that will be developed for UC12. The workstation is running Windows 11 OS (as for the target) with no application running except for the one under test. The workstation is connected via Gigabit Ethernet to an access point that let the Meta Quest 2 VR Headset connect to the workstation. The access point is near (80cm) to the Meta Quest 2. WiFi ver. 5 is used. The objective of the test was to discover the bandwidth needed for one single user for the UC12 VR application.

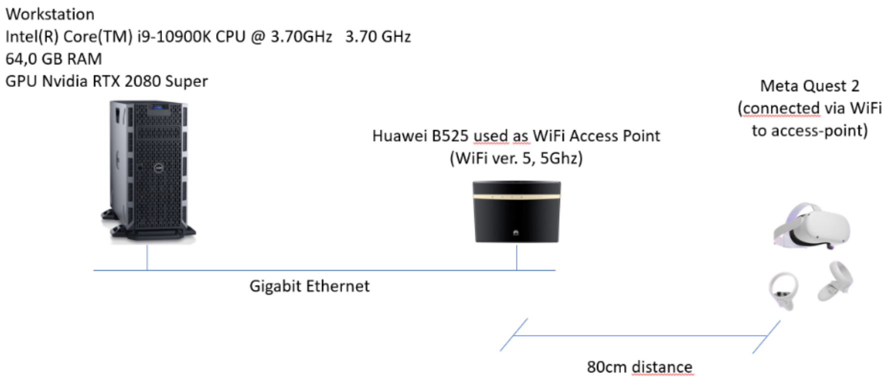


**Figure 48. Test setup for Trial 12.1.**

In Figure 49, all the IP flows that are involved for each user are described. Two videos are streamed to the VR Headset (one for each eye) encoded with H.264 and one application audio encoded with opus codec. From the VR Headset to the Workstation there are either VR Headset movement and controllers position tracking and button pressing and the microphone that comes from VR Headset encoded with opus Codec.

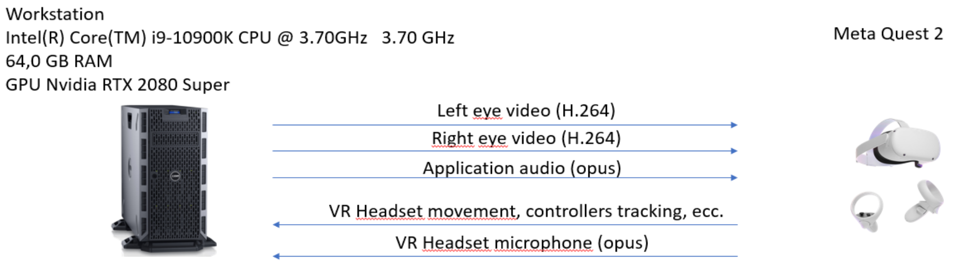


**Figure 49. IP flows for Trial 12.1 test.**

Figure 50 shows the throughput graph between Workstation and VR Headset while using the app for about 2 minutes. The dotted graph represents all the flows from Workstation to the Meta Quest 2 (maximum around 32 Mbps) and the filled graph represents the flow from Meta Quest 2 to Workstation (maximum around 2 Mbps). Each square on the Y axis is about 5,4 Mbps and about 12,2 seconds on the X axis.

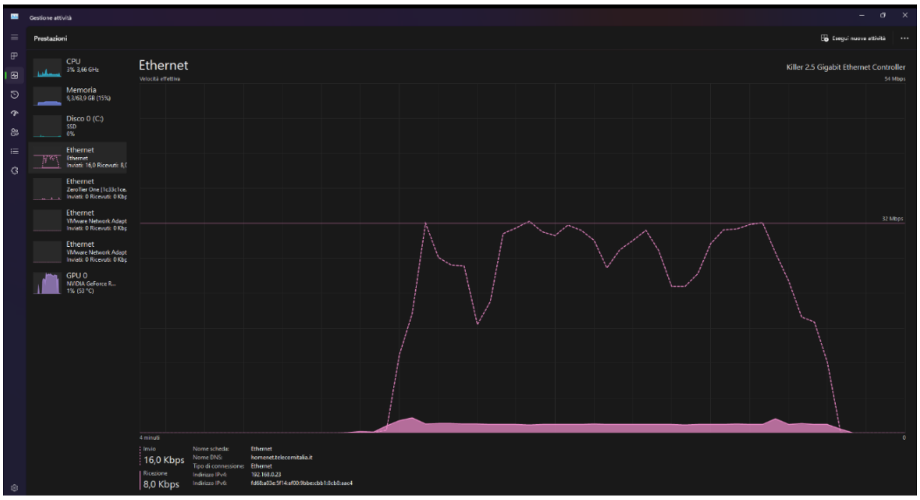


**Figure 50. Test results summary for Trial 12.1.**

In reference to KPI, network should be able to support a downlink throughput per user of 32Mbps and an uplink throughput per user of 2Mbps. Since the maximum number of users expected for the trial of VR part of UC12 is four, it needs network to support a downlink aggregate throughput of 128Mbps and an uplink aggregate throughput of 8Mbps. On the other side, latency is very critical for this use case. It is known that the maximum RTT allowed to prevent “motion sickness” is 50ms (20ms recommended) [47]. Since the total latency on VR Headset side is due to network latency plus server application latency, if the application latency is around 10/20ms, network should introduce no more than 20/30ms per user. This KPI will be crucial to be measured in the on field context when using the 5G commercial network during the trial.

The main results of the test in terms of KPIs in are shown in Table 21.

**Table 21. Test cases results for Trial 12.1.**

| Test case ID | Test requirement | Measurement result | Validation |
|---|---|---|---|
| **12.1_Lab01_01** | N/A | KPI#01: 30 Mbps<br>KPI#02: 2 Mbps<br>KPI#03: 120 Mbps<br>KPI#04: 8 Mbps | The measured values represt the baseline requirements to be ful-filled on the 5G network. |

#### 3.3.1.2 Tests on field

So far, the tests have been carried out only within TIM laboratories in Turin. The start of the field tests is planned in June and July 2024. The trials with external users will then be performed in the September and October 2024 with the participation of teams of students from high-schools, universities and research departments. One of the teams will play from remote by joining the Boss in the metaverse. They will acquire the artefacts by playing an online game e.g. i-Kout, instead of via the AR game in the park.

#### 3.3.1.3 Early demo

A slide deck has been produced in the form of slide presentation depicting the sequences of the experience with the screenshots of the different application. This has been used in the second meeting of the Design Thinking+ in order to gauge the interest and comments from the potential users. Some of these slides are shown in a previous chapter. The development of a demo in the form of a short video clip is planned in the course of the year also for the future exploitation of the innovation.

### 3.3.2 Remarks and next steps

The conclusion of the first measurements in the lab indicates that the aggregated downlink and uplink loads could be managed by the current 5G network.

## 3.4 UC13.1: Extended XR Museum Experience (Turin)

The first trial for UC13 dealt with checking the load on the 5G network of the most critical component, that is the VR part of the experience in the metaverse. The AR step has not been tested (for GAM and Palazzo Madama only) because it does not requre a high throughput since the network connection it is needed only to charge the assets on the device. A preliminary test has been performed only on a PC and not yet on tablets or smartphones for the AR step and headsets for the VR step, which will take place in the coming weeks.

### 3.4.1 Trial 13.1: Extended XR Museum Experience

The initial measurements have been done at the CROSEU lab on the Mozilla Hubs platform connected to the cloud via a 5G CPE. The main parameters of the 5G network are given in Table 22.

**Table 22. 5G network parameters for Trial 13.1.**

| Test setup parameters | Test setup ID: Lab01 |
|---|---|
| **Radio access technology** | 5G NR Rel-15 |
| **Network type** | Commercial |
| **Standalone / Non-Standalone** | NSA |
| **Cell Power** | N/A |
| **Frequency band** | n78 |
| **Bandwidth per component carrier** | 80 MHz |
| **Sub-carrier spacing** | 30 kHz |
| **MIMO** | mMIMO |
| **Duplex mode** | TDD |
| **Device type** | PC |
| **Device number** | 1 |
| **Device speed** | 0 km/h |
| **Slice Configuration** | None |
| **Background / simulated traffic** | commercial |

#### 3.4.1.1 Laboratory tests

The first test for UC13 has focused on checking the throughput and latency for the metaverse platform. In the following, the test setup is described.

**Configuration and connectivity setup**

The tests involved a PC connected via Ethernet cable to a 5G CPE. The notebook was connected in this way to the server containing the UC13 application via 5G. A video belonging to the introduction of the first part of the application has been used to test the capability of the application and the network. It is not a definite edition, but a video that will be modified as content when the final version becomes available.

**Network connectivity testing**

The 5G network connectivity tests revealed a robust performance with a download speed of 389.79 Mbit/s and an upload speed of 37.4 Mbit/s. These high-speed connections are crucial for ensuring the smooth transmission of high-quality video streams. The low ping of 15 ms indicates minimal latency, which is essential for real-time applications like streaming video.

**Traceroute analysis**

The traceroute results provide insights into the route taken by the data packets. Notable points include the initial local network node (tim.spot), various internal nodes, and the final destination. The presence of unresponsive nodes and variations in latency between nodes may impact the overall network performance. Further investigation into these aspects can provide a comprehensive understanding of potential bottlenecks.

**Transport protocol**

The protocol used is HTTPS, since the AR app is a webapp (http) with a valid security certificate. The traffic is located on the standard port, 443. The usage of HTTPS ensures secure data transfer, crucial for protecting sensitive video content during transmission**.**

**Video parameters**

Resolution: Full HD (1920x1080) 30fps, using a H.264 codec and an audio track of 128Kbit.

**Wireshark capture setup**

To delve deeper into the network performance, a packet capture was conducted at frame rates of 30fps, using Wireshark software on the receiving end. A total of 200,000 packets were captured, each with a Maximum Transmission Unit (MTU) of 1492 bytes. This comprehensive capture provides a detailed insight into the video transmission and its impact on the network (see Figure 51).

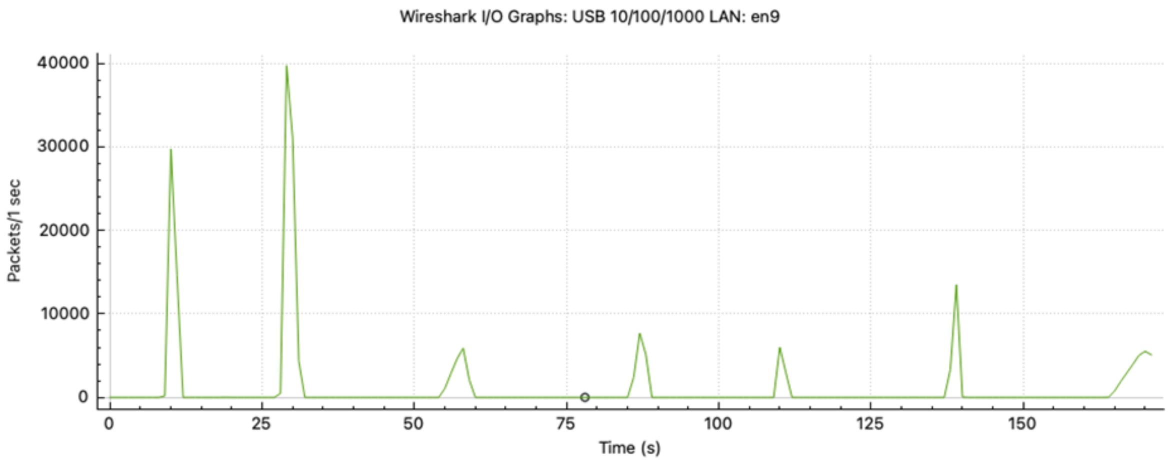


**Figure 51. Wireshark measurement results.**

**Packet analysis**

Wireshark was utilized to analyze the captured packets. The focus was on filtering out only the video stream via HTTPS from the overall network traffic.

**Capture results**
There are different bursts of data; as seen in the graphs, there were some peaks; usually it is possible to estimate that the single stream for a full HD video ranges between 3,5Mbit/s and 5Mbit/s.

**Estimated bitrate for client devices**
Based on the conducted tests, the estimated bitrate for each client device is 5 Mb/s. Considering the worst case, support for up to 90 people at the same time for a total traffic of 450 Mbit/s. Video with a resolution of 4K will be considered as the final version of the video stream.

The test summary for Trial 13.1 is given in Table 23, while the main results are shown in Table 24.

**Table 23. Test summary for Trial 13.1.**

| Test summary | |
|---|---|
| **Trial ID** | 13.1 |
| **Test setup ID** | Lab01 |
| **Facility/Site** | CROSEU Lab |
| **Objective** | To test the KPIs of UC13 |
| **Description** | Streaming of full HD video (1920x1080b- 30 fps) |
| **Executed by** | Marco Mazzaglia and Andrea Basso |
| **Components involved** | Mozilla Hubs and Web App plus H.264 video |
| **Targeted KPIs** | KPI#01 (Downlink throughput per user)<br>KPI#02 (Uplink throughput per user)<br>KPI#08 (Application round trip latency) |
| **Measurement tools** | Wireshark |
| **Ethics requirements implementation** | The tests have so far been performed only in the lab without involving users. In the future, a questionnaire will be submitted to participants for assessing KVI, along a release form regarding possible privacy and ethical concern. Access for disabled layers is also being addressed. |
| **Involvement of beta-users** | No |

**Table 24. Test cases results for Trial 13.1.**

| Test case ID | Test requirement | Measurement result | Validation |
|---|---|---|---|
| **13.1_Lab01_01** | KPI#01: 8Mbps<br>KPI#02: 2Mbps<br>KPI#08: 15ms | KPI#01: 6.25Mbps<br>KPI#02: 2Mbps<br>KPI#08: < 15ms | Network capacity and roundtrip delay is sufficient to satisfy measurements requirements. |

### 3.4.1.2 Tests on field

The tests have so far only been conducted in the TIM laboratory. The start of the field tests is planned in the coming months of June and July 2024.

### 3.4.1.3 Early demo

A slide deck has been produced in the form of slide presentation depicting the sequences of the experience with the screenshots of the different application. This has been used in the second meeting of the Design Thinking+ in order to gauge the interest and comments from the potential users. Some of these slides are shown in a previous chapter. The development of a demo in the form of a short video clip is planned in the course of the year also for the future exploitation of the innovation.

### 3.4.2 Remarks and next steps

The preliminary tests that have been carried out focused on the application side. This was installed on a local PC connected to a 5G router via Ethernet, while a Tablet was utilised for the user interface. The results of the first measurements indicate that 5G network capacity and application roundtrip delay were sufficient to satisfy the requirements of such test setup. Further tests will have to be carried out once the App is installed in the Cloud, i.e. on the servers of the PoliTO and, furthermore, when a VR headset is utilised instead of a tablet for the user interface, for which latency is a critical parameter. Future tests would also allow to estimate the maximum number of simultaneous visitors performing the experience that the local 5G network could handle.

## 3.5 UC13: Extended XR Museum Experience (Athens)

### 3.5.1 Trial 13.2 – Extended XR Museum Experience

Initial tests for the AR/VR applications were carried out at WINGS Lab (Athens). The trial activities have been organized in the following phases.

#### 3.5.1.1 Laboratory tests

For the test procedures, the following pre-conditions exist: (i) Mobile device connected to the Wi-Fi; (ii) SIM card connected to the local 5G network; (iii) VM communicating both with the 5G and local Wi-Fi. The 5G network parameters are reported in Table 25 while a test summary for Trial 13.2 is reported in Table 26.

**Table 25. UC13 (Athens) 5G network parameters.**

| Test setup parameters | Test setup ID: Lab01 |
|---|---|
| **Radio access technology** | 5G NR NSA |
| **Network type** | Experimental |
| **Standalone / Non-Standalone** | NSA |
| **Cell Power** | 1W |
| **Frequency band** | LTE 2600MHz & 5G 3500MHz |
| **Bandwidth per component carrier** | 100 MHz |
| **Sub-carrier spacing** | 30 kHz |
| **MIMO** | Up to 4x4 |
| **Duplex mode** | FDD |

**Table 26. Test summary for Trial 13.2.**

| Test summary | |
|---|---|
| **Trial ID** | 13.2 |
| **Test setup ID** | Lab01 |
| **Facility/Site** | Athens – WINGS Lab |
| **Objective** | To test the AR/VR applications of UC13 and measure initial KPIs |
| **Description** | Test the AR/VR applications of UC13 utilising both WiFi and 5G campus network |
| **Executed by** | WINGS |
| **Components involved** | AR/VR application, asset bundles loading from a server |

| | |
|---|---|
| **Targeted KPIs** | KPI#01 (Downlink throughput per user),<br>KPI#08 (Application round-trip latency),<br>KPI#09 (Application one-way latency): |
| **Measurement tools** | Windows Task Manager, iPerf |
| **Ethics requirements implementation** | The tests have so far been performed only in the lab without involving users. In the future, a questionnaire will be submitted to participants for assessing KVI, along a release form regarding possible privacy and ethical concern. |
| **Involvement of beta-users** | N/A |

For the measurements, there is a local server that is accessible by two different IPs. One IP could be pointed by the local Wi-Fi and by the 5G network. Latency metrics are done by pinging directly from both network types. For the network analysis, the following metrics were used: the timestamp of the request from the app to the server, the timestamp the bundle was fetched, and the size of the file that was received.

Figures 57-62 illustrate the results of the tests conducted for the Extended XR Museums Experience at the Athens location. Initial testing revealed that the laboratory setup fell short of the experiment's expectations due to the uplink limitations. Analysis of the results, derived from 161 bundle downloads on a single mobile device, half of the downloads utilized devices connected to the 5G network, while the other half connected through the local Wi-Fi network. Future tests will further investigate the performance of the experimental network. Data indicates that the latency experienced over the local Wi-Fi network is lower than that of the 5G connections. The metrics tables are visualized using Grafana, providing clear and immediate insights into the performance data.

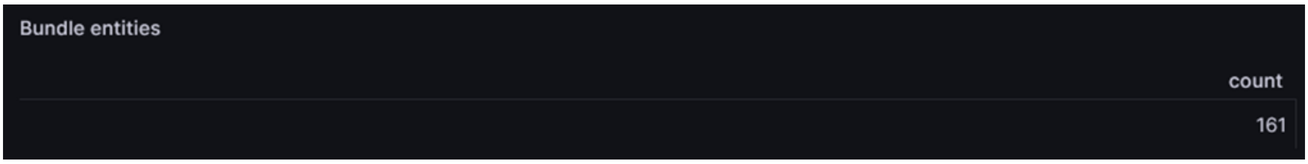


**Figure 52. Total number of asset bundles tested of metric on bundles done.**

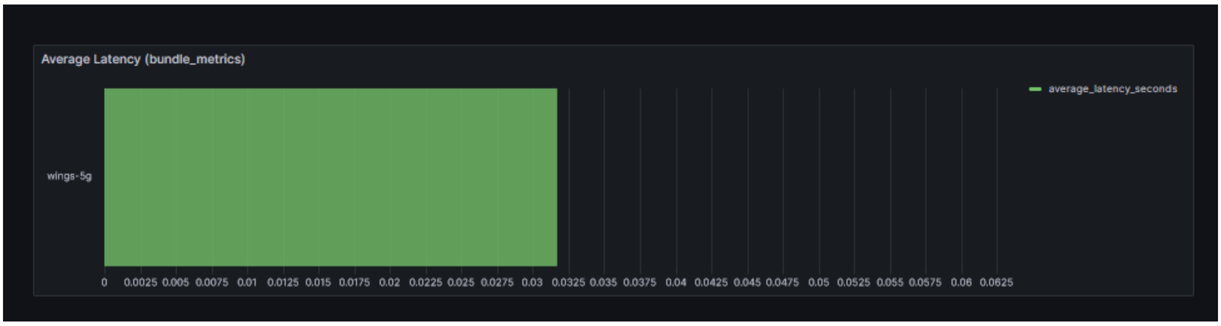


**Figure 53. Average application round-trip latency for the 161 asset bundles (sec).**

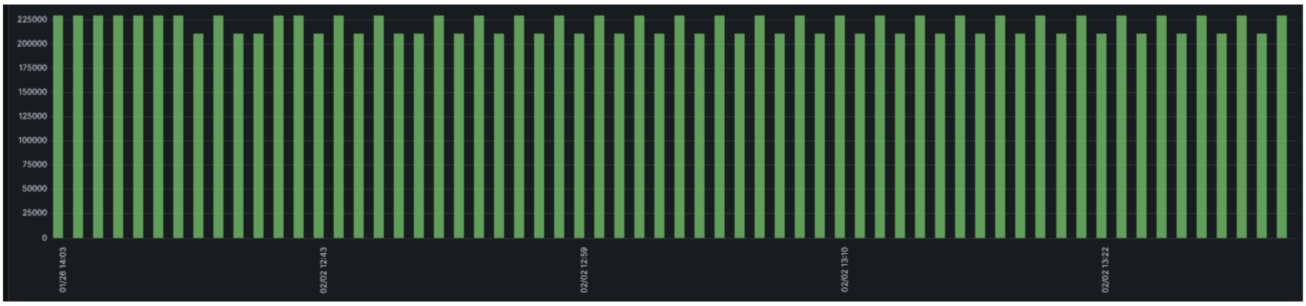


**Figure 54. File size per asset bundle (kb).**

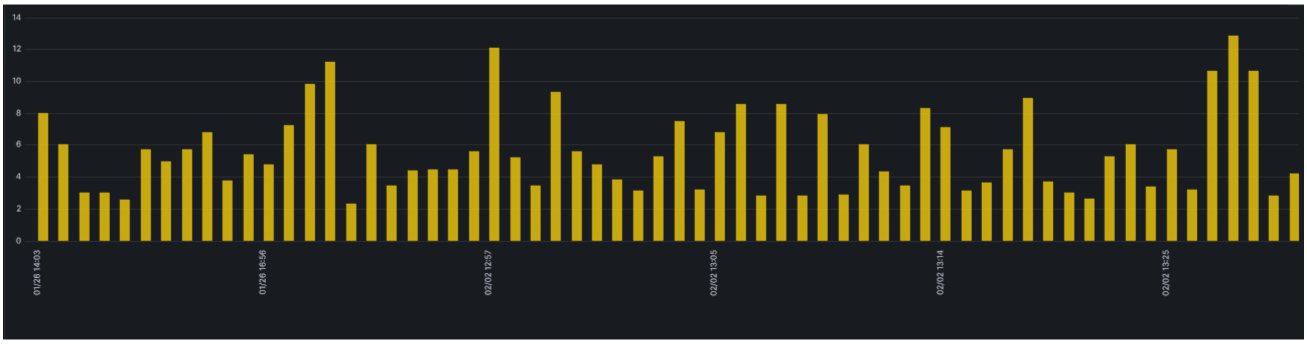

Figure 55. Throughputs achieved for the different asset bundles on the WINGS 5G campus network.

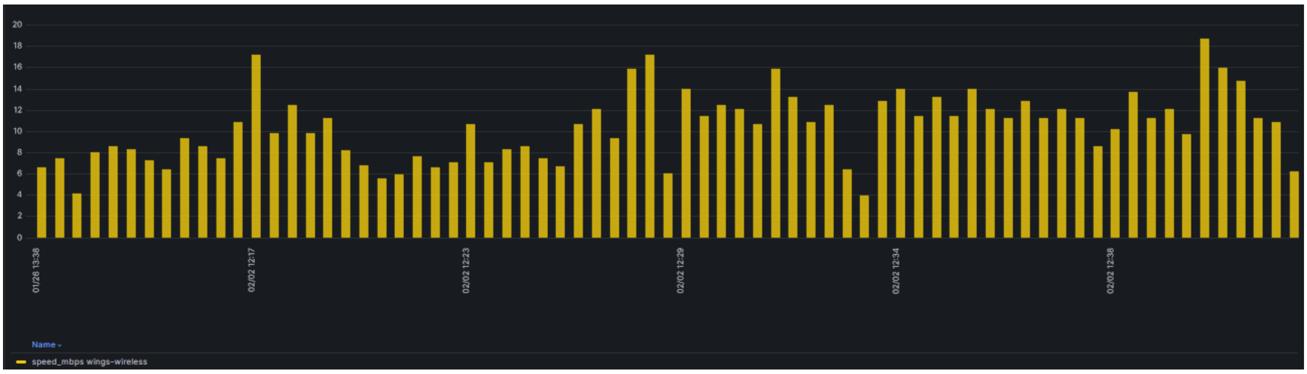

Figure 56. Throughputs achieved for the different asset bundles on the WINGS Wireless network.


Figure 57. One-way average latency for WINGS 5G campus net.

The test cases results for Trial 13.2 are reported in Table 27.

Table 27. Test cases results for Trial 13.2.

| Test case ID | Test requirement | Measurement result | Validation |
|---|---|---|---|
| **13.2_Lab01_01** | KPI#01: 50Mbps | KPI#01: up to 150 Mbps | Network capacity is sufficient to satisfy measurements requirements. |
| **13.2_Lab01_02** | KPI#08: 80-100ms | KPI#08: 20-40sec | Application round-trip latency not sufficient due to the very large size of the assets to be loaded. The tests will be repeated, using smaller asset bundles in order to validate the performance |
| **13.2_Lab01_03** | KPI#09: 50ms | KPI#09: up to 30ms | One way-latency is sufficient to satisfy measurements requirements. |

#### 3.5.1.2 Tests on field

Tests on field are planned to be performed in the following months of 2024.

#### 3.5.1.3 Early demo

In this section, the early demos related to the different applications are described.

**AR Parthenon application**

The users can tap on the screen to spawn the Parthenon AssetBundle, which is requested on demand, on any flat surface and use their fingers to scale up and rotate the 3D object as desired to discover more audiovisual information (see Figure 58). The users can tap on the numerical annotations to access the content, respawn the 3D model, and select between two languages.


**Figure 58. AR Parthenon application demo.**

**VR Parthenon application**

In this VR application, users navigate the main menu's virtual environment and select their desired location to visit, as depicted in Figure 59. By choosing between single-player and multiplayer modes, the users enter the Parthenon virtual environment to explore the famous landmark in actual size and navigate the interior and exterior area using their VR controllers. Teleportation areas around the Parthenon building enable users to follow a pathway and navigate in specific points and annotations to enrich their knowledge and interact with the content (see Figure 60). Multiplayer mode allows users to co-exist in the same environment with the ability to see and interact with each other's avatars, set their names, and communicate via voice chat (Figure 61).

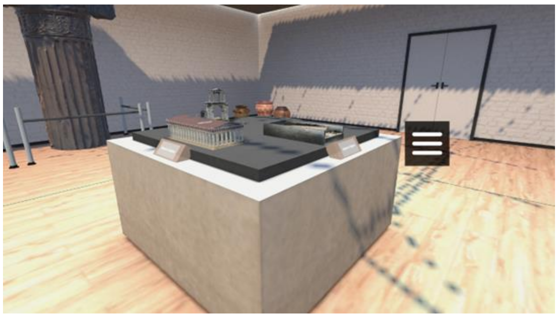

**Figure 59. VR Parthenon Main Menu Scene.**


**Figure 60. Players´ avatars interacting with each other in Multiplayer mode.**


**Figure 61. VR Parthenon environment and annotations example.**

### AR Corinth Canal application

QR codes are placed inside the museum, each corresponding to an exhibit. By opening the digital tour guide application, the visitor must locate the QR code points in the space, approach each of them, and target a code using their device's camera to discover more information and access the digital content (see Figure 62). As each QR code is detected by the camera, a panel with information and photographic material for the corresponding exhibit appears on the user's screen. Using the device's touch screen, the visitor can interact with the content, browse the information tabs and perform drag and zoom in/out operations on the photographic material.

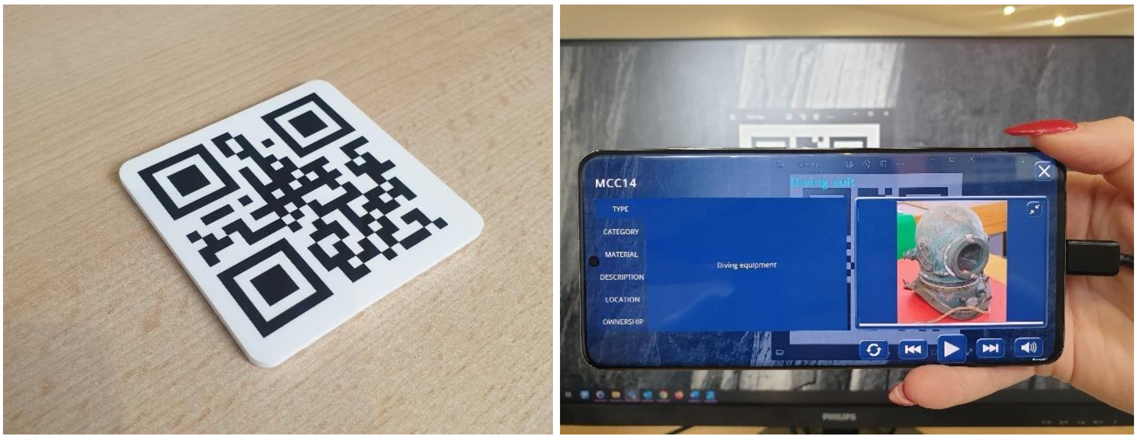


**Figure 62. Printed QR code and AR app demo trial.**

### VR Corinth Canal application

Upon entering the virtual space, the content is requested and loaded. Navigation instructions, camera and movement controls, and language settings are displayed within the virtual space. Transporting and camera rotation is done using the VR controllers joysticks and the interaction with the 3D objects. By clicking on a 3D representation of the exhibits using the controllers' ray cast, information panels are displayed in the virtual space, offering users details and audiovisual material (see Figure 63).


**Figure 63. Corinth Canal Museum.**

### 3.5.2 Remarks and next steps

In conclusion, the tests successfully demonstrated the main capabilities of the application software developed. They validate the overall architecture of the application, showing it is capable of downloading the Asset Bundles that comprise the content of both the AR and VR applications on demand. The main conclusions of the first measurements indicate that 5G network capacity and one-way delay are sufficient to satisfy the requirements of the use case. Regarding the round-trip time latency, it was insufficient but this was due to the file size of the individual asset bundles (some of them were more than 225 MB). To tackle this, the content of the applications will be re-packaged in smaller asset bundles and the tests will be repeated. In the next period, further tests will have to be done in the field to confirm these results.

# 4 Implementation Plan Updates

This section details the project implementation plan, updated to date, that outlines the key milestones and timeline that guide the progression of all initiatives. As WP5 members navigate through the implementation phases, this section aims to provide with a clear understanding of the strategic steps and pivotal moments that shape the project´s trajectory

## 4.1 UC10: Immersive Fan Engagement

As describe in D5.1 [1], the milestones of UC10 are as detailed below:

- **MS1** (Q2 2023): This milestone entailed defining user needs, technical requirements, and trials design for the activities/tasks associated with the implementation of UC10.
- **MS2** (Q4 2023): This milestone is related to the performance of the pre-test at Ericsson 5Tonic testing laboratory in Madrid..
- **MS3** (Q2 2024): This milestone involves designing the technical setup needed to implement the trial for UC10. It aims to configure the infrastructure (sensing, communicating, processing, acting) and identifying the hardware/software tools to be used. Some additional tests with the 3GPP Rel-17 new setup (pre-trial) will be required to complete the design for the trial.
- **MS4** (Q4 2024): This milestone is related to the deployment of the trial in the venue and the acquisition of the KPIs and KVIs during the trial. The review and dissemination of the trial results will be carried out throughout the remainder of the project.

As of Q1 2024, all scheduled activities/tasks for MS1 and MS2 were completed. MS3 is already in progress and may be rescheduled if testing of 3GPP Rel-17 is delayed due to external dependencies on hardware being compliant with new software and frequencies.

## 4.2 UC11: Service Robots for Enhanced Passengers´ Experience

As describe in D5.1[1], the milestones of UC11 are as detailed below:

- **MS1** (Q3 2023). This milestone involves the definition of the user needs, technical requirements, network connections, and trials design for the activities/tasks related to the implementation of UC11 (including a masterplan detailing tasks, timeline, resources and costs), the development of an App, and the execution of the pre-trial).
- **MS2** (Q1 2024). This milestone involves the start of the control and experimental sessions of the trial at the Athens airport. It tests platforms and network solutions, KPI and KVIs collection, additional UC analysis, additional development integration & testing.
- **MS3** (Q1 2025). This milestone reports on the preliminary execution results including KPIs and KVIs collection for UC11.
- **MS4** (Q3 2025). This milestone coincides with the reports of the execution of the final trial of UC11.

MS1 has been completed. MS2 will be completed by the end of April 2024 when the trialling at AIA will start as soon as the thermal cameras have been installed. This replan of one month was due to the change of cameras from optical to thermal ones to be compliant with the GDPR regulation. In parallel WINGS team progressed the platform development and testing with the thermal cameras at WINGS labs in order to be ready to start the field trials when the cameras have been deployed at AIA. Furthermore, a new analytics model for human detection is planned to be built that will fulfil the above task through thermal cameras. Having the thermal cameras, a custom dataset is going to be collected and annotated. Then the training procedure will hopefully produce an even more accurate detection model. The focus will also be on the further development of the visualization dashboard and its integration with the back-end. Finally, additional KPIs will be measured.

## 4.3 UC12: City Parks in Metavers

As describe in D5.1[1], the milestones of UC12 are as detailed below:

- **MS1** (Q3 2023). This milestone involves the definition of the user needs, technical requirements, network connections, and trials design for the activities/tasks related to the implementation of UC12 at the Borgo Medievale including a masterplan detailing tasks, timeline, resources and costs.
- **MS2** (Q2 2024). This milestone involves the pre-trial execution, initial performance analysis, additional UC analysis and the start of the trial execution for UC12.
- **MS3** (Q4 2024). This milestone reports on the preliminary execution results and KPIs and KVIs collection for UC12.
- **MS4** (Q1 2025). This milestone involves the execution of the final control, measurements and experimental sessions for the trial of UC12.

As of Q1 2024, all scheduled activities/tasks for MS1 were completed. The Milestone M2 which was planned in the 2nd quarter of 2024 has been replanned to the 3rd quarter in order to cater for the integration of the potential successful proposals that will be received in the open call. Regarding the hardware, in December 2023, COTO has received most of the devices that will be used in the trials of the use cases in Turin. Further tablets will be ordered by CROSEU in 2024 as needed. The servers of the Politecnico have been upgraded and tested and in January 2024 the application software was migrated. Activities associated to MS2 are already in progress.

In the implementation of UC12, a few challenges arose that necessitated timely interventions. Originally, the immersive experience was intended to unfold in the Borgo Medievale, a charming medieval-style village adjacent to the Rocca (the castle). Regrettably, the Borgo Medievale is currently closed for renovations spanning from the commencement of 2024 to the conclusion of 2025, rendering any access impossible. Following the insights gleaned from the initial Design Thinking+ session, the decision was made to substitute the combined physical and digital visit with a fantasy game set in the park, seamlessly integrating AR, VR, and the Metaverse. Another notable hurdle emerged in acquiring high-resolution 3D scans for the final segment of the game within the Unity engine of the Metaverse. The initial proposition to repurpose existing 3D scans of the Rocca in the Matterport format had to be abandoned. This was due to the considerable manual adjustments necessary for exporting to Unity, exceeding the scope of a proof-of-concept endeavour. Similarly, attempts to utilize the generous offer of existing 3D scans from the Politecnico di Torino of the Castello del Valentino encountered setbacks. Resolving these scans for integration would have demanded an extensive six-month graphic overhaul. Consequently, an alternative approach was adopted, leveraging existing 3D scans provided by the Links Foundation. These scans depicted a tower within a meadow in a wooded area, aligning well with the envisioned spirit of the game. Despite necessitating some adjustments, these modifications were considerably less extensive than those proposed in earlier attempts.

## 4.4 UC13: Extended XR Museum Experience (Turin)

As describe in D5.1[1], the milestones of UC13.1 are as detailed below:

- **MS1** (Q3 2023). This milestone involves the definition of the user needs, technical requirements, network connections, and trials design for the activities/tasks related to the implementation of UC13 at the Turin site, including a masterplan detailing tasks, timeline, resources and costs.
- **MS2** (Q2 2024). This milestone involves the pre-trial execution, initial performance analysis, additional UC analysis and the start of the trial execution for UC13 at the Turin site.
- **MS3** (Q4 2024). This milestone reports on the preliminary execution results and KPIs and KVIs collection of UC13 at the Turin site.
- **MS4** (Q1 2025). This milestone involves the execution of the final control, measurements and experimental sessions of the trial for UC13 at the Turin site.

As of Q1 2024, all scheduled activities/tasks for M1 were completed. The Milestone M2 which was planned in the 2nd quarter of 2024 has been postponed to the 3rd quarter in order to cater for the integration of the potential successful proposals that will be received in the open call. Regarding the hardware, in December 2023, COTO has received the devices that will be used in the trials of the Turin cluster. Further tablets will be ordered by

CROSEU in 2024 as needed. The servers of the Politecnico have been upgraded and tested and in January 2024 the application software was migrated.Activities associated to MS2 is already in progress.

In the execution of UC13, certain challenges surfaced, prompting timely interventions. In particular the insufficient illumination of the painting "Il Castello di Rivoli," rendered it impractical for AR devices to accurately recognize its details. Consequently, a decision was made to activate the AR function through touchscreen interaction, as opposed to relying on pointing to specific regions of the painting. To facilitate this, the image of the painting on the device was segmented into six rectangles. By touching a specific rectangle on the device screen, visitors could access information about the corresponding content within that segment.

## 4.5 UC13: Extended XR Museum Experience (Athens)

As describe in D5.1[1], the milestones of UC13.2 are as detailed below:

- **MS1** (Q3 2023). This milestone involves defining the user needs, technical requirements, network connections, and trials design for the activities/tasks related to the implementation of UC13 at the Athens site, including a master plan detailing tasks, timeline, resources, and costs.
- **MS2** (Q2 2024). This milestone involves the pre-trial execution, initial performance analysis, additional UC analysis and the start of the trial execution for UC13 at the Athens site.
- **MS3** (Q1 2025). This milestone reports on the preliminary execution results, KPIs, and KVIs collection of UC13 at the Athens site.
- **MS4** (Q3 2025). This milestone involves the execution of control and experimental sessions of the trial for UC13 at the Athens site.

All scheduled activities/tasks have been performed. MS1 has been completed with no issues. Activities associated to MS2 is already in progress.

# 5 Conclusions

This deliverable outlines the use cases currently being implemented in the context of the CTE domain of WP5. For each use case, the document delves into the final application design, related infrastructure components, functionalities, and initial KPIs measurements in the trial sites located in Madrid, Athens, and Turin. Additionally, the deliverable offers a comprehensive review of the initial time plan and key milestones for each use case as they progress towards trial completion.

The main remarks for each use cases are summarized hereafter:

**Use Case 10 "Immersive Fan Engagement" (Madrid):** preliminary testing of 5G testbed in 5Tonic laboratory has revealed uplink challenges prompting the need for network optimization to get improved throughput and jitter for video contributions.

**Use Case 11 "Service robots for enhanced passengers´ experience" (Athens)**: successful tests validated the application´s diverse capabilities, paving the way for potential system expansion.

**Use Case 12 "City Parks in Metaverse" (Turin):** Initial laboratory measurements of the aggregated downlink and uplink loads, conducted with a VR headset connected to a PC via Ethernet, indicate that they can be adequately managed by the local 5G network. However, one critical parameter that warrants attention is latency, which will have to be measured while considering the various system components in series.

**Use Case 13: "Extended XR Museum Experience" (Turin):** Preliminary measurements for a metaverse platform connected to a 5G network indicate that the capacity and roundtrip delay meet the requirements for the use case. Nonetheless, further field tests are necessary to validate these findings.

**Use Case 13 "Extended XR Museum Experience" (Athens):** successful tests confirmed the application´s on-demand AssetBundle download capability for AR and VR, revealing manageable 5G capacity with minor latency issues due to large file sizes, to be addressed in the upcoming retesting and field trials.

The next phase of the use cases implementation activities will also involve the final sessions of the Design Thinking+ process for UC12 and UC13 (Turin). This step aims to validate that the proposed applications align with the preferences expressed by the end-users collected during the previous meetings. Demos will be presented to participants for each use case.

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

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# Annex A

D6.1 [48] defined a harmonized list of KPIs to be adopted by all the use cases in order to have a common terminology shared at the project level. In the context of the test activities, and later to the trial phase, it is necessary to have also an efficient way to refer to each KPI in a unique and immediate manner. Therefore, for each KPI, a proper ID has been defined according to the following Table 28.

**Table 28. Harmonised KPIs from D6.1 [48] and related IDs.**

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

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