5G smarT mObility, media and e-health for toURists and citizenS

Deliverable D4.2

First Touristic City use case results

Project Details

Call	H2020-ICT-19-2019
Type of Action	RIA
Project start date	01/06/2019
Duration	36 months
GA No	856950

Deliverable Details

Deliverable WP:	WP4
DeliverableTask:	T4.1, T4.2, T4.3, T4.4
Deliverable Identifier:	5G-TOURS_D4.2
Deliverable Title:	First Touristic City use case results
Editor(s):	Luca Vignaroli (RAI)
Author(s):	Luca Vignaroli (RAI) Davide Desirello (RAI) Mario Muratori (RAI) Andrea Bertella (RAI) Giovanni Vitale (RAI) Silvio Ripamonti (RAI) Davide Milanesio (RAI) Davide Zappia (RAI) Alberto Ciprian (RAI) Álvaro Ibáñez (UPV) Aaron Montilla (UPV) Carlos Barjau (UPV) Ran Rahav (LIV) Baruch Altman (LIV) Elena Deambrogio (TOR) Elena Ghibaudo (TOR) Anna Follo (FTM) Alessandro Trogolo (TIM) Alessandro Porta (TIM) Giuseppe La Torre (TIM) Antonino Casella (TIM) Giancarlo Sacco (ERI_IT) Alfredo Palagi (ERI_IT) Mara Piccinino (ERI_IT) Marco Randazzo (IIT) Lorenzo Natale (IIT) Vadim Tikhanoff (IIT) Francesco D'Andria (ATOS) Enrique Quirós (ATOS) Kevin Picchi (SRUK) Marco Gramaglia (UC3M)

	Cristina Marquez (UC3M) Christophe Burdinat (EXP)
Reviewer(s):	Internal reviewer #1: SRUK (Ghizlane Mountaser) Internal reviewer #2: IIT (Lorenzo Natale) External reviewer #1: WINGS (Ioannis Belikaidis) External reviewer #2: B-COM (Thomas Ferrandiz, Eric Gatel) PM and TM review: Silvia Provvedi Albert Banchs Belkacem Mouhouche QAM Review: Nelly (Eleni) Giannopoulou (WINGS)
Contractual Date of Delivery:	31/12/2020
Submission Date:	29/12/2020
Dissemination Level:	PU
Status:	Final
Version:	1.0
File Name:	5G-TOURS_D4.2_FirstTouristicCityUseCaseResults_v1.0

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Deliverable History

Version	Date	Modification
V1.0	*29/12/2020*	*Initial version, submitted to EC through SyGMa*

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List of Acronyms and Abbreviations

Acronym	Description
3D	3 Dimensional
3GPP	Third Generation Partnership Project
4K-HDR	4K High Dynamic Range
5G	5th Generation mobile Wireless Communication System
5G PPP	5G Public Private Partnership
5GC	5G Core
A/V	Audio-visual
AAC	Advanced Audio Codec
AI	Artificial Intelligence
API	Application Programming Interface
APN	Access Point Name
AQI	Air Quality Index
AR	Augmented Reality
ATE	Augmented Tourism Experience
AWS	Amazon Web Services
BMSC	Broadcast Multicast Service Centre
BSCC	Broadcast Service & Control Centre
CDN	Content Delivery Network
CO	Carbon Monoxide
CO_2	Carbon Dioxide
COAP	Constrained Application Protocol
CPU	Central Processor Unit
DASH	Dynamic Adaptive Streaming over HTTP
DC	Datacentre
EBU	European Broadcasting Union
eMBB	enhanced Mobile Broadband
eMBMS	evolved Multimedia Broadcast Multicast Service
eNB	Evolved Node B
ENM	Ericsson Network Manager
enTV	Enhancement for TV Service
EPC	Evolved Packet Core
EPG	Evolved Packet Gateway
FEC	Forward Error Correction
FeMBMS	Further evolved Multimedia Broadcast Multicast Service
FTP	File Transfer Protocol
GAM	Modern Art Galley
GDP	Gross Domestic Product
GPU	Graphics Processing Unit
gNB	5G Node B
HDR	High Dynamic Range
HEVC	High Efficiency Video Coding
HPA	High Power Amplifier
HPHT	High-Power High-Tower
HSS	Home Subscriber Server
HTTP	HyperText Transfer Protocol
ICT	Information and Communication Technology
IFB	Interference Free Band
iFN	Institut für Nachrichtentechnik - University of Braunschweig
IIT	Istituto Italiano di Tecnologia
IoT	Internet of Things
JSON	JavaScript Object Notation
KPI	Key Performance Indicator
LED	Light Emitting Diodes
LIDAR	Light Detection and Ranging
LTE	Long Term Evolution
MANO	NFV Management and Network Ochestration
MAO	Museum of Oriental Arts
MAUA	Museum of Augmented Urban Arts
MBMS	Multimedia Broadcast Multicast Service
MBMS-GW	MBMS Gatway
MCE	Mobile Cloud Engine
MCS	Modulation and Coding Scheme
MCU/SFU	Multipoint Conferencing Unit / Selective Forwarding Unit
MEC	Multi-Access Edge Computing
MME	Mobility Management Entity
mMTC	massive Machine Type Communications
MNO	Mobile Network Operator
MR	Mixed Reality
MQTT	Message Queue Telemetry Transport
NB-IoT	Narrow Band IoT
NO_2	Nitrogen Dioxide
NR	New Radio
NSA	Non Standalone
O_3	Ozone
open-WRT	OPEN Wireless RouTer
OSS/BSS	Operations Support System and Business Support System
P2P	Peer-to-Peer
QoE	Quality of Experience
QoS	Quality of Service
RAI	Radio Televisione Italiana
RAI-CRITS	RAI Centro Ricerche Innovazione Tecnologica e Sperimantazione
RAN	Radio Access Network
RGB	Red Green Blue
ROS	Robot Operating System
SDI	Serial Digital Interface
SBA	Service Based Architecture
SDR	Single Data Rate
SFN	Single-Frequency Network
SGI	LTE interface to the Packet Data Network (PDN)
SLA	Service-Level Agreement
SLAM	Simultaneous Localisation and Mapping
SO_2	Sulphur Dioxide
STEAM	Science Technology Engineering Arts Mathematics
SVG	Scalable Vector Graphics

TCP	Transmission Control Protocol	*URL*	Uniform Resource Locator
TS	Transport Stream	*USB*	Universal Serial Bus
TV	Television	*UWB*	Ultra Wide Band
UC	Use Case	*VHF*	Very High Frequency
UDP	User Datagram Protocol	*VLC*	VideoLAN Client
UE	User Equipment	*VPN*	Virtual Private Network
UHD	Ultra HD	*VR*	Virtual Reality
UI	User Interface	*WP*	Work Package
UNESCO	United Nations Educational, Scientific and Cultural Organization	*XR*	Extended Reality
		YARP	Yet Another Robot Platform

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Executive Summary

This deliverable is a design document covering the use cases of the Touristic City (media production and distribution, safety and security in smart cities, museum and education, robotics) and their implementation on the 5G-TOURS platform within the Turin site.

The Touristic City of 5G-TOURS is a place where visitors of museums and outdoor attractions are provided with 5G-based applications to enhance their experience while visiting the city. This includes VR/AR applications to complement the physical visit with additional content, involving interactive tactile communications. The visitors' experience is further enhanced with robot-assisted services, telepresence to allow for remote visits, as well as live events enabled by mobile communications such as multi-party concerts and also taking into account the high-quality video and content distribution.

The scope of this document is to describe the progress in the implementation of the use cases in terms of network deployment and equipment, application and terminal equipment components and interfaces. In addition, the integration end test in labs and tests in the network are introduced in relevant sections of each of the five vertical use cases also taking into account the integration with the 5G-EVE infrastructure and platform.

In particular, the Turin "Touristic city" site will develop and test 5G-enabled services regarding the following use cases:

- UC 1 - Augmented tourism experience

  This use case aims to provide visitors of targeted museums with an improved and more engaging experience based on the use of an Application inside and outside the Palazzo Madama Museum and on the use of an interactive wall dedicated to children and students in GAM (Galleria d'Arte Moderna) Museum. Users' experience will be enhanced by augmented content such as: interactive 3-Dimensional (3D) models, virtual avatars and scenarios, immersive (360 degrees) videos and interactive walls.

- UC 2 - Telepresence

  The main goal of this use case is to test and employ a robot located inside the museum and controlling it from remote location. Telepresence robots have the potential to contribute to accessibility and inclusiveness by extending access to previous excluded audiences.

- UC 3 - Robot-assisted museum guide

  This use case foresees the use of the robotic technology to provide an enhanced museum visit experience, the R1 robot will be able to: provide basic information about collection highlights and temporary exhibitions as well as assist visitors during queuing time at ticket desk; guide visitors moving through the museum and describing the artworks. This guided tour will be performed autonomously by the robot following a precomputed path.

- UC 4 - High quality video services distribution

  This use case targets the distribution of enhanced high-quality video services for tourists to improve the user experience when visiting a city. It is directly related to the media and entertainment vertical. Users will be able to use their smartphones, tablets or VR devices to receive educational and informative content during their visits to the city and museums. The use case is based on use of 5G broadcast delivery services using the broadcasting network, and the development of a 5G core multicast component.

- UC 5 - Remote and distributed video production

  The objective of the use case is to exploit the 5G TOURS network features for remote television production, in a distributed TV video production context, the content needs to be produced by mixing local and remote audio and video contributions in the TV studio. The remote contributions are thus delivered to the main editing site via the 5G network in real time.

This document provides descriptions of the use cases implementations, the revision of the whole WP4 work plan and the analysis of critical project risks are given taking in to account main impacts due to the COVID-19 sanitary emergency.

1 Introduction

This deliverable is intended to be a document covering the use cases for the Touristic City and their implementation on the 5G-TOURS platform within the Turin site. Whole preliminary descriptions of WP4 use cases are included in the deliverable D4.1 [1].

The deliverable D4.2 describes the ongoing activities of the other work packages, in particular:

- WP2 – Use cases design for the definition of the involved use cases, see in particular deliverables D2.1 [2] and D2.2 [3].
- WP3 – Network architecture and deployment for the selection of the technologies to be deployed and the actual deployment of the trials, references are in the deliverable D3.1 [4] and in the deliverable D3.2 [5]
- WP7 – System integration and evaluation for the evaluation of the overall achieved results as depicted in D7.1 [6],
- WP8 – Business validation and exploitation for their impact on techno-economic plans, the reference documentation is the deliverable D8.1 [7].

In this deliverable, in Chapters 2, 3, 4, 5 and 6, the main ongoing implementation activities of each use case and sub-use cases are highlighted. For each UC to be deployed on the Turin node this report provides:

- UC definition;
- UC implementation in terms of:
    - Application components;
    - Terminal equipment components;
    - Interfaces;
- Integration and test in lab;
- Test in the network.

Then, in Chapter 7, a detailed description of the 5G-TOURS network implementation for the Turin site is given since there is a common infrastructure for all the involved UCs, in particular the document provides details on:

- Network deployment;
- Network equipment;
- Network enhancement.

Different implementation phases are also depicted. In addition, Chapter 7 also describes the integration with the 5G-EVE infrastructure and platform in terms of areas to be covered, deployment requirements, timeline and deployment roadmap, as well as the functionalities that will be needed for the underlying network equipment. From this perspective, also the nodes that 5G-TOURS will deploy for its specific use to take advantage of the functionalities that the 5G-EVE platform will provide as well as for the innovations studied in 5G-TOURS.

Finally, Chapter 8 is dedicated to the whole WP4 work plan, in which are described all activity milestones and a detailed analysis of the deviation from the original work plan and recovery actions. Particular emphasis is given to the impact of the COVID-19 sanitary emergency on WP4 activities and the contingency plans.

2 UC1 - Augmented tourism experience

2.1 UC1 definition

This use case aims to provide visitors of targeted museums with an improved and more engaging experience based on the use of an Application inside and outside the Palazzo Madama Museum and on the use of an interactive wall dedicated to children and students in GAM (Galleria d'Arte Moderna) Museum. Users' experience will be enhanced by augmented content such as: interactive 3-Dimensional (3D) models, virtual avatars and scenarios, immersive (360 degrees) videos and interactive walls. The UC1 is divided into two sub-cases:

UC1.a: In the very heart of Turin

Partner involved: TOR/FTM; ERI-IT; TIM; SRUK; RAI; ATOS

Location: For "City Walks": route in the city. For in "In the very heart of Turin": Palazzo Madama (apartment of Madama Reale – second floor); Senate hall, as depicted in Chapter 7 about network implementation.

This sub-UC aims to create and test an integrated, immersive visit in the Museum and surrounding areas using a mobile App based on beacon localization technology. Through the App the visitor will have access to additional information such as: possible tour to run, level of crowding in museum room, map of the Museum and related points of interest as well as have access to more contents related to specific rooms and artworks. It will be possible to interact with 3D objects or participate in a virtual scenario with the aim to improve the visitor knowledge by taking actions. Furthermore, once outside the Museum, the App will help visitors suggesting further places of interest using interaction with "smart city services". Finally, once at home, the city tourists can retrieve artworks previously stored or explore new realities not seen during the tour.

UC1.b: GAM and Edulab – Gamification, let's play artist

Partner involved: TOR/FTM; SRUK; ATOS; ERI-IT; TIM; RAI (interview to the artist)

Location: GAM and Edulab

The objective of this sub-use case is to allow users to enter into the life of De Maria contemporary artist and to directly test the art creation process as well as learn about it through gamification. It is an educational Case Study addressed to students or families with children. The experience mixes XR (Extended Reality) with gamification and will allow children to work on an interactive wall reproducing the artist canvas by choosing shape and colors contents.

2.2 UC1 implementation

UC1.a: In the very heart of Turin

The use case takes place entirely within Palazzo Madama and involves the use of a mobile application (the app) of augmented tourism experience that offers visitors a guided tour of the museum enriched with multimedia content, augmented reality experiences and typical information of a smart city to improve its visit experience.

The app will therefore rely on 5G coverage (indoor) to download multimedia contents (3D representation of pieces of arts, immersive videos, audios, etc.) on demand from an ad-hoc 5G enabled infrastructure. The use-case also requires the deployment of some sensors both internally (on the four towers) and externally (in Piazza Castello).

Technical aspects:

- Initially, the VR experience will involve two users; the possibility to have additional (remote) users will be investigated at a later stage of the implementation;
- Each user will wear a Samsung Gear VR using a 5G Samsung phone as a display; controllers will be available for the user's interactions with the environment;
- Users' avatars will be represented by the shape available by native features given from the use of Gear VR (i.e. head); a user will be able to see their own hands;
- Users will be able to move in the room using teleport, perform basic actions (e.g. grab and use objects) and eventually interacting with each other by voice or by passing objects;

Storyline:

- The VR experience will be usable by visitors in the Atrium of Palazzo Madama;
- The VR experience will be happening in the Camera delle Guardie and the users will be able to visit the room and watch the different painting and visit the room;
- After a given amount of time the room will start shaking and the frame will fall and split into pieces;
- The user will recompose the frame by placing the pieces back in the right position.

Content provisioning:

- RAI will work on 3D scans of the objects to be used by the visitors (appropriate objects will be identified by FTM and if not available, similar ones will be used) and the Madama Reale Chamber 3D reconstruction by means of laser scans for the structure and high resolutions photos as texture;
- The Involving of an actress who will animate the avatar of Madama Reale the visitors will interact with; RAI will check the feasibility of this solution in conjunction with the recording of the Turin promotional video for the project;
- In case the above solution is not viable, alternative solutions will be investigated.

In Palazzo Madama, an app to enhance the museum visit is under development, offering different ways to further understand the palace, an UNESCO site, and the collection it hosts. The guide will be focused on the first and main floor of the museum and will have a cluster experience on the second floor.

The room of the first floor were lastly remodelled by the second “Madama Reale” (the queen regent of Piedmont) in the Baroque era. The app will guide the visitor through different media: for each room of interest there will be a textual and audio guide, a video where a curator/art educator explain one of the main artwork in permanent exhibition in the room and a photo gallery underlining some of the architectural/artistic details that are hard to see. The app will also include an experience to enjoy the ceramic collection on the second floor of the museum. Due to their frailty, all the ceramics are exhibited in glass cases that sometimes do not allow visitors to fully appreciate the artwork. A selection of objects will be scanned to generate 3D models. Visitors will be able to interact with these objects through the app, by rotating and moving them, so to have a complete vision from all the point of views. The 3D models will be complemented with very brief text clarifying some of the peculiarity of the objects that are not easily appreciated by the general public (e. g. the marks and logos on the bottom of porcelain is often a key to understand the history and value of porcelain and is something visitors seldom get to see).

The use case will be set in the following areas of Palazzo Madama (for which it will therefore be necessary to have 5G indoor coverage, as depicted in Chapter 7):

- **First floor**: On the first floor the app will provide visitors with textual, audio, photographic and video contents and augmented reality interaction experiences.
- **Second floor**: Visitors will be able to enjoy an interactive version of some ceramics that will be suitably modelled in 3D for this purpose.
- **Main hall**: There are two times when visitors will be in the hall:
    - At the <u>beginning of the visit</u>, when visitors register for the app and can obtain recommended tours based on current crowding of the rooms. This aspect will be very important to meet the access restriction put in place after the COVID emergency.
    - At the <u>end of the visit</u>, the app will show visitors how to continue their visit of the city, possibly supporting them in finding other museums to visit and suggesting the best modes of transport to reach them.

The execution flow of the app, shown in Figure 1, will cover five main scenarios:

The stage 1 “Museum visitors begin the experience” consists of the following steps:

1. The visitor gets close to a beacon installed in the main hall.
2. The app, previously installed on the visitor's device, gets from the beacon links to useful info about the museum possible tour to run, crowding level of each room etc.
3. The app retrieves and shows in a proper way the information mentioned before.

The stage 2 "The visitor enters a room of the museum" consists of the following steps:

1. The visitor enters one of the considered rooms.
2. The app scans for beacons and detect one (by analyzing beacons signal). This allow to identify the room where the user is located. This information is sent to the backend, allowing to update crowding information.
3. The app receives general information about the room description and displays a map/picture of the room enhanced with information about the space itself, how the room was used in the Baroque era and what its main artistic features are.

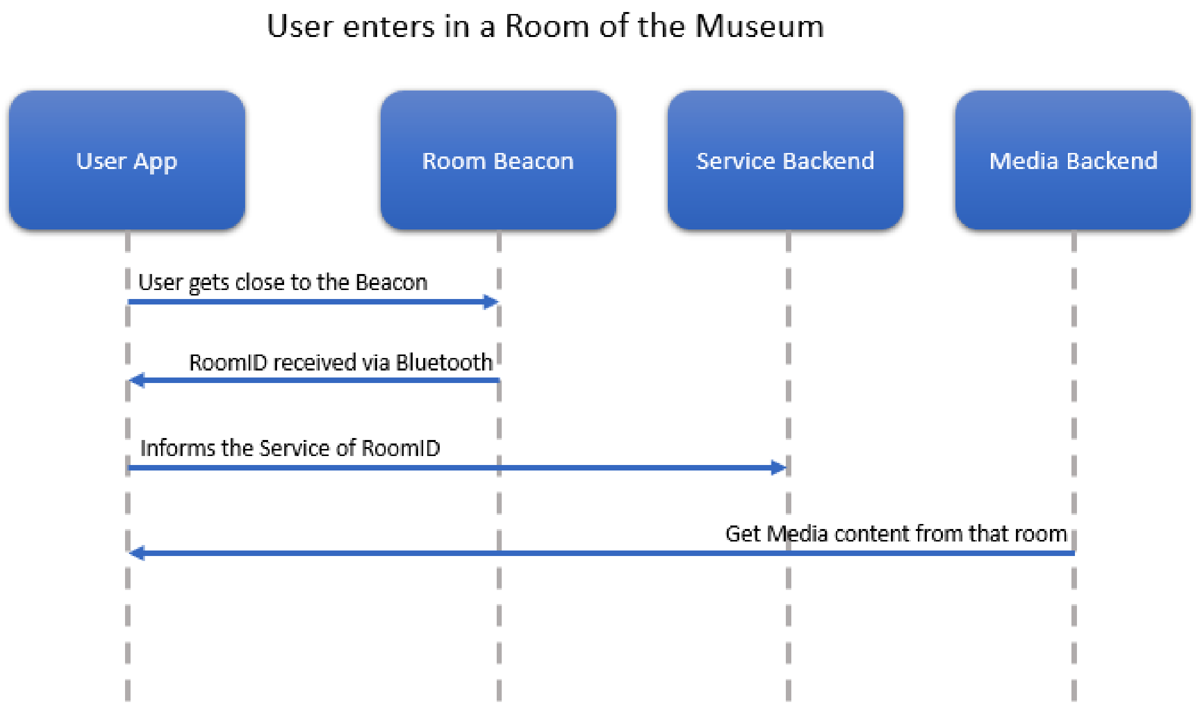

Figure 1 - The execution flow of the application.

The stage 3 "Visitors explore artworks" consists of following steps:

1. The visitor approaches the artwork placed in one of the considered rooms (see stage 2).
2. The app scans the artwork and recognizes the target.
3. The app shows up the video giving more detail information on the artwork. the visitor will be able to:
   a. Select the multimedia content to consume;
   b. On the second floor that exhibits the ceramic collection, the visitor can interact with the 3D representation of the artwork (rotate it, make it bigger to see hidden details of the artwork, etc.);
   c. Mark the artwork with a star, this way it will be available to interact with it later in the Favorites section.

The stage 4 "Visitor leave the museum" consists of following steps:

At the end of the visit, the application will offer additional information for continuing the visit of the city, it will suggest to tourists' further potential places of interest and the best ways to reach them (on foot, by bus, with car-sharing). The application will therefore interact with the "smart city services" which will make use of information "from the city", which can be both open-data (bus lines, opening hours, information on museums, etc.) but also measurements (e.g. pollution, weather, traffic, availability of bike sharing, etc.) carried out by an appropriate network of IoT sensors that will be installed in the Piazza Castello area.

In this case, the visitor will be offered a series of places to visit to continue his experience of visiting the city. After selecting the desired place, the application will show the different ways to reach it:

- On foot (if the distance is not too great and current weather and pollution conditions allow it);
- By bicycle, showing the nearest bike sharing stations;
- By public transport, showing the stops closest to the journey times;
- By car, showing the nearest car sharing stations and any parking areas near the destination area.

Each of the involved rooms requires the installation of one or more beacons (depending on the size of the room). Beacons do not require network coverage since they use Bluetooth Low Energy to send their ID to devices able to catch them, such as smartphones. Each room will be then described (in a JSON format) with the list of artworks and the ID of the beacon(s) installed in that room. For each artwork, a set of multimedia contents (audio, video, pictures) have been stored on a server and they are publicly available.

UC1.b: GAM and Edulab – Gamification, let's play artist

This use case takes place at 'Galleria d'Arte Moderna' (GAM) in Turin. It consists of an interactive wall where children ages 6-12 can create compositions based on the artwork by artist Nicola de Maria. The setup consists of three main points:

- Experience input: The experience is controlled with motion. It is important to highlight that among the requirements it is key to maintain users highly engaged with the experience; therefore the input must be through a device that supports a way of capturing movement. We have settled on using Nordic Thingy [8] devices to capture motion and recognize gesture from the users.
- Application: The application consists of a wall where kids can translate, scale, and rotate different shapes based on De Maria's work (Figure 2) by doing different movements while holding the Nordic Thingy in their hands. The shapes and colors will be provided by the Museum in RGB and vector format (like SVG). The application itself is based entirely on Web technology, making it accessible through many devices. It is based on HTML canvas, so a renderer or similar tool (like PixiJS [9]) is used for its creation.
- Display: The application is projected onto a wall at GAM, where the intended way of interaction is to be in front of the wall, creating compositions with colors and shapes provided. The interaction is through movements enabled from the input hardware described below.

The type of compositions is based on the following artwork:

Figure 2 - De Maria's work.

Fast connectivity is required to accurately map movements of the users with the input devices to the final composition in GAM. The movements go from the Bluetooth enabled device to a server that sends the position information to the museum. Therefore, low latency is important to avoid breaking the interaction mechanism.

2.2.1 Application Components

UC1.a: In the very heart of Turin

The Augmented Tourism Experience use-case involves the development of an application for Android mobile operating system which aims to assist the user during both the visit of the museum but also throughout his tourist experience in Turin.

Inside the museum, the Android application will allow the user to obtain "augmented" information on the works of art present in the various rooms, through the supply of related multimedia contents. In this regard, the application is able to recognize the physical "context" of the user, that is, to identify the room in which he is located, by recognizing beacon devices that will be specifically installed.

Once the contents present in an environment have been identified, they will be proposed to the user, both through images, audio and video, and in augmented mode, through 3D models with which the user can interact. The engine that allows the recognition of a work of art (for example through a target) and which subsequently takes care of the rendering of the 3D model, constitutes the fulcrum of the Android application. Much of the effort for the realization of this use-case is in fact aimed at all the 3D modeling part of the environments and works of art to be shown to the user through the Android smartphone.

The application also integrates some Smart City Services, to support the visitor in the logistics of moving within the city, to reach other places of interest with different mobility solutions.

Figure 3 shows in detail which are the main application components involved, highlighting those of them that are internal and those which are external to the Android application.

2.2.1.1 Android app Architecture

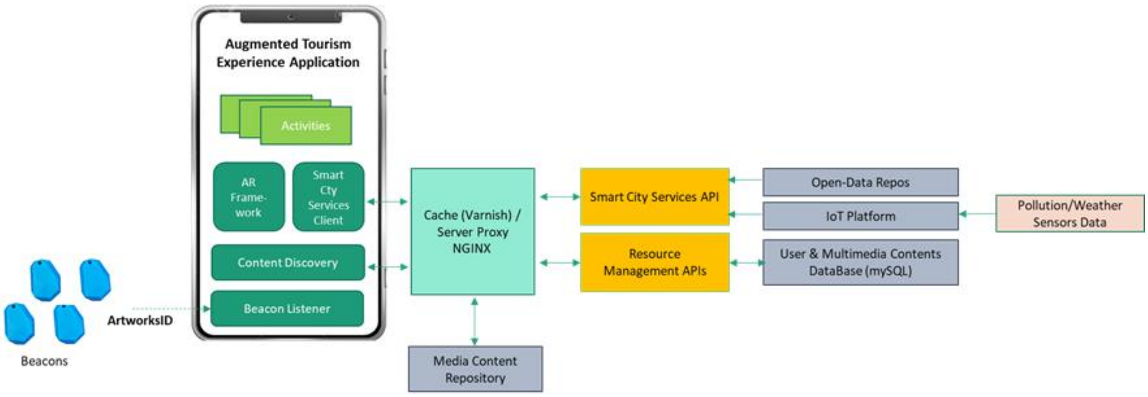

Figure 3 - Augmented Tourism Experience application components.

Beacon Listener

The Beacon Listener is a thread that is active throughout the life cycle of the Android application. Its main purpose is listening to the signal transmitted by any beacons that are close to the user. The other software components of the Android application will be notified when the application detects a beacon nearby. The discovery of a new beacon will have the meaning of the user entering the museum room. The beacon listener module also has the task of identifying the most relevant beacon (and therefore the correct room in which the user is located) if multiple signals from different beacons are received in broadcast at the same time.

Content Discovery

This module will take care of downloading media content on the fly when the user needs them. After the AR app detects a target picture it will obtain everything necessary (e.g. 3D models, video, audio and pictures etc.) to make it available to the user in the shortest time possible.

Smart City Services client

This module acts as a client to the Smart City Services APIs and has the task of interpreting the data received (for example in JSON format) to formulate different mobility solutions to a chosen place. These solutions will then be conveyed to the user on the screens during stage 4 as shown in Figure 4.

AR Framework - Application Screens

The mock-up of the application aims to give the tourist additional information in terms of other tourist places, solutions to reach the selected place and directions taking into account the point of view of the integration with Smart City Services.

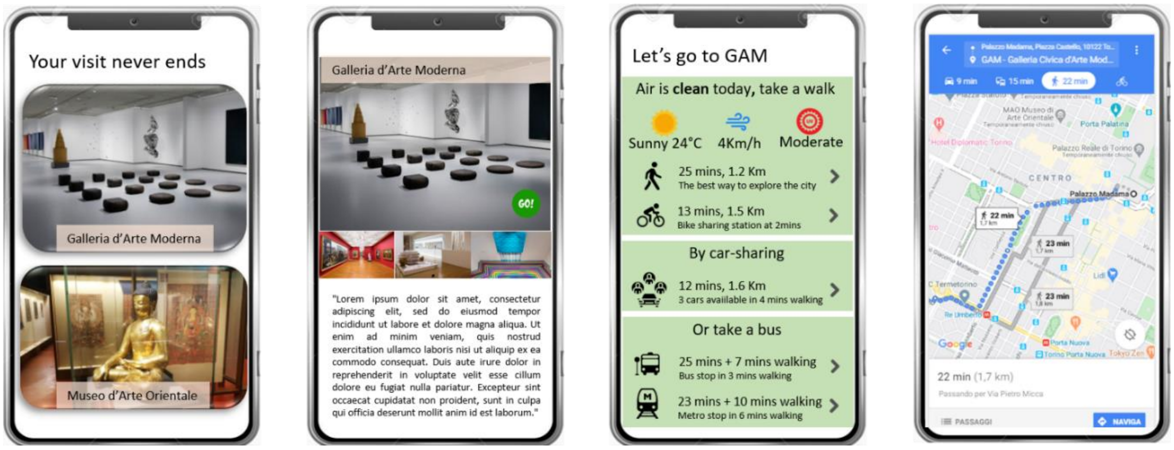

Figure 4 - Smart City Services mock-up.

Figure 4 shows the mock-up of the application screens that will be proposed when the visit of the museum is about to end, and the user is in the hall near a beacon installed there.

The first screen offers the user a series of additional tourist places (museums, squares, monuments) that he could visit. This proposal of places could also be optimized on the basis of the artistic interests that the user expressed during his visit (e.g., by keeping track of the number of contents and how long they have been used). For each place, a photo and name are briefly shown (e.g., Modern Art gallery). By clicking on one of the photos, the application will display the next screen.

The second screen shows details of a selected place. It will be possible to view a photo gallery and text that will invite the tourist to visit that place. By clicking on the GO! the application will move to the next screen.

The third screen is the most relevant from the point of view of integration with Smart City Services. In fact, the various solutions to reach the selected place are proposed, leveraging the Smart City data. Mobility solutions are ordered according to a green-first approach, thus promoting solutions with lower environmental impact with higher priority. Aspects such as pollution, UV radiation or the likelihood of rain will also be taken into consideration, when the user is offered to reach a place by walking or cycling.

Finally, the fourth screen displays the directions for reaching the chosen place on a Google map according to the mode selected. For example, in the case of bike or car sharing it will be indicated first how to reach the rental point and then how to reach the destination. Similarly, in the case of mobility by public transport, it will be indicated how to reach the bus or metro stop and then how to get to the destination. In the case of a walk, on the other hand, the route on the map could be enriched with further information on the places that the user crosses during the journey (e.g., information on squares or monuments).

Pollution telemetry data are sent periodically (e.g., every 5 minutes) to the IoT platform using the 4G connectivity and protocols such as MQTT or HTTP. The IoT platform requires a static public IP address in order to be reached from the devices. On the other hand, data relating to structural vibrations are collected by devices equipped with NB-IoT connectivity. In this case, the data are sent first to an operating TIM platform (OMA LWM2M compliant) and then forwarded to the IoT platform (which must therefore be able to communicate both inbound and outbound with LWM2M platform). Smart City services also require information from open data (e.g., meteo forecast) that is managed by third parties (e.g., Comune di Torino). The backend must therefore be able to reach the endpoints that make this data available via the Internet.

Figure 5 shows the welcome screen that will appear at the start of the visit and will show relevant information about the museum and a map with the crowding level of every room in real time. This map will provide a suggested tour to visit the museum based on that crowding level.

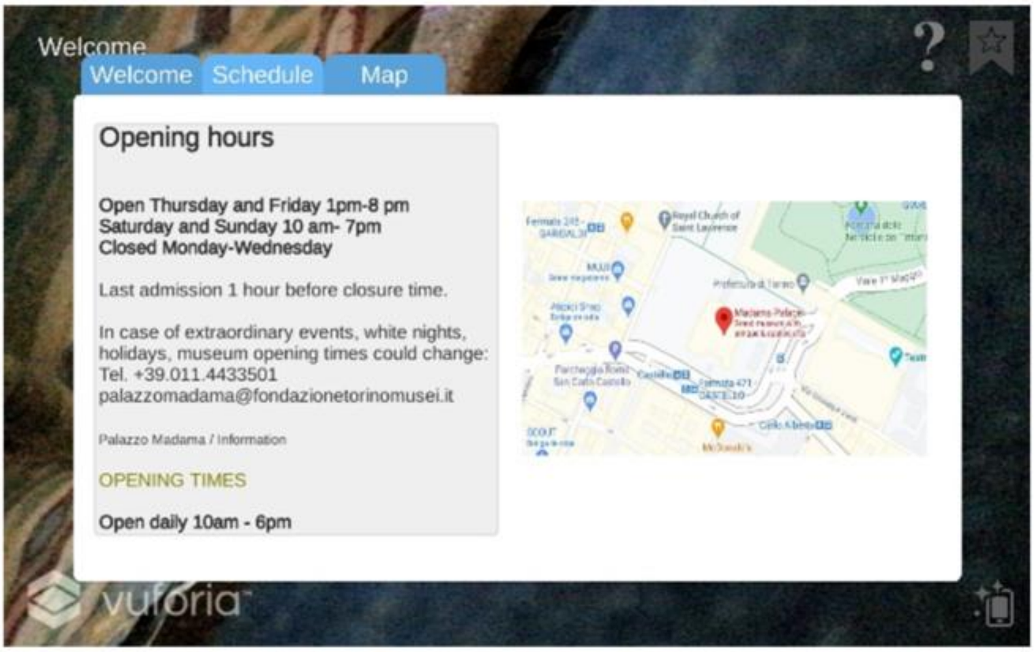

Figure 5 - AR app - Welcome screen.

Figure 6 shows how the 3D examination and manipulation will work. The app allows to zoom in and out to inspect the model of an object present in the room, revealing details that may be hard to notice in the real object, for example, at its bottom.

Figure 6 - AR app - 3D model examination.

Figure 7 shows how the video player is integrated. The app knows its location thanks to the Beacons system and will have different videos available depending on the current room.

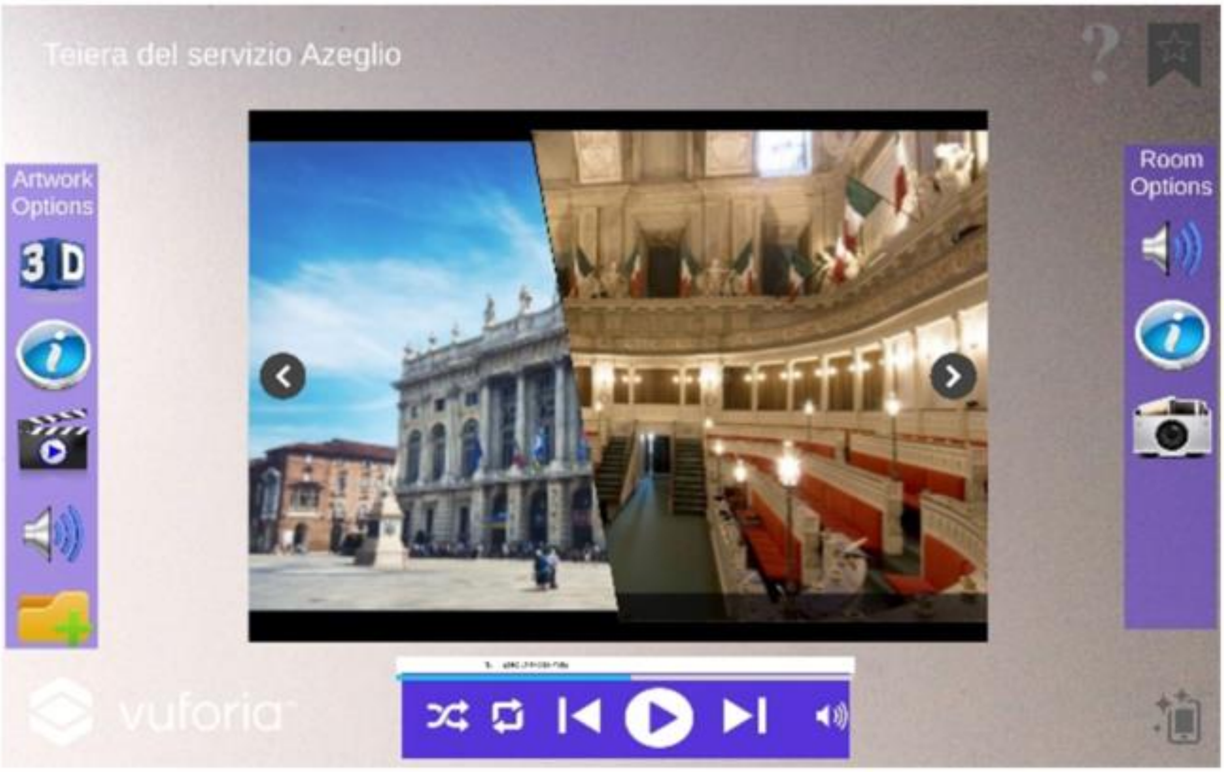

Figure 7 - AR app - Video player.

VR Framework

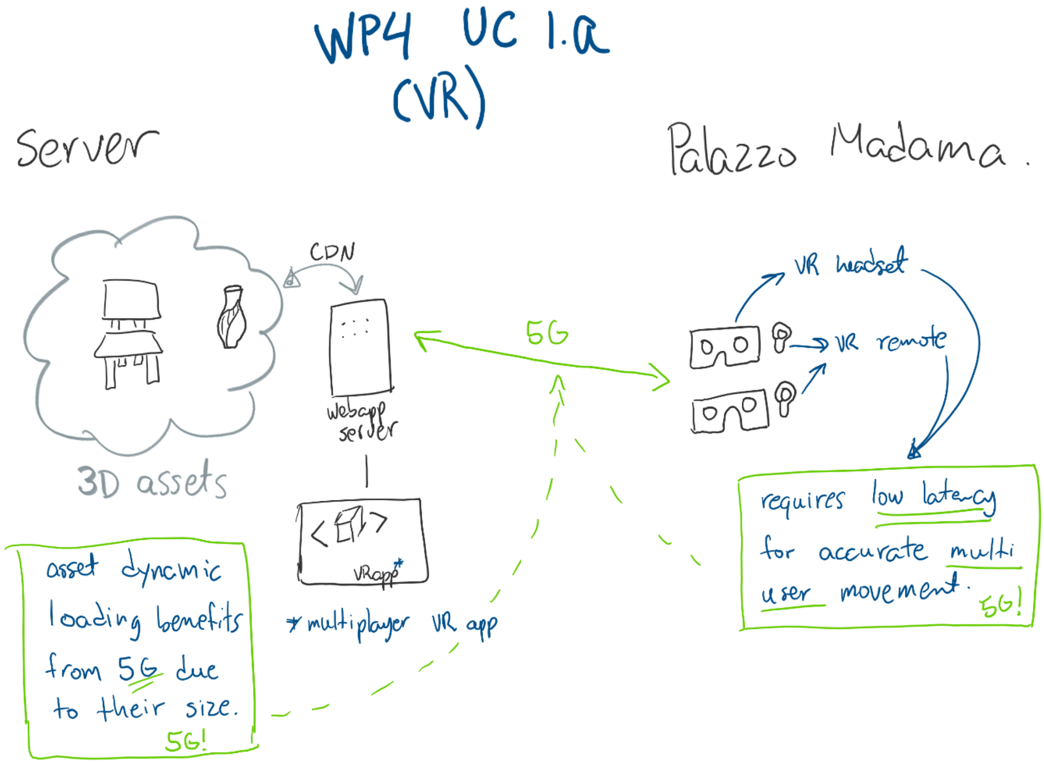

Figure 8 - The VR experience application components.

The VR experience is based in WebXR technology [10], all application components will be based on Web technology, enabling compatibility with multiple headsets and mobile devices. All interactions from-to the application (if needed) will be enabled by services available through the web, although the experience itself is self contained and accessible through the browser.

2.2.1.2 3D Models Creation

In the context of this use case RAI is creating content to be used in the implementation of the use case: this includes models of the rooms and artistic objects to be used as additional content to enhance the visit of the museum, in particular, scanned rooms will be used also for virtual navigation of the robot in UC3.

In the television field it is common to use virtual "environments" and "objects" to generate "Virtual Reality" (VR), "Augmented Virtuality" (AV), "Mixed Reality" (MR) and "Augmented Reality" (AR) environments which are exploited both for the production of TV programs adopting new formats and for side applications supporting the television production.

In the television field, virtual objects and environments are often used to implement innovative formats: for a long time now it is common to add simple "flat" information in AR to the TV signal. It is also common to use of 3D modelling tools to design sets. In this case it is possible for the designer to place the scene objects and, in addition, to place both the light sources and the cameras defining precisely their characteristics, thus obtaining complete, very precise and likely set designs. In any case the generation of virtual "environments" and "objects" is necessary.

This task requires measuring the dimensions of the element to be reproduced and building the 3D models. It is a time consuming and expensive process. The use of scanners allows to quickly generate accurate 3D models from the real world, with a consequent substantial reduction of the costs. However, scanners do solve all the problems, but for 3D modelling they help reducing the costs related to the TV programs production.

A 3D model is a mathematical representation of a three-dimensional object. It is a key element of 3D computer graphics, industrial design, architectural design, and three-dimensional printing. The process involved in creating a 3D model is called 3D modeling.

In order to realize such models it is required, often, a great amount of work for the measurement of the element of which you want to obtain the 3D model and for the generation of the virtual model; the entity of the work, so the time of development, with the relative costs, increases with the complexity of the model and the realism of the rendered object.

Basically, the scanners for measure, always associated to a software of "support" that integrate them, allow to generate the three-dimensional models of the scanned objects quickly and with a remarkable realism. Therefore they are very suitable to obtain virtual copies of real elements with contained costs. Moreover the models are dimensionally correct and are defined in a measurable space.

Laser Scanner

Laser-based scanner systems consist of a scanning unit and supporting software, similar to systems based on structured light scanners. The scanning unit of the laser scanner contains a rotating mirror that deflects the laser beam along the meridians of an imaginary sphere whose center coincides with the optical center of the scanner. A mechanism rotates the scanning unit in order to cover - meridian after meridian - the entire spherical horizon.

In daily use, a single scan is never enough to eliminate any shadow zones, so the scanner is moved to different positions, resulting in as many point clouds that the system is able to align during the recording phase. The laser scanner we used in this project is the Leica RTC 360 [11]. By construction, this scanner is suitable for creating 3D models of areas, rooms and squares. Its measuring range is from 0.5 to 130 meters. This scanner does not only creates the point cloud, but also has the ability to capture images of the environment with the quality of 432 Megapixel 360°x 300°. Generally, this texture quality is sufficient for most cases, but there are some special cases, as in our case inside the museum, where it is better to integrate the texture of some details with high-resolution pictures.

Figure 9 - Leica scanner in Palazzo Madama.

Structured Light Scanner

Structured light scanners (Figure 10) project different luminous figures onto the surface of the scanned object and records the distortions of these figures due to the shape of the object. The points of the model are obtained using the known position of the camera and the projector and the information related to the luminous figure.

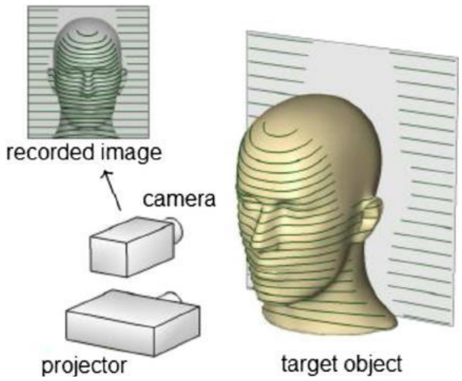

Figure 10 - Structured light scanner features.

To be effective, it is necessary to have a one-to-one correspondence between the projector and the pixels of the camera. So these are systems that operate at short distances, approximately up to 3 meters, are easily portable and are sed holding them in your hand; therefore they are more suitable for scanning small objects, for example mechanical parts, life-size anthropomorphic statues.
The scanner used for this project is Artec Eva [12]. Artec Eva is ideal for quickly obtaining an accurate and already textured 3D model. It can scan medium sized objects in a range from 0.2 to 6mt.

Scanning Workflow and Results

3D Models of Ceramics

The work of content creation began at Palazzo Madama with the scanning of Ceramics (Figure 11). As already mentioned, we used the Artec Eva scanner and a support PC. We scanned about 13 ceramics, but we were able to create a satisfying 3D model only for 10 of them.

Figure 11 - The Artec Eva for making 3D model of medium sized objects.

Scanning Workflow provides:

- Scanning the object from all internal and external points of view;
- Process the scan with the Artec Studio software, align the point cloud and clean it from any errors;
- Create the 3D model, repair any problems and/or rebuild any missing parts;
- Apply the texture and correct any imperfections. Export the model and check it in external software e.g., Blender.

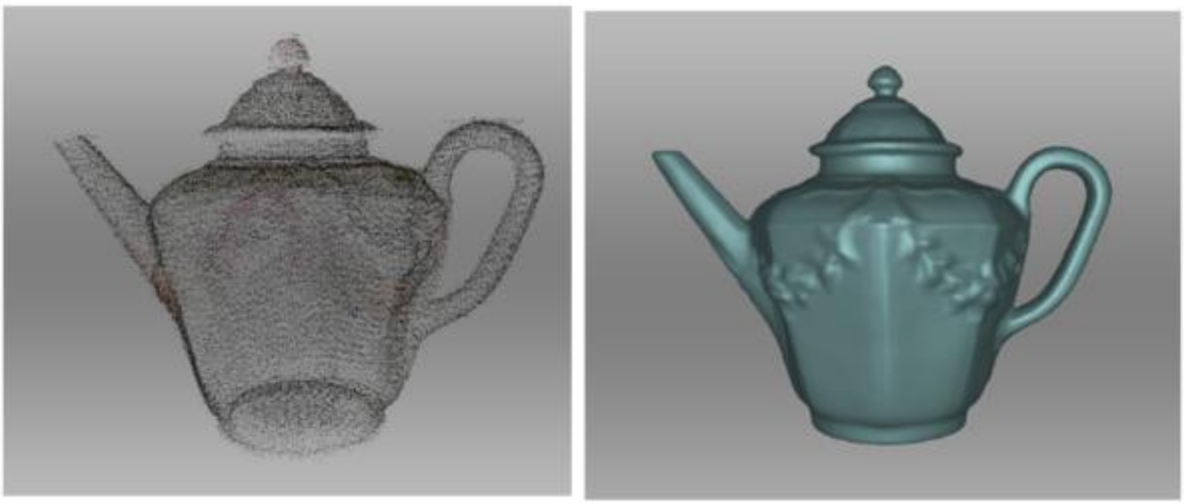

Figure 12 - Teapot point cloud and 3D Model.

Figure 13 - Teapot textured 3D model.

Environment 3D Models

In order to scan the rooms of Palazzo Madama we used the Leica RTC 360 laser scanner. The main rooms chosen were the "Camera delle Guardie" and the "Gabinetto Rotondo". This workflow shares some similarities with the previous one, but in practice, it is substantially different.

Scans should be made in specific points of the room so that there are as few "shadow zones" as possible. For "Camera delle Guardie" we have done 3 scans in different points, while for "Gabinetto Rotondo" only 1 scan is done, because the room is quite small.

After scanning, a process of importing and initial alignment of the point clouds begins. It is very important to perfectly align the scans at different points in the same room to have a complete cloud. The complete cloud is now imported into the Leica Cyclone 3DR post-production software.

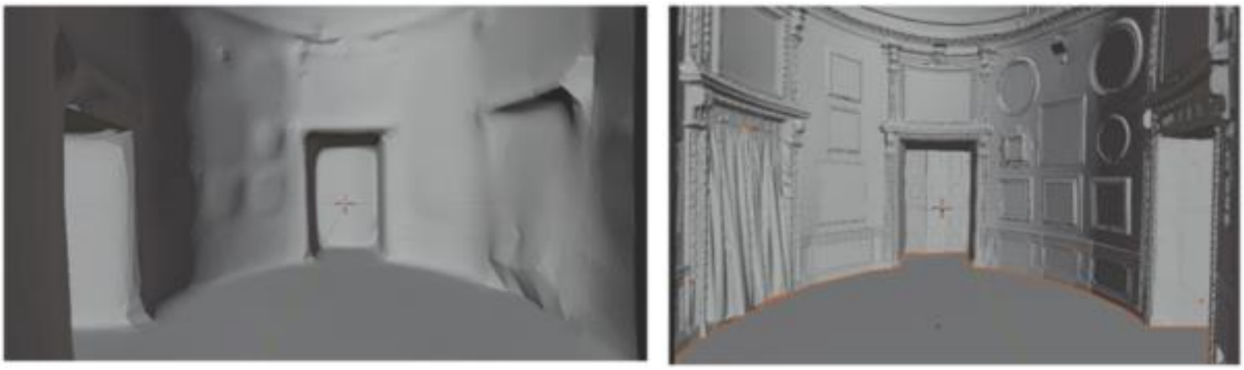

Figure 14 - Gabinetto Rotondo simple 3D model and final 3D model.

In this phase the bottom to top paradigm is followed, because a complete, simple 3D model with few polygons is created first. Then we try to make the 3D model as simple as possible in the areas with less details, while complicating it in the parts with finer details. In this way it is possible to obtain a large number of polygons only where needed, reducing complexity and size of the whole model.

When we have created a satisfactory 3D model we move on to the texturizing process. Usually HDR photos of the scanner are sufficient in most cases, but in some cases (e.g. the "Chamber of the Guards"), we decided to improve the textures using high quality photos.

Obviously in this way the result is considerably better, but the time for content creation and post production increases remarkably. Also, since the scanner covers only the view of 360°x300°, it means that textures will be missing in some parts of the scans. Then the floor is reconstructed from the parts that are available, or completely recreated.

Figure 15 - Camera delle Guardie textured 3D model and reconstructed floor.

The 3D content creation needs a relevant post-production phase in order to obtain a good final release of the involved model in terms of quality and number of polygons to be correctly managed from applications. The sharing of created 3D models between project partners is under investigation, also because object files can be very large in terms of storage, at the moment a cloud sharing folders is used for this type of data exchange.

2.2.1.3 Backend and external resources

Beacon analytics backend

This service receives location update of every user that are generated from the Android application when the user move from a room to another. This allows to offer the following functionalities that are exposed by means of API:

- Crowding map, it contains the crowding level of each room.
- Museum tour, returns a possible tour of the museum taking into account the available time and the crowding level.

Network architecture Resources Management API

At this level it is necessary to maintain an association between i) an environment (e.g. a museum room), ii) the piece of arts contained therein and iii) the multimedia contents related to each piece of art. Figure 16 shows the UC1.a Network Architecture Scheme.

Multimedia Contents Repository

It consists of one or more nodes, with high storage capacity, in which all the multimedia contents (pictures, video and 3D models) will be stored. Access to contents stored on these nodes must be ensured through appropriate file transfer protocols (such as FTP, HTTP).

Smart City Services API

These APIs allow the front-end to convey to the tourist information, obtained from IoT sensors and open-data of the Smart City, to help the tourist to discover places of interest and to support him in the logistics of travel to reach them.

In the scope of the use case, the considered IoT data are related to pollution (gas and fine dust). The open-data refer instead to information on weather conditions and forecasts, the availability of bike / car sharing stations near the user and any bikes / cars available, or information on bus / metro stops close to the user and any waiting times.

Smart City Services come into play in the final phase of the visit to Palazzo Madama, when visitors will be offered a selection of other places to visit (potential interest to them) and different ways to reach a selected destination (on foot, by bike- sharing, in car-sharing or by public transport).

The priority and ordering of the proposed solutions will strongly depend on the surrounding environment: in the case of clean and good weather conditions (e.g. with few UV radiation and no rain), a walk or a bike ride will be incentivized, otherwise it will be proposed the use of car-sharing or public transport.

Open-Data repositories

The Municipality of Turin provides a large open-data dataset. Among these, the data that will be used to build Smart City Services are:

- List of museums: http://aperto.comune.torino.it/dataset/musei
- List of historical sites: http://aperto.comune.torino.it/dataset/luoghi-storici
- List of tourist offices: http://aperto.comune.torino.it/dataset/uffici-turistici
- Car sharing stations IOGuido: http://aperto.comune.torino.it/dataset/stazioni-car-sharing-ioguido
- Bike sharing stations: http://aperto.comune.torino.it/dataset/stazioni-bike-sharing
- GTT public transportation feed: http://aperto.comune.torino.it/dataset/feed-gtfs-trasporti-gtt

IoT Platform

An IoT platform has the task of receiving and collecting data from field sensors, and then offering it through APIs to Smart City Services. An IoT platform is often able to receive data from sensors through the most common lightweight protocols such as MQTT and COAP. It also manages the virtualization of a physical device (such as an IoT board equipped with several sensors) in a digital copy (digital twin) on which APIs can be called up to obtain the historical data associated with it.

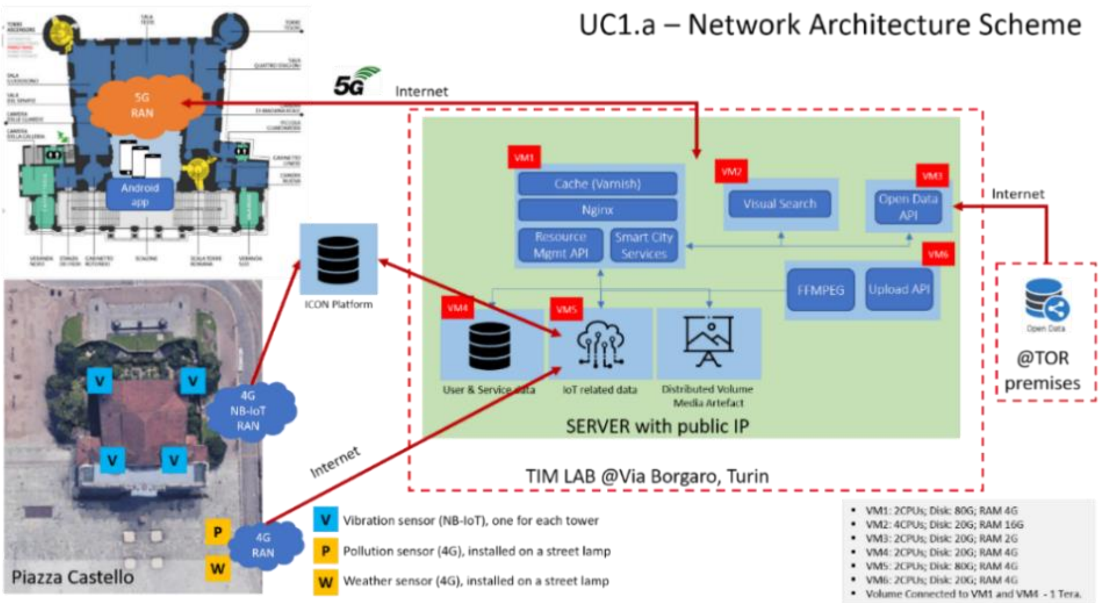

Figure 16 - UC1.a Network Architecture Scheme.

UC1.b: GAM and Edulab – Gamification, let's play artist

For UC1.b a preliminary components diagram is depicted in Figure 17:

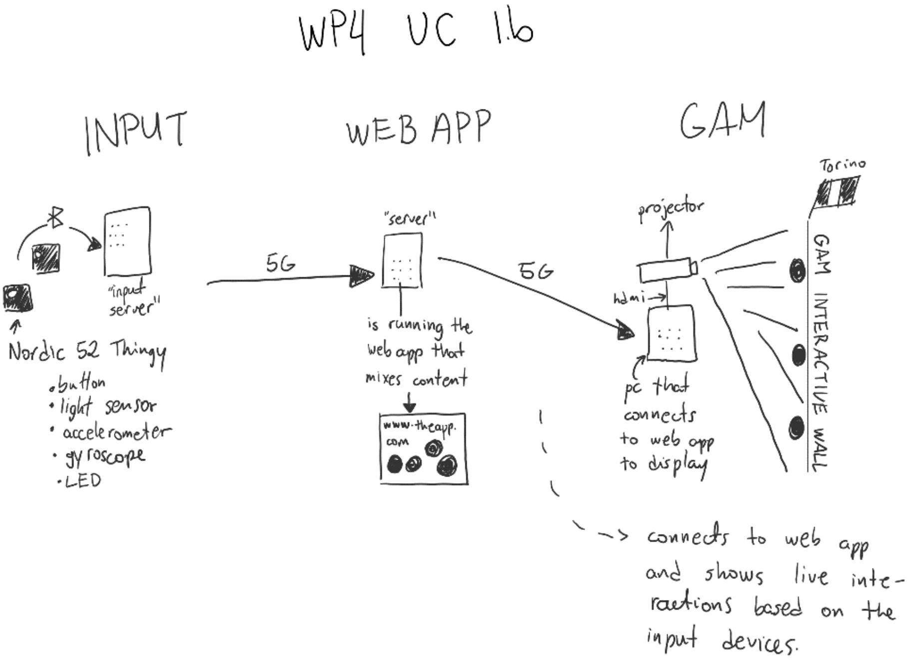

Figure 17 - UC1.b a preliminary components diagram.

In this sub-UC, the application is projected onto a wall at GAM, where the intended way of interaction is to be in front of the wall, creating compositions with colors and shapes provided.

The application consists of a wall where kids can translate, scale, and rotate different shapes based on De Maria's work. The shapes and colors will be provided by the Museum in RGB and vector format (like SVG). The application itself is based entirely in Web technology, making it accessible through many devices. It is based on HTML canvas.

2.2.2 Terminal Equipment components

UC1.a: In the very heart of Turin

The use case provides the interaction with Smart City services, which rely on information gathered from IoT sensors and open-data. For demo purposes, only one kind of sensing station will be installed in Piazza Castello to measure the pollution level It comprises of a 4G gateway and sensors for CO, O3, NO2, SO2, PM1, PM2.5 and PM10 (a 5G version of this device is not available yet).

Another kind of sensor, which will be integrated in this use case is the structural vibrations sensor. A set of NB-IoT devices equipped with this sensor will provide early-warning notification to users in case an earthquake happens.

The VR experience is based on:

- Involvement of maximum two users; possibility to have additional (remote) users will be investigated later;
- Each user to wear a Samsung Gear VR using a 5G Samsung phone as display; controllers will be available for the user's interactions with the environment;
- Users' avatars to be represented by the shape of the Gear VR (i.e. head); a user will be able to see its own hands.

UC1.b: GAM and Edulab – Gamification, let's play artist

The Nordic Thingy 52, a compact multisensory prototyping platform, will be used to create the application interacting with the wall. For the UC1.b the hardware for input is based on the Nordic Thingy 52 that is shown in Figure 18.

Figure 18 - Nordic Thingy 52, compact multisensory prototyping platform.

This small device, the Nordic Thingy 52, is a compact multisensory prototyping platform. It is used to create demos and prototypes without having to build specific hardware. It contains inside different sensors that can be used from an application, such as light, colour, motion sensor, accelerometer, temperature sensor, humidity sensor, microphone and even a button that the kids can push to interact with the wall.

The benefit that this device brings is that we can have availability of many more ways of interacting with the wall than we would have with either Kinect (just hand movement) or mobile devices (just tapping).

As an example, you can see a demo SRUK created in Samsung Internet several years ago, where we paired the Thingy 52 with a web application that had a VR experience. There is a video embedded in the post that shows a brief demo [8].

The capabilities of this device allow us to maintain movement of the users, guaranteeing a very interactive experience where users can rotate, scale, move and change the colour of the different shapes from the composition in the wall inspired by Demaria's style. At the moment partners are defining how to map the user interactions to the wall, and how we can make it easy for the children to create this composition with movement and other ways allowed by the sensor, a detailed update will be provided once the testing is completed. The device is small and would be used by being held by hand. This solution removes the need for the mobile devices and solves the concern of lack of movement.

2.2.3 Interfaces

For these sub-use cases the detailed description of interfaces between different devices is still ongoing, Figure 8, Figure 16 and Figure 17 depict a preliminary data interchanging between components.

2.3 Integration and test in labs

Due to the COVID 19 restriction the use case has been validated through laboratory tests, the user interactions have been tested by manipulating or just consuming multimedia contents provided by RAI and Fondazione Musei Torino about the Palazzo Madama Museum. The whole ATE Application execution flow will cover the five main steps related to the main activities of museum visitors:

- **Step 1:** Museum visitors begin the experience, so the app retrieves and presents useful information about the museum and the museum visit through personalized information.
- **Step 2:** Museum visitors enter one of the selected museum rooms.
- **Step 3:** Museum visitors explore a specific piece of art.
- **Step 4:** Museum visitors leave the museum but not the experience.
- **Step 5:** Museum visitors in other locations retrieve their favorite artworks or explore new artwork.

Steps 1, 4 and 5 are under development, on the other hand, steps 2 and 3 have been fully developed and tested. Users interacted with multimedia content (pictures, text, audio and 3D Models) exhibited in the museum. The beacon detection system, the feature that allows visitors to jump from one step to another, has also been developed and integrated with the AR app. Several tests were performed between ATOS client app and TIM Beacon service.

For the experiments, an Android app was used to simulate the physical beacon device, making a smartphone to emit a Bluetooth signal exactly like the one emitted by the Beacon. That signal was received by the ATOS client app that read the ID of the Beacon and then called the TIM Backend service to notify the system that someone new had entered that specific room. TIM used this information to calculate the crowding level of every room in real time. After that, ATOS app asked the Beacon service about the actual crowd in every room, and use the data received to draw it in an easy-to-understand map in the app.

2.4 Test in the network

According to the current network deployment time plan, the first tests on the real 5G network will be performed in Turin in the first half of 2021.

3 UC2 - Telepresence

3.1 UC2 definition

The main goal of this use case is to test and employ a robot located inside the museum and controlling it from remote location. Telepresence robots have the potential to contribute to accessibility and inclusiveness by extending access to previous excluded audiences. The UC2 is divided into three subcases:

UC2.a: Palazzo Madama exclusive exhibitions for all

Partner involved: TOR/FTM; TIM

Location: Palazzo Madama (permanent collection)

The idea of this sub-use case is to enlarge the public for selected exhibitions in order to make these experiences more accessible to all for a longer period as well as use virtual exhibition as promotional activity to attract foreign visitors or tourists. The specific sub-use case will be set in Palazzo Madama and will be characterized by two or three curator led visits to the temporary or permanent exhibitions.

UC2.b: Play and visit modern art from museum to school

Partner involved: TOR/FTM; TIM

Location: GAM (Educational LAB)

The objective of this sub-use case is to offer enhanced educational activities to students at school. The target audience for this application are children from 6 to 13 years old. The selected location will link students located at the Edulab premised with GAM. As for UC1.b, and because of the UC's target, it will be used gamification throughout the creation of a virtual "Treasure Hunt".

UC2.c: Surveillance of the museum

Partner involved: TOR/FTM, TIM, IIT, ERI-IT

Location: GAM and Palazzo Madama

Robots will be used for tele-surveillance of the museum both during day and night hours. The selected test beds will be Palazzo Madama and GAM. The use case directly interacts with data collected in UC1.a through sensor networks about safety conditions as well as the indoors or outdoors presence of people. A possible pivoting of this use-case could involve social distancing monitoring in the museum.

3.2 UC2 implementation

UC2.a: Palazzo Madama exclusive exhibitions for all

During the preliminary visit of the museum the candidate areas of Palazzo Madama involved in the UC2.a were identified. Possible locations will be 1st floor, 2nd floor, basement floor, and underground floor (a restricted access area not accessible by the public) as depicted in chapter 7.

At the beginning of July the first on field test of the "Double3" robot took place at Palazzo Madama, to test the capability of the robot to move in the areas of the museum previously identified. After this test underground floor and «Piano Nobile» have been chosen as location for UC2.a implementation.

The first trial application for UC2a will almost certainly be a guided tour, from an equipped room inside the museum, to the underground spaces of the museum that are not accessible to the public for safety reasons. In a second phase location inside Edulab should be used as remote visitor room to extend the UC public involved.

At the application level, a preliminary analysis was performed to better define the use case requirements related to the use of "Double3" telepresence robot in the UC. This results in the following definition of four type of required endpoints needed to cover the different scenarios foreseen for the UC2.a:

- **Endpoint type 1:** The robot inside the museum, with bidirectional audio/video communication with the other subsystem (connected with 5G mobile indoor coverage);

- **Endpoint type 2:** The robot's pilot, that control the robot via UI, and optionally one or more people in the same room that look at the robot video, and interact with bidirectional audio/video with the robot side of the system (connected with broadband cable);
- **Endpoint type 3:** One or more people in another location, without piloting system, connected with bidirectional audio/video with other endpoints (connected with 5G mobile or broadband cable);
- **Endpoint type 4:** One or more people in another location, only connected with downlink audio and video (connected with 5G mobile or broadband cable).

From the server side at least two different node types will be required:

- Robot control and management (will require low latency connection with endpoint type 1 and 2);
- Media streaming and MCU system (will require broadband and low latency connection with endpoint type 1, 2 and 3, connection to endpoint type 4).

UC2.b: Play and visit modern art from museum to school

After the preliminary visit to the museum location together with TOR/FTM the candidate areas inside the GAM involved in the UC2.b were identified, according to the map reported in the Network Deployment section of the document.

The location inside GAM will be the permanent collection area on the first floor.

At the beginning of July, the first on field test of the “Double3” robot took place at GAM, to test the capability of the robot to move in the spaces of the museum, and also to check the movement speed capabilities of the robot. After these tests, it was highlighted the need to reduce the area involved in the "treasure hunt" to avoid long movements of the robot that would waste time and reduce the level of attention and usability of the service. The area called “Manica Lunga” on first floor have been chosen as location for UC2.b implementation.

During the tests, it was confirmed the need to have the robot driven by a person with a minimum of training and not directly by the public. The service can therefore be enjoyed by the public in the same room as the guide (who will also be the pilot) or in a secondary visitor room.

The location inside Edulab should be used as secondary visitor room.

At the application level, a preliminary analysis was performed to better define the use case requirements related to using the “Double3” telepresence robot in the UC. This results in the following definition of three type of required endpoint needed to cover the different scenarios of the UC2.b:

- The robot inside the museum, with bidirectional audio/video communication with other subsystem (connected with 5G mobile indoor coverage);
- The robot's pilot, that control the robot via UI, and one or more people in the same room that look at the robot video, and interact with bidirectional audio/video with the robot side of the system (connected with broadband cable);
- One or more people in another location, without piloting system, connected with bidirectional audio/video with other endpoints (connected with 5G mobile or broadband cable).

From the server side at least two different node types will be required:

- Robot control and management (will require low latency connection with endpoint type 1 and 2);
- Media streaming and MCU system (will require broadband and low latency connection with endpoint type 1, 2 and 3).

Endpoint type 3 and MCU system necessity are under investigation.

UC2.c: Surveillance of the museum

Location for UC2.c will be defined after the consolidation of UC2a. b and UC3, and will be a subset of the location involved in UC2.a, UC2.b and UC3. Control room will be in Palazzo Madama. Surveillance UC will be provided using two different robots, which provide a different level of autonomy from pure teleoperation (Double 3) to mixed teleoperation/autonomous navigation (R1).

Double 3 robot

Double 3 robot solution provided by TIM will be a teleoperation only system, usable during daytime or in ambient where a sufficient level of artificial illumination is available.

At application level, a preliminary analysis was performed to better define the use case requirements related to using the Double 3 telepresence robot in the UC. This results in the following definition of two type of required endpoint needed to cover the different scenarios of the UC2.c daytime:

- The robot inside the museum, with bidirectional audio/video communication with other subsystem (connected with 5G mobile indoor coverage);
- The robot's pilot, that controls the robot via UI, and one or more security people in the same room that look at the robot video, and interact with bidirectional audio/video with the robot side of the system (connected with broadband cable) Robot may be driven by security people with a minimum training period.

From the server side at least two different node types will be required:

- Robot control and management (will require very low latency connection with endpoint type 1 and 2);
- Media streaming and MCU system (will require broadband and low latency connection with endpoint type 1 and 2).

The server side requirements for the integration of the Remote Surveillance UC using IoT data provided from UC1 platform are defined as the following:

- T.B.D. Server side integration with IoT platform from UC1.

R1 robot

The R1-based surveillance application, is a mixed solution which includes autonomous navigation (patrolling) and tele-operation. The autonomous navigation is currently under development in a simulated environment. Some of the work is therefore common between UC2.c and UC3. This includes hardware upgrades for 5G connectivity and reading sensors for indoor localization, and software components developed for UC3, where the autonomous navigation is predominant. Advancements on these tasks are thus reported in section 4.2.2 and 4.2.3.

Regarding the tele-operation task, instead, the robot will require to transmit to the operator large amounts of data (the video stream) and receive from it small amounts of data (the control commands) but with minimum latency. In this UC we do not transfer video streams from the surveillance operator to the robot, so the downlink bandwidth required on the robot side is basically limited to the robot control commands (whose size is extremely small compared to a standard video stream as described in the following).

3.2.1 Application Components

Double 3 robot

Regarding Double 3 robot solution a preliminary scheme of the application components required by UC2.a/b/c is described in Figure 19. Not all the parts are used in all the sub UC scenarios, but the most complex architecture necessary to implement UC2 may include all the shown components.

The application is distributed and allow robot access and control and the establishment of the multimedia session necessary to give the telepresence experience necessary for the Use Case. The different logical block can be described as follows:

- **Robot side:**
    - **Onboard Robot Control System**: is the main OS of the robot containing all the software component necessary to control the robot movement (wheels, stand, pole), the device of the robot (camera, pan-tilt-zoom controls, microphone, navigations sensor);
    - **Onboard Robot Adaptation System**: is the application interface between the robot system and the service application, that allows robot remote connection and operation establishing a peer to peer control channel between robot and pilot application;

- **Onboard Media System**: the multimedia system (web-rtc audio video streaming function) that enables bi-directional audio video connection between the robot and the other endpoint involved in the use case. Will handle the signalling and call setup functions interacting with the Media Control Layer in the backend, and will handle the peer to peer multimedia flow streaming and receiving;
- **5G Adapter**: is the tools and driver necessary to give the robot the ability to connect to a 5G network, since the robot doesn't support natively the 5G connection but only the Wi-Fi connection.

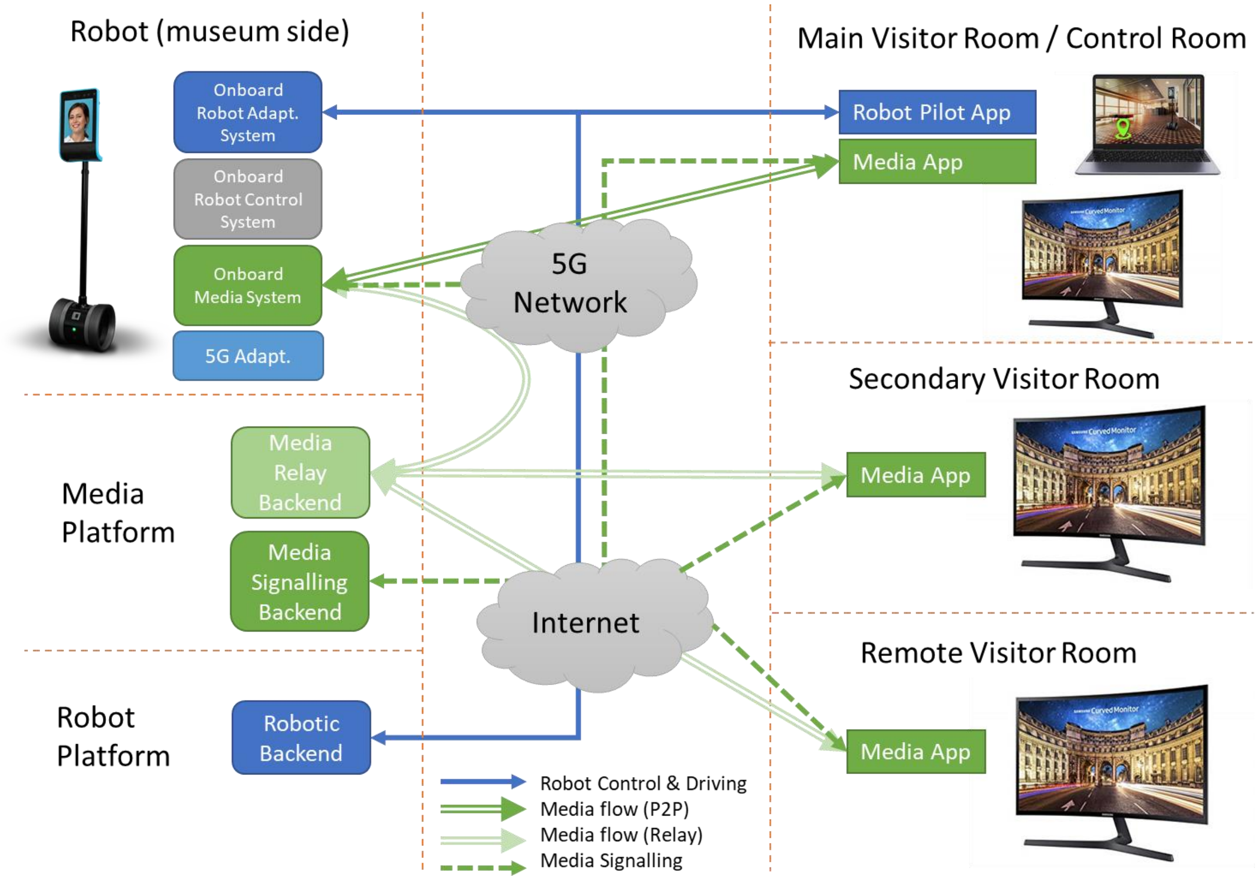

Figure 19 - preliminary schema of the application components required by UC2.a/b/c.

- **Robot Platform**: is the server platform involved in the application. Localization of this server is under investigation, to understand if it can be located everywhere on the internet, or if it is better to be placed near to the 5G edge network to reduce latency.
  - **Robotic Backend**: will perform all the platform related server functions, such as user authentication, robot connection and discovery, robot management and mediation.
- **Media Platform:**
  - **Media Signaling Backend** will handle all the media related signaling and session operation needed to setup the media flow, directly in peer to peer mode (preferred solution to reduce latency) or via MCU/SFU function. If necessary, based on the architecture of the network used, it can also perform the functions of STUN / TURN server.
  - **Media Relay Backend**: will handle the media flow session relay, necessary in some networking configuration or, in multi user mode, the MCU/SFU functions.
- **Main visitor room / Control room**: is a web browser-based application that allow the pilot to perform all the necessary operation to discover and connect to the robot remotely, move it in the space of the museum using the point and click enhanced navigation interface, control the camera pan-tilt-zoom functions:

- **Robot/Media pilot application**: full control application with robot control and remote audio video visualization;
- **Media application**: visualization only application to give the public a better vision experience without the superimposed graphical interface used for navigation.

- **Secondary visitor room**: another peer of the application may be located in different room, joining the telepresence session as third-party player without control of the robot:
  - **Media application**: teleconference only application integrated with call control used to establish the connection to the main connection. Media stream is bidirectional to allow the secondary user to interact with other peers.
- **Remote visitor room**: the telepresence session may be watched remotely via streaming function, without any interaction with other peers:
  - **Media application**: Similar to application used in Secondary visitor room, will be used to establish downlink only audio/video stream, without user interaction. To be defined the media stream architecture.

To achieve best performance in terms of delay and interaction the main media flow (between robot and visitor/control room) will be peer to peer to benefit from the low latency and band performance of the 5G network. Behaviours of secondary media flow are under investigation, to understand if it is possible to use peer to peer connection also in this case, or if it is necessary to use MCU/SFU system to allow multi user connection. Also the main control data flow between the robot and the pilot application can be handled in peer to peer mode, in order to minimize latency and maximize the user driving experience.

Application architecture is constantly evolving and defining. First draft was designed based on the study of the available documentation. Other details are being defined with the progress of the tests and the analysis of the robot architecture, and the first integration tests. This may require changes in the illustrated architecture and in some of the functions assumed for use cases.

To better clarify the components involved in the different UC2 sub scenarios, Figure 20 shows the architecture needed to implement UC2a remote visit to the underground floor, in which the museum guide will be also the pilot, and will be in the same room with the visitors.

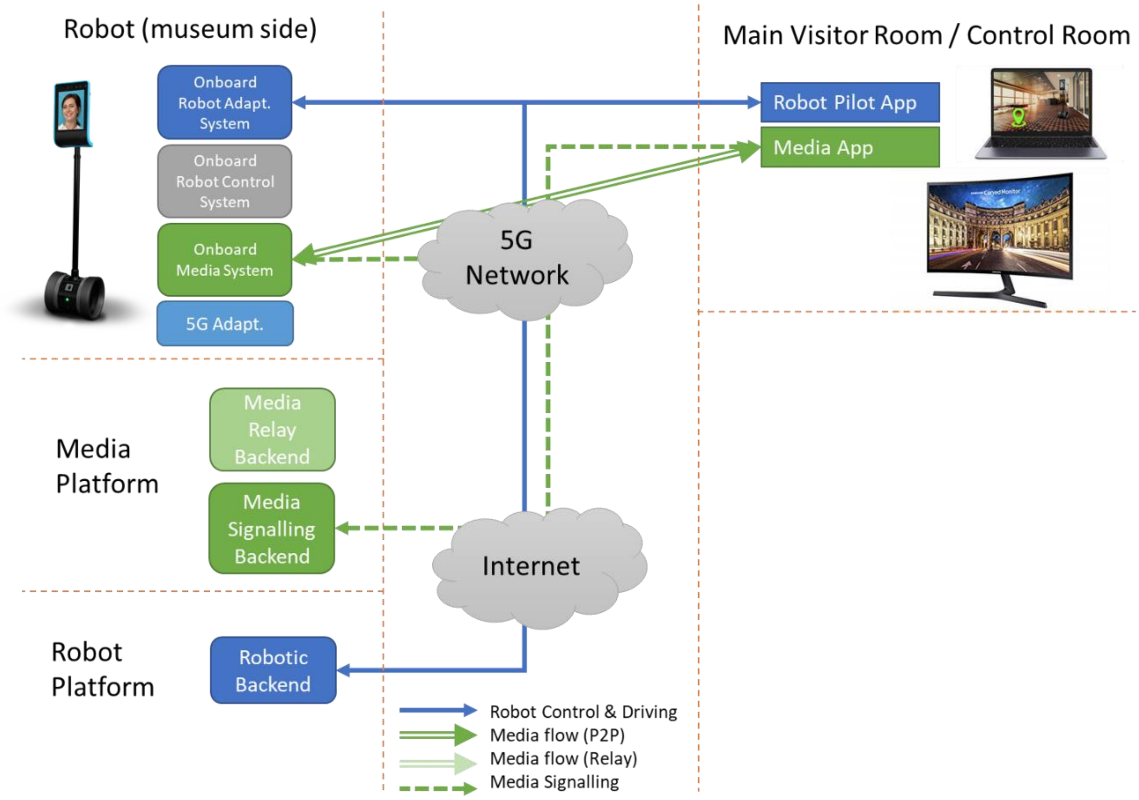

Figure 20 - preliminary schema of the application components required by UC2.a.

Another example is the UC2b scenario in which the robot pilot / museum guide is in one site, and the group of visitors should be in another location as shown in Figure 21.

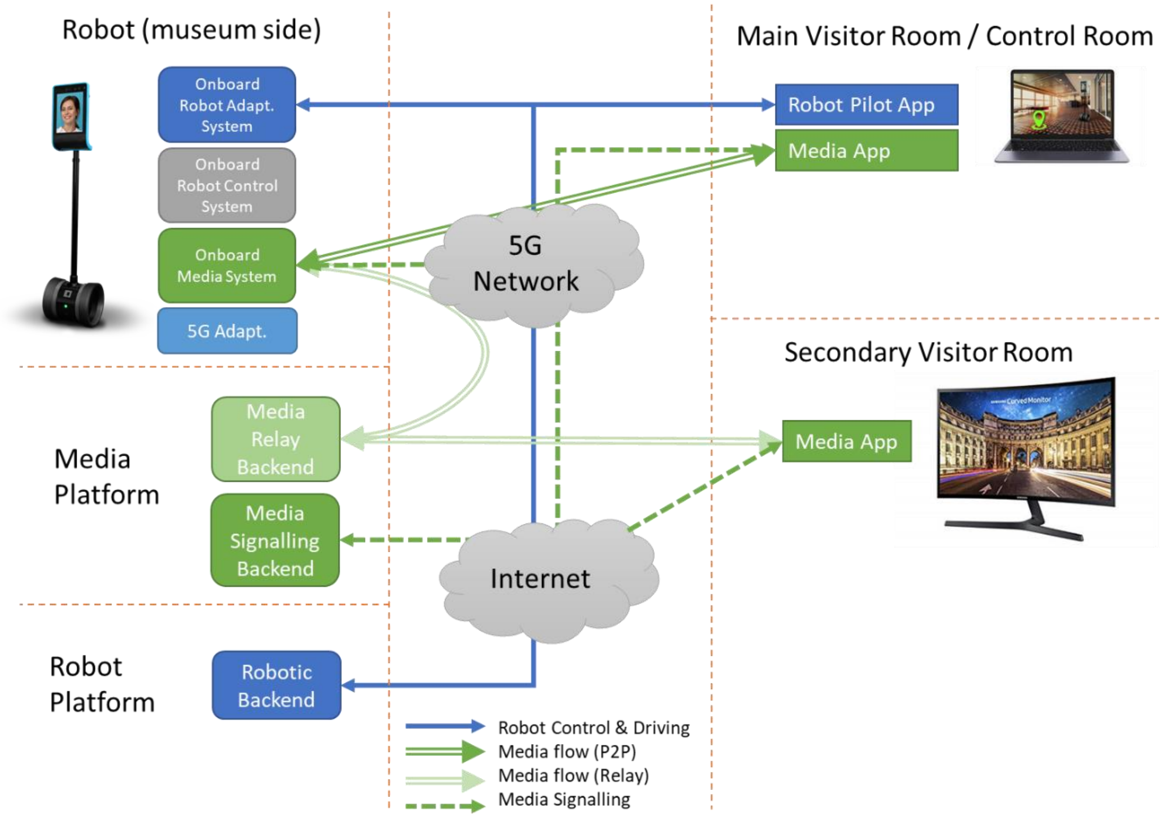

Figure 21 - preliminary schema of the application components required by UC2.b.

Finally, the case of UC2.c remote surveillance is shown in Figure 22 in which the IOT part is highlighted.

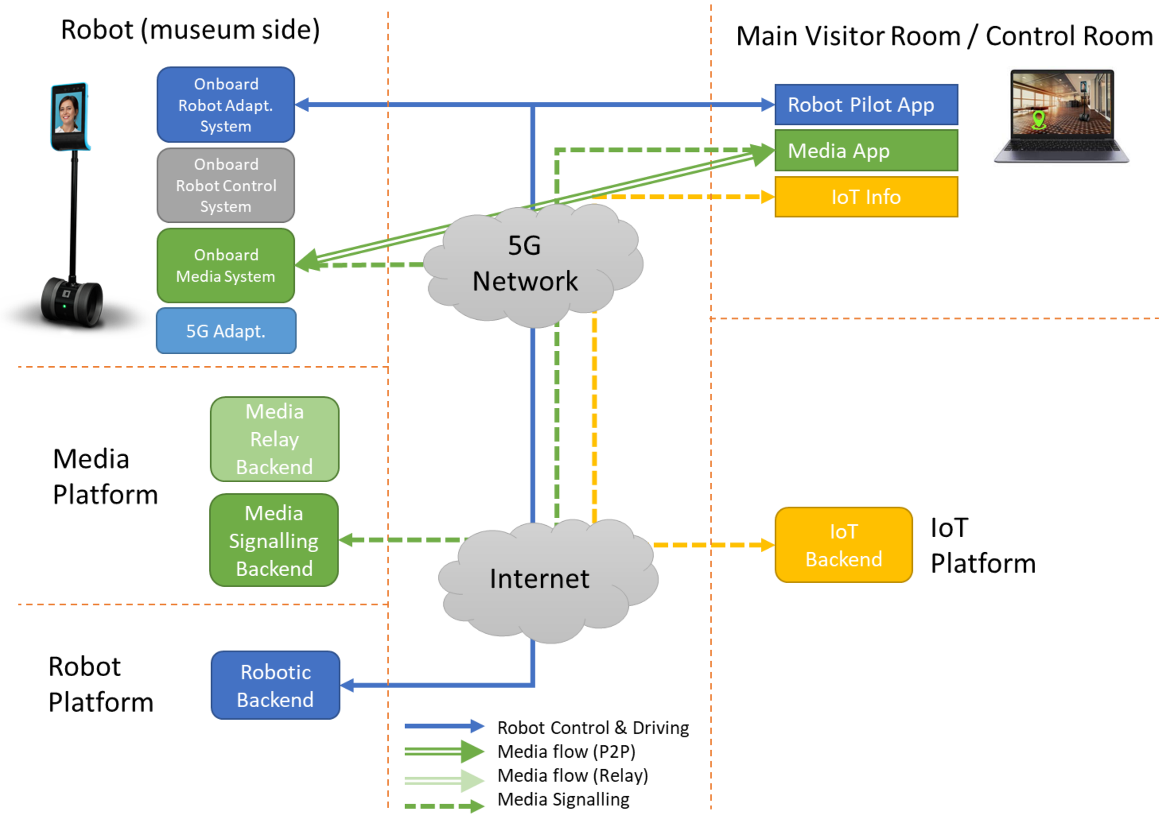

Figure 22 - preliminary schema of the application components required by UC2.c

R1 robot

Regarding the R1-based surveillance application, this consists of two main blocks, depicted in Figure 23.

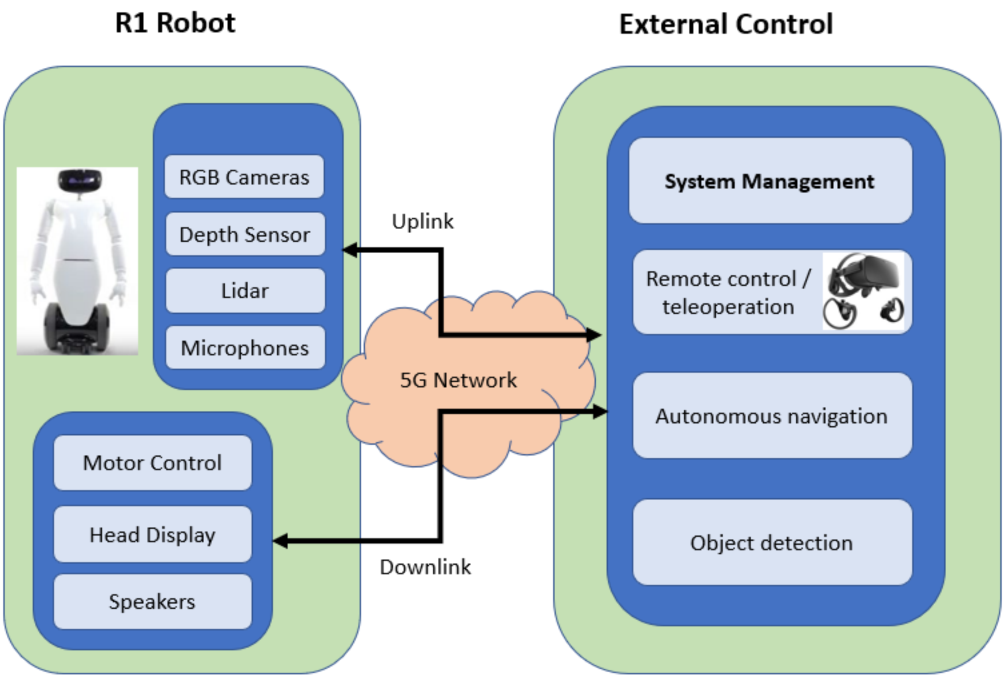

Figure 23 - The R1-based surveillance application main blocks.

1. **The robot**: R1 is a network composed of three different computational units. Each machine controls a specific hardware subsystem, e.g. motors, cameras etc. and communicates with the others. A 5G connection toward the mobile network allows the robot to exchange data with a remote server located, for example, in the museum control room or in TIM premises.
2. **The external control room**: it consists of one (or more) machines which:
   - Perform intensive computations to control robot trajectory and/or run AI algorithms for object recognition/detection;
   - Allow a human operator to monitor the museum environment seen by the robot and teleoperate it;
   - Perform system management, checking periodically the status of the robot (both hardware and software), monitoring the data flows and triggering alarms. A human operator needs to have access to the machine dedicated to system management to start, stop and reconfigure the robot for a different application.

3.2.2 Terminal Equipment components

Double 3 robot

Regarding Double 3 solution, connection of the robot to the 5G network can be achieved using either a 5G USB dongle (when available) or a mobile phone connected via USB tethering. Wi-Fi pairing with a 5G mobile phone will be considered as last option if the previous one is impossible to be implemented.

Analyzing the technical specification of the robot, the availability of a compatible 5G USB device is related to Ubuntu driver support and configuration. A set of tests on the robot was performed using available 4G USG dongle, to check the onboard software and network configuration implication. A new set of tests must be performed as soon as a 5G USB dongle will be available.

R1 robot

Regarding R1 solution, the network architecture is currently under investigation. Figure 24 describes our current architecture, i.e. how R1 is used in IIT labs, with Wi-Fi communication and no 5G involved.

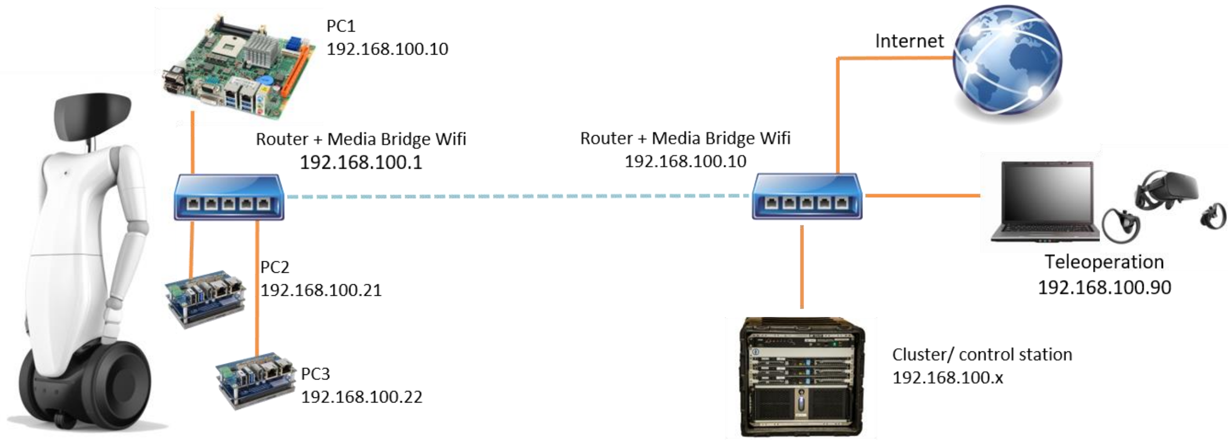

Figure 24 - Connection of "Double3" robot to the 5G network.

R1 is currently equipped with an internal Wi-Fi router. The orange solid line represents Ethernet cable connections. The blue dotted line represents the wireless channel. This is the channel that will require the high performances (in terms of bandwidth and latency) provided by the 5G connection.

IIT is investigating the required modifications to adapt this architecture to the 5G mobile network. In particular, we are looking for a commercially available 5G router in order to replace the main Wi-Fi bridge inside the robot. This component is represented in the picture by the device with IP address 192.168.100.1. Besides the integration of a compact 5G router inside the robot chassis, we are also considering different connectivity solutions. For example, partners are considering the employment of a tethered USB connection between the Samsung 5G handsets and a standard open-WRT router.

3.2.3 Interfaces

The interfaces employed in Double 3 solution will be defined in future documents, as soon as the architecture specification will be consolidated.

The interfaces employed in R1 solution for UC2.c are the same used in UC3 and are described in section 4.2.

3.3 Integration and test on-field / in labs

Double3 Robot

Regarding "Double3" robot, preliminary tests began at the end of June when the robot was delivered, and it was possible to use it. At the beginning of July the first on field test of the "Double3" robot took place at Palazzo Madama (Figure 23), to test the capability of the robot to move in the spaces of the museum on the different kinds of floors and rooms, to check the automatic obstacle avoidance system behavior in front of glass, mirrors and other precious and fragile artworks present in the museum, and also to check the reaction of the robot in the narrow spaces of the basement of the building. In the same day the field test took place also at GAM to check the interaction of the robot with the museum spaces and artworks, and also to evaluate the movement speed of the robot in the wide space of the gallery.

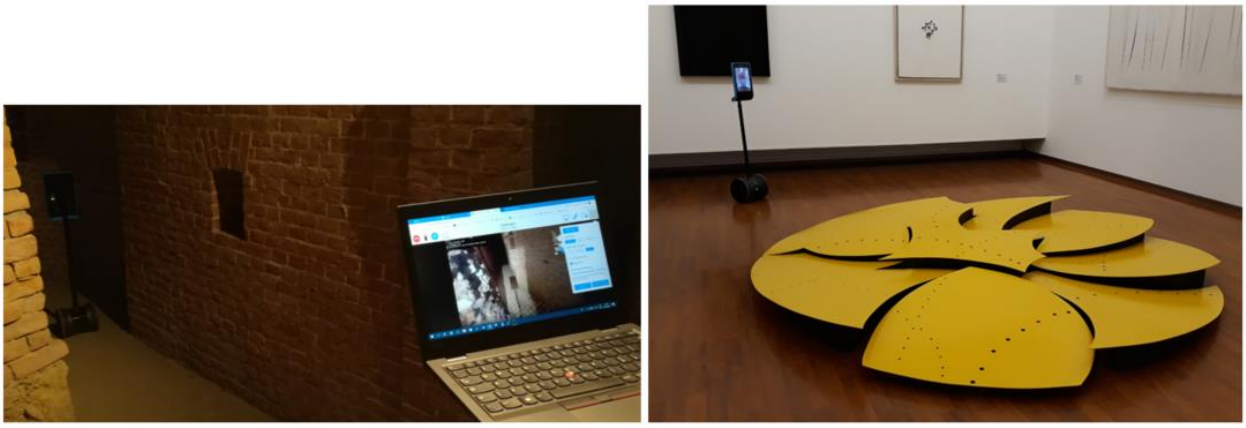

Figure 25 - On-Field test in Palazzo Madama and GAM.

The test showed some Robot movement issue on shiny dark floor already addressed with the manufacturer, who is working on a firmware upgrade to mitigate the problem. However, for the trial is a minor issue since the floor in the room involved in the UC2 are matte (tbc. for UC2c).

Observing the robot moving in the wide spaces of Palazzo Madama and GAM, highlighted the relative slowness of movement. It is necessary to plan the setting, the path and the storytelling in both locations, for the virtual guided tour (Palazzo Madama) and for the treasure hunt (GAM) to make it interactive and interesting, regardless of the relatively slow motion of the robot.

Confirmed the need to have a trained person pilot the robot, certainly not the public. It is necessary to identify the appropriate control rooms according to the UC (a, b or c). Also can be helpful to highlight the points where the robot will stop during the guided tour to speed up and facilitate driving.

Regarding the location, during the preliminary on field test was addressed the need to find a protected area (not accessible by visitors) where to install the Robot charge docking station, with a power supply socket and a good level of 5G radio coverage.

Other preliminary tests were performed to verify the quality and the zooming capability of the camera equipment, necessary i.e., to show details of the museum objects during “treasure hunt” game.

The integration of the 5G connectivity will require hardware and software test to check the compatibility of the available device with the native O.S. of the robot, and also application test to verify how the robot can get the connection when powered up, to define a user-friendly setup procedure to be performed during the trial by the museum employee that will follow the trial. At present time, a set of test regarding this aspect was performed using a 4G USB dongle, but must be repeated as soon as the 5G dongle will be available.

The “Double3” robot has a back panel that cover the USB ports necessary to connect the 5G device and a threaded connection hole that can be used to fix the device to the robot. May be useful to develop a 3D printed bracket to securely fix the device to the robot itself.

From the application and architecture perspective, various test and study were performed on the Double Robotic API and Platform to evaluate the better solution to integrate the product in the Telepresence UC.

First step is related to the web-rtc engine used to establish the A/V communication, analysing the session management, STUN/TURN capabilities of NAT traversal necessary to setup a point to point media connection on different network configurations (i.e., using NAT 4G mobile connection or public IP 4G mobile connection) and different connection devices (USB dongle, Wi-Fi, USB tethering etc.,).

Second step is related to application and system customization to meet UC2 requirement such as the multi user configuration and the possible integration of IoT dashboard on the Robot Control application for UC2c case.

Third step is related to platform enhancement to implement the whole UC2 requirement, in particular the study of feasibility to add a remote video feed different from the driver video (necessary for more complex UC2 scenarios), the study of feasibility for integration of an edge multimedia relay server (that could be necessary in multi user scenarios to maximize the performance).

All the tests mentioned above were carried out for a small part “on-field” in the museum site, the rest in “smart-working” since TIM laboratory are closed since February 2020.

R1 Robot

About the “R1” robot, IIT tested different solutions in order to efficiently encode the cameras video stream and transmit it on the mobile network. More in particular, the following encoders, made available by the FFmpeg library, were integrated with the robot software: Mjpeg, H264 and H265. To validate them, the performances of YARP (i.e., the robot software infrastructure) were assessed on a 4G LTE mobile network in ERI-IT E2E Lab in Genoa. This software infrastructure is common to both UC2.c and UC3 and additional details of the conducted experiments are reported in section 4.2.

A graphical interface for the teleoperation of the robot was also developed (Figure 26). The interface shows an augmented reality view of the environment in front of the robot, as seen from its cameras. On the top of the video stream, the free areas (i.e. areas without obstacles) are highlighted in the green. The user is thus visually notified of the areas which “R1” is able to reach, and can send navigation command by clicking on the image. In this way the robot can be safely teleoperated in an unknown environment, without the risk of colliding with walls or other obstacles.

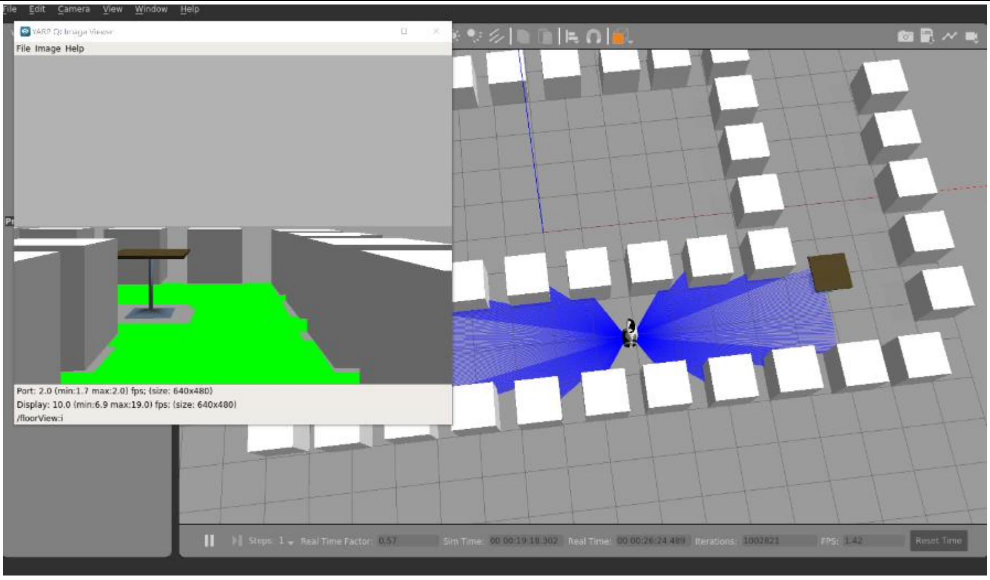

Figure 26 - Graphical interface for the robot teleoperation (in simulation).

3.4 Test in the network

According to current network deployment time plan, the first tests on the real 5G network will be performed in Turin in the first half of 2021. Regarding the tests with R1 robot, experiments are planned to be made in the ERI-IT E2E Lab in Genoa in December 2020, using a mirror of the network which is going to be deployed in Turin. The first experiments with R1 in the real location in TOR, instead, are going to take place in 2021.

4 UC3 - Robot-assisted museum guide

4.1 UC3 definition

Partner involved: TOR/FTM; IIT; ERI-IT

Location: Palazzo Madama (main hall, sala acaja and ceramics room); GAM (preferred location: at the entrance for general information or in the permanent collection spaces).

This use case foresees the use of the robotic technology to provide an enhanced museum visit experience both in Palazzo Madama and GAM.

R1 (Figure 27) will be able to: provide basic information about collection highlights and temporary exhibitions as well as assist visitors during queuing time at ticket desk; guide visitors moving through the museum and describing the artworks. This guided tour will be performed autonomously by the robot following a precomputed path. Human intervention will be required only in emergency situations.

Figure 27 - the humanoid robot R1.

4.2 UC3 implementation

As previously mentioned, the consortium is considering two different locations for this use case: Palazzo Madama and GAM. The areas in which the robot is expected to operate are defined according to the maps reported in section 7.1.3 Network coverage. More in particular, partners are evaluating the deployment of the robot in the areas shown in Figure 28. At Palazzo Madama R1 humanoid robot will be able to operate at the museum entrance, in Sala Acaja (ground floor) and in the ceramics gallery. At GAM, R1 will be able to operate at the entrance (outdoor) and in the permanent exhibition area.

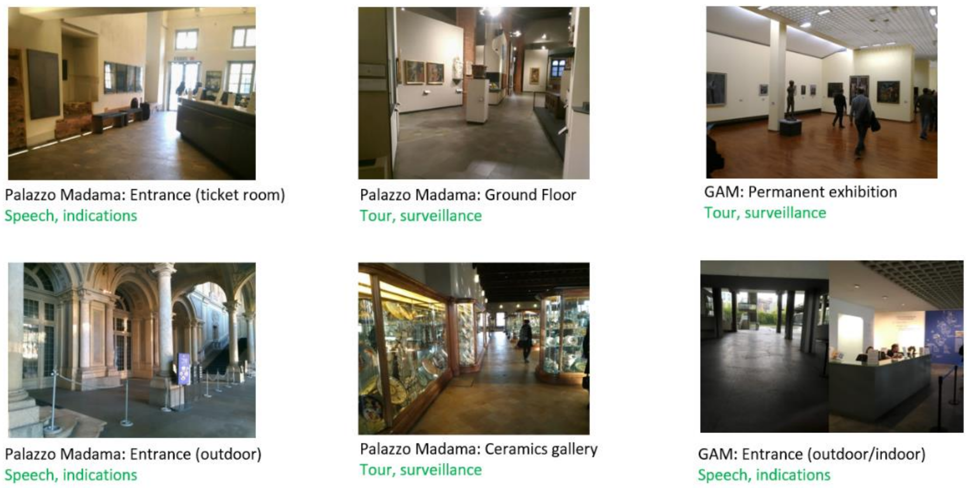

Figure 28 - locations for UC3.

4.2.1 Application Components

The application is similar to UC2c (Figure 29) and re-uses some of its components. For example, the system management block, responsible for controlling the application status, is identical. However, in this UC, the robot will be able to navigate autonomously, and no tele-operation will be required (Figure 29). To accomplish this task, the autonomous navigation component will be able to localize the robot in the environment, using a map of the museum where all the tour waypoints and the artwork locations are indicated. The UC also implements a speech synthesis and recognition system which is employed to answer to the visitors' question and to describe the artworks during the guided tour. For this purpose, the application needs to access to the internet and exchange data with cloud services (e.g. Amazon AWS, Google Cloud Services or IBM Watson). While some details of this system component are still under investigation and depend on some specific technical choices (e.g. the use of single service provider or a combination of multiple ones), it is likely that parts of the dialog system (e.g. human intent analysis) will run completely on the cloud while other parts (the finite-state-machine which controls the tour progression) will execute on the dedicated machines located in the external control room.

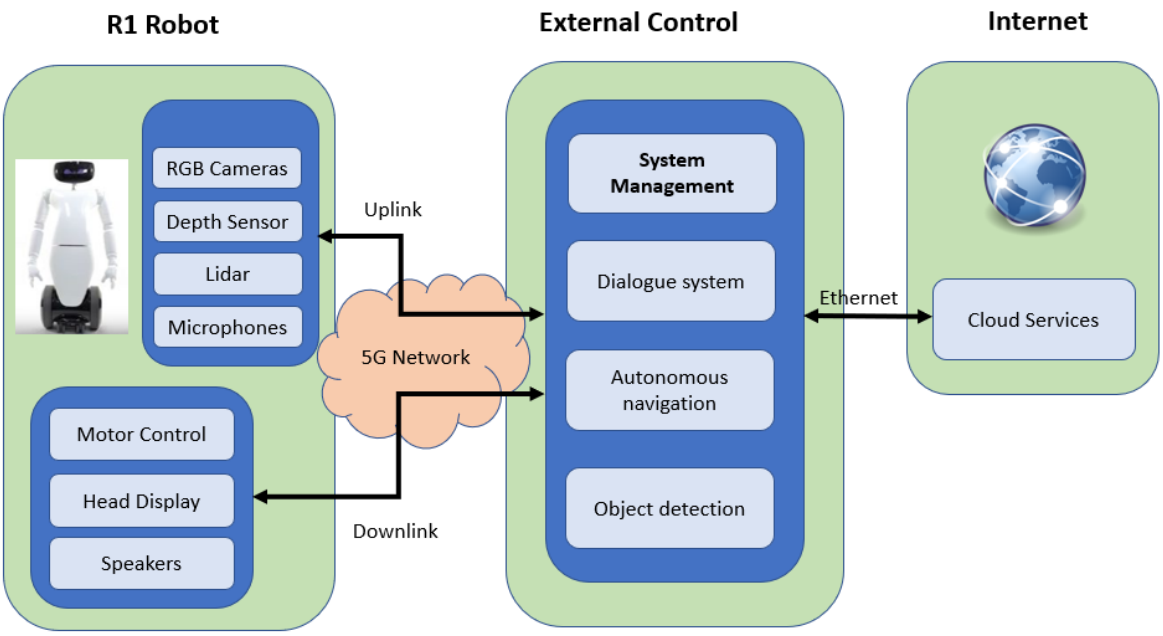

Figure 29 - Application Components.

4.2.2 Terminal Equipment components

As mentioned in section 3.2, we are currently investigating the possibility of adding to the robot a router which allows USB tethering in order to connect to it the 5G smartphone S20 provided by Samsung. For this reason the covers of the R1 robot were redesigned to host additional hardware (Figure 30), including an additional GPU-embedded module (NVidia AGX Xavier) for increased computational power.

Figure 30 - the covers of the R1 robot redesigned to host additional hardware.

Figure 31 shows the new router (Mikrotik Hap Ac[2]) successfully integrated in the robot. The new router is also powering the 5G Smartphone, which is attached to the robot arm, externally to the covers, in order to provide accessibility. The router also runs its own software, which has been configured to manage the VPN, as described in the following sections.

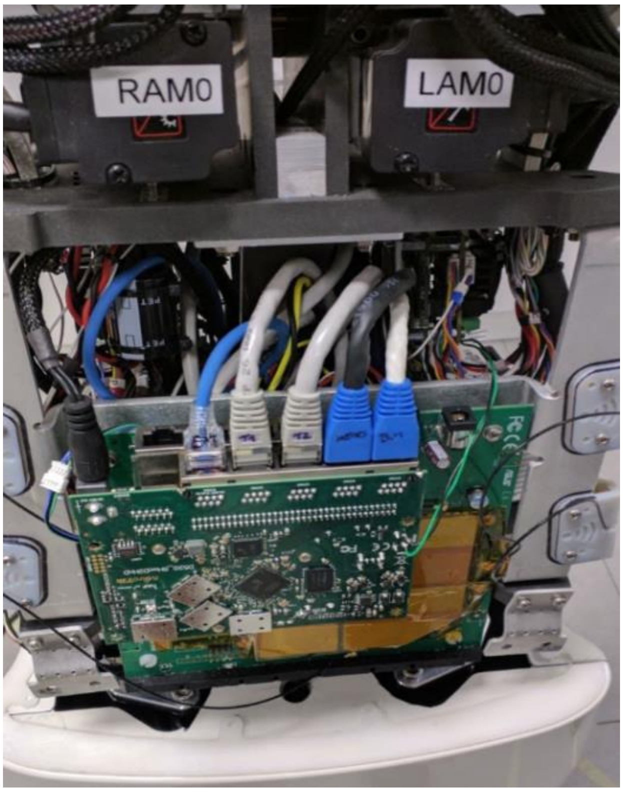

Figure 31 - the new Mikrotik router integrated inside the robot.

4.2.3 Interfaces

From the software point of view, R1 humanoid robot is based on a middleware developed by IIT called YARP [13]. All the application software employed in this UC, running both in the robot and on external machines, is built on top of the YARP libraries, which are responsible for managing the data exchange across the network. YARP implements communication through special objects, called *ports,* which deliver messages to any number of observers (other ports). The computation can thus happen locally, i.e. on a single machine, or can be distributed across any number of machines, each of which are running multiple processes, using any of several underlying communication protocols. In order to allow YARP to work properly, all the machines must belong to same subnet and have a reachable IP address. This condition is normally achieved in a laboratory private network but this is difficult to achieve on commercial mobile network, where the individual IP addresses are typically not public. To overcome this difficulty, partners are currently investigating the configuration of a VPN tunnel between the robot internal network and the remote computational unit, as show in Figure 32.

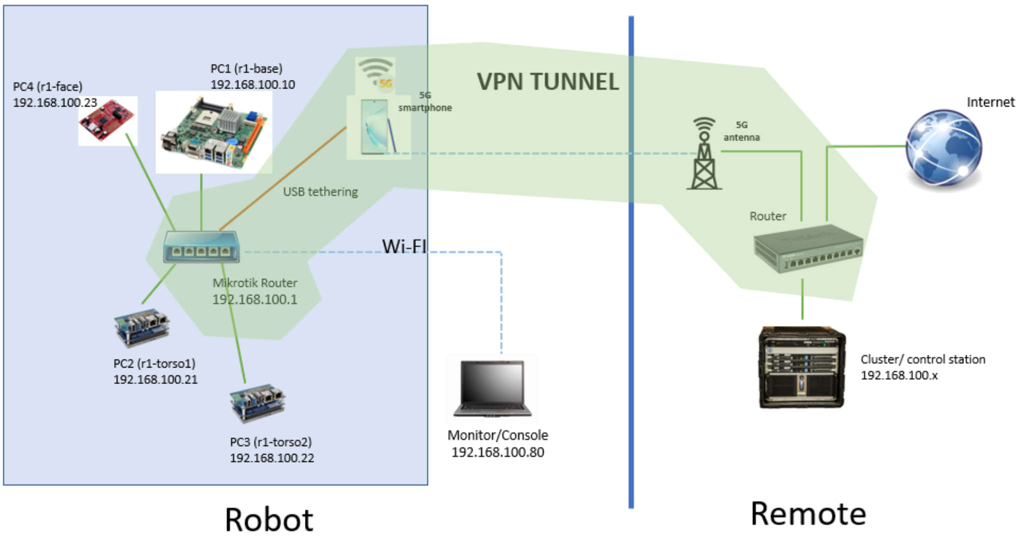

Figure 32 - VPN tunnel between the robot internal network and the remote computational unit.

4.3 Integration and test in labs

IIT and ERI-IT performed a preliminary test of R1's middleware (YARP Figure 33) using the 4G LTE mobile network available in Ericsson Labs. The very first experiments were performed using IIT robot simulator, based on Gazebo, in order to generate a network traffic similar to the one originated by R1 in the real application. Two traffic types were considered: TCP-based (for critical control commands) and UDP-based (for audio/video data and sensor streaming). For both the traffic types the possibility of setting the QoS (Quality of Service) flag to change the priority of the stream was investigated. IIT also investigated strategies to allow YARP to handle occasional out-of-order UDP packets and measuring the system end-to-end latency while executing the software application in native mode or inside a docker container.

A set of experiments were planned to complete this work and address more advanced topics, such as the management of VPNs and the traffic routing through a tethered device (i.e. the 5G handset provided by Samsung).

The first round of experiments with the real robot were performed in September 2020, when R1 was brought to the Ericsson labs to test the VPN connection through the mobile network for the first time (Figure 33). During the session, the complete system (router+5G mobile handset+VPN) was successfully tested, even if some slowdowns were observed, due to a sub-optimal VPN configuration. Because of this limitation, it was not possible to deploy all the modules of the YARP application, and some module of the software were executed on-board instead of running in the remote server. With the robot connected through the mobile network, a preliminary test of the navigation stack was also tested in the corridors of the Ericsson labs. The collected navigation data were stored for subsequent playback and parameters optimization.

Figure 33 - R1 during the test session in Ericsson Lab.

A second round of experiments with R1 in Ericsson Labs is currently planned in December 2020 (the exact schedule may vary in accordance to the current restrictions and exceptional regulations due to COVID-19). In this new session, the tests will be performed using an exact mirror of the network that will be setup in the museums, as well as an improved VPN configuration. This will allow to test outside the robot the application modules that were executed onboard during the first session. To prototype the robot-assisted tour application in the museum scenario, IIT is currently using a simulator, which is based on Gazebo [14] defining a pipeline to produce a realistic simulation environment starting from the planimetries provided by TOR. First of all, the .pdf files containing the maps into Autocad were imported, all text labels and icons were removed, and were exported to the generic .dxf format. Then, the files were imported in Autodesk Fusion 360, the drawing scale was verified and the planimetry was extruded, obtaining a full 3D model. The resulting .obj/dae files can be now used as an environment for robot simulation in both Gazebo and/or Unity.

IIT is currently performing experiments in order to verify if the robot is able to correctly localize itself in the simulated environment, exploiting only its lidar sensors and the provided ground-truth maps. Figure 34 shows R1 navigating through the generated 3D model of the permanent exhibition gallery at GAM. To increase the complexity of the simulation, virtual visitors, moving in the environment, were added to the scenario, in order to disturb lidar readings. In this case, additional recovery strategies based on visual appearance of the surrounding environment, are currently under investigation.

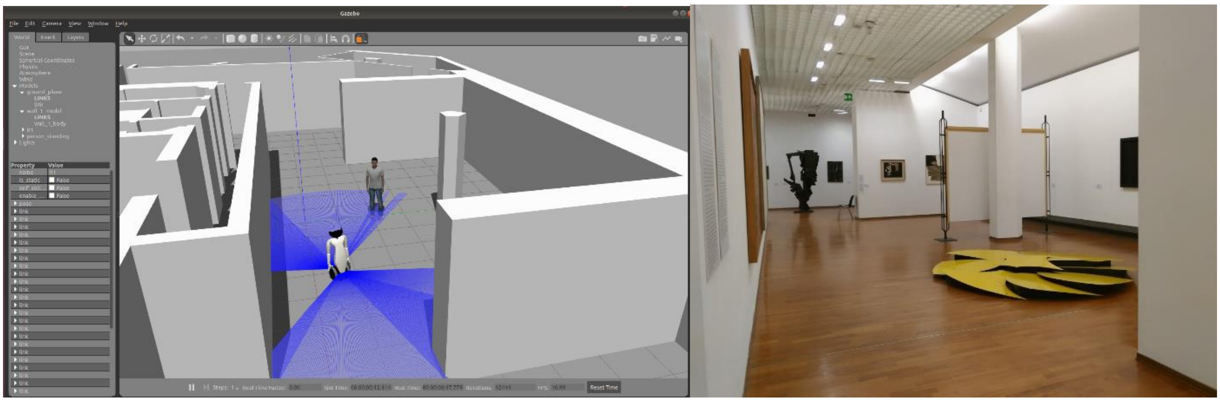

Figure 34 - R1 navigating through the generated 3D model.

4.4 Test in the network

Due to their common infrastructure, experiments for UC3 are going to take place simultaneously with those scheduled for UC2c. According to the current time plan, experiments will be run in the ERI-IT E2E Lab in Genoa in January 2021, using a mirror of the network which is going to be deployed in Turin. The first experiments with R1 in the real location in TOR, instead, are going to take place in 2021.

5 UC4 - High Quality video service distribution

5.1 UC4 definition

This use case targets the distribution of enhanced high-quality video and immersive services for tourists to improve the user experience when visiting a city. It is directly related to the media and entertainment vertical. Users will be able to use their smartphones, tablets or VR devices to receive educational and informative content during their visits to the city and museums. Video sources, which can be either professional 4K-HDR or 360º videos, will be produced in collaboration with the RAI Television Production Centre. This audio/video (A/V) product will be used for the demos in 5G-TOURS and serve as promotional activities about the city and its culture at the same time.

UC4 is divided in turn into three sub-use cases: (i) transmission of mixed unicast/broadcast services using TIM's laboratory network, (ii) use of 5G broadcast delivery services using RAI's broadcasting network, and (iii) development of a 5G core multicast component in UPV's laboratory.

Focusing on the first sub-use case, it was reported that LTE eMBMS was never rolled-out on TIM network since it requests a huge amount of network resources (impacting on the other services) and without any consistent commercial demand. Based on this, TIM took the action to evaluate a possible implementation of LTE eMBMS in TIM laboratory network that is used as a test plan of the commercial network. After a long study phase with TIM's Engineering department, it was decided that the setup of a trial on LTE eMBMS will require an additional and consistent effort (and budget) that cannot be provided since TIM is now focused on the 5G network deployment; an activity targeting a legacy feature on a legacy system (involving both radio and CN parts) that is not going to be implemented in the network cannot justify such a type of investment. On such basis, it was decided to cancel the UC4a.

UC4.b and UC4.c are described below.

UC4.b: 5G Broadcast delivery to massive audiences

Partners involved: UPV, RAI, EXP, SRUK
Location: Palazzo Madama and surroundings.

The content is transmitted via the broadcasting network of RAI in a downlink-only mode to all users at once. The performance does not change regardless the number of devices receiving the signal. This option is a broadcast-centric receive-only approach that utilizes a High-Power High-Tower (HPHT) topology to transmit the content. Note that this approach was not originally envisioned in the proposal. The trials will be divided into two phases.

- Phase 1- enTV Rel-14. This stage consists of transmitting 3GPP enTV Rel-14 services to all users by using a broadcast tower. RAI already tested this technology under different scenarios, such as the European Championships 2018 in Aosta Valley, the Feast of San Giovanni or the RAI-CRITS tests mobile TV broadcast demonstrator. This demonstration will be done under the umbrella of 5G-TOURS, and additional measurements will be provided;
- Phase 2 - enTV Rel-16. In this stage, the consortium is committed to update 5G Broadcast to Rel-16 and explore the advantages that this technology brings to real users such as citizens or tourists. In the HPHT context, expected improvements are a larger coverage or reception at higher mobility speeds.

Following the discussions in task 3.4 for the service layer, the sub-use case has been recently enriched to consider the delivery of MPEG-DASH formatted content allowing the use of the adaptive bit-rate HTTP-based streaming solution.

UC4.c: 5G Core Multicast

Partners involved: UPV, EXP
Location: UPV's lab.
After completion of D4.1, it was decided to consider the last stage of UC4.a into a specific sub-use case, i.e. UC4.c "5G Core Multicast" that will be implemented in a laboratory context. This use case entails the development of a multicast component in the 5G core available in UPV premises. There is no demonstration involved, but partners agree on the fact that its development is a great addition to the 5G-TOURS final outcome.

5.2 UC4 implementation

5.2.1 Network Deployment

UC 4.b: 5G Broadcast delivery to massive audiences

RAI experimented in the Aosta Valley the FeMBMS broadcast profile of 3GPP Release 14, the most advanced precursor of 5G broadcast technology. The trial was implemented on the Rai / Rai Way broadcast network using five terrestrial high-power transmitters operating in SFN. Two demonstrations were organized to illustrate the potential of 5G broadcast. The first demonstration took place during the European Athletics Championships held in Berlin (2-12 August 2018), using live images produced by EBU at the Berlin stadium. The second one took place in Turin in June 2019 during the annual Feast of San Giovanni. Unlike the previous trials, in which the last mile between the receiver and the mobile terminals had been covered using a Wi-Fi access point (and therefore with a limited capacity available), during the Feast of San Giovanni the program broadcasted was available to a large group of teachers and students of the Politecnico of Torino who, thanks to an innovative solution developed by Global Invacom and based on a Wi-Fi multicast distribution, were able to appreciate the new technology directly on their own mobile phone equipped with a special app.

In the framework of the UC4.b the testbed of Torino will be used to transmit a program to all users at once via the broadcasting network of RAI in a downlink-only mode. As described in the previous section, the trial will be split into two phases. In the first one, partners will use 3GPP-Rel-14, adopted during the previous demonstrations with some minor updates on the transmitter and receiver depicted in the following, while in the second one the transmitter and receiver equipment will be updated to Rel-16. Immersive services will be showcased in this phase to highlight the capabilities of the 5G network in terms of bandwidth resources.

The available radio-frequency channel for the trial in Torino is the VHF 11 (216-223 MHz, centre frequency 219.5 MHz) in vertical polarization. There will be one HPHT transmitter located in Torino Eremo (the main RAI transmitting site for Torino), placed on a hill at about 650 m above sea level and 4 km away from Palazzo Madama and Rai CPTO studios (city centre). The available output power is about 125 W with an ERP of 500 W. The area covered by the signal will be the whole town of Torino.

Figure 35 shows a map of Torino and reports the locations involved in the trials:

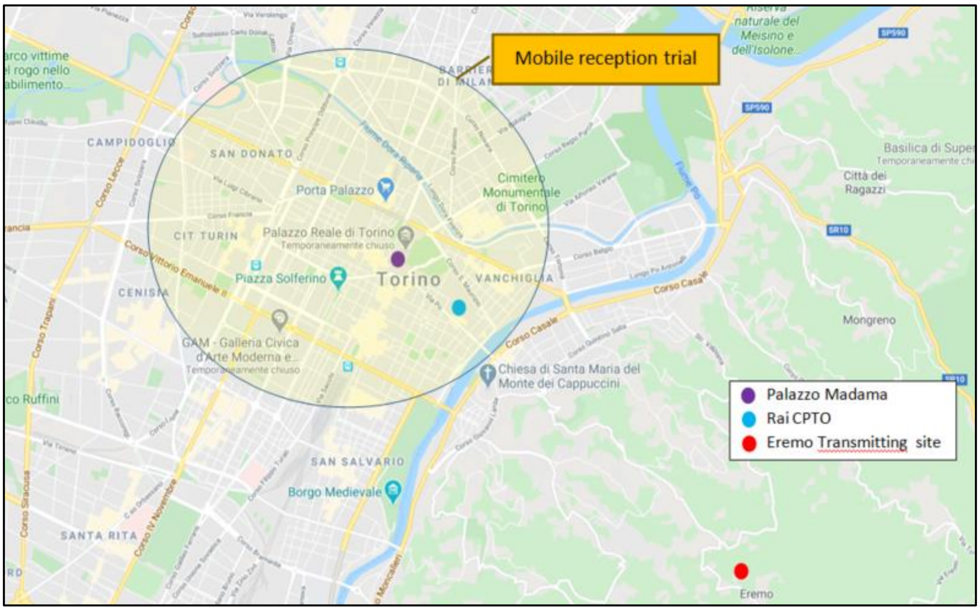

Figure 35 - Locations involved in UC4.b trials.

Despite the fact that available frequency is not intended for 5G broadcast the results of the trials could anyway be useful to show the potential of this technology and to give important outcome regarding the network implementation.

The trials foreseen during the two phases are:

- Phase-1 is based on indoor scenario (Palazzo Madama or RAI CPTO premises) and Wi-Fi unicast or multicast distribution to a large panel of users of live or pre-recorded video signal.
- Mobile in-car scenario in the city centre and unicast Wi-Fi distribution in the car of live or pre-recorded video signal.

In order to give to the final user an immersive experience a 360° video, pre-recorded or real time, could be used as source for the broadcast transmission.

During a special event, the video live signal will be generated by a direction located in the surrounding of Palazzo Madama. The SDI signal will be then compressed in HEVC with an Encoder by Elemental. The chosen bit-rate will be decided on the basis of the modulation scheme (MCS) adopted during the trial. In the previous demonstrations and trials RAI tried different solutions to find the best trade-off between the capacity and the robustness of the signal. For example, during the Feast of San Giovanni, RAI used the MCS 21 that guarantees a net bit-rate of about 10.4 Mbit/s and a very good robustness also in a mobile environment. Anyway many other valid solutions will be kept into account and adopted if necessary. The output of the encoder are:

- A TS (Transport Stream) over IP. The Transport stream specifies a container format encapsulating packetized elementary streams, with error correction and synchronization pattern features for maintaining transmission integrity when the communication channel carrying the stream is degraded.
- A live DASH content (i.e. a sequence of media segment files), served over HTTP served before ingestion by the BM-SC.

UC4.c: 5G Core Multicast

The 5G Core Multicast software development is an on-going effort that will span 2020 and most of 2021. The goal is to design, develop, implement and validate a set of new enhancements to the 5G Core Network that enables multicast communication, focused on the high-quality video distribution and delivery. The design phase was mostly completed as part of 5G-Xcast [15] work, but it is currently being reviewed and adapting it to the latest Rel-17 3GPP work. In Deliverable 3.2 [5] the new Network Functions (XCF and XUF) proposed are explained.

5.2.2 Network Equipment

UC 4.b: 5G Broadcast delivery to massive audiences

The network scheme to be used during phase 1 of the trials is shown in Figure 36.

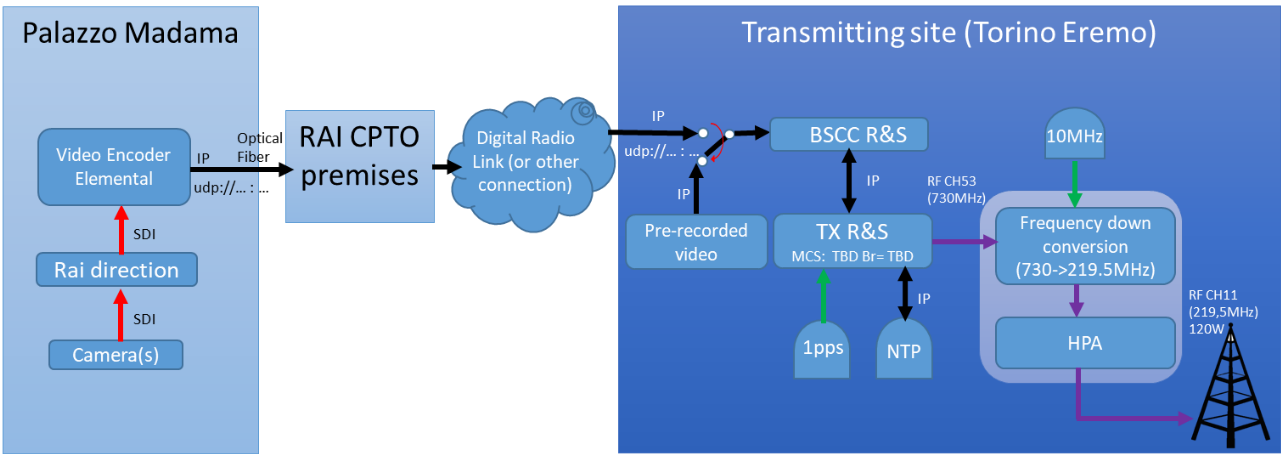

Figure 36 - Phase-1 trials' configuration.

The BM-SC is the-core network function ingesting the multimedia contents and distributing it to the 5G broadcast network. It can receive the signal from a live source during an event as a UDP stream, coming from the direction via a digital radio link (or another kind of connection if it will not be possible to implement the radio link) or a pre-recorded signal (for example a promotional video of Torino). This function is played by the Broadcast Service & Control Centre (BSCC) by Rohde & Schwarz. The 5G broadcast transmitter is a product by

Rohde&Schwarz that receives the IP signal from the BSCC and gives an RF output at 730 MHz (channel 53, UHF). This RF signal is then converted at 219,5 MHz (ch.11, VHF), amplified and sent to the antenna system.

Alternatively, the BM-SC provided by Expway can be used especially for ingestion and distribution of live DASH Content, requiring its integration with the Rohde&Schwarz transmitter according to M1 and M2 standardized interfaces (Figure 37).

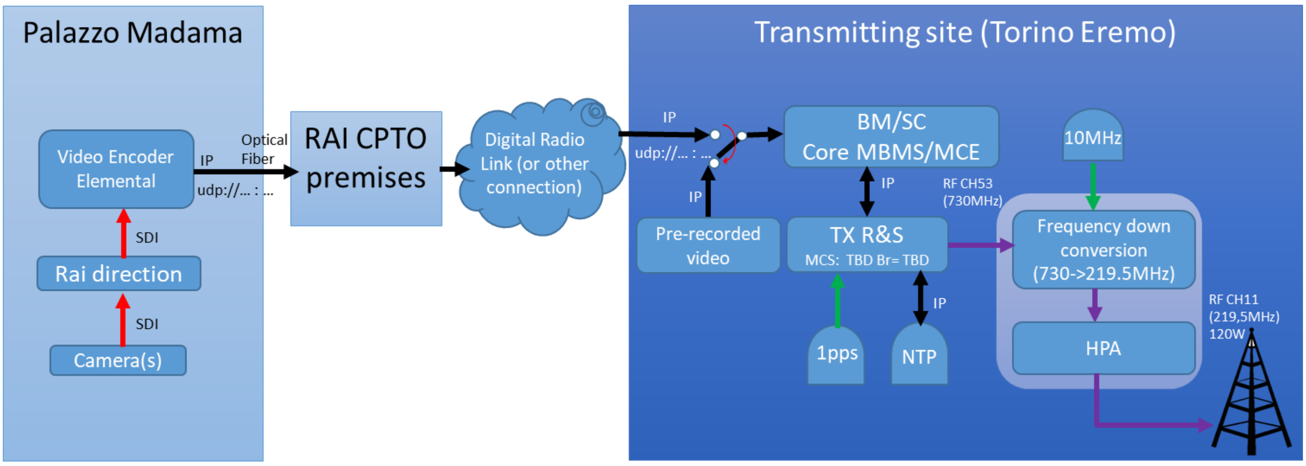

Figure 37 - trials configuration for DASH content delivery.

The signal will be transmitted from Torino-Eremo towards the city of Torino and will be received both in indoor (at Palazzo Madama) and mobile scenario (in the city center) as described in section 5.2.3. The details are reported in section 5.2.4.

UC4.c: 5G Core Multicast

As previously mentioned, the Campus5G located in UPV premises features cutting-edge 5G equipment. For the 5G Core Multicast development, a commercial and software-based 5G Core Network will be enhanced with the two multicast functions and their related interfaces.

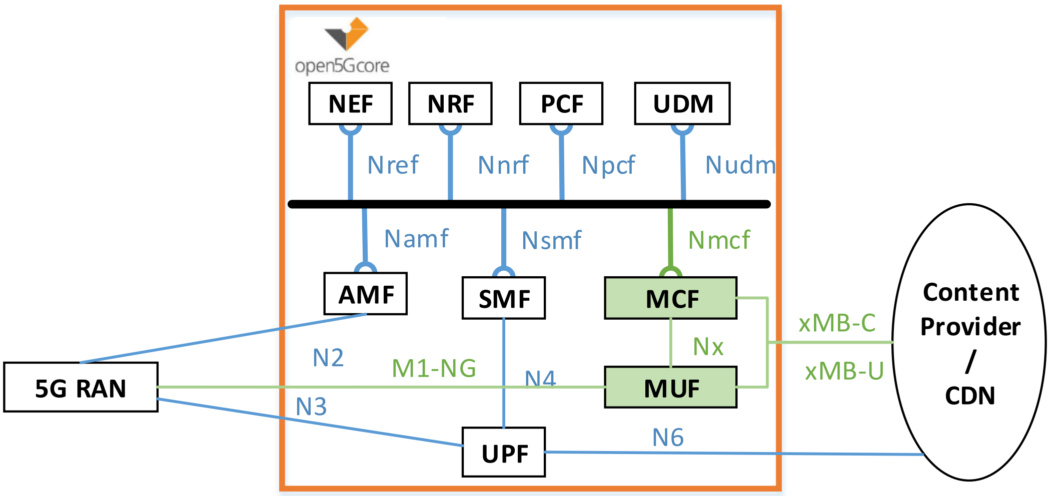

Figure 38 - Open5GCore architecture in UPV premises featuring the Multicast Functions.

UPV also provides Rel-15 compliant gNB for testing however this equipment is proprietary and does not allow for software enhancements. The development will be validated via a simulated and multicast-enabled 5G RAN, also part of the Open5GCore suite [16] (Figure 38). To test the Core Network, UPV has acquired some Landslide licenses. Spirent Landslide is a professional Core Network Testing software for 4G and 5G. It can emulate several UEs, RAN and Core Network from several technologies (3G,4G,5G) in order to verify the correct behaviour of the element under test in several scenarios e.g. handover, service discovery, attach/disconnect. Landslide has been used in UPV 5G testbed to stress the limits in number of users and data throughput of the OAI (both Core and RAN) and srsLTE (Core and RAN).

5.2.3 Application Components

UC 4.b: 5G Broadcast delivery to massive audiences

Since 5G broadcast terminals are not available in the market, the signal reception at the end user will be achieved by using a special hardware/software defined receivers (SDR), for both indoor and mobile in-car scenarios.

Indoor scenario

In this scenario, two solutions will be used for the communications between the SDR and the end user devices:

- For TS over IP streams, a special mobile app (Bx-WiFi-GI for Android/iOS) by Global Invacom will be used. After downloading it on the device, users will be able to receive the video stream coming from Torino-Eremo and locally redistributed via Wi-Fi (multicast mode).
- For DASH content delivered over broadcast, a multicast client (the Cube Agent by ENENSYS Expway), is used to discover the DASH content, receive, and decode the media segments. The multicast client, acting as a CDN edge, caches the media segments, making them available over Wi-Fi (unicast) to the end devices.

Mobile in-car scenario

In this case, the scope of the application is to show the performance of a 5G broadcast signal in mobility mode, rather than its broadcast feature.

A single terminal will be used in this scenario, still connected to the SDR via Wi-Fi. In this case, to watch the video, the final user can use a free downloadable client app such as VLC, Good Player, etc.

Moreover the van will be equipped with a measurement receiver by Kathrein which is able to log the reception parameters together with the position of the van.

UC4.c: 5G Core Multicast

Currently, there are no plans on the development of application components for UC4.c.

5.2.4 Terminal Equipment components

UC 4.b: 5G Broadcast delivery to massive audiences

Indoor scenario:

Coming from Torino-Eremo transmitting station, the 5G broadcast signal will be received at Palazzo Madama by means of a VHF antenna for indoor reception; in case of bad indoor reception conditions, alternative reception techniques will be considered (i.e. rooftop antenna).

Inside the building a receiving station will be arranged, in order to emulate mobile terminals for 5G broadcast reception (Figure 39). The Rx station will be composed by:

- 1 SDR receiver by Rohde&Schwarz and iFN
- 1 or more SDR receivers developed by UPV (Rel -16 compliant)
- 1 multicast client by ENENSYS-Expway for DASH content reception and caching + 1 access point.
- 1 special server + access point by Global Invacom to perform multicast Wi-Fi redistribution
- Smartphones (connected in Wi-Fi)

For the fixed reception in the palazzo, both the R&S SDR device and the SDR receiver developed by the UPV will be used to process the signal from the HPHT at Torino-Eremo. Both devices are able to perform both the signal software demodulation and the signal decoding.

To reach the end users, as mentioned in section 5.2.3, the “last mile” towards the smartphones will be covered via Wi-Fi. The IP stream from the SDR receiver will feed a server which is able to receive, transcode (if requested) and apply a FEC at application level. The server has also the task to configure and monitor an ad hoc Wi-Fi access point. The ad hoc access point, whose firmware has been modified by Global Invacom, will receive the stream from the server and send it via multicast Wi-Fi to a high number of simultaneous terminals. The users will be able to watch the video either on their own smartphones or on a number of smartphones provided by

RAI. In case they would use their own devices, the users will be requested to download the Bx-Wi-Fi-GI app designed by Global Invacom in order to enable the multicast connection with the GI server.

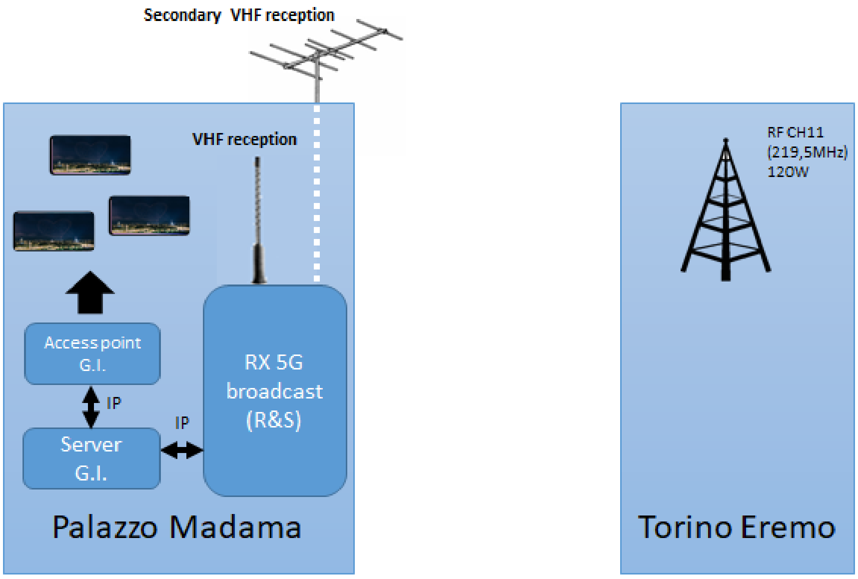

Figure 39 - Terminal equipment components for UC4.b.

For the delivery of DASH contents (Figure 40), DASH segments over broadcast are received and cached on a local HTTP server by a multicast client, acting as a local CDN edge. The HTTP server is accessible to the smartphones via a separated access point. To consume live DASH contents, smartphones only need the content URL on the local HTTP server, which can be made available by a flash code. No dedicated application is required, as the DASH content can be played by native players.

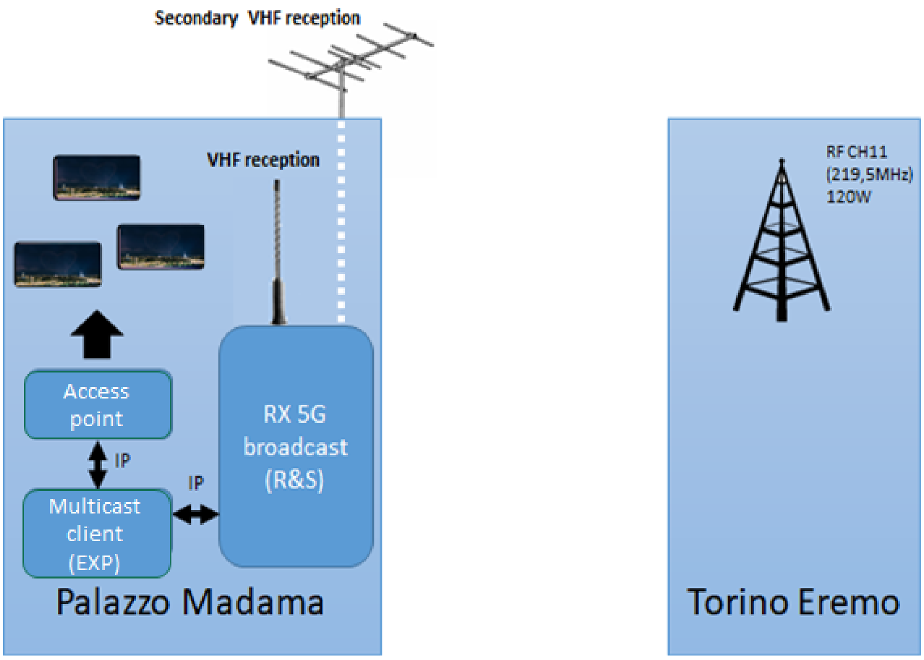

Figure 40 - Terminal equipment components for UC4.b and live DASH content delivery.

<u>Mobile scenario:</u>
In this scenario, a professional special van will be equipped with:

- 1 VHF car roof antenna
- 1 SDR receiver by Rohde&Schwarz and iFN
- 1 measurement receiver by Kathrein
- 1 or more SDR receiver by UPV (Rel-16 compliant)
- 1 access point to cope the “last mile” towards the end user
- 1 smartphone for in-car handling

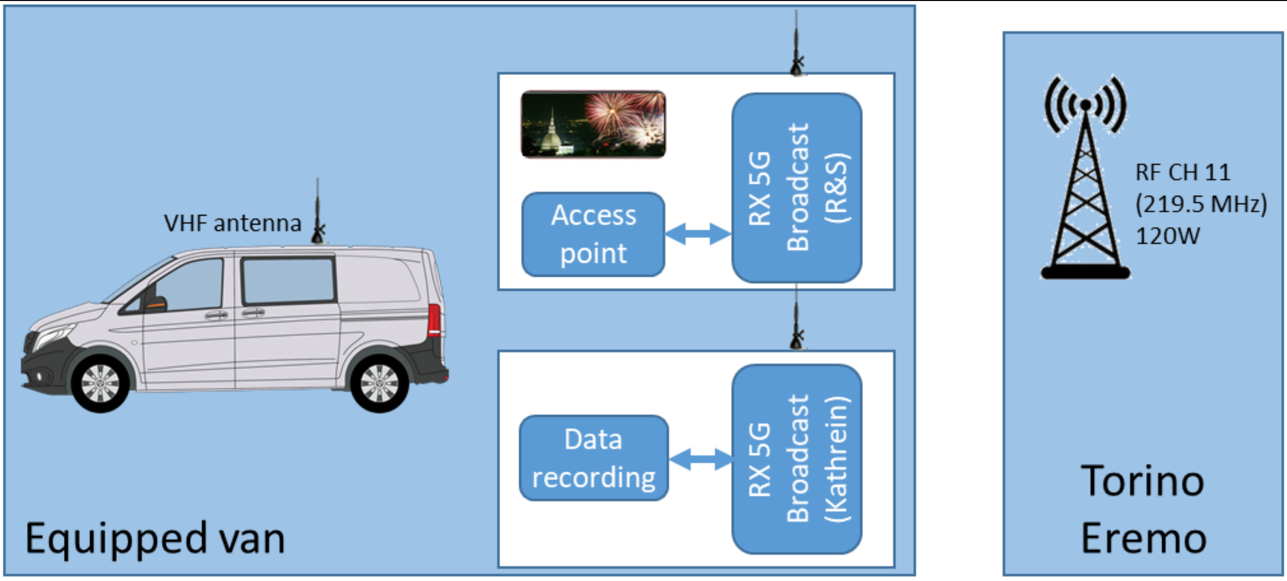

Figure 41 - Mobile scenario.

The equipment involved in the trials will be the following (Table 1):

Table 1 - UC4b list of the equipment.

Reference name	Number	Model	Minimum specifications (CPUs, RAM, storage, etc.)	Public/private IP	VPN required	Provided by
Broadcast Service and Control Center (BSCC)	1	R&S (BSCC1.0 for Live Tv)		private	no	RAI
Broadcast Transmitter System	1	R&S (TMU9C)	includes SDE900, TCE901 and PMU905 (UHF amplifier band IV-V, DTV 400 W rms, Doherty)	private	no	RAI
BM-SC	1	EN Core MBMS/MCE				EN
RF converter and amplifier	1	ONEtastic - ONECOMPACT HV		private	no	RAI
VHF antenna	2	OffelE11Y6,R&S TSMDVB-Z2 antenna magnet mount		_	_	RAI
SDR receiver	1	R&S FEMBMS receiver	includes TX9-B82 (single CPU, DekTec interface), DTA-2131 UHF/VHF multistandard RX	private	no	RAI
SDR receiver	2-3	USRPs B210				UPV
Measurement receiver	1	Kathrein		private	no	RAI
Server and access point	2	Global Invacom BX-WiFi, D-Link DIR-615		private	no	RAI
Smartphones	2	Galaxy S10 5G		_	_	SRUK
Smartphones	3	Samsung Galaxy S10, LG V40, Sony Xperia XZ4	4G only devices	_	_	RAI
Video Encoder	1	AWS Elemental Live		private	no	RAI

UC4.c: 5G Core Multicast

This use case involves technologies which are beyond the current state of the art of 5G. At the moment, there are two 3GPP study items being discussed strongly related with the topic. These study items refer to the i) Core and ii) RAN implementation of multicast capabilities. The due dates are December 2020 and December 2021 respectively. The implementation of a 5G RAN with multicast capabilities is delayed due to the necessity of input information about 5G core study item [16] conclusions.

The FS_5MBS Study Item proposes 3 different architectures depending on the functionality used and the interfaces involved. From those 3 options, the Transparent Multicast branch is better suited in the overall 5G-TOURS vision. UPV is currently developing a prototype solution for this Use Case realization.

On the Radio side, it will depend on 3GPP progress manufacturer adoption of Rel-17 novelties the availability of terminals that support 5G Multicast in the radio side. However, while expecting 3GPP progress, simulated devices and radio environments can be used instead. In this role, the professional network validation tool called Landslide is the main available solution. Dealing with the traffic and RAN elements simulation in the core testing.

5.2.5 Interfaces

UC 4.b: 5G Broadcast delivery to massive audiences

The interfaces used by different devices are reported in Figure 36 and in Figure 37, in which the network scheme to be used during phase 1 of the trials and the DASH configuration is shown.

UC4.c: 5G Core Multicast

3GPP study item where 5G Multicast in 5G Core discussion is included, is still ongoing. Thus, there is not a standardized model yet. For that reason, UPV propose an architectural model based on the 5G-Xcast proposal for early development in UPV premises, Figure 42.

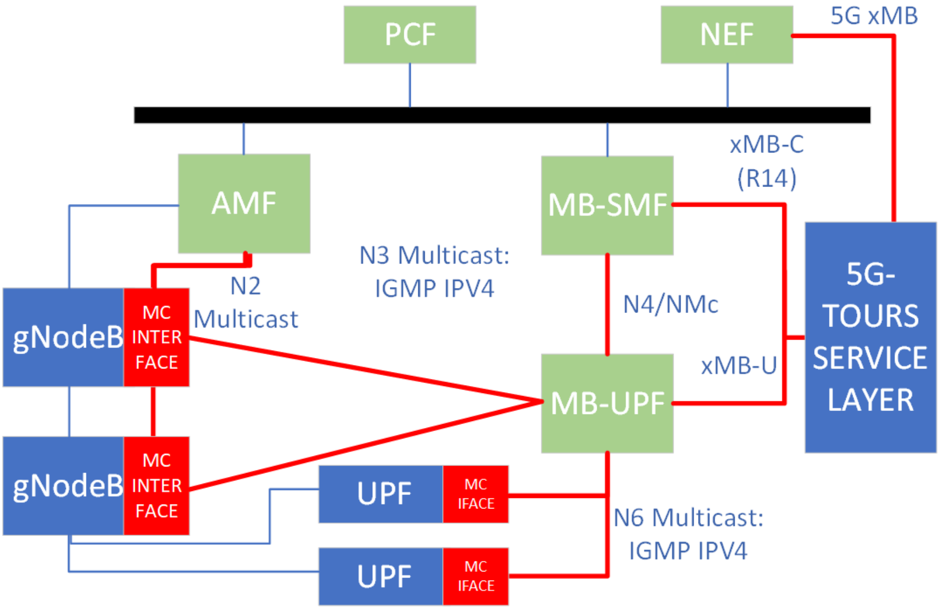

Figure 42 - UPV proposed architecture.

UPV will implement a testing environment implementing the "Transparent Multicast" architecture. Where MCF (Multicast Control Function) and MUF (Multicast Use Function) represent MB-SMF and MB-UPF from 3GPP respectively.

UPV had an internal discussion about what protocol was worth to use in the N3 and N6 interfaces. The protocols included in the discussion were IGMP IPv4, QUIC, MDL IPv6 and Nb Routing. IGMP IPv4 was chosen among these. Furthermore, it is necessary to implement some updates in N2 interface and AMF to adapt the system for multicast traffic accommodation. The connection with the content provider, similarly to 4G, will be performed by the xMB interface. In this new system, MC interface is the endpoint for multicast tunnels as it is not expected to have commercial gNBs compatible with these protocols. Behind MC interface, usual 5G unicast protocols are used.

5.3 Integration and test in labs

Preliminary tests are needed both in the network and user equipment. Regarding UC4.b, the software and hardware equipment in both transmitter and receiver stations described in Section 5.1 will be tested prior to the demonstrations envisaged in the project. UC4.c will also need the integration and testing of the different components that entail the use case.

UC 4.b: preliminary test in lab

The transmitting chain is currently under test in the RAI CRITS laboratory. During the test a pre-recorded and encoded video signal is sent to the R&S BSCC. The block diagram of the test bench adopted in the laboratory test is the following:

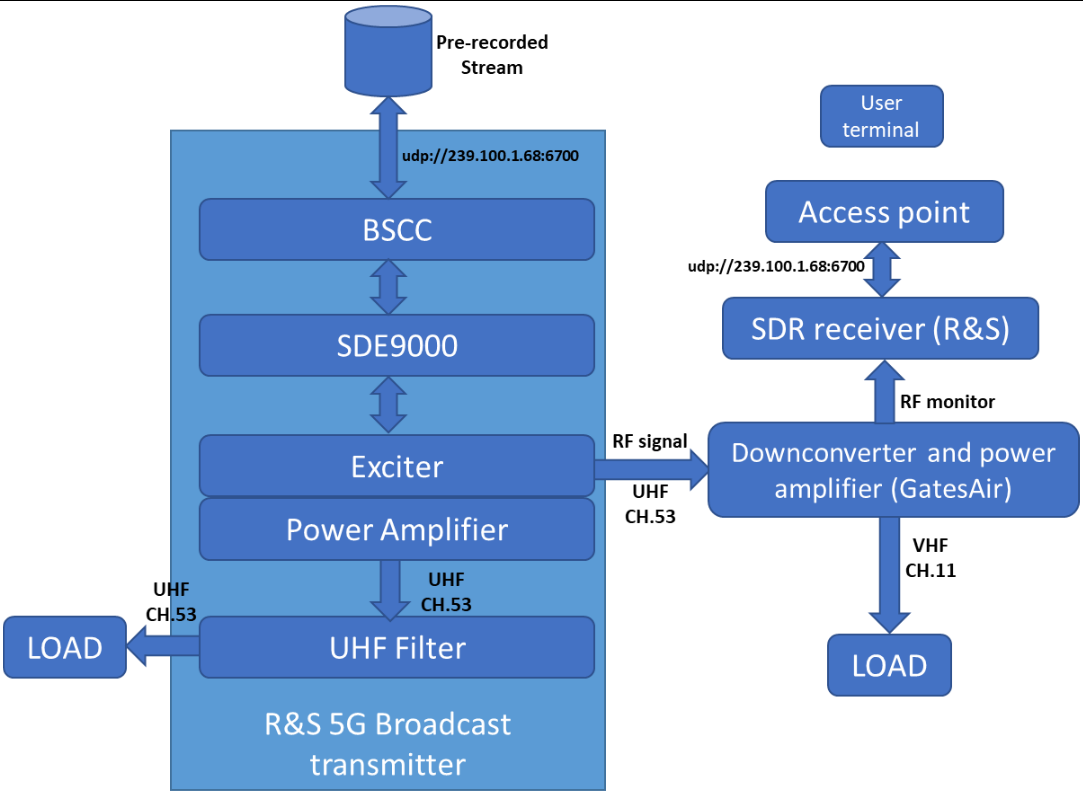

Figure 43 – Laboratory set-up block diagram.

Figure 44 and Figure 45 reports the equipment during the test carried out in RAI CRITS laboratory:

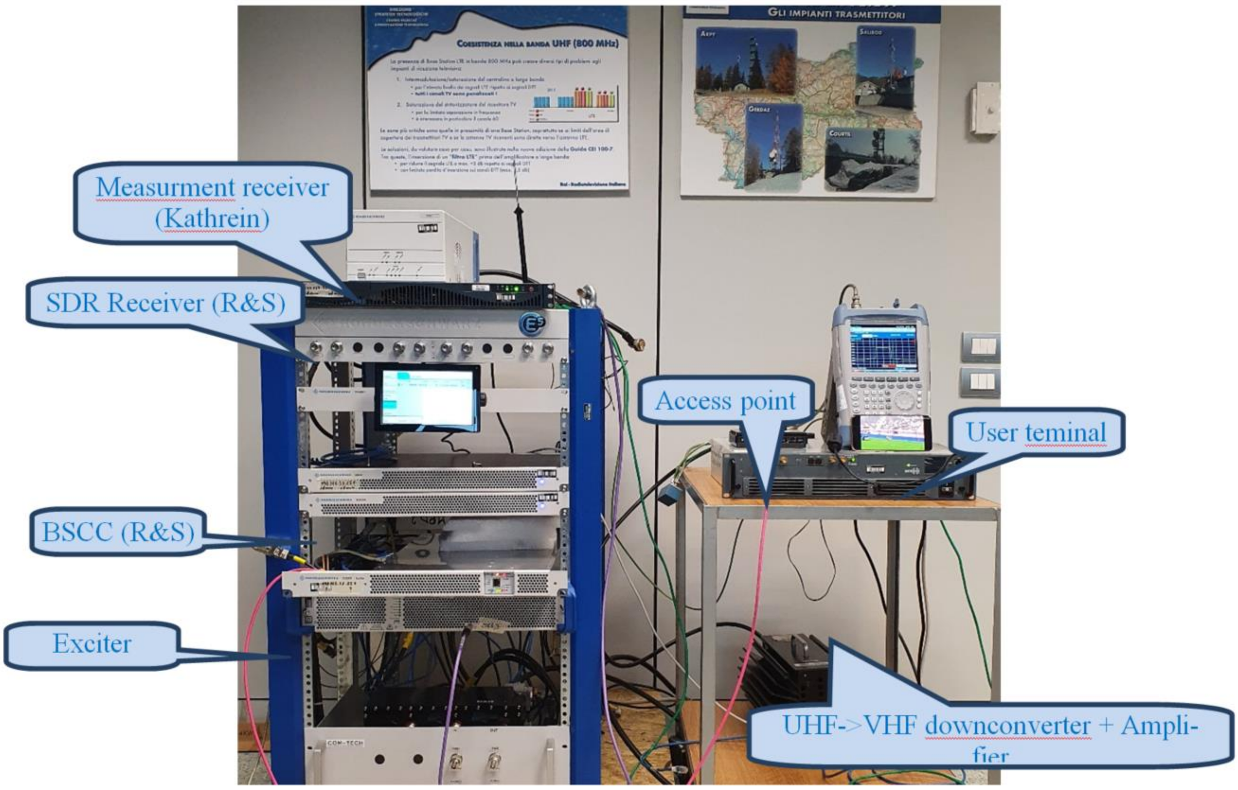

Figure 44 - Laboratory setup.

Figure 45 - Laboratory setup.

During the laboratory test all the elements of the transmitting chain (BSCC, exciter, frequency down-conversion and amplifier) and receiver chain (receiver by Rohde&Schwarz and iFN, measurement receiver by Kathrein, access point and smartphones) have been tested.

The following table (Figure 46) shows all the available modulation code scheme (MCS) with the related bit rate and the measured C/N@TOV (less than one video/audio error in 30 s), considering a bandwidth of 5 MHz and a CP of 200 µs.

Figure 46: 5G Broadcast capacity and C/N@TOV with 1.25 kHz subcarrier spacing, 200 µs CP duration, 5 MHz channel bandwidth.

MCS	Modcod	Bit rate [Mbit/s]	C/N@TOV [dB]
0	QPSK	0,662	NA
1	QPSK	0,879	NA
2	QPSK	1,065	NA
3	QPSK	1,375	NA
4	QPSK	1,747	-0,2
5	QPSK 0.37	2,150	-0,1
6	QPSK 0.43	2,522	0,6
7	QPSK 0.52	3,018	1,5
8	QPSK 0.59	3,390	2,6
9	QPSK 0.67	3,886	3,7
10	16QAM 0.34	3,886	4,0
11	16QAM 0.37	4,258	4,4
12	16QAM 0.42	4,816	5,1
13	16QAM 0.48	5,560	6,5
14	16 QAM 0.54	6,257	7,7
15	16QAM 0.59	7,001	8,4
16	16QAM 0.64	7,497	9,3
17	64QAM 0.43	7,497	9,8
18	64QAM 0.46	7,745	10,2
19	64QAM 0.51	8,861	11,6
20	64QAM 0.55	9,605	12,4
21	64QAM 0.60	10,349	13,7
22	64QAM 0.64	11,093	14,3
23	64QAM 0.71	12,186	15,7
24	64QAM 0.76	13,116	16,8
25	64QAM 0.79	13,674	17,9
26	64QAM 0.85	14,790	19,4
27	64QAM 0.89	15,348	20,0

Figure 46 - reports the graphical representation of the measured values.

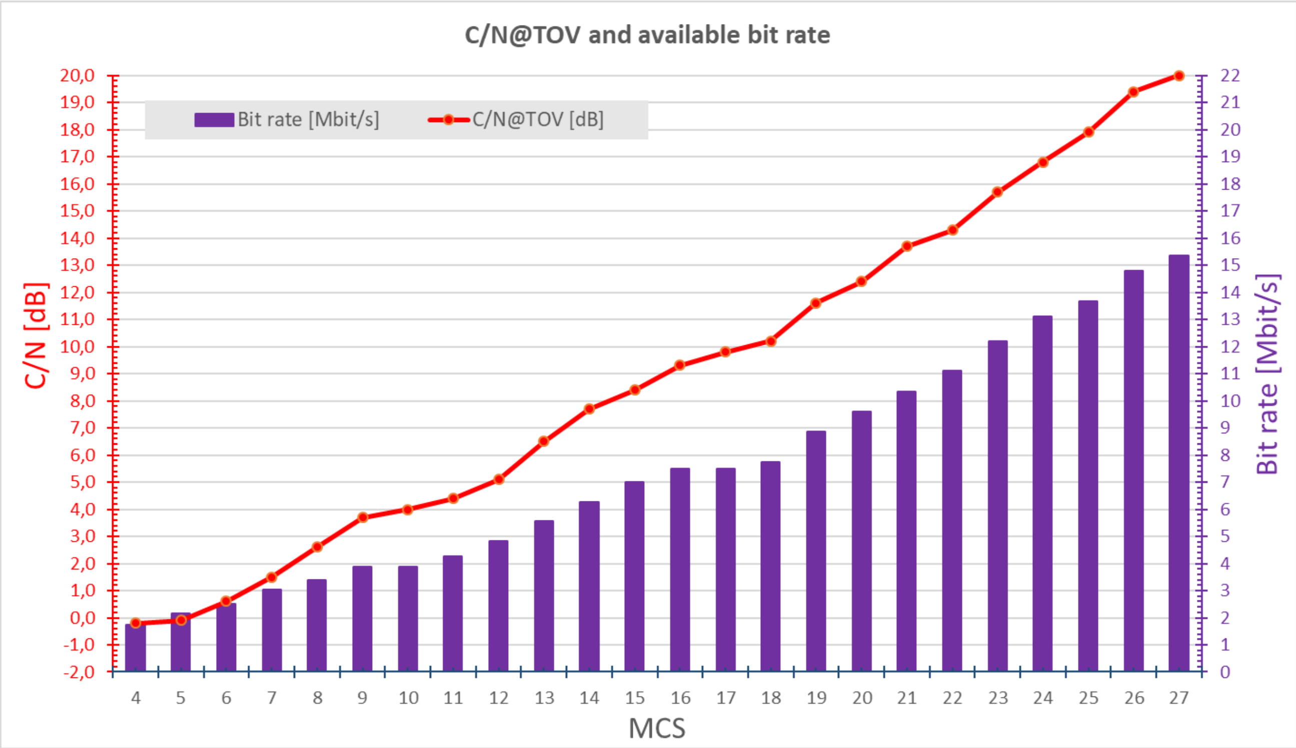

Figure 47 - 5G Broadcast capacity and C/N@TOV with 1.25 kHz subcarrier spacing, 200 µs CP duration, 5 MHz channel bandwidth.

The test bench adopted for the C/N evaluation with Additive Withe Gaussian Noise (AWGN) is depicted in the following scheme shown in Figure 48.

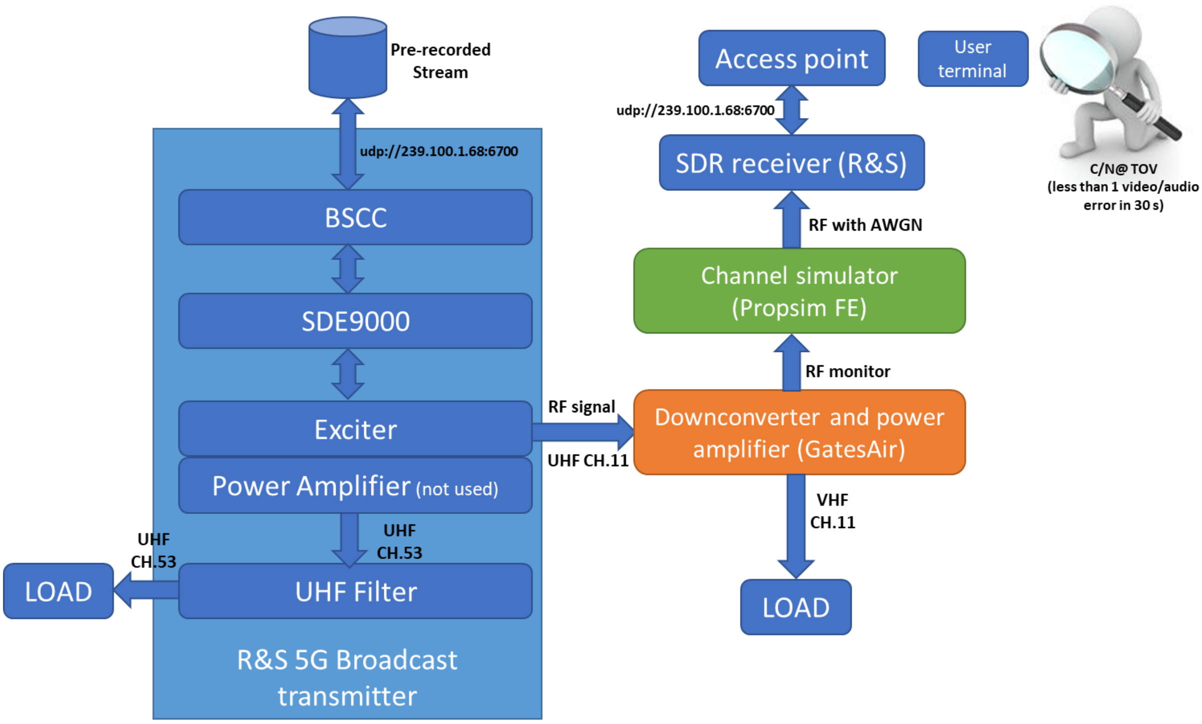

Figure 48 - C/N with AWGN test bench.

5.4 Test in the network

This section only applies to UC4.b. Prior to each of the planned demos, additional tests will be performed in real network environments. The first tests for phase-1 are expected by the end of 2020. The delay of UC5 will also involve a combined demonstration with UC4.b.

6 UC5 - Remote and distributed video production

6.1 UC5 definition

Partner involved: RAI; TIM; ERI-IT; LIVEU; TOR

Location: Palazzo Madama – Sala delle Feste

As described in D4.1 [1], the main objective of the use case is to exploit the 5G TOURS network features for remote television production, analyzing how 5G networks could support various scenarios in which high-quality video is generated and transmitted.

In a distributed TV video production context, the content needs to be produced by mixing local and remote audio and video contributions in the TV studio. The remote contributions are thus delivered to the main editing site via the 5G network in real time.

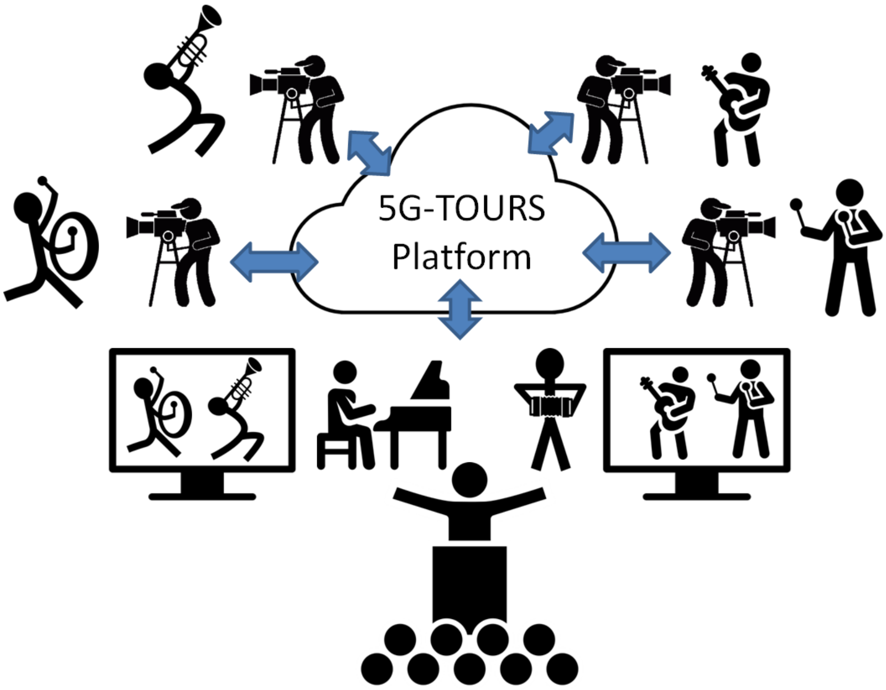

Figure 49 - The Itinerant Orchestra.

The challenging implementation for the Use Case is the Itinerant Orchestra in which some musicians located in the main concert hall play together with some other itinerant musicians walking in the streets while approaching the concert hall. Each itinerant musician is followed by one (or more) cameraman shooting their performance and providing cues to stay in synch with the main orchestra performance. The high-quality AV signal is transmitted via the 5G network to the main editing facility where it is properly processed and mixed with both the rest of the itinerant musicians and the orchestra located in the concert hall.

The spectators in the concert hall will watch the itinerant musicians playing and walking in the streets towards the Palazzo Madama (as real time virtual presence) on one or more LED walls and listen to their performance via an amplification system, mixed to the local orchestra, until they enter the concert hall and join the orchestra.

6.2 UC5 implementation

In this section partners involved in the UC try to analyze the Remote TV production environment in terms of signals exchanged from/ to all elements involved in a typical situation of remote production and in particular for a possible Itinerant Orchestra solution.

Figure 50 shows signals that are generated or received from/ to the cameraman:

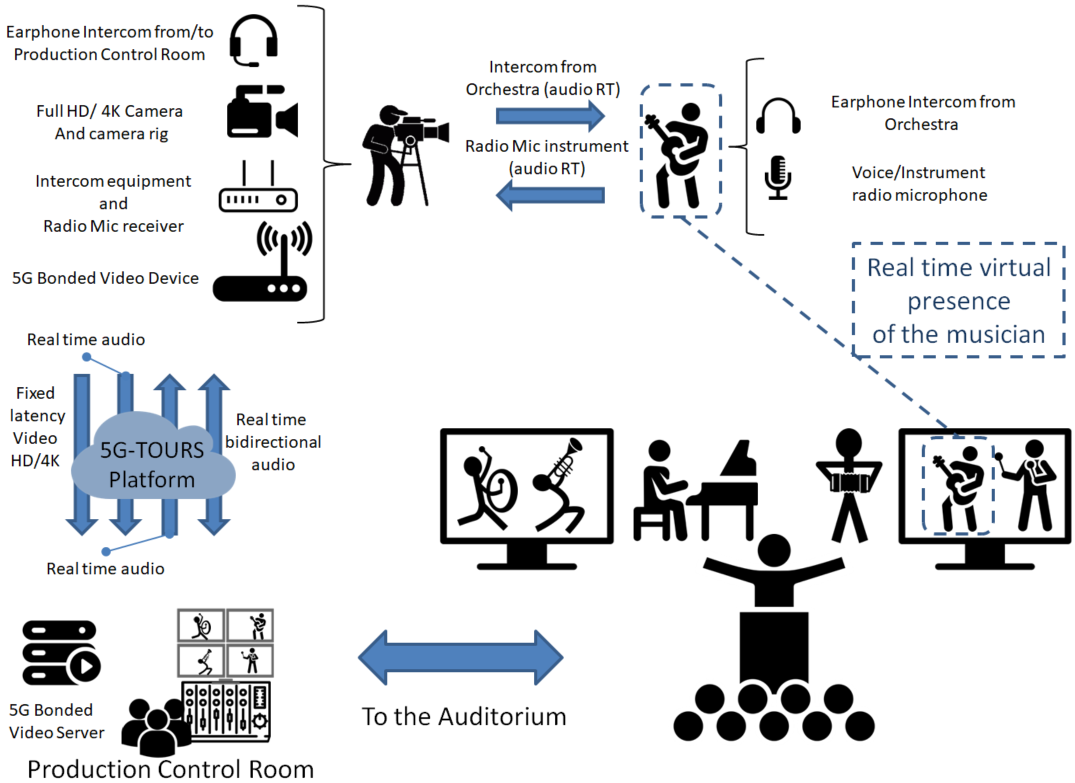

Figure 50 - Data Flow of remote TV production.

The Remote Musician:

- Radio microphone to transmit audio (music in case of musician) to the equipment of the cameraman this audio signal is strictly real time and high quality and one way from the player to the operator (Uplink). Single stereo channel;
- Intercom audio (IFB/return audio) real time communication: typically is the audio signal originated from the Production Control Room (Downlink);
- The "interphone" signal towards the musician is instead trickier. It could indicate a sync signal ("click"), certainly a signal to indicate the right moment of attack on the musician. It is not excluded that it may also convey other sound information. Also, at this stage this signal cannot pass through the LiveU backpack (5G bonding backpack device) and therefore be transmitted to the musician with a radio link that could be connected by a second radio microphone. No bidirectionality is expected.

The Cameraman:

The cameraman is equipped with:

- A full HD/ 4K professional camera (and camera rig): this is the source of the video to be transmitted to the Production Control Room;
- Intercom equipment: to manage the communication to / from the Production Control Room also for the actor/ speaker/ musician. The intercom signal is generally requested by the director to maintain a connection to the cameraman, in order to communicate camera events, movements or information. As best practice, it is strongly recommended to have a two-way intercom communication, even if the cameraman-to-director direction is supposed to be little used;
- Radio Mic receiver: receiver of radio microphone of the actor/ speaker/ musician;
- 5G bonded video device: 5G equipment able to connect and exchange data with the 5G cell.

Signals that are carried out by the 5G network are:

- Low Latency HEVC coded video Full HD/ 4K (audio current default is AAC 192 kbps total for both 2 audio channels/single stereo) from the 5G video transmission unit to the Control Room;

- Real time compressed Audio from the Control Room (orchestra) to the speaker/ musician for the synchronization;
- Real time AAC Audio from the speaker/ musician to the Control Room (orchestra) for the mixing management, embedded into the 4K video stream from the camera to the 5G video transmission device;
- Real time bi-directional audio (also in low quality) for the intercom between remote people (cameraman and musicians) and the Production Control Room.

The Production Control Room

The Production Control Room is equipped with:

- The bonded video HW & SW server to grant the data receiving / exchange from/ to remote operators, the number of cameramen will be from 1 to 4;
- The Production Control Room Intercom Management System;
- A/V Mixer and all equipment for the management (and recording) of different signals (also the distribution of A/V real time content to Auditorium's displays and speakers in case of the Itinerant Orchestra event).

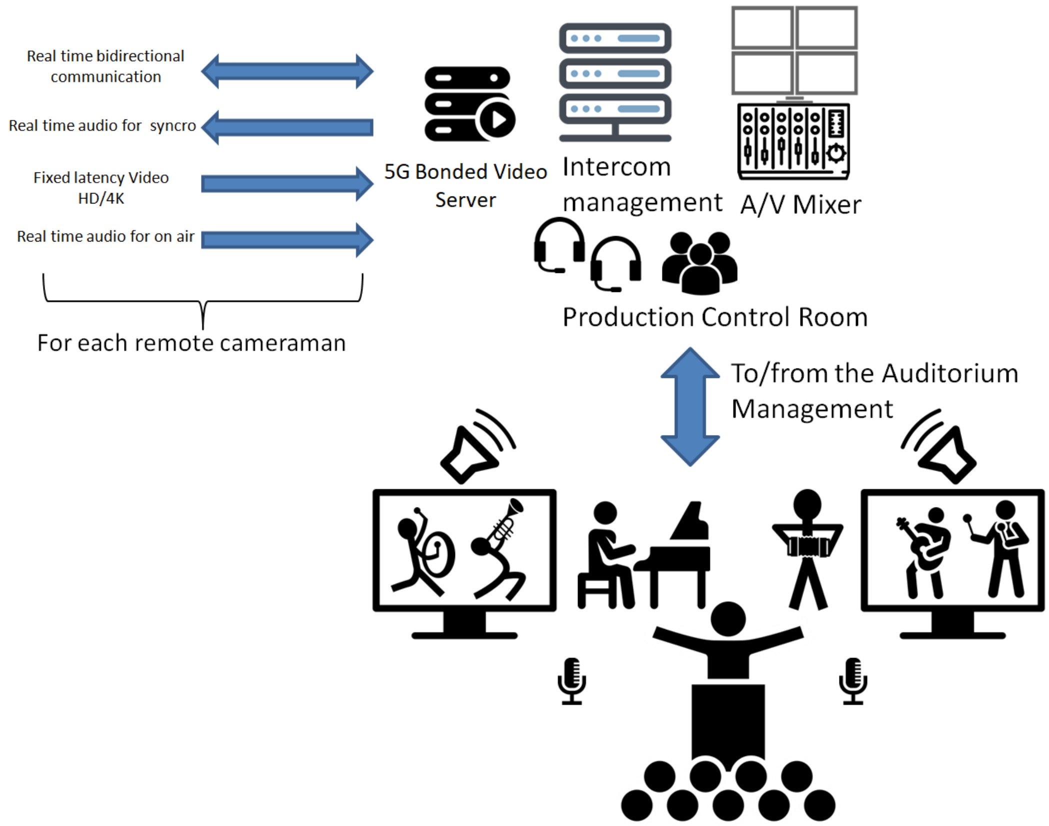

Figure 51 - The Production Control Room.

In the context of the Itinerant Orchestra implementation is to be underlined that, of course, low delays are needed in order to allow the musicians to play together while also getting timely synch cues from the conductor/orchestra, but even more important is that each remote site has to manage the same, fixed, delay.

Preliminary network deployment studies have been carried out by TIM and ERI-IT based on outdoor and indoor coverage of Palazzo Madama for UC5. RAI and LIVEU define the technical solution for the TV remote production use, in particular in Palazzo Madama and for the Itinerant Orchestra scenario.

In compliance with the network architecture a number of musician paths are defined, in particular:

Palazzo Madama OUTDOOR

Outdoor coverage with commercial 5G network (see Chapter 7 for details).

Palazzo Madama INDOOR

- Ground floor: Atrium and stairways, Staffarda Hall and Sala Acaia (left side towards Torre Elevator) and part of the Roman Tower.
- First floor: stairs and area in front of the hall of the Senate, Chamber of Madama Reale, Round Cabinet and Chamber of Guards.

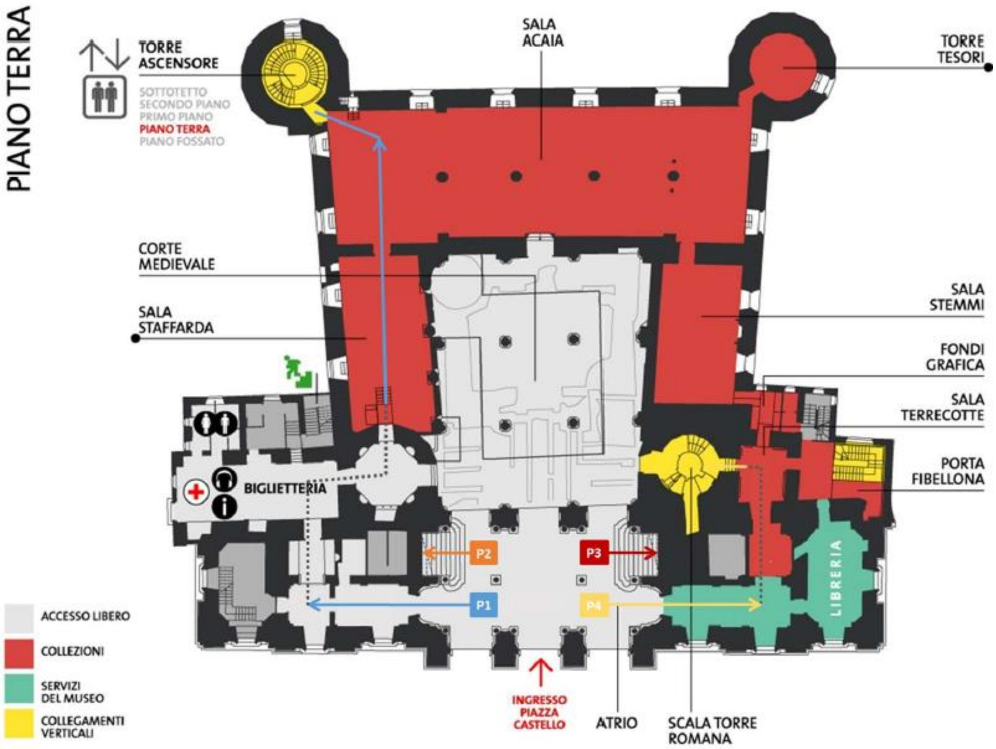

Figure 52 - Ground floor musician paths.

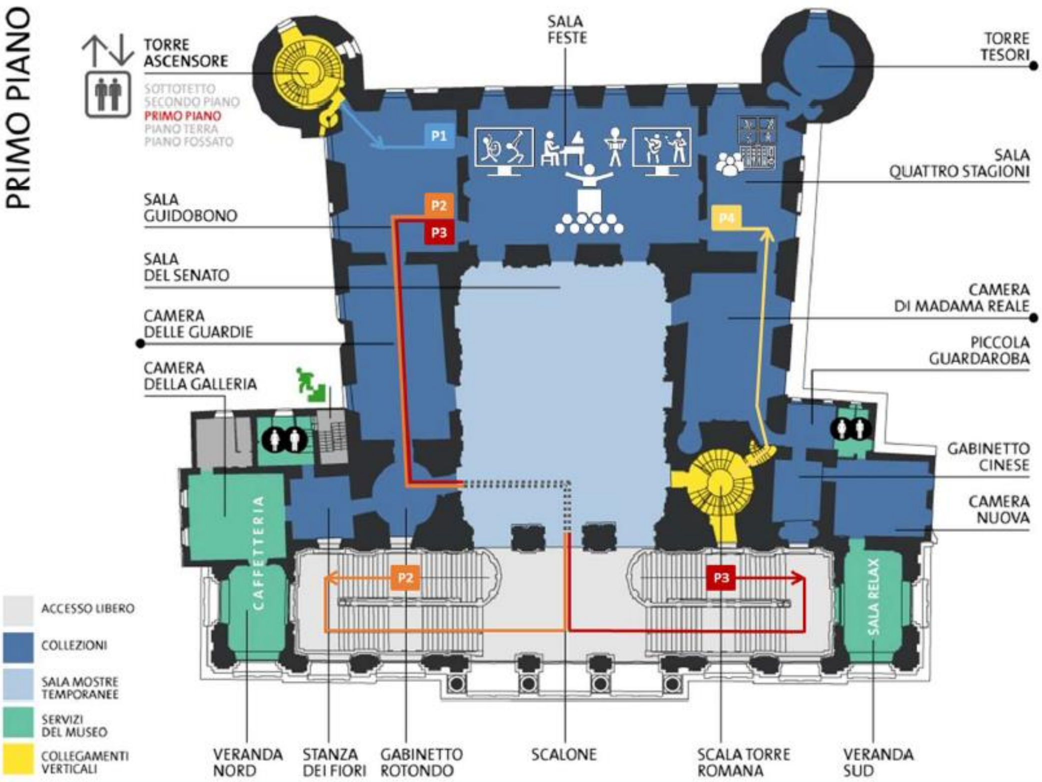

Figure 53 - First floor musician paths and concert location.

6.2.1 Application Components

Audio

Regarding the audio mixing part only 4 microphones for the orchestra are indicated but there can be more of course, depending on the requirements of the audio people. The main drawing remains substantially the same but the number of lines for the microphones increases as needed.

For the Itinerant Orchestra trial, due to practical reasons related to the number of musicians and cameramen and the requirements to have a complete synch between the audio and the camera feed, it is necessary to transmit the musician audio via the cameramen 5G LiveU bonding device rather than have the musicians use a separate LiveU device. In particular, in addition to the video signal generated by the camera used by the cameraman, there are other audio important signals.

The "main" audio signal is the one generated by the musician's instrument. It must be sent to the director with the highest possible quality and with the minimum possible latency. It was decided to use the LiveU backpack's audio channel, so it is necessary to transmit the signal from the musician to the cameraman via real-time short range radio link for the connected movements.

The main signal is generated by a microphone placed on the instrument according with the standard in live shows. The connection to the director must ensure a very high sound quality and a low latency.

To transmit this signal to the LiveU backpack a short range real time radio microphone is used in order not to limit the relative movements between musician and cameraman. This audio stream is fed into the camera as a standard mic, and the camera embeds it into its Audio/Video output (SDI) into the LiveU backpack. Thus the complete audio-video synch is also achieved.

Video operator intercom

The intercom that connects the director to the cameraman is a "classic" system. It is provided in the LiveU 5G bonding backpack device, from which it is extracted with a headset or earphones connected with wire. The LiveU solution also includes audio from the cameraman back to the production room as shown in Figure 54.

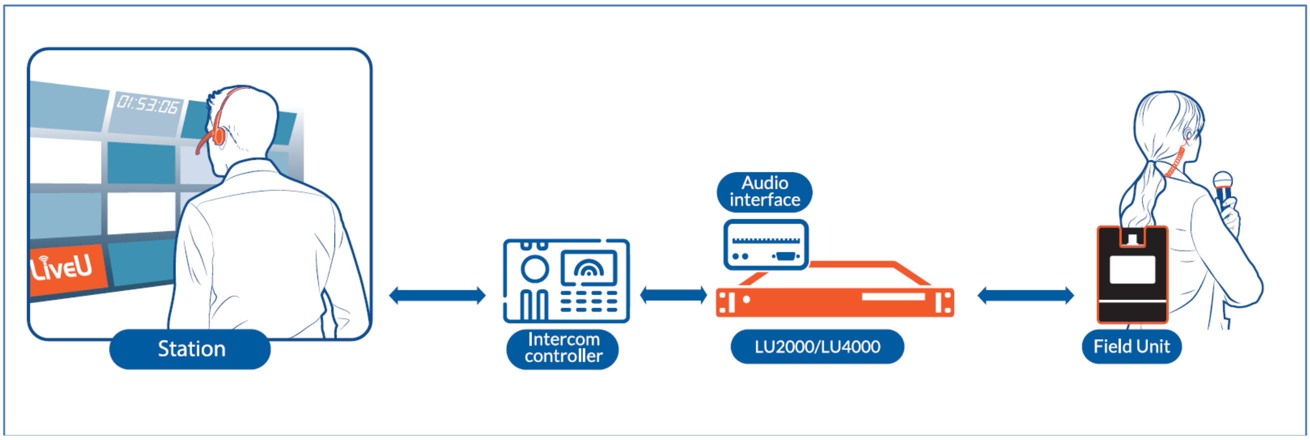

Figure 54 - Video operator intercom.

It is connected to a traditional intercom centrally located in the control room.

RAI:

- Intercom Scarlett 18i20
- Field headset, mic

LiveU:

- Intercom SW (supported devices: https://www.youtube.com/watch?v=vgntNUA8-Lk)

Musician Intercom:

The connection between director (music assistant) and musician is useful for:

- Indications of "cue": it is the hint that the musical consultant can appropriately indicate to the musician the exact instant to start. Keep in mind that the musician has no other information about the piece being played so the accuracy of the sound trigger becomes important. It is to be evaluated, but it is thought that the latency of the connection must be very low.

- Synchronism signal ("click"): there is no doubt that the professional musician knows how to adopt and maintain the right rhythm, but it seems appropriate that he can be guided on the current rhythm held by the orchestra, unless the piece is written in so as to minimize the importance of synchronism.
- Directions of "director": it is not considered that the direction is given directions "of direction", that is concerning the position of the musician, the speed of translation, or other information; but it is not to be excluded, above all if one intends to realize something different from the usual.

This connection does not require high bit rate capability but very low latency, some online-gaming intercom solutions such as Discord and Mumble has been investigated, further details in section 6.2.3.

6.2.2 Terminal Equipment components

LiveU provides the portable 5G bonding device that is used daily and globally to cover live news, sports and entertainment events. The device has an advanced HEVC H.265 real time encoder working in conjunction with the software that monitors the momentary performance of the connected links and decides what the video encoding configuration is and what packets are transmitted over which of the links at each point in time. There may be any combination of IP links connected, from a single connection (e.g. a single 5G modem) to 12 IP links combined of any 4G, 5G, Wi-Fi, SATCOM and LAN connections from any operator. The encoded video is transmitted to the IP address to which LiveU video server is connected which decodes them and outputs the video, while communicating with the field units. This capability is many times referred to as “bonding”.

In this test cycle the LiveU unit will be LU600 HEVC. It will be equipped with a 5G module if such are available in time. Due to delays in the whole supply chain of the modules, from the chip vendor through the module vendors, as of the date of this report there are still no USB 5G modules in the market. In case such a module will not be available at time for the cycle 1 tests we shall use the 5G smartphones provided by Samsung as external modems connected to the LU600. In this testing cycle the UC will use a single 5G modem and connection per unit, i.e. not use the bonding capability.

The LU600 has an SDI interface to get the embedded SD/HD/4K audio-video feed from the camera. It has its battery for about 4 hours of transmission. External DC power feed is also possible. The expected end-to-end latency is about 600 millisecond, including video capture, video encoding, transmission, reception, video decoding and video output.

Figure 55 - The LiveU LU600 device.

The LiveU server at the Palazio Madama production room is shown in Figure 56.

Figure 56 - The LiveU server at the production room.

6.2.3 Interfaces

In the following figure a preliminary schema about interfaces between solution modules for the content contribution is given. The schema shows basic data types exchanced in the context of the implementation of the Itinerant Orchestra between the onfield part (musician and cameraman) and the control room.

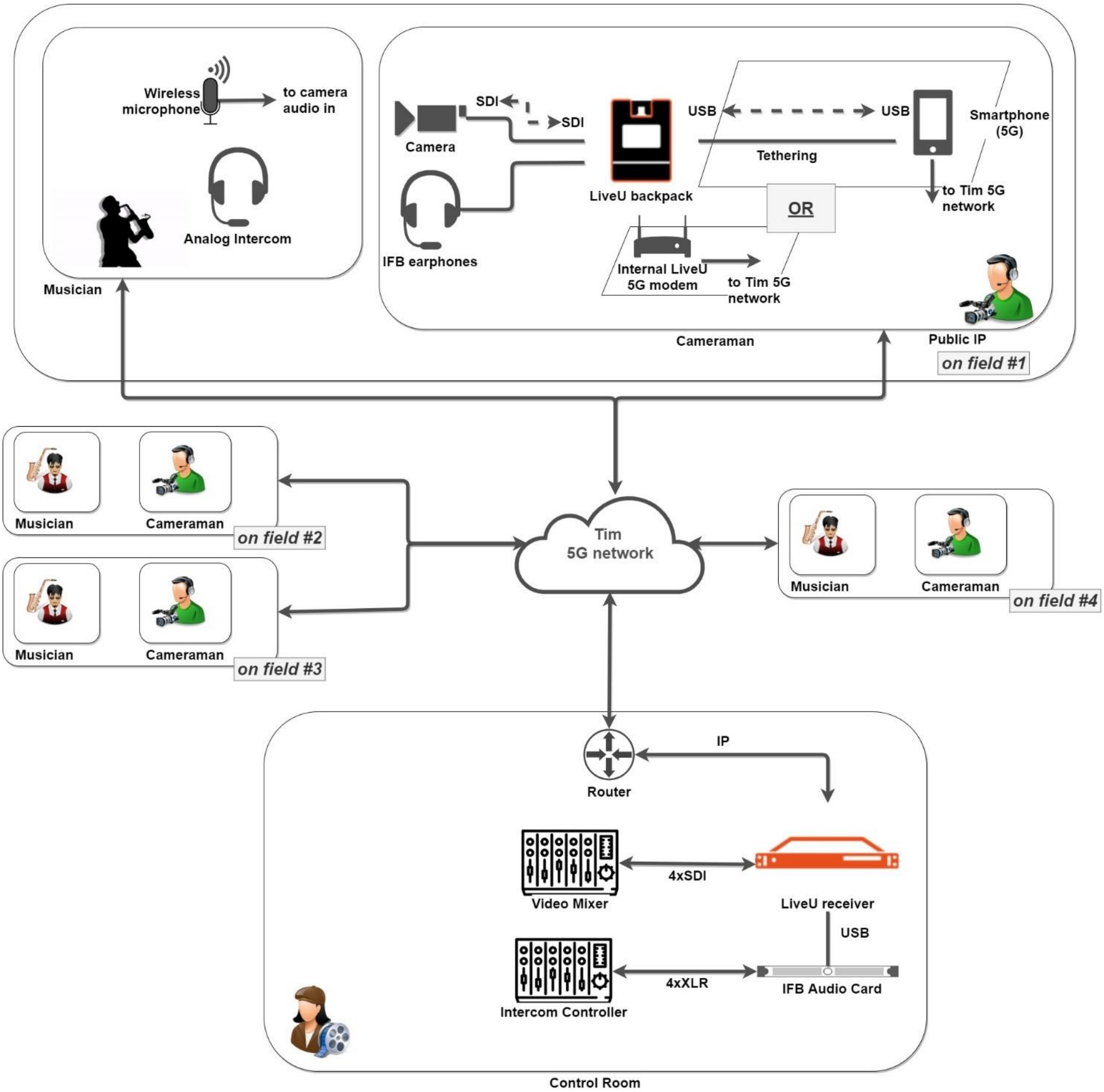

Figure 57 - Preliminary schema for content contribution

In this version of the system we updated the intercom channel between the Music Assistant in the MCR and the musician from a digital based to analog based. The main reason is to reduce the overall latency of the system.

The 5G modem related to the backpack unit is still under evaluation and test and we are still open to the possibility of work on 5G tethering, by using Samsung 5G phone.

6.3 Integration and test in labs

The UC comprises of complex multi-party multi-components architecture. Therefore, the integration is done in incremental steps.

The first step is the installation of the LiveU 5G bonding server (receiving the video from the street musicians) in the lab. The second step is testing, including the relevant IT network configuration, This is done by transmitting from Israel using the LiveU bonding device over standard 4G networks into that server in the RAI lab.

The next steps will include sending the bonding device (LU600) to RAI and performing local tests in the RAI lab, then move to the 5G TIM network.

Integration and preliminary verification in lab started in July 2020.

6.3.1 Server functional test

Because we were unable to perform tests in RAI premises over a VPN connection we moved the server at TimLab in July 2020. The setup is the following:

- Connection FTTH with 200Mbps, Hp Z6 with Ubuntu 16.04LTS and LiveU L2000 server installed. This test is important to see if the server can handle the streams properly in terms of CPU and RAM loads.
- All transmissions is done from LiveU lab to Italy TIM lab server, using LAN and/or WiFi (over LAN). The importance of this test is to assess the load of 4 simultaneous test stream on the server.
- First streaming test on the server is performed with a client LU600 using input: 1080i50, with 0.6 sec. of delay; the bitrate is 20Mbit/sec. Output in order to monitoring the stream on RTMP server 1080p, 6Mbit/sec. Time:13:40-14:00 IL. – 20 min. 2NIC used.

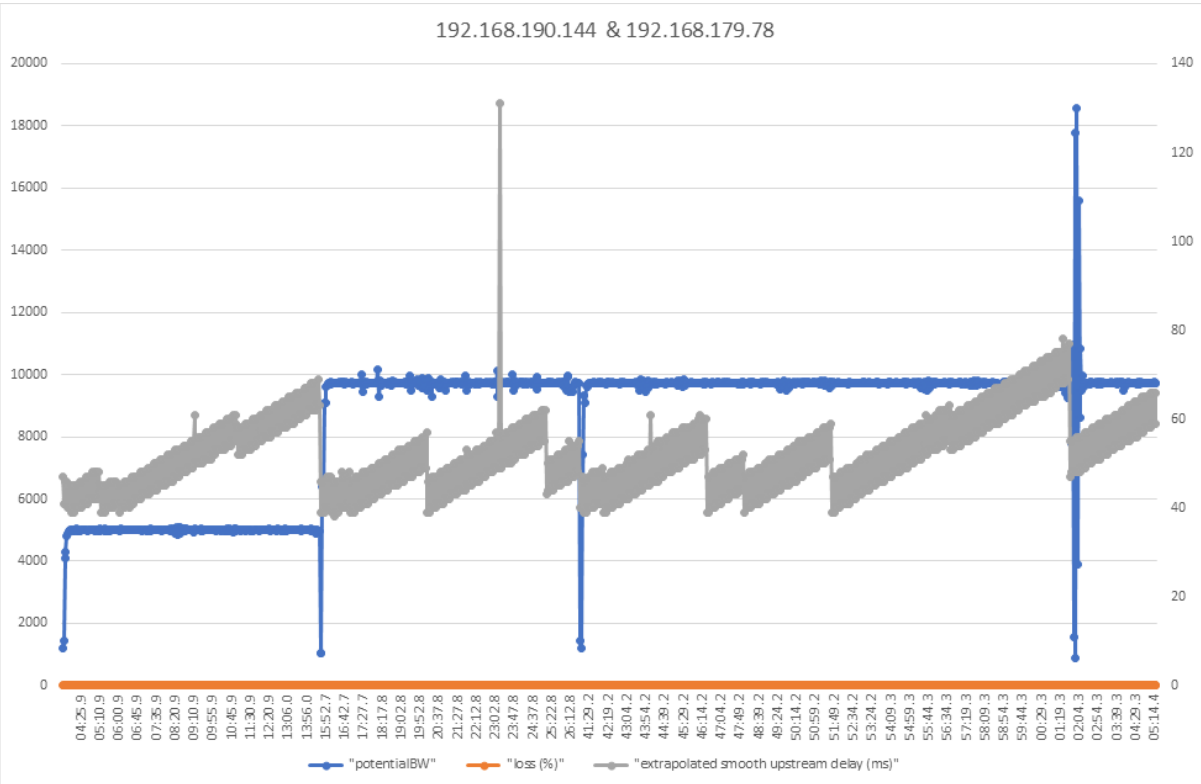

Figure 58 - Server functional test graph.

The plot on Figure 59 displays the bandwidth [kbps] on the left, primary Y axis. Latency [msec] and loss rate [%] use the right, secondary Y axis. Each point is 5 secs snapshots. In case the transmission used two interfaces, they are both on the same graph, not aggregated, one point adjacent to the other modem/end point (so the total BW at each point is the aggregation of both).

The “extrapolated latency” shown in the graph is part of the overall 600 msec latency. It represents what the LiveU application logs as a snapshot at 5 secs intervals, as to what it estimates/predicts/believes/anticipates the network latency is (for example also including any latency within the 3rd party cellular modem), after that "extrapolation" and other calculations, based on its own packets exchange between unit and server.

The second test is performed with 4 simultaneous inputs at 1080i50, 0.6 sec. of latency, 3 input at 20Mbit/s and 1 input at 12Mbit/s with a total of 72Mbit/sec. Again with 4 outputs in RTMP format 1080p, 4x6Mbit/sec Youtube, with a total amount 24Mbit/sec exact time of the test: 11:58-12:18 IL. The test time is about 20 minutes with a server load in average: ~30%.

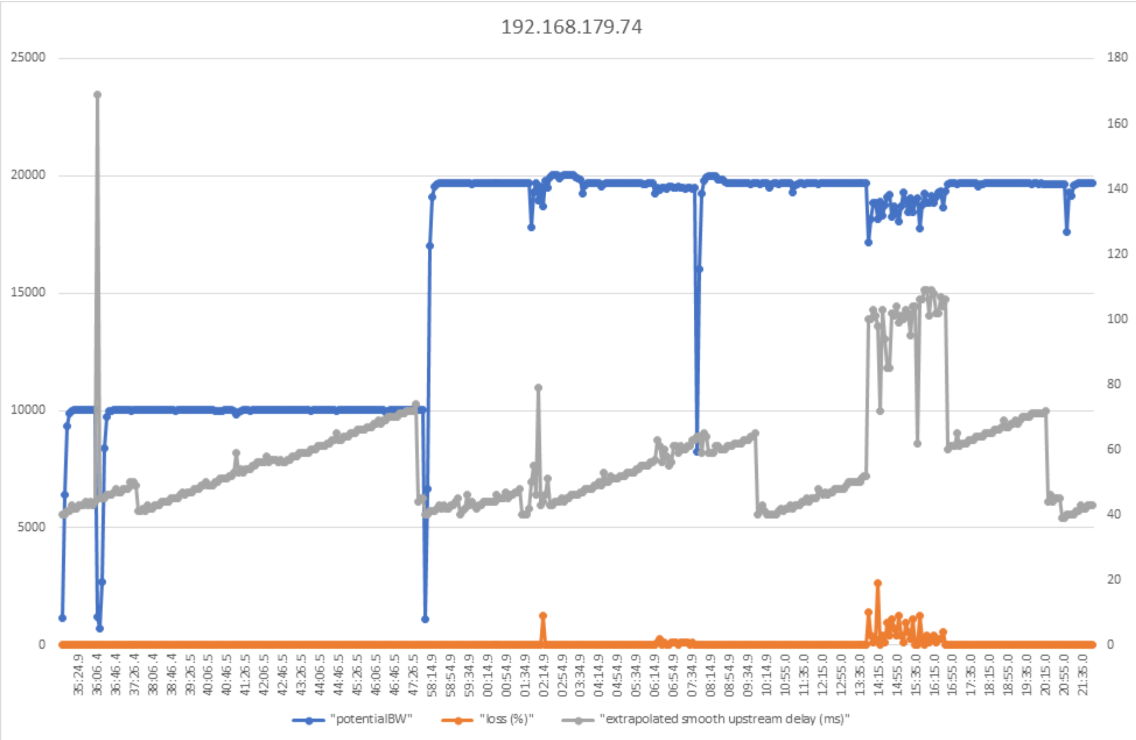

Figure 59 - First unit.

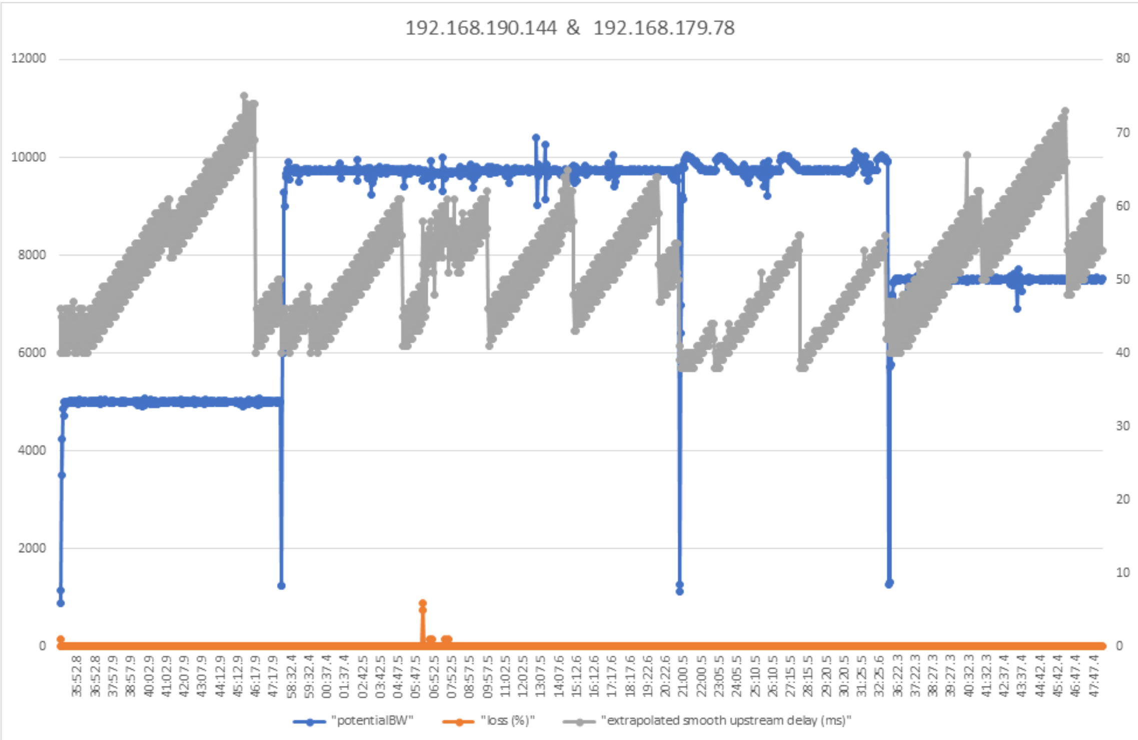

Figure 60 - Second unit.

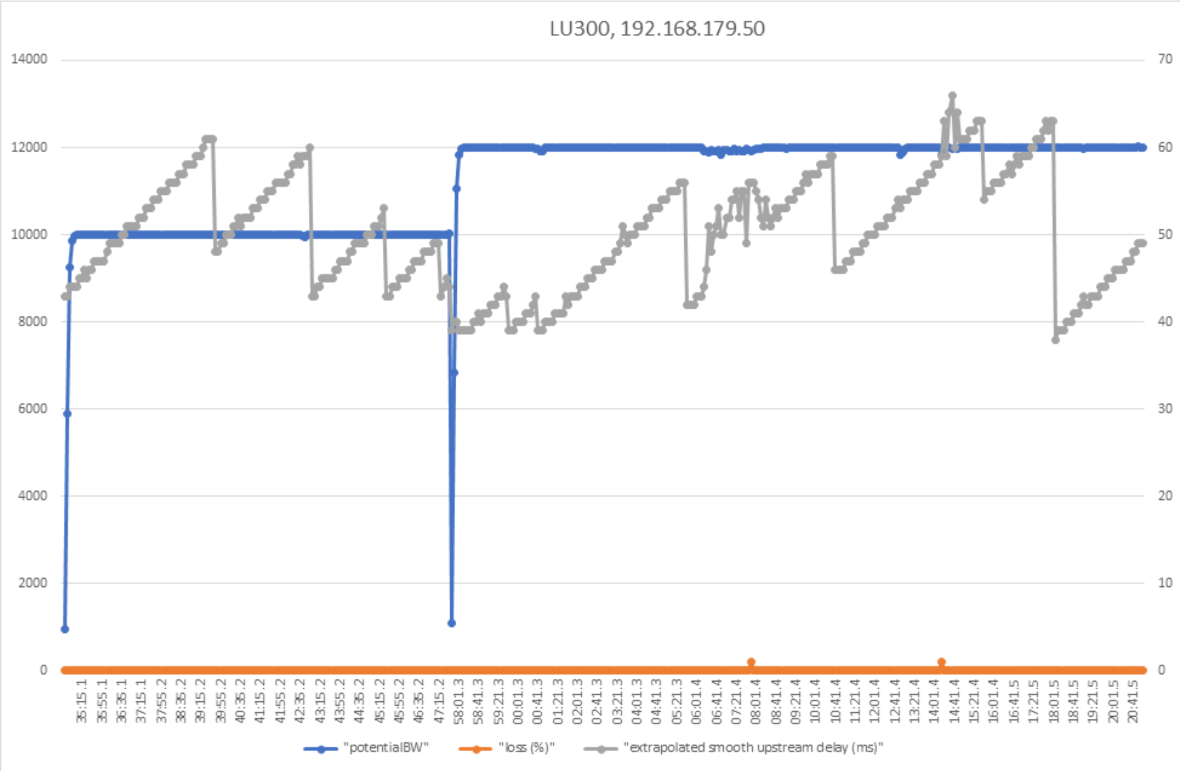

Figure 61 - Third unit.

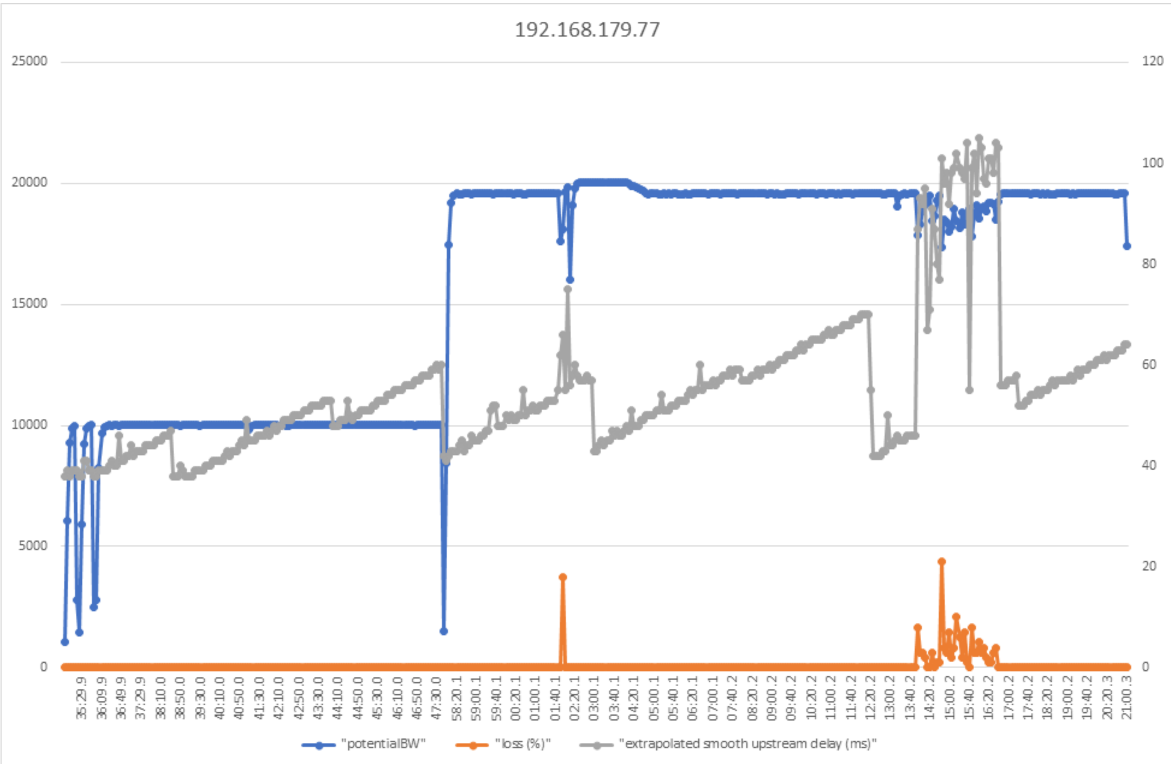

Figure 62 - Fourth unit.

In Figure 59, Figure 60, Figure 61 and Figure 62 bandwidth latency and loss rate of the four units on the server are plotted. The summarized test are also available on the LU central, the LiveU dashboard administration tool, in Figure 63.

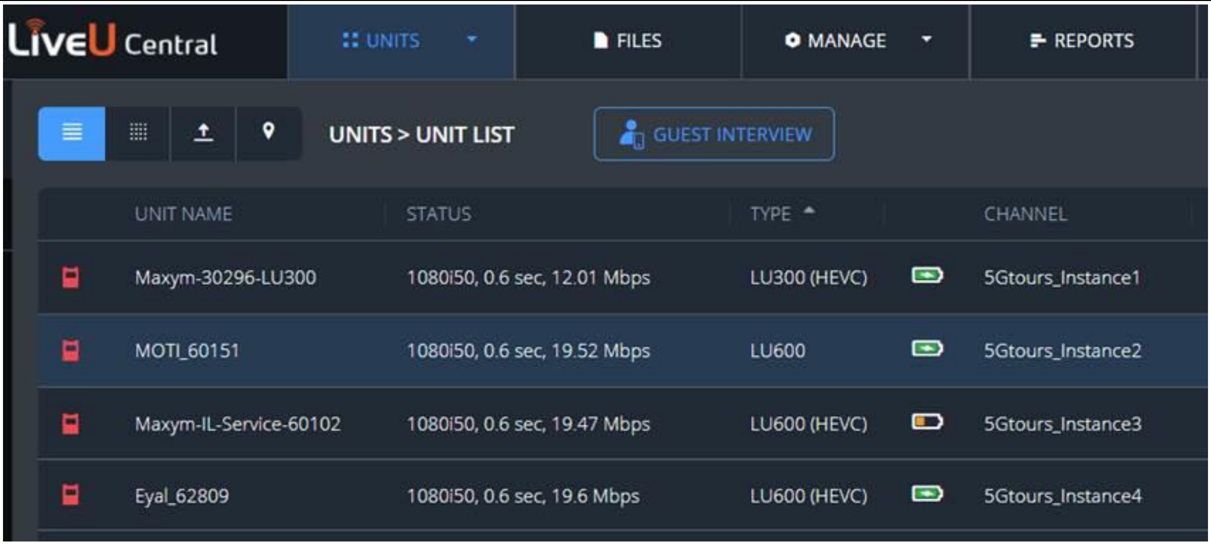

Figure 63 - LiveU central dashboard.

6.3.1 Backpack functional test

During the second test phase at TimLab we were be able to perform successfully a stream from TimLab with the LiveU LU600 backpack unit. During the test phase we tested a single stream coming from a LU600 backpack unit attached via tethering with a Samsung S10 smartphone on Tim 5G commercial network. During the test on site, we discovered some issued related to the authentication on the remote server, but at the time of writing it is not clear if the issues are related to the network filtering or something else. Further investigation is needed.

With LTE we had no issues with the connection and the streaming, but, when we switched on 5G the backpack was not be able to establish the connection with the lu-central.liveu.tv and hub1.liveu.tv/hub2.liveu.tv visible in Figure 64.

In this situation we were not be able to operate remotely on the backpack from lu-central.liveu.tv dashboard. In order to proceed with the test we turned on the Ethernet cable and the 5G connection, so the backpack was be able to authenticate with the server and start the stream on the Z6 machine (LiveU receiver) see Figure 64. Next we unplugged the eth1 connection from the backpack and the streaming switched to the 5G tethered smartphone see Figure 65.

To summarize, we used the eth1 connection just for the first phase of authentication with cloud server and managed to use the 5G network for the streaming, from LU600 to MMH server in Figure 66.

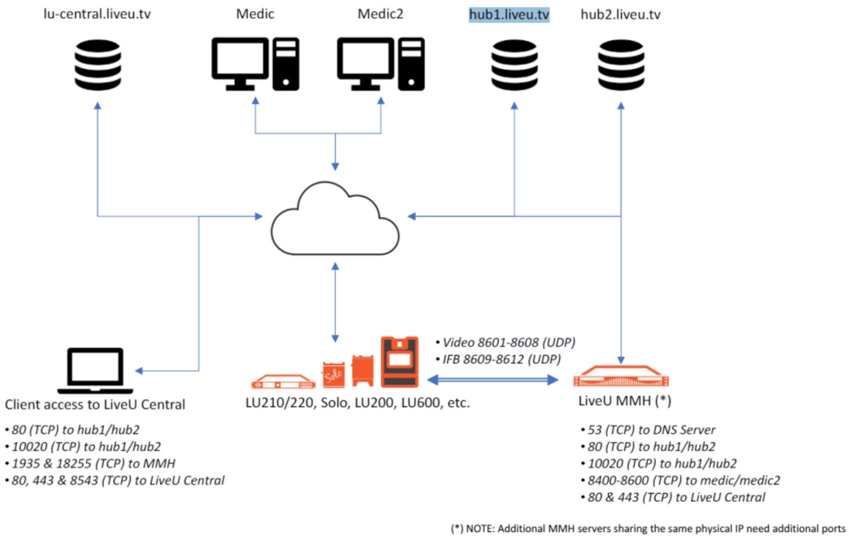

Figure 64 - LiveU network diagram.

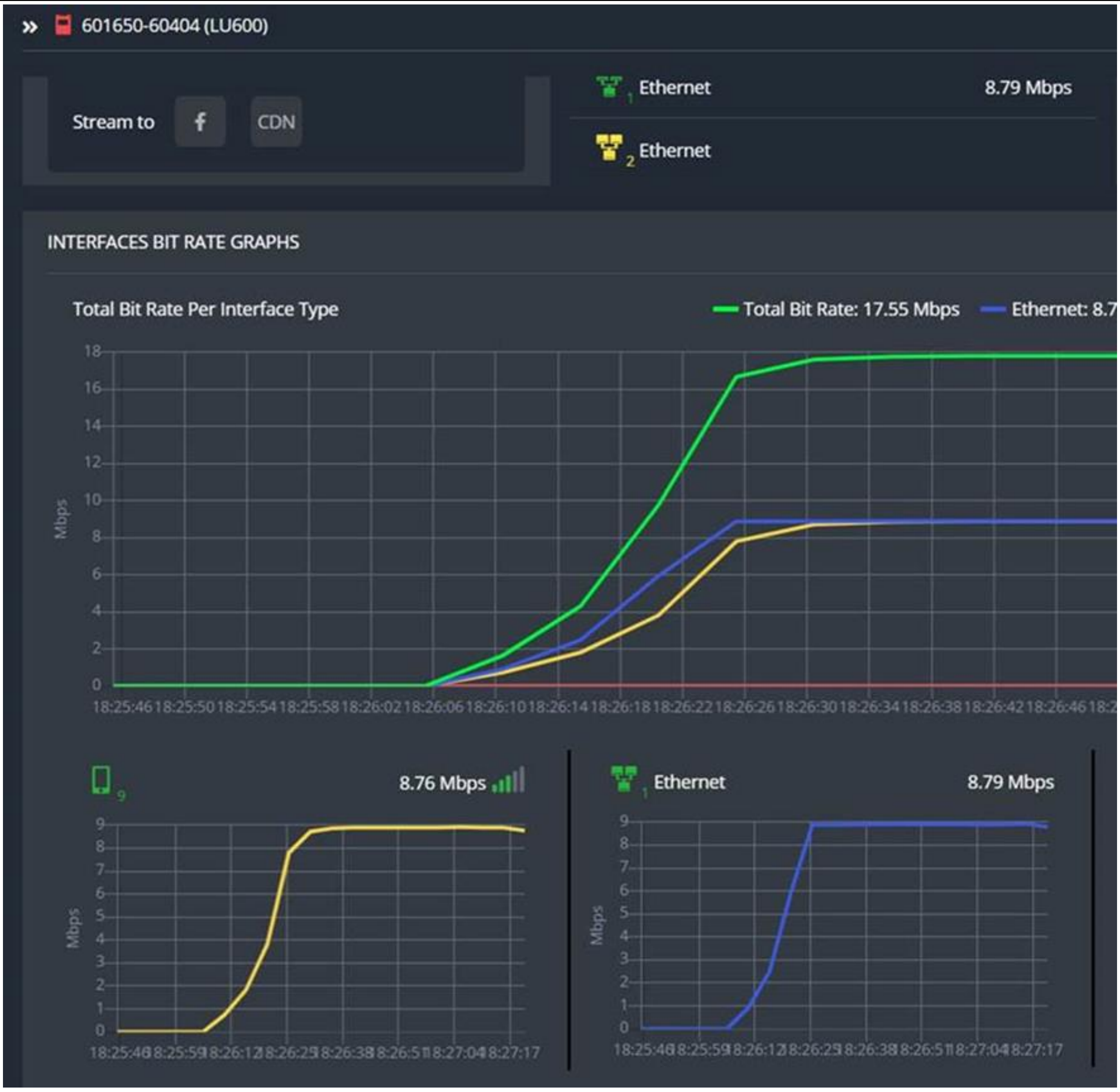

Figure 65 - Backpack data rate per interface.

Figure 66 - Backpack data rate 5G.

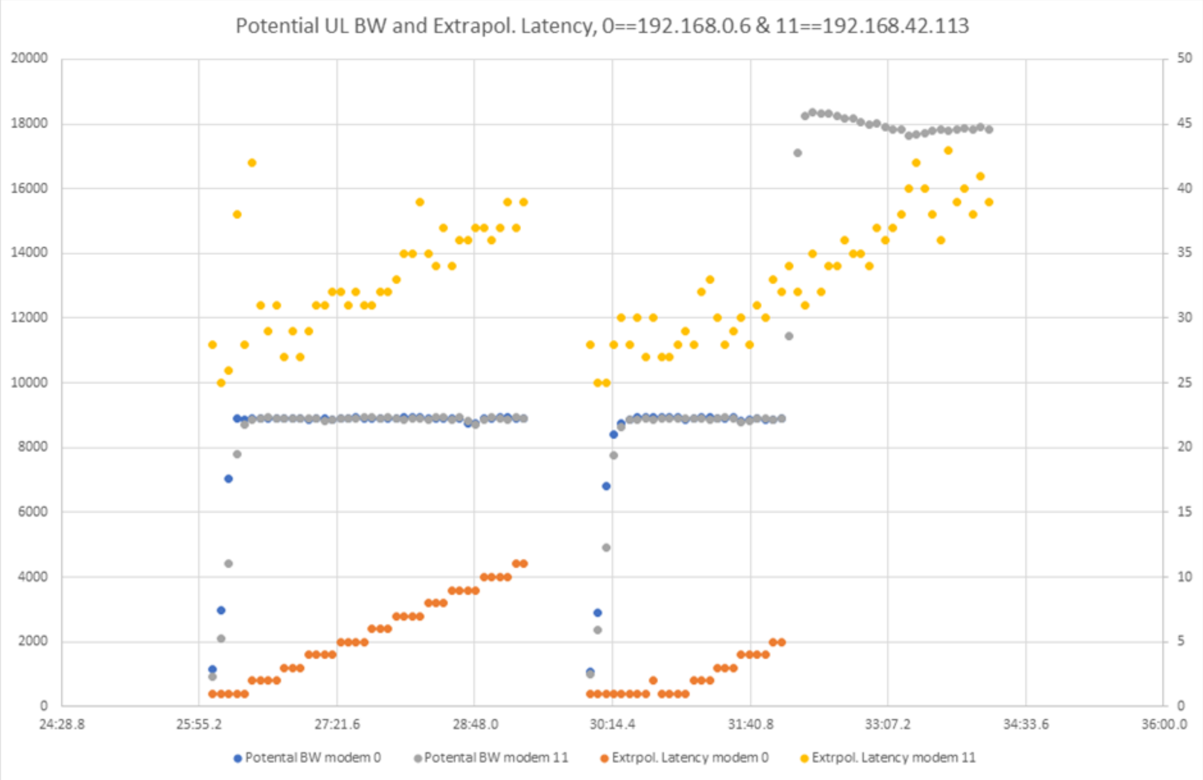

Figure 67 - Latency and bandwidth on 5G.

Figure 67 reports the bandwidth and the latency of 5G connection and Ethernet interface. Modem-0 refers to eth1 interface, and Modem-11 refers to the 5G interface. You can see the trend difference between modem 0 and modem 11 during the unplugging of interface modem 0, around 31:40.8.

The latency of 5G is slightly higher than Ethernet interface.

During the second round of test we performed a functional test during a real case transmission outside the Tim site. The cellular antenna is on top of the tower of TimLab (red arrow). Condition of weather was sunny.

During the path represented in Figure 69 we tested the stream over 450 meters of walking outside the TimLab, around the 5G antenna and following the TimLab's perimeter.

The stream was most of the time good, in some cases you can see a resolution drop due to the degradation path algorithm used by LiveU. The resolution drops down from 4K to HD and then to SD if the network cannot perform consistently. More tests will be performed to further investigate this point.

In chart presented in Figure 70 we can see the chart of bandwidth and latency during the walking, related to the video provided with this document. We can see some spikes on BW and latency recorded related probably to the SD resolution dropout. Also "loss rate" (which might be a real loss or a very high latency). In both chart we can see the same issue with some spikes on latency and drop of BW.

Figure 68 - SD drop compared with HD.

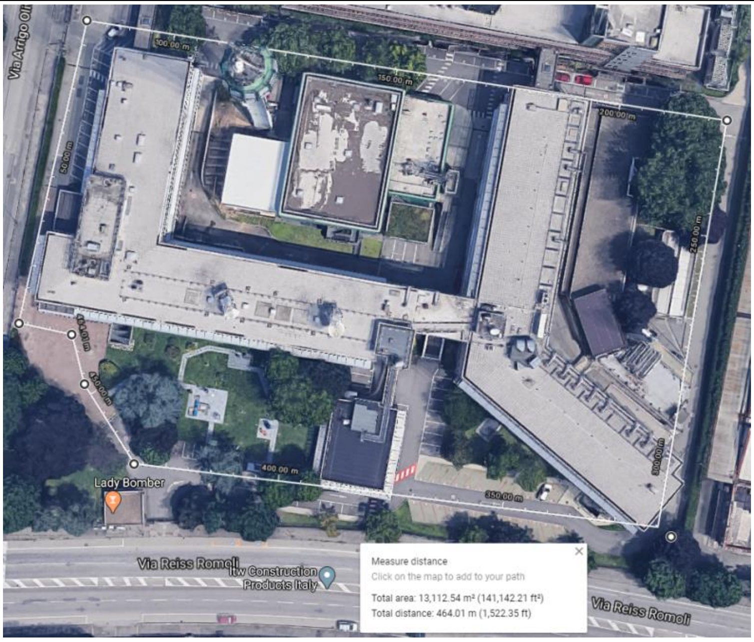

Figure 69 - Tim-lab site and path.

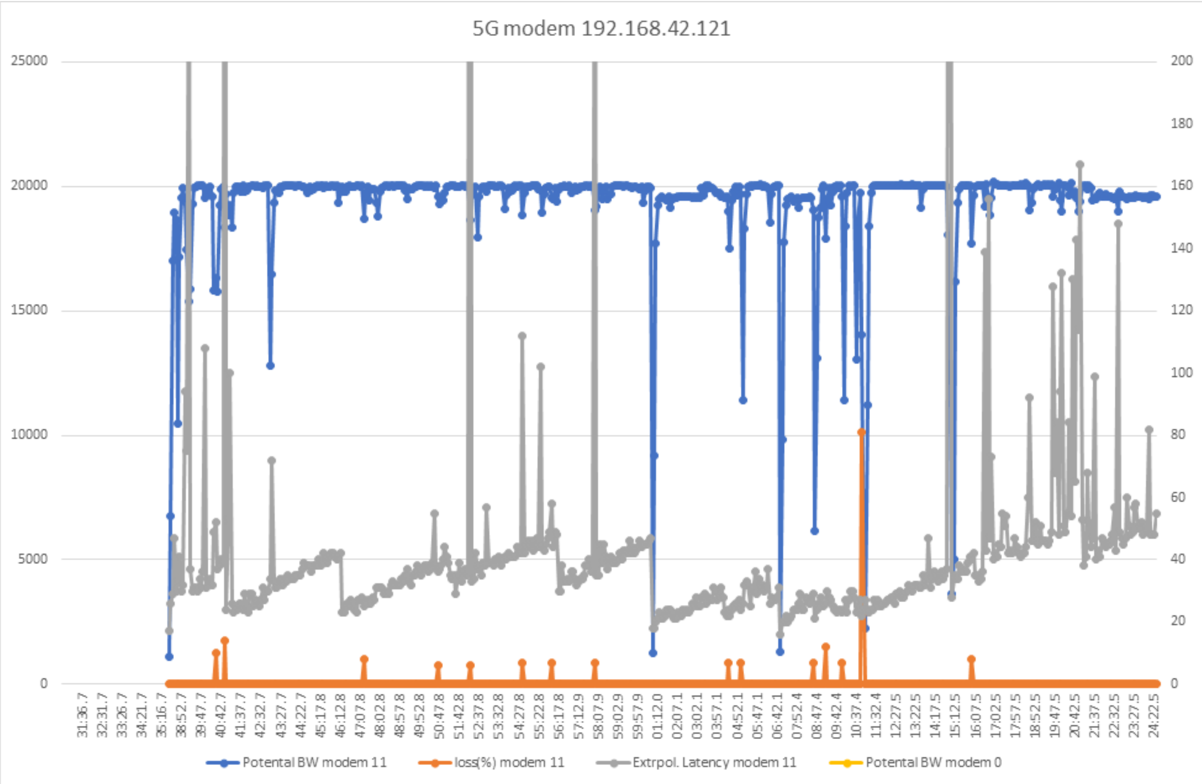

Figure 70 - outdoor test with backpack.

6.3.2 Overall system test

The system setup test was performed in October 2020 at TimLab with the 5G commercial network. During this test the complete MCR setup was installed at TimLab and the first measure on the delay was performed with outdoor cameras. The team involved during this test phases included technicians from RAI production center and the Music Director. During this test phase one of the most important assessment performed was the "check-list" provided by the music director in order to assess the performance of the network in term of overall latency. The requirements from music director point of view:

1. A configurable delay in each channel is needed in order to send the same signal to remote musicians but with different offset.

2. Intercom style communication: from the Control Room: need to send “3 2 1 go”, “lento”, “veloce” to a single musician or the whole remote band.
3. The dynamic: background noise is not a bad factor and can be used in the composition. It is important to be able to capture also delicate touch of musicians with our microphones.
4. Talking Sax: a third person will join the musician and start to engage a conversation with the sax player, we need to check if the radio microphones can capture also an external voice and what is its quality.
5. Delay: must remain stable and equal on each sax. The delay is measured in ms and it is equal to: Delay = T_{FB}(ms) - T_{GO}(ms) where T_{FB} is the signal delayed by the entire chain (remote musician signal - Figure 71) and T_{GO} is the reference signal coming directly from the audio mixer (“3 2 1 go” from the director, reference signal - Figure 71).
6. Sync test far (>10m): 2 sax “3 2 1 go” + click track start on go.
7. Sync test close(<3m): 2 sax “3 2 1 go” + click track start on go.
8. Sync test concert hall: with computed delay we can give the “3 2 1 go” to director with a given delay in order to have an overall sync situation.
9. Setup music test: musical techniques like legato and so on to be tested.

The most important point is the point 5, i.e., the measure delay. In order to measure the exact delay of feedback from the field, this is the difference between the “3 2 1 go” signal from MCR and the sound returned from the musician. In order to measure this delay and adjust each remote contribution properly we realized a measure delay system with the schema presented in Figure 71.

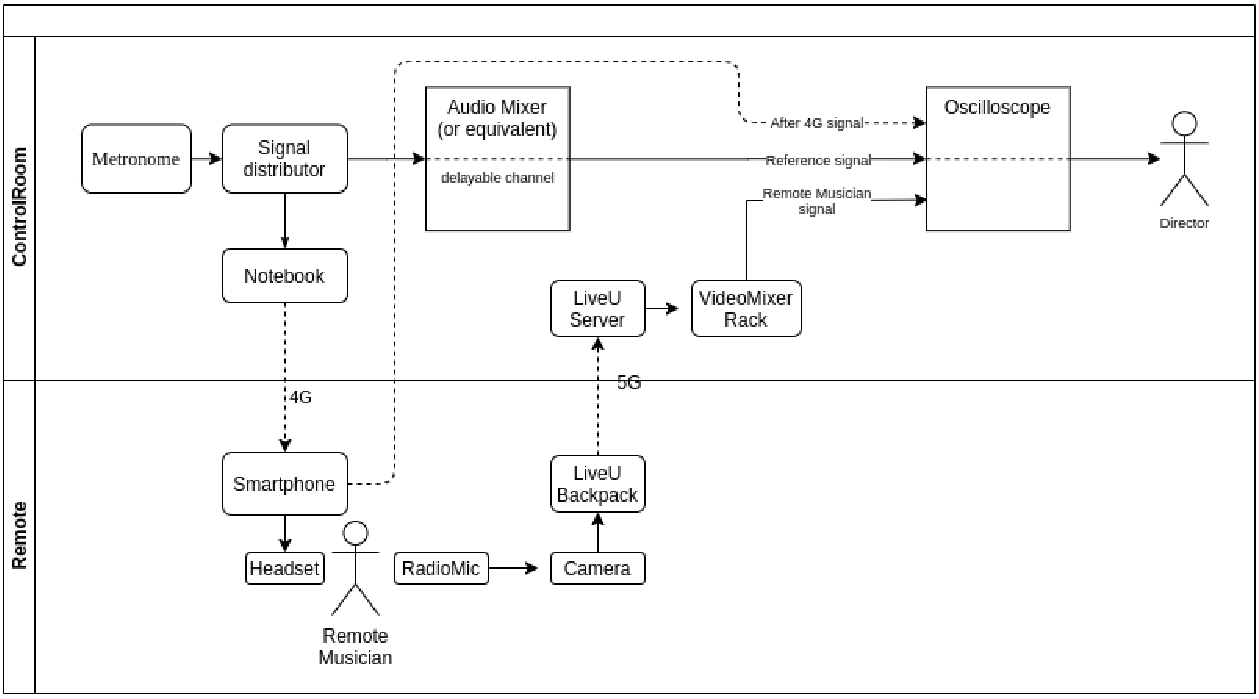

Figure 71 - Measure delay system.

With this type of system, we will be able to measure various delays introduced by each chain of signal. We can identify two main sources of delay:

1. Intercom from MCR to remote musician
2. Audio return from camera to the video mixer

The intercom delay from MCR to the remote musician (1) represents the delay from the channel of communication from Master Control Room to the musician (Table 2).

Table 2 - Intercom from MCR to remote musician.

Intercom	Average (ms)	Min (ms)	Max (ms)	Standard Deviation
Mumble	325	310	330	6.32
Discord	350	350	350	0
LiveU IFB	379	370	390	7

It is interesting to note the amount of delay introduced by this kind of technology. In order to reduce this contribution in the overall delay we are planning to adopt an analogic solution instead of a digital one to provide reference signal from MCR to remote musician.

The audio returned from the camera to the video mixer (2) is pretty constant and appears stable.

Table 3 - Audio return from camera to the video mixer.

Average (ms)	Min (ms)	Max (ms)	Standard Deviation
900	900	900	0

Please note that all the measures were performed with a 5G modem but running with 4G because we are still unable to use the commercial 5G network of TIM. Further work needs to be done and others test plans are planned in November 2020.

6.4 Test in the network

Integration and preliminary verification in the network, outdoor and indoor in Palazzo Madama, have been executed on the 14-15 December 2020. Some images are provided below.

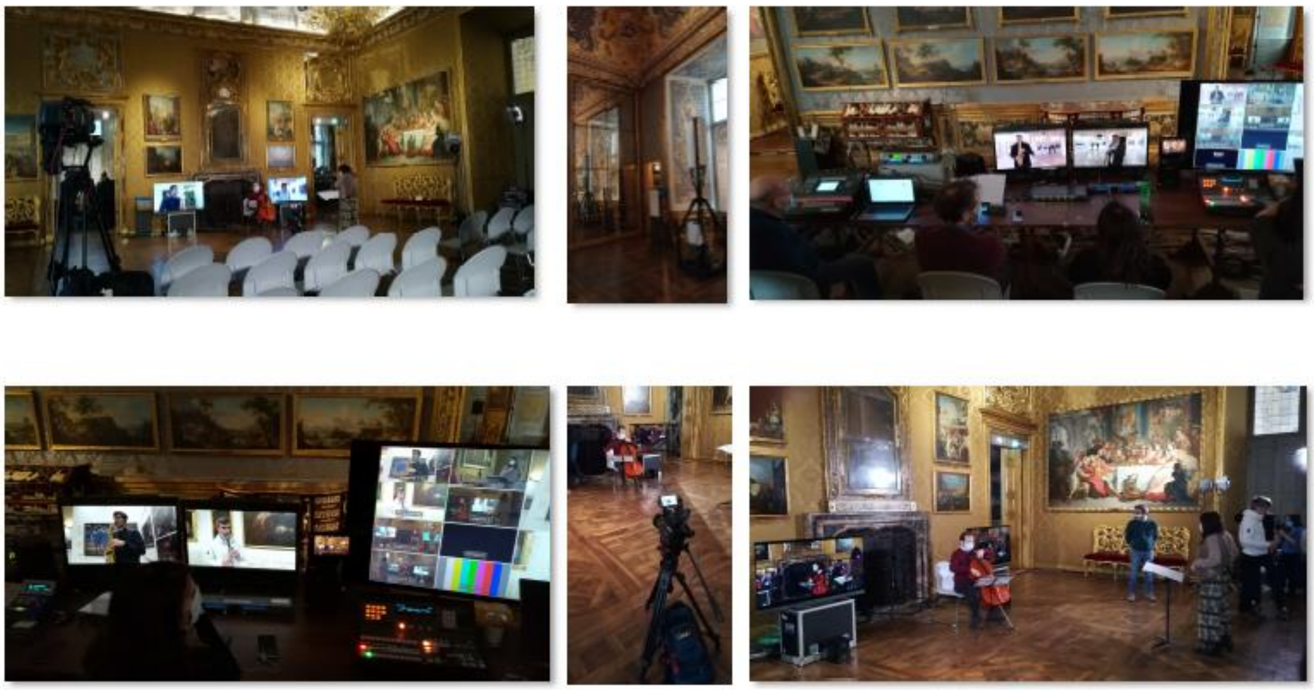

Figure 72 – Itinerant Orchestra Trial – 14-15th December 2020, Turin, Palazzo Madama.

7 5G-TOURS network implementation aspects for Turin site

This section covers the 5G-TOURS network implementation aspects for the Turin site according to the use cases description and implementation reported in D4.1 [1], D3.2 [5] and in this document. The network deployment described in this section is based on the requirements coming from UC1, UC2, UC3 and UC5 and will be exploited by such use cases; UC4 will rely on the different network deployments that has been described in section 5.1.1.

7.1 Network deployment

The general scheme on which the 5G-TOURS network deployment will be based, consists in the provisioning of a network composed by the combination of (i) commercial deployments based on infrastructure owned by TIM and provided by ERI-IT, and (ii) pre-commercial facilities deployed to test Rel-16/17 equipment and 5G-TOURS innovative functionalities (see section 0), relying mostly on indoor environments. In addition to that, one important aspect that has to be taken into account is the integration with the 5G-EVE infrastructure and platform in terms of areas to be covered, deployment requirements, timeline and deployment roadmap, as well as the functionalities that will be needed for the underlying network equipment. From this perspective, also the nodes that 5G-TOURS will deploy for its specific use cases (mainly radio nodes providing indoor coverage) will need to be contextualized as complementary components of the 5G-EVE infrastructure to take advantage of the functionalities that the 5G-EVE platform will provide as well as for the innovations studied in 5G-TOURS.

The network deployment process that leads to a network that is up and running on field consists of several activities that have to be performed. The main activities are hereafter described:

- **Use cases requirements**: this activity consists in collecting all the requirements coming from the use cases that will be implemented in order to dimension the network accordingly (in terms of coverages and performances); one of the key point of this activity is then to consider the most stringent among received requirements to design a network that can support all the use cases, providing at the same time an optimized solution in terms of number of radio equipment to be installed, their connections to the appropriate baseband units, etc. as part of the network design activity;
- **Network design**: once all the requirements and relevant information are collected, it is possible to start with the network design activity in which coverage and position of the radio equipment are evaluated by means of simulation based on the maps of the areas and the building plans. In a second stage, this activity requires also to perform measurements on field to verify and properly review the results provided by the simulation; indeed, factors such as attenuations due to walls and other physical barriers, interference issues with other signals operating in the same or adjacent bands, etc. need to be verified in the concerned locations where the coverage have to be deployed since these are usually not fully covered by the simulation assumptions and propagation models. In addition to that, the site inspection will also permit to check all the installation and cabling aspects that will involve additional constraints to the network deployment;
- **Verification and validation**: the hardware that will be installed in the network need to be verified and validated by the mobile network operator; indeed, it is important to have the guarantee that such equipment (and the related functionalities) will respect the operator's internal requirements as well as are fully compliant with the equipment that are already installed in the network;
- **Authorization process**: once the network design has been completed, in order to proceed with the physical installation of the equipment, an authorization process with the concerned private parties (e.g. the entities that manage the museum) as well as the local authorities (e.g., Municipality and the agencies for the environmental protection) is required. The main aspects that will be evaluated on the basis of the network design are essentially the environmental impacts that the installation of the equipment might have; if from one side it is fundamental that the electromagnetic emissions will respect the limits imposed by the regulatory body, on the other side the visual impacts of the equipment's are also considered in order to preserve that architectural and decorative aspects of the city and its buildings. Usually the authorization is provided for a certain period of time that depends on the network type (e.g. experimentation, commercial deployment, etc.).
- **Network equipment installation**: finally, after all the requested authorizations have been granted, it is possible to start with the physical installation of the equipment. The time requested by this activity is quite variable and depends on multiple factors. It has anyway to be highlighted that once the installation

has been completed, a subsequent measurements campaign is requested to verify the compliance with the network design. In addition to that, once the network is in operation, a constant monitoring of the electromagnetic emission is also requested and should be reported to the authorities in order to demonstrate that the limits are respected.

7.1.1 Implementation requirements

Based on the network deployment process described above, at the time of writing this document, all the use cases requirements have been collected so that the network design activity is starting. The use cases requirements can be summarized as follow:

- **5G coverage requirements**: according to D4.1 [1] the use cases will be implemented at Palazzo Madama (UC1.a, UC2.a/c, UC3 and UC5) and GAM (UC1.b, UC2.b and UC3) museums. More in detail, for Palazzo Madama it will be required a mixed outdoor / indoor coverage essentially to support the UC5 of the Itinerant Orchestra while the other use cases will be implemented only inside the museum as for the use cases at the GAM. The outdoor coverage will rely on the commercial network, while for the indoor one there are two different deployment approaches that will be reflected in the phases described in section 0. The equipment that will be used to provide both coverages (i.e., antennas, radio units - RU - and baseband units - BBU) are described in section 7.2. The frequency that will be used is the TIM licensed portion of band in the 3.7 GHz band (i.e., 80 MHz from 3720 MHz to 3800 MHz).
- **5G service requirements**: as reported before, the network design will be based on the most stringent requirements coming from the different use cases. Such requirements are the downlink bitrate, the uplink bitrate and the latency and have been defined as described hereafter:
    - DL bitrate: 800 Mbps (per cell) - maximum requested bitrate derived from UC1 where multiple users, e.g. 15 to 30 devices, will download multimedia contents of considerable dimension such as 3D scans of artefacts;
    - UL bitrate: 80 Mbps (per cell) - this value derives from UC5 in which 4 concurrent high-quality audio-video streams will be transmitted in uplink (one stream corresponds to one itinerant musician / cameraman with a bit rate of 20 Mbps);
    - E2E latency: < 10 ms - this is the latency requested by UC3 to pilot the R1 robot to have an almost delay-less interaction between the commands and the corresponding robot movements.
- **Broadband connection requirements**: the networks infrastructure will require the support of a broadband wired connection over optical fibre to the museums. In both cases, the optical fibres will be used to provide the connection between the equipment that will be installed in the museum for the indoor coverage and the appropriate baseband units; the number of optical fibres will depend on the network solution that will be adopted. An additional optical fibre will be requested to provide a fast Internet connection for specific servers that will be necessary to install on site for some use cases.
- **Planning and operational requirements**: an important aspect that has to be taken into account during the design phase of the network is related to the network planning, which consists of determining the coverage provided by the different cells. An optimal network planning will guarantee a good service provision in terms of connection stability and performances. In case of a mixed outdoor / indoor coverage such as the one that will be deployed at Palazzo Madama, the network planning plays a fundamental role to determine the boundaries of the respective cells to properly manage the mutual interference that may occurs between the two coverage types. This aspect becomes even more relevant in case the two coverage refers to two different networks (e.g., CN to which these cells are connected); concerning the Turin site, such problematic will be more significant in the phase 2 of the network deployment (see section 0). Besides the planning aspects, the operational functionalities (i.e., network radio features) are another important factor that contributes to the network radio performances. Handover support as well as DL (or UL) carrier aggregation (or dual connectivity) are just a couple of examples of such functionalities; the first will guarantee the service continuity when the device will pass from one cell to another (i.e. from the outdoor to the indoor coverage), while the second will improve the throughput by aggregating different carriers of the same or different technologies such as LTE and NR (as in the case of 5G NSA - Non-Standalone - network architecture).

7.1.2 Implementation phases

According to the requirements that have been defined (see previous section), the large number of rooms that will be covered at Palazzo Madama and GAM, the time plan of the different use case, and, last but not least, the need for integration with the 5G-EVE infrastructure (at the moment still under deployment), it is clear that it would not be possible to deploy a network that would meet all these aspects already at its first implementation. Therefore, it has been decided to follow a two phases implementation approach; it has to be highlighted that this approach is still fully compliant to the scope of addressing the two main objectives of 5G-TOURS that are to validate the need of 5G (**OBJ1**) and to demonstrate the benefits of the 5G-TOURS innovations (**OBJ2**). The main aspects of the two implementation phases are summarized hereafter:

Phase 1

The phase 1 of the network implementation foresees that the 5G indoor coverage of Palazzo Madama and GAM will be connected to the TIM commercial network whose CN node is located in Milan (i.e., Field Core TIM). From this perspective, the indoor coverage will be a full-fledged extension of the outdoor coverage for such use cases that will require both of them (at the moment the UC5). Since the implementation of phase 1 will exclusively rely on the commercial network, in order to avoid impacts on the commercial services and its customers, it will not be possible to experiment any functionality that is not part of the deployed release. Therefore, the network implementation of the phase 1 will address only **OBJ1**. From the 5G-EVE infrastructure / platform integration point of view, the possibility to include the 5G-TOURS coverage infrastructure in the 5G-EVE ecosystem will be anyway evaluated; in addition, even if the use of the 5G-EVE platform (i.e., portal) will not be required for this phase, at the same time, it will not be precluded (depending on the previous point). For the phase 1, the current roadmap is to have a running network by the end of 2020 / beginning of 2021 so that the first UC's trials can take place according to the respective time plans; for UC5 a trial has been performed in December 2020, therefore the network deployment will be prioritized in the interested areas.

Phase 2

The phase 2 of the network implementation foresees that the 5G indoor coverage of Palazzo Madama and GAM will be connected to the TIM laboratory network that will be provided by the 5G-EVE infrastructure (i.e., 5G-EVE lab CN). In this case, the outdoor and the indoor coverage will practically be two independent networks coexisting in the same area and operating on the same frequency range; preventing/managing mutual interference between the two networks will become a critical factor to be taken into consideration. The network implementation of phase 2 will address both **OBJ1** and **OBJ2**, taking advantage of the 5G-EVE laboratory network functionalities that will be made available to 5G-TOURS. From this perspective, the demonstration of 5G-TOURS innovations will focus on a sub-set of the UCs that will be eventually revisited for this specific scope. The phase 2 will therefore provide an almost full integration with the 5G-EVE infrastructure (i.e., laboratory network); therefore, some UCs could be considered also to take place in 5G-EVE locations (e.g. 5G-EVE mile of technology) and, at the same time, 5G-EVE platform (i.e., portal) could be used depending on the needs. The phase 2 roadmap will strictly depend on the status of the 5G-EVE infrastructure deployment, and its feasibility needs to be carefully investigated in all the concerned aspects.

7.1.3 Coverages at Palazzo Madama and GAM

This section reports the coverage areas at Palazzo Madama (Figure 73, Figure 74, Figure 75, Figure 76, Figure 77) and GAM (Figure 78). The indoor coverage of the two museums will be prioritized for the rooms highlighted in green, while the room highlighted in yellow will be deployed in a second stage according to the effective UCs evolution and the application contents availability.

Figure 73 - Outdoor coverage at Palazzo Madama (UC5).

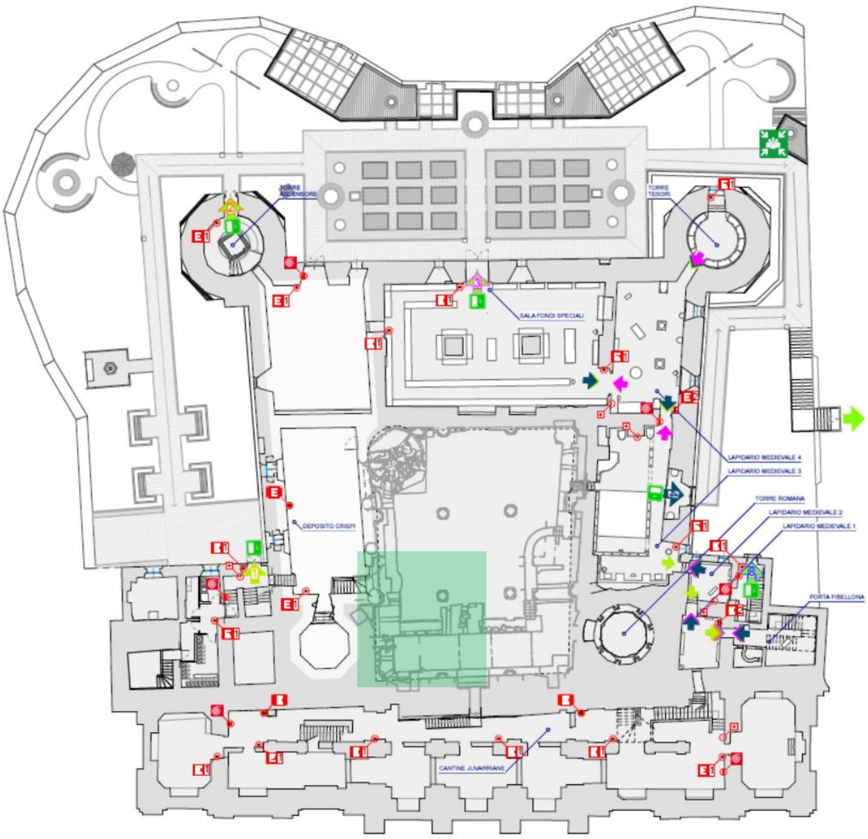

Figure 74 - Indoor coverage at the basement level at Palazzo Madama (UC2.a).

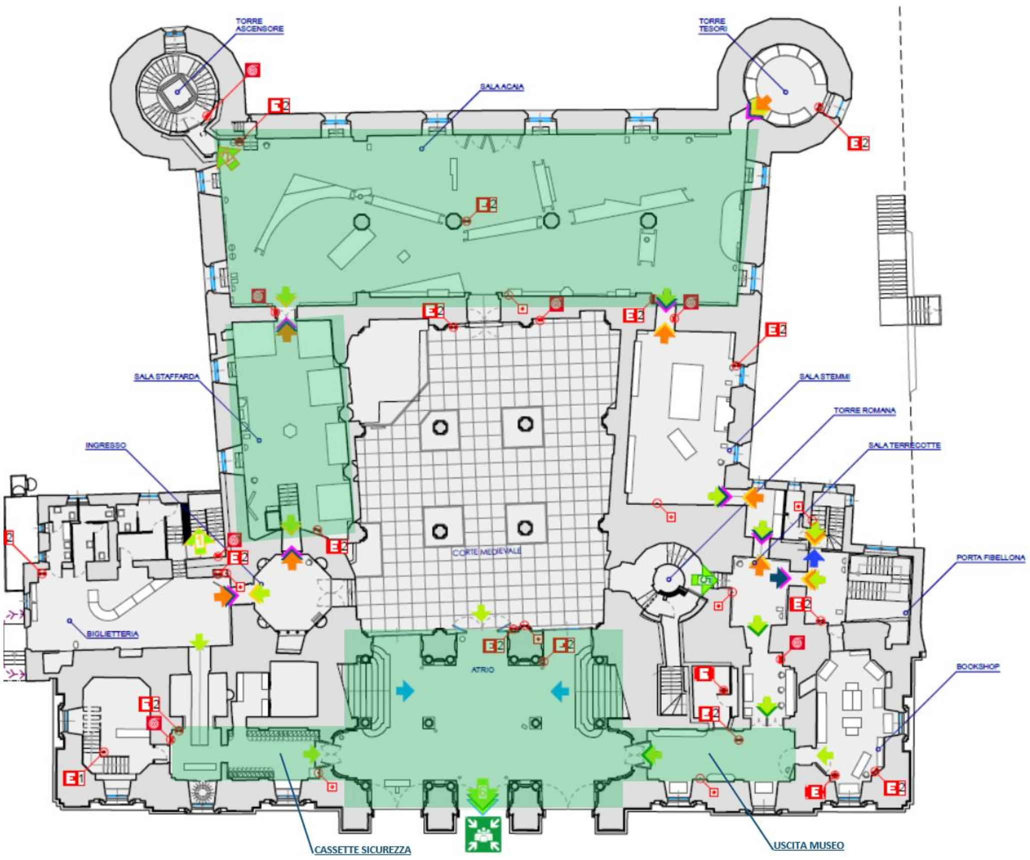

Figure 75 - Indoor coverage at the ground floor at Palazzo Madama (UC1.a, UC3 and UC5).

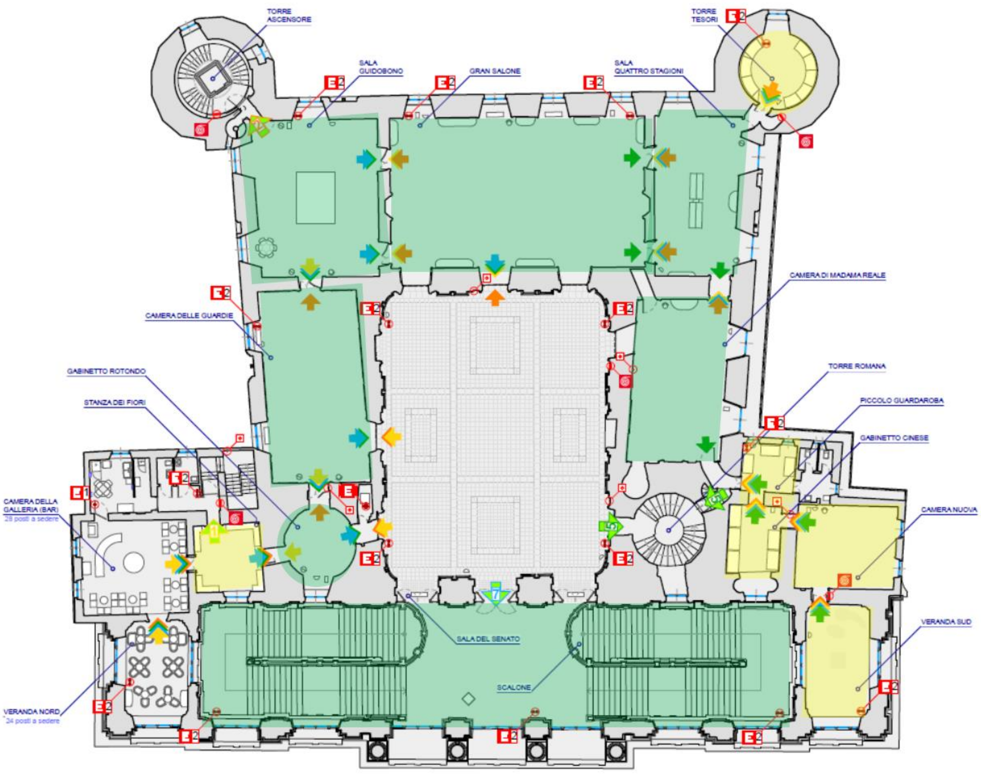

Figure 76 - Indoor coverage at the first floor at Palazzo Madama (UC1.a, UC2.a/c and UC5).

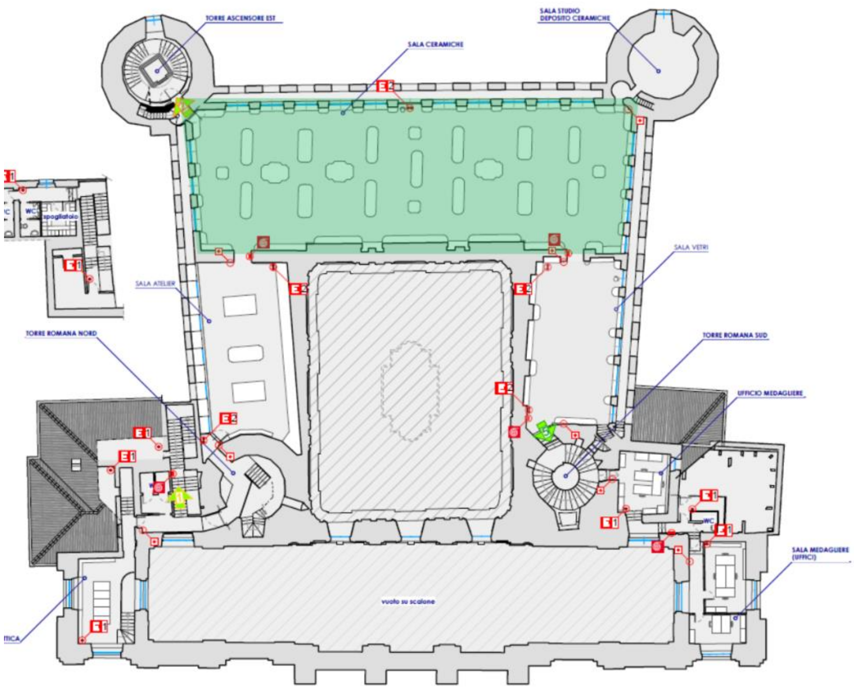

Figure 77 - Indoor coverage at the second floor at Palazzo Madama (UC3).

Figure 78 - Indoor coverage at GAM - ground floor (UC1.b and UC3) and first floor (UC2.b/c and UC3).

Figure 79 shows the plan of the 5G Network coverage utilization by each Use Case inside Palazzo Madama and GAM. The detailed Milestone scope is described in Chapter 8.

	oct-20	nov-20	dec-20	jan-21	feb-21	mar-21	apr-21	may-21	jun-21	jul-21	aug-21	sep-21	oct-21	nov-21	dec-21	jan-22	feb-22	mar-22	apr-22	may-22	jun-22	jul-22
Coverage Requirement									*Event*										Opening to visitors and/or events to be planned			
Caption:		Event/Openin to Visitors																				
		Trial/Test Session																				

Figure 79 - Plan of the 5G Network coverage utilization by each Use Case inside Palazzo Madama and GAM.

7.2 Network equipment

The two phases network implementation approach described in Section 0 consists in reusing the pre-existing network infrastructure (5G-EVE and TIM commercial network) adding or extending 5G radio coverage on sites where the UCs will be implemented (i.e. Palazzo Madama and GAM museums). For this reason, installation of new equipment, is targeting radio access domain only. The equipment selected for this purpose are all part of Ericsson Radio System (ERS) [17] and are described in detail in the next sections.

The Network Deployment process addressed the Network Solution implementation capturing the technical requirements. When it comes to the Authorization Process for the indoor coverage, strong constraints were raised by the Agency of Cultural Heritage. This topic drove the implementation to a solution for Palazzo Madama (location of the use cases involved so far) based on a temporary installation (the presence of four radio stations was allowed only at closing time of the museum). The Radio solution identified to fit the coverage requirements and the Cultural Heritage constraints, is the Ericsson 5G Radio 4422, mounted on ad hoc built pole to ensure the best stability of the installation and allow the mounting of all required components in term of Radio, power supply, cabling of the access point (fiber and RF) and Antennas; all those components are standing to the pole without any need to be anchored to the Museum walls.

For the next steps of the Use Cases implementation, and to identify a solution matching the criteria to get the authorization to leave the installation in the museum for longest period of time, a joint path with the Cultural Heritage Agency will be approached.

The current Radio station is depicted in Figure 80:

Figure 80 – Radio Station installation.

7.2.1 Radio

Indoor coverage is implemented by the Ericsson Radio 4422 installed inside Palazzo Madama and GAM museum. The Radio 4422 supports NR technology and it is 4T/4R radio with 4x40W max output power; it provides up to 100MHz NR carrier bandwidth and provides four antenna ports 4.3-10. On connection to Digital Unit side, this radio supports up to CPRI8 (10.1 Gbps) connections.

Figure 81 - Radio 4422.

The antennas mounted on top of the pole are Kathrein type 80010922 working at frequency range: 3300 – 3800 and four 4.3-10 ports.

Figure 82 – Kathrein 80010922.

Outdoor coverage extension is implemented by the AIR 6488, an Advanced Antenna System (AAS), with 64 transmitters and 64 receivers.

Figure 83 - AIR6488.

Enhanced bitrate per user achieved through interference suppression by applying beamforming capabilities in the downlink and the uplink. Capacity increased by scheduling users in the cell on different layers supporting both Single User MIMO (SU-MIMO) and Multi User MIMO (MU-MIMO). Application coverage is improved through beamforming in both the vertical and horizontal dimensions.

7.2.2 Baseband

Ericsson Baseband 6630 flexibly handle compute functionalities for all generations of radio access technologies, including LTE and NR.

Figure 84 - Baseband 6630

In 5G network extension scenarios of Turin sites it will be connected via fibre link to AIR6488 and IRU 8846 to ensure outdoor and indoor coverage.

7.3 Network enhancements

The 5G-TOURS network enhancements envisioned in WP3 will be introduced in the Turin site, during the phase 2 (see Section 0) of the network deployment, in which the full assets from the 5G-EVE project will be available. In the following, we discuss in detail how the inclusion of these enhancements will be targeted by WP4, with a per use case discussion.

7.3.1 Broadcast support

One of the most important network enhancements that 5G-TOURS is planning to include in the 5G EVE infrastructure to support innovative service is the broadcast support. Currently, broadcast has only a very limited support in commercial networks [18]. However, the use cases envisioned in Turin heavily rely on the implantation of the broadcast capability in the network.

UC4.b will showcase a bleeding edge technology deployment for the HTHP broadcast technology. It will be structured in two phases: the first showcase will entail Rel. 14 technologies, which are very similar to the ones employed by Rel. 16, while the second trial will employ a fully-fledged Rel. 16 deployment, with specific hardware provided by Rohde and Schwarz. Both trials will be provided using the RAI infrastructure.

UC4.c will enhance the existing 5G core with two new multicast functions, MCF and MUF. The additional functions will allow and perform multicast sessions in both the control plane and user plan.

7.3.2 Enhanced MANO

Too often the state-of-the-art MANO solutions employ rigid and static rules during the network operations that risk to not meet the requirements on the usability of the network imposed by the verticals, which will result in a low adoption of the 5G network from them. Thus, in 5G-TOURS we propose to extend the MANO with new functionality to allow the zero-touch management of the network, but also with new interfaces towards the vertical, which will be used for a wiser usage of the network by the vertical service provider. This additional functionality is part of the service layer design detailed in WP3. Specifically, this additional functionality is split as follows:

Real time KPI monitoring

Several use cases require continuous monitoring of the network services KPIs, as specified by WP2 and WP7, such as:

- UC1: latency and user throughput
- UC2: latency
- UC3: latency
- UC4: coverage, bandwidth
- UC5: latency and user throughput

Currently, such kind of monitoring is not possible through the 5G-EVE elements. Thus, they will be specifically implemented for the 5G-TOURS use cases and exposed to the verticals, that will use this live feed to check the fulfillment of their network requested network parameters. This will require to create specific probes in the network and interface them with the orchestration environment. This activity will be developed in conjunction with WP3 and the other use cases related WP5 and WP6.

Dynamic SLA management

An additional feature that is requested by verticals is the capability to set up dynamic SLA parameters to the network slice, which will allow flexible decisions on the requested parameters, which may change during the network slice lifecycle. For instance, requirements on the maximum number of users in the network may vary throughout the day, so the vertical may request rapid changes to such KPI, without going through the usual OSS/BSS procedures that are being used nowadays. Specifically, this feature will be enabled on the UC1, with the following parameters:

- Number of users: the verticals will be able to specify a range in the number of active users at any point in time. The enhanced MANO will enforce this rule as long as the minimum QoS is reachable;
- Amount of resources: the interaction with the network operator and the vertical service provider will be eminently based on monetary interactions (i.e., operators will charge the verticals according to the QoS levels which, in turn, will be based on the amount of resources allocated to the network slice offering the services). The verticals can set up specific values (e.g., such as the number of allocated servers) or let an Artificial Intelligence module handle it (more details below).

7.3.3 Big Data and Artificial Intelligence

5G-TOURS will enable zero-touch management of the network, by enabling intelligent management and orchestration decision to be implemented in the network. Specifically, 5G-TOURS will enable this functionality for the UC1, as part of the enhanced MANO extension envisioned previously (although other use cases such as UC5, may also leverage this functionality). Specifically, the AI module will use the monitoring information gathered by the orchestration infrastructure (e.g., the infrastructure load, exposed as time series, and the previous re-orchestration events) to generate re-orchestration decisions (on behalf of the vertical) that will be suggested on behalf of the vertical, which can indirectly steer the decision through high level parameter. The details of the implementation (which will be based on the accepted ETSI ENI PoC), are available in WP3 deliverables [4] [5].

8 WP Workplan

8.1 Milestones description

Trials summary time plan provides the time schedule of the use cases implementation in terms of milestones.

Table 4 - Trials summary time plan.

	2019							2020												2021												2022				
	Q1Y1				Q2Y1			Q3Y1			Q4Y1			Q1Y2			Q2Y2			Q3Y2			Q4Y2			Q1Y3			Q2Y3			Q3Y3			Q4Y3	
	J-19	J-19	A-19	S-19	O-19	N-19	D-19	J-20	F-20	M-20	A-20	M-20	J-20	J-20	A-20	S-20	O-20	N-20	D-20	J-21	F-21	M-21	A-21	M-21	J-21	J-21	A-21	S-21	O-21	N-21	D-21	J-22	F-22	M-22	A-22	M-22
Milestones																																				
UC1								M1						M2					M3								M4-5							M6		
UC2										M1												M2				M3					M4-5			M6		
UC3											M1							M2		M3				M4a				M4b			M5					
UC4									M1									M2			M3									M4						
UC5								M1											M2			M3	M4			M5										

<u>**Use case 1 Milestone description**</u>

UC1, M1: Design activity

- Definition of the storytelling, identification of existing contents and production of new ones
- Requirements gathering
- Architecture design activity
- Target: January 2020

UC1, M2: solution implementation phase 1

- Alpha release delivery
- Target: September 2020

UC1, M3: solution implementation phase 2

- Beta release delivery
- Target: January 2021

UC1, M4: solution implementation phase 3

- Candidate release delivery
- Target: September 2021

UC1, M5: Release candidate Trial

- Trial with candidate release
- Target: September 2021

UC1, M6: Final Validation

- Experiment assessment and final evaluation
- Target: February 2022

<u>**Use case 2 Milestone description**</u>

UC2, M1: use case, technical and application requirement defined

- Definition of the application/technical requirements of three sub-use cases
- Target: March 2020

UC2, M2: application development, robots and system integration

- Application development will proceed in parallel for different sub-use cases
- Double 3 robot and system integration will be based on the API provided by robot manufacturer
- Target: delayed to March 2021

UC2, M3: Double robot solution deployment

- Control room and visitor room setup
- Backend setup
- IoT sensor setup

- Beta testing on preliminary network in lab and on field
- Integration test on field
- Target: delayed to May 2021 at Palazzo Madama, and September 2021 at GAM

UC2, M4: Double 3 robot trial monitoring and final evaluation

- Trial monitoring and final evaluation of Double robot
  Target: December 2021 (This milestone should not change even if we need to shorten the trial duration)

UC2, M5: R1 robot solution deployment and first test in 5G network

- R1 robot in using 5G connectivity. Tests will be done in ERI-IT E2E lab (Genoa) instead of TOR.
- Target: December 2020

UC2, M6: R1 robot testing in real condition

- R1 solution testing in TOR in real conditions using 5G connectivity
- Target: May 2021

UC2, M7: R1 robot trial monitoring and final evaluation

- Robot testing in TOR in real conditions using 5G connectivity
- Target: December 2021

<u>Use case 3 Milestone description</u>

UC3, M1: use cases and technical requirements defined

- Definition of the guided tour path, user interaction and robot dialog
- Target: April 2020

UC3, M2: use case development

- Application SW development and validation in Laboratory
- Target: November 2020

UC3, M3: Beta test of application

- First test with the robot using 5G connectivity. Tests will be done in ERI-IT E2E lab (Genoa) instead of TOR
- Target: Postponed to January 2021

UC3, M4a: Test of application in real condition

- Robot testing in TOR (Palazzo Madama) in real conditions using 5G connectivity
- Target: May 2021

UC3, M4b: Test of application in real condition

- Robot testing in TOR (GAM) in real conditions using 5G connectivity
- Target: September 2021

UC3, M5: R1 robot trial monitoring and final evaluation

- Robot testing in TOR in real conditions using 5G connectivity
- Target: December 2021

<u>Use case 4 Milestone description</u>

UC4, M1: use cases and technical requirements defined

- Technical requirements definition
- Target: February 2020

UC4, M2: LTE-broadcast implemented

- The NSA 5G network of ERI-IT incorporates the implementation of LTE-broadcast capabilities in the RAN

- Target: November 2020

UC4, M3: phase-1 trials completed

- The first phase of the trials is successfully completed using ERI-IT's NSA 5G network with LTE-Broadcast RAN capabilities. The first phase of the trials is successfully completed using RAI's broad-casting network with enTV Rel-14 capabilities
- Target: February 2021

UC4, M4: phase-2 trials completed

- The second phase of the trials is successfully completed using a 5G network with unicast/broadcast switching capabilities. enTV Rel-16 is implemented. The second phase of the trials is successfully com-pleted
- Target: November 2021

Use case 5 Milestone description

UC5, M1: Design and technical definitions

- Technical requirements and specifications document
- Target: January 2020

UC5, M2: First round of development, system integration and preliminary functional test

- First prototype implementation of portable 5G camera transmission system (backpack) and functional tests
- Target: July 2020

UC5, M3: First on-site trial and functional test

- Technical on-site tests to demonstrate the fulfilment of the requirements
- Target: December 2020 (reached on the 14-15 December 2020)

UC5, M4: Second round of development

- Full prototype implementation of backpack and remote control room
- Target: March 2021

UC5, M5: Second on-site trial with musicians

- Technical and operational test involving a small ensemble to demonstrate the feasibility and sustaina-bility of a real public performance
- Target: April 2021

UC5, M6: Final trial, Main Event

- Final trial including a public performance of the Itinerant Orchestra
- Target: June 2021

8.2 Deviation from work plan and how to recover

In the WP4, deviations from the work plan are given by the impact of COVID-19 emergency restrictions, in this section partners analyze main risks for activities and how to try to recover it for each use case.

8.2.1 UC1

Concerning UC1.b and considering COVID restrictions, an alternative proposal in order to maintain interactive value of the Use Case, is being evaluated and confirmed before the Plenary Meeting that took place in May. The new implementation includes the use of a device called the 'Nordic Thingy 52', particularly suitable for children use.

Further improvements regarding the software module for beacons discovery, which will be integrated into UC1.a Android mobile application, has been provided. The activity of content creation (3D models of ceramics and rooms of Palazzo Madama) for UC1.a has started at the beginning of the year and was completely stopped during the COVID19 emergency period. The sensors choice together with the installation plan has been designed. Technical partners and vertical have collaborated to the refinement of the UC1.a storytelling and end-user requirements and to define the system (Infrastructure and Network) requirements of the UC1.a. with the objective to develop an improved AR/VR demo for Android, testing technologies for future implementations. TOR and FTM partners have continued to provide key information about the locations, the logistic organization of on-site activities, the definition of real needs of the museum in relation to the use cases identified in order to achieve the best technical solutions. Moreover, during the last Plenary Meeting, COVID 19 added functions as the detection of crowd or the maintaining of distances has been evaluated as possible new functions to be included in this use case.

Due to COVID-19 emergency RAI stopped scanning activity in February 2020, at this moment we scanned a few objects and rooms, the scanning activity will restart as soon as possible after the COVID19 restriction period.

8.2.2 UC2

Due to Coronavirus restriction TIM employees are in Smart Working since 24th of February unable to access to the labs (the Turin offices are closed for all access, except in cases of non-extendable activities but special authorization is required).

The shipment of the Double Robotics equipment was delayed of six months, due to restriction imposed worldwide by the pandemic.

The onsite visit at Palazzo Madama and GAM to test the Double3 was postponed due to coronavirus emergency. Preliminary test inside Palazzo Madama spaces was planned at the beginning of March 2020 but was canceled due to Coronavirus restrictions. A single on site session was performed on July 2020 using the Double3 robot. All other tests on the robot were carried out in the home environment for the continuation of the smart-working regime for TIM employees. The lack of space, equipment and network availability is slowing down development and integration.

8.2.3 UC3

Due to the Corona virus emergency IIT had to postpone hiring of new personnel to work on the project. In addition, access to the laboratory for experimental tests was delayed. To mitigate delays the navigation system of R1 was developed using the robot simulator. Integration of the 5G modem on the R1 robot was also delayed due to the emergency. To further monitor the progress, we decided to add internal milestones.

The first of this milestone corresponds to the experiments which were conducted in October in Ericsson premises. The initial experiments were successful and we were able to achieve the connection between the robot and the laboratory network, using a specially-designed VPN. Additional experiments in the labs were planned in December 2020, but they have been postponed to January 2021 due to Corona virus restrictions which have become again severe due to the worsening of the general situation.

An additional experimental session in Turin is also planned in the very first few months of 2021, but without the network connectivity, and only focused on the robot navigation in the real environment. The purpose of this test is to validate the performances of the system to localize itself in a large environment, its robustness to a crowded environment, its capability to safely avoid obstacles and move around the museum on different floor types. At the current stage, these tests are not as critical as the network tests, but the progress needs to be constantly monitored because the system has been tested so far only in simulation or in the laboratory environment, which is very different respect to the one of the museum.

8.2.4 UC4

Due to COVID-19, TIM employees are still working mostly remotely and therefore are unable to access to the labs. A similar situation happened in RAI and UPV premises.

In general, integration and testing activities are delayed due to the impossibility to access the different premises involved in UC4.

UC 4.b: 5G Broadcast delivery to massive audiences

Initial work plan:

- Phase-1: enTV Rel-14 provision of multimedia services. First demo: December 2020;
- Phase-2: enTV Rel-16 upgrade. Second demo: June 2021.

COVID-19 impact:

- Phase-1: no major impact. The plan remains the same if events are allowed (demo by end of 2020);
- Phase-2: 3GPP Rel-16 specification delayed by 6 months. Impact on R&S equipment development. Potential delay but still unknown.

Note that in the second phase of the trials, the transmitter (BSCC and modulator) and the receiver will be updated to Rel-16. The new release should be available in Q4 2020, although some delays are expected due to COVID-19. The scheme of the network will be the same with minor adjustments.

UC4.c: 5G Core Multicast

Initial work plan:

- 5GC multicast development during the project (5GC in UPV, already received);
- Demo will depend on the availability of Rel-17 equipment by the end of the project.

COVID-19 impact: the plan remains the same.

- The setup and activation of the 5GC equipment is being slower (remote access). Laboratory not fully installed;
- Training for the equipment online.

8.2.5 UC5

The Itinerant Orchestra event, originally planned for June 2020 in Palazzo Madama, has been postponed to December 2020 (Trial only without public audience) due to the COVID19 emergency, the Itinerant Orchestra event with public audience is planned in spring 2021.

The event previously planned in June 2020 was cancelled, and in general technical and social restrictions affect the trial organization which was held on the 14-15 December 2020. A lot of work has been done in proactive way in terms of network, application and integration design and also the artistic part, to prepare the Itinerant Orchestra event with public audience planned in spring 2021.

Social restrictions

From the point of view of social restrictions, we must take into account that the demonstration will be feasible only if:

- Free public access to museums.
- Possibility to organize public indoor events with spectators inside the museum.
- Possibility to move between countries.
- Free access to laboratories and offices.
- Possibility of organizing audio-visual shooting teams of many people inside and outside the venue.

Technical restrictions

From the technical point if view:

- Huge delays in 5G modules launch by all vendors (due to Qualcomm delays and to the modules vendors own R&D and manufacturing during COVID time); Contingency for this test cycle 1: use the Samsung 5G phones (of LIVEU and partners) as a single external modem to the LiveU existing devices.
- Delays on network deployment.
- Technical integration and test very difficult to be arranged.

All technical activities for the trial in December 2020 have been started at full speed beginning of July 2020 to make possible the organization of the trial in the middle of December 2020. The event was retargeted as trial due to the impossibility of organizing a full event.

Network deployment

The main impacts on the network deployment activity are summarized hereafter:

- The network design phase includes also site visits in order to check the spaces for the installation of the radios, their wiring and perform measurements;
- The closure of the museums as well as company's policies due to COVID-19 emergency are delaying this activity (tracking and further updates on this point are monitored);
- The authorization process usually requires two/three months in normal conditions; at this stage, and depending on how the COVID-19 situation will evolve, is not possible to identify the impacts on this phase;
- The network deployment and testing phases will require technicians (also from third party companies) on site; timing and modalities will be evaluated in a second stage;
- In general, company's policies and prioritizations of their activities according to the COVID-19 emergency evolution might have impacts on the overall time plan.

For the UC5 trial carried out on the 14-15 December 2020, a tight monitoring of the activities progress of each partner has been required (i.e. check points establishment) in order to meet the deadline and uncertainties have been perceived till the last days. However, the trial has been executed on time and with good results. For the full event in 2021, all the conditions above will be re-assessed and the authorization process could encounter further issues, due to the higher complexity of the trial and the presence of the public.

9 Conclusion

In this deliverable, D4.2, “First Touristic City Use Case Results”, we described the design and implementation of the Touristic City use cases hosted in the Turin node with the aim to enhance museum visits, interaction with robots, remote video production and broadcasting of media contents.

The document interacts closely, on several levels, with almost all the WPs of the project in defining use cases, selecting the suitable technologies, and evaluating the impact on techno-economic plans.

The scope of this report is to describe the progress in the implementation of use cases in terms of network deployment and equipment, application and terminal equipment components and interfaces. Also the integration end test in labs and tests in the network are introduced in relevant sections of each of the five vertical use cases.

This document shows, for each UC in the WP4, the status of the applications design to be deployed for the implementation of the trials, the detected devices to be used as well as the application development progress for each of the UCs according to the expected KPIs. Furthermore, this deliverable aims to be a basis for the evaluation of the progress made according to UC implementation time plans.

A revision of the whole WP4 work plan and the analysis of critical project risks are given taking into account main impacts due to the COVID-19 sanitary emergency. A contingency plan has been provided to counter the effects of the COVID-19 pandemic as well as first results have been showed, like the first UC5 real condition trail of the “Itinerant Orchestra” which was held on the 14-15 December 2020.

Acknowledgment

This project has received funding from the EU H2020 research and innovation programme under Grant Agreement No. 856950.

References

[1] 5G-TOURS, “D4.1 Robotic, Media and Smart Cities solutions for Touristic Cities,” October 2019.

[2] 5G-TOURS, “D2.1 Use cases, deployment and techno-economic requirements - high level description,” September 2019.

[3] 5G-TOURS, “D2.2 Touristic city use cases, safe city use cases, mobility-efficient city use cases – final version,” August 2020.

[4] 5G-TOURS, “D3.1 Baseline architecture and deployment objectives,” October 2019.

[5] 5G-TOURS, “D3.2 Technologies, architecture and deployment initial progress,” july 2020.

[6] 5G-TOURS, “D7.1 Evaluation methodology,” February 2020.

[7] 5G-TOURS, “D8.1 First report on innovation management, dissemination, standards and exploitation plans,” May 2020.

[8] P. O'Shaughnessy, “Creating a physical and immersive web mashup,” Samsung, [Online]. Available: https://medium.com/samsung-internet-dev/creating-a-physical-and-immersive-web-mashup-b5418f14b982.

[9] P. team, “The HTML5 Creation Engine,” PixiJS, [Online]. Available: https://www.pixijs.com/.

[10] W3C, “WebXR Device API Working Draft,” W3C , [Online]. Available: https://www.w3.org/TR/webxr/.

[11] L. Geosystems, “Leica RTC360 3D Laser Scanner,” Leica Geosystems, [Online]. Available: https://leica-geosystems.com/it-it/products/laser-scanners/scanners/leica-rtc360.

[12] Artec3D, “Artec Eva Fast 3D scanner for professionals,” Artec3D, [Online]. Available: https://www.artec3d.com/portable-3d-scanners/artec-eva-v2.

[13] Y. Team, “YARP - Yet Another Robot Platform,” YARP, [Online]. Available: https://www.yarp.it/.

[14] T. GAZEBO, “GAZEBO - Robot simulation made easy,” Open Source Robotics Foundation, [Online]. Available: http://gazebosim.org/.

[15] 5G-Xcast, “5G-Xcast – The official website for the 5G-Xcast project,” 5G-Xcast, [Online]. Available: https://5g-xcast.eu/.

[16] Open5GCore, “Open5GCore – The Next Mobile Core Network Testbed Platform,” [Online]. Available: https://www.open5gcore.org/.

[17] Ericsson, “Ericsson Radio System,” Ericsson , [Online]. Available: https://www.ericsson.com/en/portfolio/networks/ericsson-radio-system.

[18] 5. EVE, “5G EVE - 5G validation platform for extensive trials,” 5G EVE, [Online]. Available: https://www.5g-eve.eu/.

[19] Telstra, “Telstra deploys Australia’s first LTE-Broadcast technology to support sports streaming,” Telstra, Media Release, 11 July 2018. [Online]. Available: https://www.telstra.com.au/aboutus/media/media-releases/Telstra-deploys-Australias-first-LTE-Broadcast-technology-to-support-sports-streaming.