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

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First Integrated 5G-TOURS Ecosystem

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List of Acronyms and Abbreviations

Term	Description
3D	3 Dimensional
4G	4th Generation mobile wireless communication system
5G	5th Generation mobile wireless communication system
AIA	Athens International Airport
AOC	Airport Operations Centre
API	Application Programming Interface
AR	Augmented Reality
BS	Base Station
BBU	BaseBand Units
BNG	Broadband Network Gateway
DL	Downlink
DVI	Digital Video Interface
E2E	End to End
ECG	Electro CardioGram
eMBB	enhanced Mobile Broadband
eMBMS	Evolved Multimedia Broadcast Multicast Services
GAM	Modern Art Gallery
GB	Gigabyte
GHz	Gigahertz
gNB	gNodeB
GUI	Graphical User Interface
HD	High Definition
HPHT	High-Power High-Tower
IIT	Istituto Italiano di Tecnologia
IoT	Internet of Things
IP	Internet Protocol
IT	Information Technology
KPI	Key Performance Indicator
KVaP	KPI Validation Platform
LTE	Long Term Evolution
MANO	Management and Network Orchestration
Mbps	Megabits per second
mMTC	Massive Machine Type Communication
MTC	Machine Type Communication
NB-IoT	Narrow Band IoT
NR	New Radio
OSM	ETSI Open Source MANO
QoE	Quality of Experience
QoS	Quality of Service
RAN	Radio Access Network
RTV	Real Time Video
SDI	Serial Digital Interface
SMPTE	Society of Motion Picture and Television Engineers
STARLIT	Smart living platform powered by ArtIficial intelligence & robust iot connectivity
TV	Television
UC	Use Case
UDP	User Datagram Protocol
UHD	Ultra-High Definition
UI	User Interface
UL	Up Link
UPF	User Plane Function
URLLC	Ultra-Reliable Low Latency Communication
vEPC	virtual Evolved Packet Core
VNF	Virtual Network Function
VR	Virtual Reality
WP	Work Package

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Executive Summary

The 5G-TOURS project aims at deploying full end-to-end trials involving real end-users (volunteers who consent to participate) and vertical operational services in three different European cities (Turin, Rennes, and Athens). In the 5G-TOURS "ecosystem" realised in the three cities, 13 use cases related with the themes of the touristic city (5 use cases), the safe city (4 use cases) and the mobility-efficient city (4 use cases) are being deployed. The ultimate goal of this approach is to trial the use cases in a real environment by continuously collecting network, service and vertical KPIs and evaluate them against a set of predefined vertical-oriented criteria.

Towards this direction, WP7 - System integration and evaluation, focuses on delivering the integrated 5G-TOURS ecosystem that will allow for the realisation of pilots in all three sites and drive the evaluation of the results of the trials.

This deliverable is the second document produced by WP7 and presents the first version of the 5G-TOURS integrated ecosystem. The term "ecosystem" includes the site infrastructure, the 5G-TOURS platform and 5G-TOURS innovations, the hardware and software components and services which belong to use cases owners and in general all the required functionalities which are required for the smooth and successful execution and evaluation of the 5G-TOURS trials. It also includes all the methodologies and means for the collection, analysis and validation of the KPIs. In this deliverable, the initial 5G-TOURS integrated ecosystem is presented with focus on:

- The final 5G-TOURS evaluation methodology, which covers QoS, QoE and vertical satisfaction aspects. In the first deliverable D7.1 (5G-TOURS, D7.1, 2020), the initial 5G-TOURS evaluation methodology was reported, which covers QoS aspects that can guide the pilot sites. In this deliverable, this initial evaluation methodology is extended beyond QoS, in order to also evaluate the level of satisfaction of end-users and verticals' players with the use cases deployed. This includes users' QoE as well as the feedback from the vertical players on how the technology provided can improve their business operations. For 5G-TOURS evaluation methodology, we consider two phases. The first phase is realized during the trials execution and collects both the QoS metrics, automatically obtained from the infrastructure, and the QoE metrics (and vertical satisfaction), collected using appropriate questionnaires. The second phase, realized after the trials' executions and, is responsible to analyse the collected metrics, to validate the KPIs against the predefined targets, to provide insights and finally to create a model for QoS-QoE correlation by using correlation-regression analysis.

- The plan for the actual technical validation of the 5G-TOURS use cases. Initially, a feasibility study was realised in each use case (UC) in order to identify which of the KPIs can be technically validated. This study, the outcome of which is presented in this deliverable, takes into consideration: a) the validation plan of each UC; b) the capabilities, characteristics and deployment approaches of the sites; c) the UC requirements stated in D2.2 (5G-TOURS, D2.2, 2020). For the KPIs that are characterised as feasible, a technical validation plan was generated. These plans which are described in the current document include all the required guidelines to the technical WPs (WP4/5/6) in order to collect the required metrics including: a) probe positions in the network; b) probe positions in the protocol layers; c) trial details (e.g. duration, sampling period, collection method; d) assumptions during collection.

- The integrated 5G-TOURS ecosystem. The three sites can be characterised as an integrated ecosystem of different hardware and software components, including the 5G EVE infrastructure, the 5G-TOURS extensions on this infrastructure, the 5G EVE platform, the 5G-TOURS innovations, and also the services, the software and hardware brought by the use cases. This complex integration activity is managed by WP3 and WP7, where WP3 focuses on the architecture design and hardware deployment and WP7 on the software integrations. The first outcomes of this integration activity, which ensures the smooth deployment of the UCs, are presented in this document as well.

The next steps toward the integration and validation activities (to be reported in the next WP7 deliverable, D7.3) are: 1) the provision of the second version of 5G-TOURS ecosystem after the finalisation of the integration process; 2) the overall orchestration of trials and validation processes including the analysis of the validation results toward providing the first version of validation results and initial QoE-QoS correlations.

1 Introduction

The 5G-TOURS project goal is to demonstrate the benefits of 5G technology in the pre-commercial environment for real users, tourists, citizens and patients by implementing 13 representative use cases in 3 different types of cities: (i) Turin, the touristic city (5 use cases) ii) Rennes, the safe city (4 use cases) iii) Athens, the mobility-efficient city (4 use cases).

In this direction, WP7 is responsible to provide the overall 5G-TOURS integrated ecosystem (the 3 cities together) for the smooth deployment and trials of the aforementioned use cases, as well as a detailed KPI collection, analysis and validation methodology for the evaluation of the trial results.

Regarding the integration objective, this document presents the current progress of the integration activities realised in all the three 5G-TOURS sites. These integration activities include the integration and expansion of the 5G EVE infrastructure, the integration and expansion of the 5G EVE platform, the integration of the 5G-TOURS innovation and the integration of all the pieces ranging from mobile network functionality to applications and services into the sites in order to ensure the smooth use case deployment and trial execution.

Regarding the validation objective, this document presents the final 5G-TOURS evaluation approach. In addition to the validation of QoS results, which illustrates mainly the performance of the network KPIs and can be compared against the 5G PPP targets (which is presented in D7.1), it is of paramount importance to validate the actual satisfaction of end-users and also the satisfaction of the vertical players (either as service providers or users of secondary service flows). In this direction, a set of questionnaires per UC were generated that will be used for the QoE/vertical satisfaction validation. This was a long interaction process between WP7 and WPs 4/5/6 based on three rounds of interactions and also with WP8 for the economical aspects. The final 5G-TOURS evaluation methodology, described in this document, defines a two-phase process. In the first phase, the QoS metrics (from the network and application layer) are collected together with the QoE (and vertical satisfaction) metrics collected using appropriate questionnaires. In the second phase, the metrics are analysed and validation, but also correlation-regression analysis, is used which tries to create a model for QoS-QoE correlation.

In addition, this document describes the technical details for the collection of the QoS related metrics, presenting guidelines (per use case and per KPI) for the metric collection from the sites including probe positions (in terms of network and protocol position), collection methods and further details of collection approaches.

1.1 Role of WP7 in 5G-TOURS evaluation activities

As shown in Figure 1, WP7 interacts with all other WPs due to its horizontal role in the 5G-TOURS project. In particular, WPs 4/5/6 provide the description of the UCs, perform the trials, and provide the results to WP7. WP7 defines the methodology, the technical validation and analyses the results that are fed back to WPs 4/5/6 for further refinements. In addition, WP7 interacts with WP2 for the refinements of KPIs and QoE analysis by the end user. Finally, the interactions between WP3 and WP8 are mainly about the network architecture and the business cases emerging from the UCs.

As Figure 1 shows, the process of performing the trials and the results' analysis has started. The analysis will feed into WPs 4/5/6 the recommendations and insights to be applied in future trials, hence, steps 3 and 4 may have several iterations.

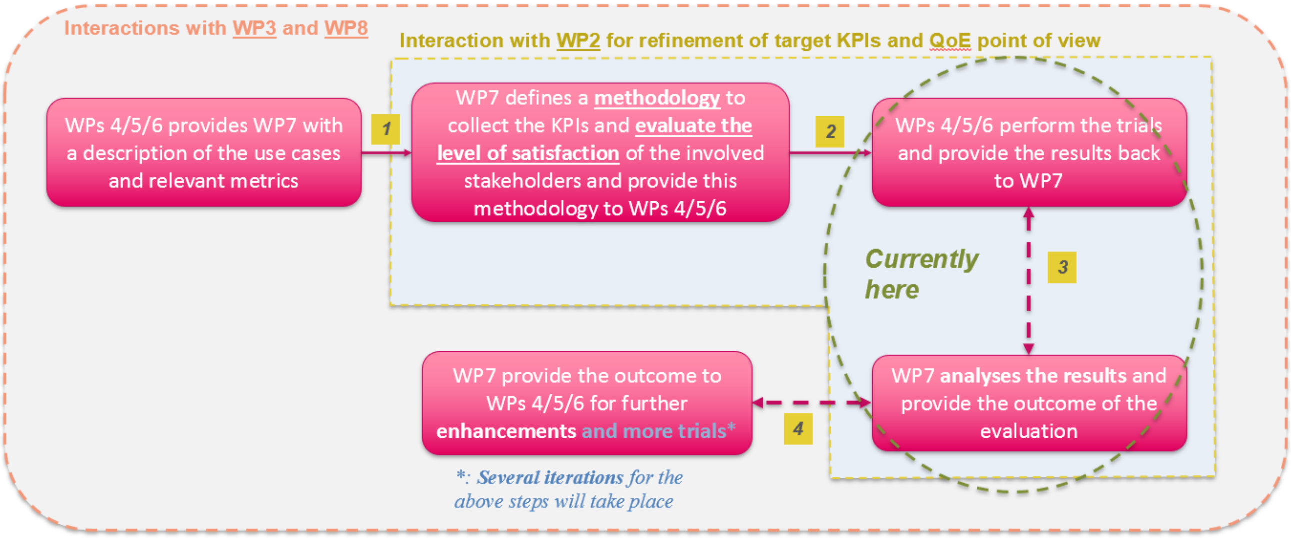


Figure 1. Interaction of WP7 with other WPs.

1.2 Document structure

In this document, the following topics are addressed:

- Section 22 presents the overall 5G-TOURS evaluation approach in terms of quality of service and quality of experience. The QoS and QoE evaluation methodologies are also presented in detail.
- In Section 3, the touristic integrated ecosystem is shown. In particular, an overview of the ecosystem, the technical validation, and the integration part are illustrated. Results from the first trials are also presented and discussed.
- Section 44 shows the safe city integrated ecosystem, use case deployment, trial and technical validation. Results from the initial trials are shown.
- Similarly, Section 5 shows the mobility-efficient city integrated ecosystem, use case deployment, trial and technical validation, while it also presents initial results from the trials and the validation process.
- In section 66, the conclusions are drawn presenting the current progress on integration and validation activities and the next steps.

2 5G-TOURS QoE/QoS evaluation approach

The current section starts by presenting the high-level view of the 5G-TOURS evaluation methodology that covers both the QoS aspects as well as the user and vertical satisfactions aspects. Then, the adopted evaluation methodology is presented in details, explaining the procedures, the KPIs, the relation with the UC requirements in the case of QoS evaluation, QoE model, the questionnaire generation and the case of QoE evaluation.

2.1 High level view of QoE/QoS evaluation methodology

In recent years, the technical community has shifted some attention from one related gauge, quality of service (QoS), to a more consumer-centric metric, quality of experience (QoE). Network operators and service providers from the very advent of telecommunications wanted to know, the level of service quality which is provided to the end users. This is because that knowledge can be extremely useful when trying to manage network topology, optimize its capacity and operating costs, introduce new services or plan investments and expansion of a network. This is particularly true in a scenarios such as 5G, where we have extreme requirements resulting from new applications and the QoS values required to provide a good experience to end-users are not known.

International Telecommunication Union (ITU) defines QoE as the overall acceptability of an application or service, as perceived subjectively by the end-user (ITU, Definition of Quality of Experience, 2007). ETSI and 3GPP defined QoE as an overall acceptability of an application or service, as perceived subjectively by the end-user (643, 2019), (3GPP, TR 26.944 V10.0.0, 2011), QoE can be considered as an extension of the traditional QoS in the sense that QoE provides information about the delivered service from an end-user point of view (P. Ameigeiras, 2010). For example for a video service, QoE may include items such as: service setup delay; re-buffering duration; end to end delay; corruption duration; mean time between corruption; content quality(e.g. digital TV-like quality, analog TV-like quality, DSL-like video conference quality ISDNlike video conference quality, etc.); audio/video synchronization (or 'lip sync'); service availability (3GPP, TR 26.944 V10.0.0, 2011).

Whereas QoS stands between the network and an application, QoE is centred on the subscriber. In particular, QoE focuses on person-as-user who interacts with an application and person-as-customer who deals with a service provider, see Figure 2 (Tombes, 2012).

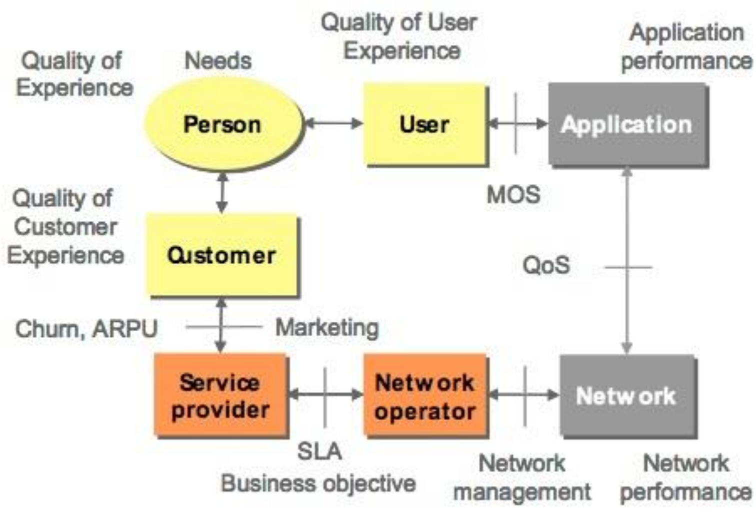


Figure 2. QoE model

Thus, the service quality has some properties (for example, service setup delay; re-buffering duration, etc.) and subjective properties (for example, user's opinion of QoE only with user's feeling and experience). Obviously, the user will hardly be satisfied if a network performance (QoS) is poor. For instance, if the re-buffering of a video is frequent during the streaming session, a user will most certainly be annoyed and unsatisfied. But it was also shown that achieving the QoS targets does not necessarily ensure satisfied users. Something was still missing.

The difference between QoE and QoS is underlined below:

- QoS – Quality of Service:
  - network characteristics/behavior
  - performance guarantees given by network provider based on measurements
- QoE – Quality of Experience:
  - impact of network behavior on end user
  - some imperfections may go unnoticed
  - some imperfections may render application useless
  - not captured by network measurements

QoE is not directly dependent on radio channel conditions, but the expectation will increase with higher performance. QoE considers a user's expectation, while QoS is more rational based on technical measurements (Figure 3).

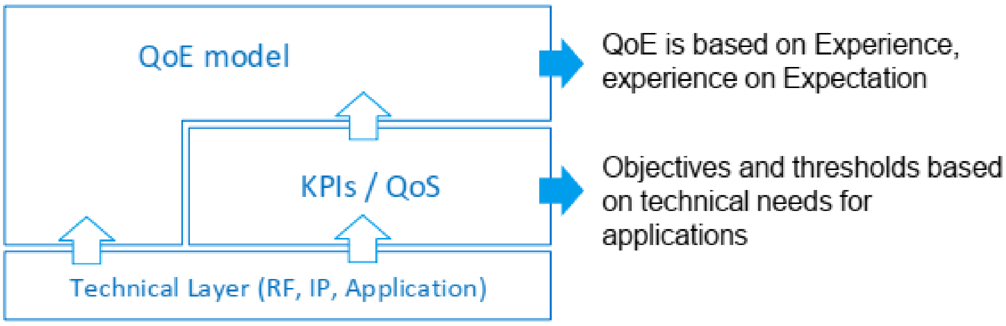


Figure 3. Relationships between QoE, QoS, KPIs.

Based on the above, the following approach is proposed for evaluating the overall QoE using QoS metrics, that can be estimated in a more objective way.

To implement this approach, a set of services (UCs) S was introduced that should be analyzed:

$$\{\bigcup_{i=1}^{n} S_i\} = \{S_1, S_2, \ldots, S_n\},$$

where $S_i \subseteq S$, $(i = \overline{1, n})$, n – a number of services, and

$$S_i = \{\bigcup_{j=1}^{m_i} S_{ij}\} = \{S_{i1}, S_{i2}, \ldots, S_{im_i}\},$$

with S_{ij} $(j = \overline{1, m_i})$ – a subset of the elements of the QoS assurance system.

The subsets of QoE metrics $S_{ij} \subseteq S_i$ can be represented as:

$$S_{ij}=\{\cup_{p=1}^{r_{ij}} S_{ijp}\}=\{S_{ij1}, S_{ij2}, \ldots, S_{ijr_j}\},$$

where S_{ijp} $(p = \overline{1, r_{ij}})$ – QoE indicators that characterize the QoE for S_{ij};

where r_{ij} is the number of such indicators.

At the second stage, QoS and QoE indicators S_{ijp} are selected, using multi-factor correlation-regression analysis (Odarchenko, 2018). To construct multi-factor regression model, the following steps have to be completed:

- *Step 1.* Select all possible QoS factors that affect the QoE indicator (or process) that is being investigated. For each factor, it is necessary to determine its numerical characteristics. If some factors cannot be quantitatively or qualitatively determined, or statistics are not available to them, then they are removed from further consideration.

- *Step 2.* Choose the form of a regression or multivariate model, that is, finding an analytic expression that best reflects the relationship of factor characteristics with the resultant, that is, the choice of function:

$$\hat{Y} = f(x_1, x_2, x_3, \ldots, x_n),$$

where $\hat{Y}$ is the effective sign-function

and $x_1, x_2, x_3, \ldots, x_n$ are factor signs.

On the next stage, subsets of QoS indicators have to be calculated using corresponding algorithms and formulas for their calculations (5G-TOURS, D7.1, 2020). QoE has to be calculated using for example MOS (Patrick Le Callet, 2013), DSCQR (K. Kawashima, 2014), ACR (ITU, Subjective video quality assessment methods for multimedia applications, 2009) or other appropriate methods/techniques. In 5G-TOURS, the special questionnaires were developed to estimate the QoE for each use case.
On the last stage, the obtained values are compared with the maximum permissible, possible to ensure the normal functioning of the network and achieved KPIs.
To compare the values obtained as a result of calculations with the maximum allowable value we introduce the logical function of equivalence:

$$E(x, y) = \begin{cases} 1, & if\ x > y, \\ 0, & if\ x \leq y. \end{cases}$$

where *x* is the current value of the KPI and *y* is the maximum allowable value of this KPI.

QoE is the most important parameter, it estimates user experience and compare it with users' expectations. Respective approach based on the principles of machine learning has been developed to assess and optimize the state of the network in order to improve the QoS provision to users.

2.2 QoS evaluation methodology

In this section, we present the QoS evaluation approaches that will be adopted by the 5G-TOURS for the three sites (Turin, Rennes, and Athens), to evaluate technical KPIs so as to assess the correct functioning of the UC. A more precise and specific definition of the evaluation procedure is described in sections 3.3, 4.3 and 5.3 where the focus is on specific UCs.

Quality of service (QoS) is the description or measurement of the overall performance of a service. KPIs are metrics used to evaluate the QoS of a network.

The goal of the end-to-end trials is to demonstrate 13 use cases at the three pilot sites in a real environment by continuously collecting network, service and vertical KPIs and evaluate them against a set predefined vertical-oriented criteria (or requirements), see more details in Sections 3.3, 4.3 and 5.3.

This deliverable utilizes the QoS evaluation methodology specified in D7.1 (5G-TOURS, D7.1, 2020) as we move towards the integrated 5G-TOURS ecosystem.

The first step of the evaluation, was to understand what are the vertical needs concerning trial execution in all three 5G-TOURS pilot sites, and design a set of pilot tests. In 5G-TOURS, we map the vertical requirements in an efficient way into the set of pilot tests. Next step is for WP7 to work together with WP4/5/6 in order to specify test plans, prepare the sites and perform the actual execution of the pilot tests on the three pilot sites. The final step is for WP4/5/6 to collect the specified KPI metrics, and WP7 will analyse and evaluate these against the predefined criteria. These QoS evaluation results provide a basis for evaluating the level of satisfaction of end-users and vertical key players.

The final version of the 5G-TOURS evaluation methodology is reported in this deliverable (D7.2). It comprises of two parts: one that can be applied to all the project use cases; and one specialised part that defines evaluation procedures that are specific to some use cases and involve particular KPIs. In this way, the 5G-TOURS evaluation methodology is both generic as well as flexibly extendable (vertical specific).

Evaluation methodology describes mechanisms for collecting the basic information for the generation of KPIs; including steps, tools and agreements on how and where to measure them. The evaluation methodology in 5G-TOURS is based on procedures described in standards such as 3GPP and ITU-R.

In 5G-TOURS, the terminology used in 5G EVE for testing and validation methodology will be reused. The main target of the evaluation methodology is to provide the appropriate guidelines to the pilot sites in order to design the test cases, to prepare the tests, to execute and finally evaluate the test results. The high-level workflow for the evaluation process, consists of four phases; Test Design, Test Preparation, Test Execution and Monitoring, and Result Analysis and Evaluation as illustrated in Figure 4. This process is described in detail in D7.1 (5G-TOURS D7.1).

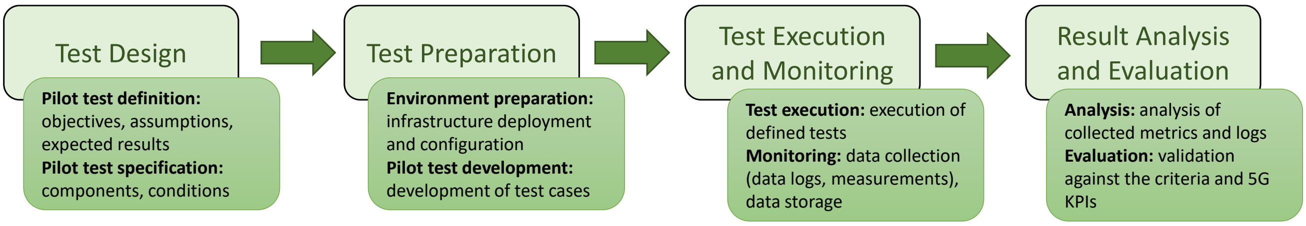


Figure 4. 5G-TOURS evaluation process workflow.

The term "evaluation methodology" is used to describe the general approach that will be followed by the project involving all the steps starting from collecting the requirements and ending by providing the evaluation results. The term "evaluation procedure" is used to describe the step-by-step procedure that should be followed for the evaluation of a specific KPI including the test definition, execution, and metrics collection.

Based on the gathered results, the values of the KPIs are verified if they fulfil the success criteria. If they do, the final test report will indicate that the test has passed; otherwise, feedback will be provided for improvements or that the test has failed.

The set of network KPIs that are measured by 5G-TOURS are presented in detail below. In the cases that the 5G EVE platform is reused, the set of KPIs supported by 5G EVE will be also collected in addition to 5G-TOURS KPIs. The collected KPIs will be used in order to validate the results against the 5G PPP KPIs and as a way to ensure that the obtained results are valid. KPI measurements will also be performed in real time, using network probes.

In 5G-TOURS, in order to cope with the complexity of the network technology versus the vertical needs, we retain a high level of interaction between the telecom and technology experts and the verticals for the vertical requirements to be mapped in an efficient way into the set of pilot tests. Therefore, a lot of effort has been put in the related template to make it understandable for experimenters, hiding the network related components as much as possible.

In alignment with the 5G-PPP targets for the experimentation phase of 5G, 5G-TOURS will measure the following KPIs to assess the performance of the end-to-end system, please see D2.2 (5G-TOURS, D2.2, 2020) where radar charts of general requirements against the 4G/5G networks capabilities are shown:

- **Latency (msec)**: In this deliverable, two forms of latency are considered, namely RAN latency and end-to-end (E2E) latency. The former one defines the one-way time it takes to successfully deliver an application layer packet from the radio protocol layer 2/3 SDU ingress point to the radio protocol layer 2/3 SDU egress point over the air interface. RAN latency measurement requires clocks at the transmitter and receiver to be accurately synchronized. The second one describes the round-trip time it takes for successful delivery of a packet from transmitter to receiver plus the time it takes to send the response back. Unlike RAN latency, E2E measurement does not require the clocks to be synchronized at the transmitter and receiver. They are, however, at the mercy of the receiver's response time. Latency measurements should report the minimum, average and maximum values, if possible, obtained over the measurement period. The reported average latency should be compared to the target value for latency validation.

- **Throughput (Mbps)**: Two procedures are described in 3GPP for throughput evaluation: i) Per UE basis procedure which provides the average UE throughput in DL/UL. This measurement is intended for data bursts that are large enough to require transmissions to be divided into several slots; ii) Per network or network slice procedure which describes the throughput in DL/UL of one single network slice instance by computing the packet size for each successfully transmitted DL/UL IP packet through the network slice instance during each observing granularity period and it is used to evaluate integrity performance of the end-to-end network slice instance.
- **Availability (%)**: This KPI can be discriminated between network or service availability. Network availability measures the amount of uptime in a network system over a given time period. Uptime refers to the amount of time a network is fully operational. Network availability is measured as a percentage and is monitored to ensure that the service being offered continues to operate for end-users. It is, however, difficult to measure it in some use case since it requires large operational times. On the other hand, service availability is used in cases that measurements are collected for small or medium operational times. Service availability is calculated as one minus the measured packet error rate (at application layer) during the operation of a service. Both network and service availability are measured in percentages.
- **Reliability (%)**: This KPI can be discriminated between network or service reliability. Network reliability is defined as likelihood of a failure occurring in a system. In this case, reliability will track how long a network's infrastructure is functional without interruption where in a fully reliable system has 100% availability. Again, network reliability requires large operational times. In cases of small or medium operational times, network reliability can be estimated using analytical calculations of the reliability of each network component. On the other hand service reliability is defined as the success probability of transmitting a layer 2/3 packet within a maximum latency required by the targeted service (ITU-R M.2410). Both network and service reliability are measured in percentages.
- **Mobility (km/h)**: Maximum mobile device speed at which certain performance requirements (QoS) can be achieved. In 5G-TOURS the KPI mobility will be evaluated mainly using predefined metrics such as latency, jitter, packet loss and throughput that are already available on the different pilot sites (refer to D7.1 for more details). Table 1 shows the defined classes of mobility.
- **Broadband connectivity (Gbps)**: High data rate achievable during high traffic demand periods and it is equal to the Peak data rate offered by the 5G network.
- **Device Density (dev/km^2)**: Total number of devices connected per unit area that meet a specific quality of service (QoS).
- **Slice deployment time (min)**: Period of time it takes for a slice to be established after the initial trigger has occurred to create or activate a slice. It is available only if network slicing; that is a logical network that provides specific network capabilities and network characteristics; is supported.
- **Security (Y/N)**: Ability to protect 5G customers from common security threats such as providing secrecy, resilience and availability of the network against signalling related threats, including overload or smart jamming attacks (NGMN, NGMN 5G Initiative White Paper, 17-February-2015).

The evaluation methodology of security KPI highly depends on the objectives of the use cases and the already available capabilities. In 5G-TOURS a set of security metrics were identified in D7.1, which are related with the 5G-TOURS security targets to fulfill various security requirements. Each pilot site will be responsible for choosing a subset of the security metrics that best represent the capabilities of the site in terms of security functions already present and security software already deployed and reflect the requirements of the pilot tests cases on a per use case basis.

- **Capacity (Mbps/m^2)**: Defined as the total data rate of all users per unit area.
- **Location accuracy (m)**: Ability to provide location with a degree of accuracy for both indoor and outdoor scenarios using 3GPP-based and hybrid positioning services. Location accuracy can be measured in the horizontal as well as in the vertical direction. For the need of the 5G-TOURS only horizontal accuracy is considered.

Table 1 shows the defined classes of mobility (ITU, M. 2410, 2017).

Table 1. Mobility Classes

Mobility Class	Speed (Km/h)
Stationary	0
Pedestrian	0 to 10
Vehicular	10 to 120
High speed vehicular	120 to 500

The aforementioned KPIs are related with the network requirements of WP2 and the 5G PPP KPI as explained below. Table 2 summarized the 5G PPP KPIs as described by 5G IA (5G-IA, 2021).

Table 2. 5G PPP KPIs

#	5G PPP KPI
P1	Providing 1000 times higher wireless area capacity and more varied service capabilities compared to 2010
P2	Saving up to 90% of energy per service provided. The main focus will be in mobile communication networks where the dominating energy consumption comes from the radio access network
P3	Reducing the average service creation time cycle from 90 hours to 90 minutes
P4	Creating a secure, reliable and dependable Internet with a “zero perceived” downtime for services provision
P5	Facilitating very dense deployments of wireless communication links to connect over 7 trillion wireless devices serving over 7 billion people
P6	Ensuring for everyone and everywhere the access to a wider panel of services and applications at lower cost

During the requirement collection phase (realised in WP2) a set of network requirements were defined. Then these requirements were translated to KPIs (in WP7). Network requirements are described in detail in D2.2 (section 2.4), while KPI definitions are presented in detail in D7.2 (section 2.2).

Table 3 illustrates the mapping between the “network requirements” as described in detail in D2.2, the KPIs considered in D7.2, as well as their relation to the 5G PPP KPIs (presented in Table 2). In addition, in the last column the relative target values of the KPIs as presented based on the 5G PPP phase II KPIs document (5GPPP, 2021).

Table 3. Requirements to KPI to 5G PPP KPI mapping

Network requirement	KPI	5G PPP KPI	5G PPP KPI value
Latency (ms)	Latency (ms)	P1	10 ms
RAN latency (ms)	RAN latency (ms)	P1	1 ms
Throughput (Mbps)	Throughput (Mbps)	P1	50 Mbps
Reliability (%)	Reliability (%)	P4	99.999%
Availability (%)	Availability (%)	P4	99.999%
Mobility (Km/h)	Mobility (Km/h)	P1	500 Km/h
Broadband connectivity (Gbps)	Broadband connectivity (Gbps)	P1	20 Gbps
Network slicing (Y/N)	Slice deployment time (min)	P3	90 min

Security (Y/N)	Per use case (e.g., grade, secrecy, resilience)	P4	"Carrier grade"
Capacity (Mbps/m^2)	Capacity (Mbps/m^2)	P1	10 Mbps/m^2
Device density (dev/km^2)	Device density (dev/km^2)	P5	1M terminals/km2
Location accuracy (m)	Location accuracy (m)	P1	1m

Table 3 shows an almost perfect one to one mapping between the requirements and KPIs (both in names and units). The only exception to this are: a) "Network slicing" for which the "Slice deployment time" is considered as dominant KPI and; b) "Security" for which the mapping to KPIs is highly related to the use case.

Regarding 5G PPP KPIs, the table illustrates that the network KPIs considered in 5G-TOURS validation process covered 5G PPP KPIs P1, P3, P4 and P5. In addition, in UC6, "Battery Life" (service specific requirement) is considered as related KPI to P2. Finally, P6 is also addressed during the technoeconomic analysis (realised in WP8).

In addition, Table 4 shows the KPIs to be validated by the three sites namely Turin, Rennes and Athens. The other KPIs are either not critical to the UC or difficult to measure.

On the security side, the trials rely on the security provided by the 5G network.

Table 4. KPIs to be validated by the 5G-TOURS sites

5G-TOURS KPI	Turin (Touristic City)	Rennes (Safe City)	Athens (Mobility-Efficient City)
Latency (msec)	√	√	√
Throughput (Mbps)	√	√	√
Availability (%)	√	√	√
Reliability (%)	√	√	√
Mobility (Km/h)			
Broadband connectivity (Gbps)		√	
Slice deployment time (min)			
Security (Y/N)			
Capacity (Mbps/m^2)			
Device density (dev/km^2)	√		
Location accuracy (m)			√

The colour code used, in Sections 3, 4 and 5 “UC technical validation”, for the categorisation of KPIs (green - measurements that are important for the given KPI, black - not relevant KPIs, red - difficult to be validated KPIs) makes it easy to identify the set of individual KPIs assigned to each UC. The KPI which are marked as red, are KPIs that are technically no feasible to be validated for several reasons including lack of specialised probes, no high number of devices/UEs to provide reliable results etc (details on this are provided in the dedicated section of each UC inside the document). In cases that these KPIs are important for the specific UC, other methods of evaluation will be used (e.g., simulations). KPIs marked with “green” colour code are expected to be performed in a realistic time perspective, and will be completed in full in the final phase of the project. This is due firstly to the current 5G-TOURS infrastructure development and secondly to the degree of difficulty in implementing certain measurements.

As discussed in sections 3, 4 and 5, we provide a detailed KPI verification methodology. However, some of the KPIs included may be difficult to be evaluated for a number of reasons, being the most important ones:

- The size of the testbed: 5G-TOURS aims at a large scale trials of innovative 5G use cases, however, their size is still not at the same level as commercial deployments open to the public. Therefore, KPIs such as density or capacity will necessarily suffer from this condition.
- The duration of the deployment: as UCs will be deployed for a limited amount of time (the platform, especially the cloud, may be shared with other projects leveraging the ICT 17 platform and the showcasing is only performed into well specified event), evaluating characteristics such as the overall reliability of the system may be achieved with a limited statistical relevance.

For the affected KPIs (marked in red under the definition "Difficult to be measured ", we will i) study the impact of the thorough evaluation of the specific KPIs on the successful UC deployment and ii) resort to different solutions to solve this shortcomings.

These may be i) simulation or emulation techniques, ii) analytical evaluation to understand lower and upper boundaries and, in some cases, iii) deploy specific hardware and software to stress the network in these conditions (e.g. specific elements in the Athens site).

In this deliverable, initial results from the KPI collection, analysis and validation process are presented. These results are presented and explained in detail in sections 3.4, 4.4 and 5.4. Due to the covid pandemic, the project faces difficulties in accessing the trial locations, having as a consequence that only a small set of results could be collected and therefore presented in the current deliverable. The plan is to accelerate this process during the next period in order to also compensate for the slow start due to the covid pandemic.

2.3 QoE evaluation methodology

5G-TOURS partners developed the QoE evaluation methodology in order to evaluate the level of satisfaction of end-users and verticals’ players with the deployed use cases. This includes users' QoE from the vertical players on how the technology provided can improve their business operations.

In addition to the validation of the QoS results which illustrates mainly the performance of the network KPIs and can compared against the 5G PPP targets (5G-PPP, 2019), it is indeed of paramount importance to validate the actual satisfaction of both i) end-users and ii) the vertical players (either as service providers or users of secondary service flows). In this direction, the 5G-TOURS QoE evaluation methodology was developed, the high-level architecture of which is presented in Figure 5.

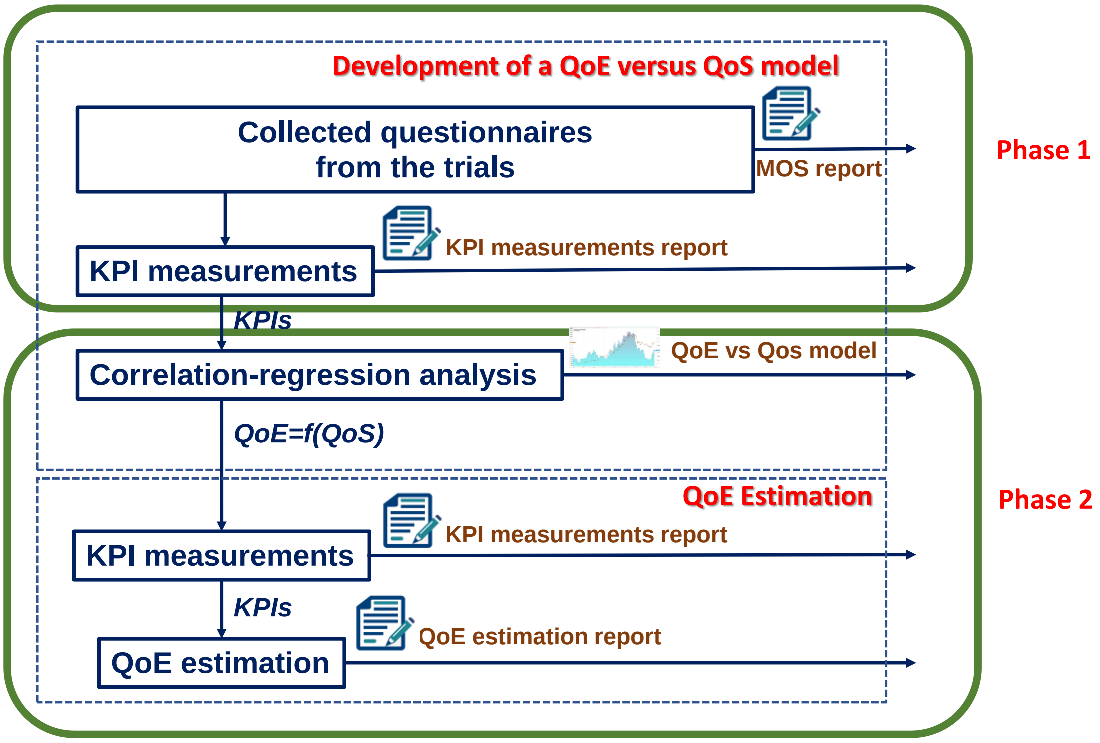


Figure 5. WP7 approach for evaluation methodology.

We discriminate between two phases. Phase 1 is realized during the trials execution and collects both the QoS metrics, automatically collected from the infrastructure, and the QoE metrics (and vertical satisfaction) collected using appropriate questionnaires. As discussed, the user's definition of QoE does not consider measurability and so set of QoS parameters, which together provide a service and mostly influences the QoE, has to be defined. The most important parameters from this set can be measured and quantified. To define this set of parameters, Phase 2 is realized after the trials executions and by using correlation-regression analysis which aims to create a model for QoS-QoE correlation.

2.3.1 QoE and Vertical satisfaction Model

Quality of experience is essentially a human related experience that is difficult to measure using quantitative techniques, although quantitative methods have been proposed for the assessment of QoE in videos (Steven Latr, 2008). QoE is traditionally measured through Mean Opinion Scores and questionnaires. These questionnaires include a set of multiple questions with a specific weight usually defined with a specific scale, as originally proposed by (Likert, 1932), extended with some open questions.

The rationale behind this decision is to exploit the questionnaire filling procedure to also achieve some insights behind the ones already obtained by the questions. Clearly those open questions cannot be mathematically evaluated, as discussed next, but they can provide further useful feedback.

The final version of the mentioned questionnaires tried to address four critical requirements:

a) Validate both the user satisfaction as well as the vertical satisfaction (in each UC questionnaires are generated for both users and main shareholders)
b) Cover aspects that will become useful during the QoE-QoS correlation process
c) Share some commonalities between UCs
d) Deal with cost and pricing aspects allowing WP7 to provide WP8 at a next stage with important insights

For the estimation of the overall QoE level we rely on the hypothesis function:

$$h(\theta) = \theta_0 \cdot x_0 + \theta_1 \cdot x_1 + \ldots + \theta_n \cdot x_n,$$

where n: the number of features in the data set; x – QoS parameters, θ – weight coefficients.

For estimation of the θ, it was proposed to use the next Normal Equation (Bendersky, 2014):

$$\theta = \left(X^T X\right)^{-1} \cdot \left(X^T y\right).$$

In the above equation,

- θ (Estimated QoE): hypothesis parameters. It is subjective characteristic.
- X (Input QoS parameters): Input feature value of each test instance. For example: bandwidth, delay, jitter, etc.
- y (Output QoE): Output value of each test instance. It has to be defined with the questionnaires.

2.3.2 Generation of the questionnaires

As part of the evaluation methodology WP7 generated a set of questionnaires per UC that will be used for the QoE/vertical satisfaction validation.

It was a long interaction process (three rounds) between WP7 and WP4/5/6 (Stage 1 in Figure 6) as well as with WP8 for the economic aspects.

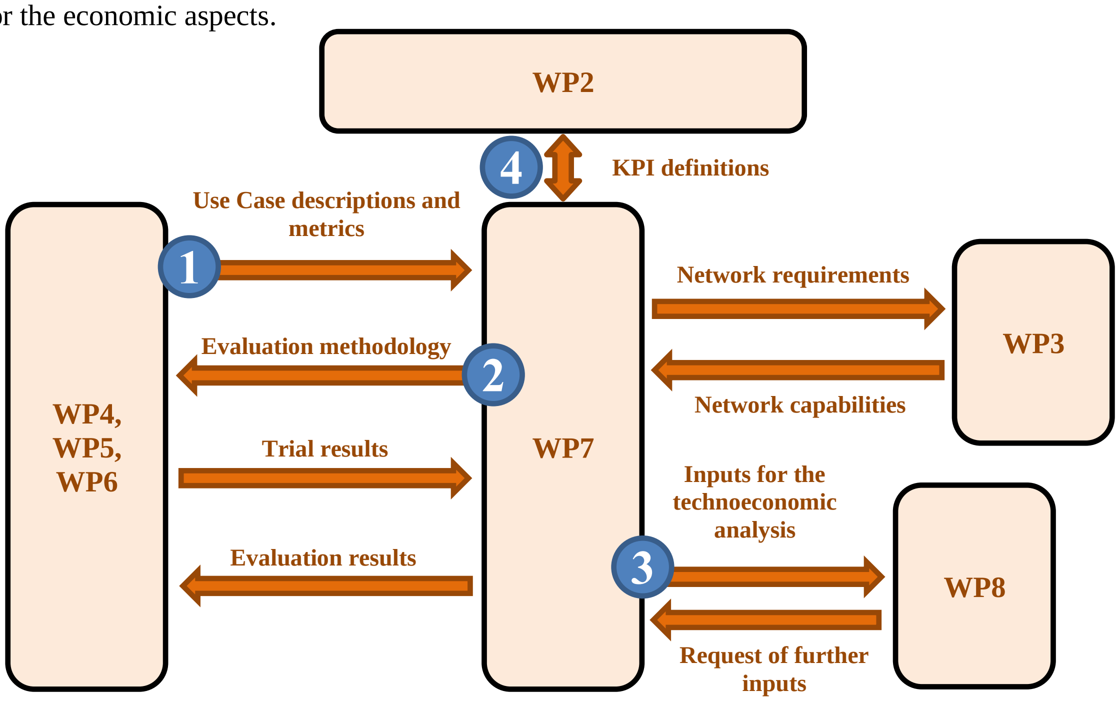


Figure 6. Interaction between the WPs during the evaluation process.

Final version of the Questionnaires includes a set of multiple questions (following the well-known Likert approach) and some open questions, which will not use the numerical validation discussed before. The questionnaires try to (Stage 2 in Figure 6):

- Validate user experience;
- Cover aspects that will become useful during the QoE-QoS correlation process;
- Deal with cost and pricing aspects allowing WP7 to provide WP8 with important insights at a next Stage 3 in Figure 6.

To provide the most effective process of questionnaires' creation, the following methodology was defined and followed for each UC:

1. UC owners defined the most relevant characteristics that have the largest influence to user satisfaction in the UC. For instance, for UC3 the smooth movement as well as speed of the robot have a fundamental impact on the user satisfaction, while other UCs have other peculiarities.
2. According to the most relevant characteristics (defined in Step 1) several questions have to be proposed. For instance, some of the questions designed for UC3 are:
    a) What was the speed of the robot movement?

- Answer: (1 - 0 kmph; 2 - too slow; 3 - slow; 4 - less than optimal; 5 - optimal speed)

b) Does the robot stop abruptly its operation?

-Answer: 1 - stops very frequently, ..., 5 - doesn't stop

3. For such questions (defined in Step 2), UC owners (involved partners) prepared non-technical explanations for non expert users.
   e.g. for Question 1: Optimal speed of the robot movement is 2-3 km/h.
4. For each characteristic (defined in Step 1) UC owners (involved partners) defined weight coefficients ($K_1, K_2, ...K_n$), where n - is the number of characteristic. $K_1+K_2+...K_n=1; 0<K_1,K_2,..K_n<1$. This allows to rank the different characteristics, according to their importance.
5. Finally, the overall mark can be calculated as follows:
   $QoE= K_1*Answ_1+K_2*Answ_2+...K_n*Answ_n$

As an example, different types of questions from the final version of UC questionnaires are presented below:

- How do you rate the time taken by the application to download the 3D model? *Excellent, Good, Fair, Poor, Very Poor (**QoS / End user satisfaction question)***
- How was the quality of the video streaming experienced during the visit? *Excellent, Good, Fair, Poor, Very Poor (**QoS / End user satisfaction question**)*
- Please state how much you agree with the following statement: I would like to pay an extra fee for the usage of the augmented tourism experience *Strongly agree, agree, neutral, disagree, Strongly Disagree (**Cost/pricing aspects question)***
- Please state how much you agree with the following statement: Your interaction with the additional surveillance functionalities helped you to do better your job? *Strongly agree, agree, neutral, disagree, Strongly Disagree (**Vertical use satisfaction question)***
- If you like, please provide your open feedback on your experience during the Museum visit *'Open comment' (**Open questions**)*

The final versions of the questionnaires for all UCs can be found in Appendix A.

For almost all the use cases, it is very important to know also the feedback from the vertical itself, for aspects mostly related to the:

i. QoE provided by the network;
ii. The flexibility and easiness of use provided by the service support system used by the 5G-TOURS project: the 5G-EVE portal and the extensions provided by the Service Layer;
iii. Economic aspects.

The feedback provided by the verticals, in both form of quantitative and qualitative questions, will be used to assess the QoE/QoS mapping as discussed before and provide feedback to WP2 (on the validation of their hypothesis, Stage 4 in Figure 6), and WP8 (for the technoeconomic analysis, Stage 3 in Figure 6).
It has to be mentioned that, during the whole methodology design, phase WP7 continuously monitored the outcomes of WP2 and updated its methodology accordingly (Stage 4 in Figure 6).

3 Touristic city integrated ecosystem, use case deployment, trial and validation

3.1 General description

Turin site focuses on 5G TOURS "touristic city" Use Cases (UCs) that use 5G-enabled applications to improve citizens and tourists experience in their visit to the city with its museums and outdoor attractions. Deployed UCs provide added value services and media applications to enrich and complement physical visits and enable remote ones through VR/AR applications, robot-assisted visits/telepresence as well as multi party content production on live events and broadcast distribution.

The aim in common to all five UCs is to enhance accessibility of the city heritage and culture in an immersive, inclusive and multimodal manner that takes advantage of the availability of the three different kind of services provided by 5G architectural flexibility (i.e., enhanced Mobile Broadband, Ultra Reliable and Low Latency communications, and massive Machine Type communications) on the same network infrastructure.

The Turin node deployed UCs are:

- UC 1 - Augmented tourism experience, which is further divided into two sub-UCs:
  - UC1a is about the enhanced visiting experience through Virtual Reality
  - UC 1b is about the gamification experience in a museum via Augmented Reality services
- UC 2 – Telepresence
  - UC2 sub-UCs (a,b, and c) are related to the robot-assisted enhancement of the number of user that can visit the museum, in different contexts such as the remote visit guided by a robot or the remote surveillance during night.
- UC 3 - Robot-assisted museum guide
- UC 4 - High quality video services distribution
  - UC4a relates to the video broadcasting to the crowd, while UC4b is related to the development of a full broadcast capable mobile network.
- UC 5 - Remote and distributed video production

More details on touristic city UCs are available on WP2 and WP4 deliverables, see (5G-TOURS, D2.2, 2020) and (5G-TOURS, D4.2, 2020).

Network available in Turin site is composed of a combination:

(i) Commercial deployments based on infrastructure owned by TIM and provided by Ericsson

(ii) Experimental/pre-commercial facilities deployed to test Rel-16/17 equipment and 5G-TOURS innovative functionalities, relying mostly on installations, that complement 5G EVE existing infrastructure to benefit of its platform in the implementation of innovations studied in 5G-TOURS.

More details on Turin node deployed network, its architecture and characteristics are available in 5G-TOURS D3.2, (5G-TOURS, D3.2, 2020) and (5G-TOURS, D4.2, 2020).

3.2 Integrated ecosystem

The Turin trial site is composed by a number of assets that will be deployed to successfully deliver the 5 use cases proposed in the project that showcase the need of 5G in the context of smart tourism. In the following, the Turin site is depicted in its different aspects.

As reported in (5G-TOURS, D3.2, 2020), the infrastructure deployment in the Turin site is structured along two phases. While in the phase 1 the 5G indoor and outdoor coverages specifically deployed for the implementation of the use case at Palazzo Madama and GAM are connected to the TIM commercial network (therefore providing a 5G connectivity), phase 2 will move towards the integration with the 5G EVE infrastructure in order to integrate the 5G-TOURS network innovations in the context of the overall 5G network solution of the Turin site. In the following, the focus is on the phase 2 planned deployment, although some initial KPI evaluation has been already performed on the infrastructure deployed in phase 1.

A possible instantiation of the architecture proposed by 5G-TOURS in the Turin site is depicted in Figure 7 below, which takes as an example UC1 and the different network slices deployed therein. More specifically, UC1a encompasses all the three 5G slices such as:

- The eMBB slice for the Augmented Reality experience
- The mMTC-alike slice for the Internet of Things service
- The URLLC slice devoted to the Virtual Reality gamification part

They are depicted in Figure 7 below with different orange patterns: there are three different applications running in the site:

- Virtual Reality (VR, for UC1a) which requires a Mobile Broadband slice type
- Augmented Reality (AR, UC1b), which requires low latency and can be classified under the URLLC slice type
- A set of sensors deployed in the city, which are an IoT deployment under the massive Machine Type Communications (mMTC) slice

They share common network deployment (marked in purple in Figure 7).

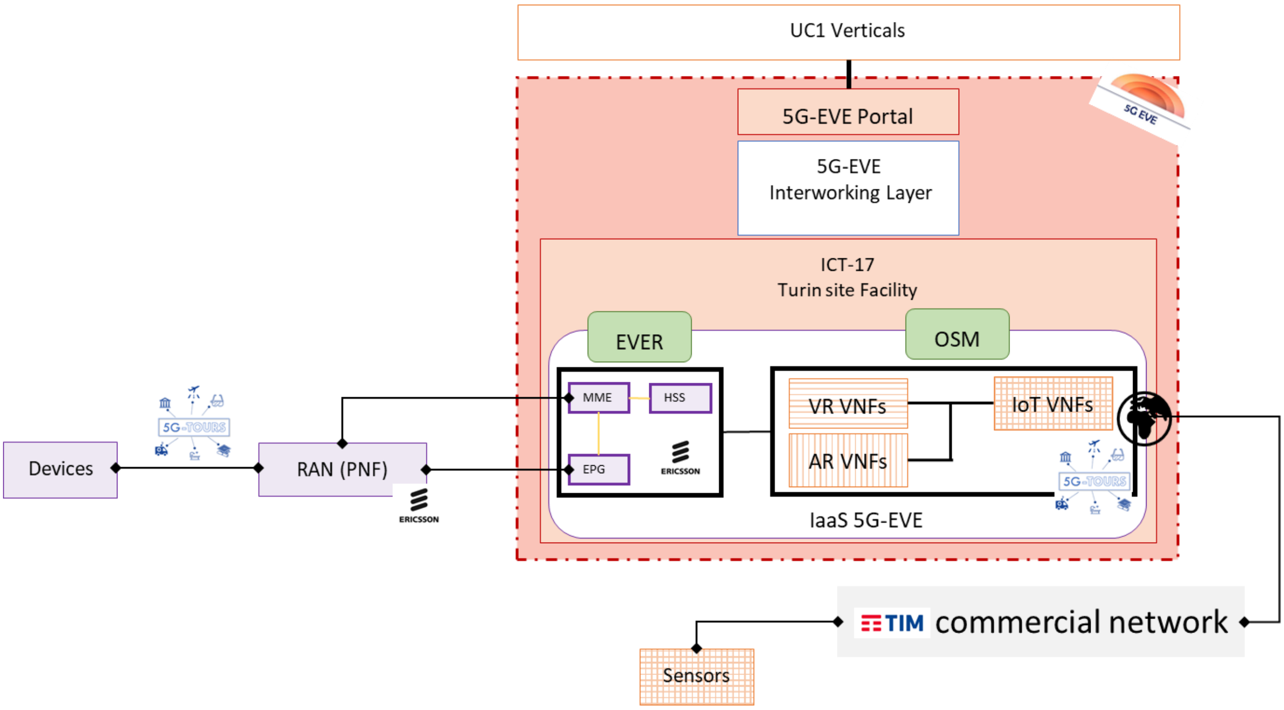


Figure 7. The architectural instantiation of UC1a in the Turin Site. The different network slices are depicted with different patterns

The Turin site overall infrastructure depicted in Figure 7 consists of hardware, software and transport network assets, in which the 5G-TOURS and 5G EVE logos highlight the two project's assets respectively. Among the hardware we can identify the Infrastructure as a Service platform deployed between the TIM Laboratory and Politecnico of Turin and the radio access network based on Ericsson solutions. In particular, the radio access network providing the 5G coverage for the use cases could be deployed both at the museum's sites (Palazzo Madama and GAM) and TIM Laboratory premises. Studies are currently ongoing in order to find the most efficient and effective deployment solution to accomplish the objectives related to the use cases implementation (according to their roadmaps) and 5G-TOURS innovation showcase (based on the 5G EVE infrastructure functionalities and availability). Currently, the ad-hoc deployment of 5G Networks is connected to the commercial 4G Core network of TIM, in a Non Standalone mode, as envisioned for the phase 1 solution.

The edge sites and the TIM Laboratory are connected through a metro fibre network, which is capable to support the requirement imposed by the gNB to Core connection. In terms of software components, a substantial number of components are inherited from the 5G EVE platform. Most importantly, the management and orchestration framework developed by the 5G EVE project, including the 5G EVE portal, that will be used to onboard the VNFs implementing the UC1a application through the 5G EVE Interworking Layer and the two orchestrators available in the Turin site: the OSM-based service orchestrator in charge of deploying the specific VNFs related to services (deployed at the Politecnico of Turin) and the Ericsson EVER Orchestration (deployed at TIM Laboratory) that takes care of the RAN and Core Network Functions (implemented by Ericsson as well). More details can be found in D3.2 (5G-TOURS, D3.2, 2020).

While the Mobile Broadband and Low Latency communications rely on this infrastructure, the specific case of the IoT network (i.e. mMTC slice) uses the TIM Commercial LTE network, due to the current unavailability of 5G IoT modules (both sensors and Narrowband IoT enabled base stations). The IoT specific VNFs, which are handling the data coming from the sensor network deployment (5G-TOURS, D4.2, 2020), are deployed in the Infrastructure as a Service facility available in Turin, though.

On top of this baseline architecture, the innovations proposed by WP3 will be instantiated. These innovations allow to improve the network performances (on the KPIs achieved by the network and on the configuration flexibility for network slices). Specifically, in Figure 8 below we depict how the different innovations will be instantiated in the network.

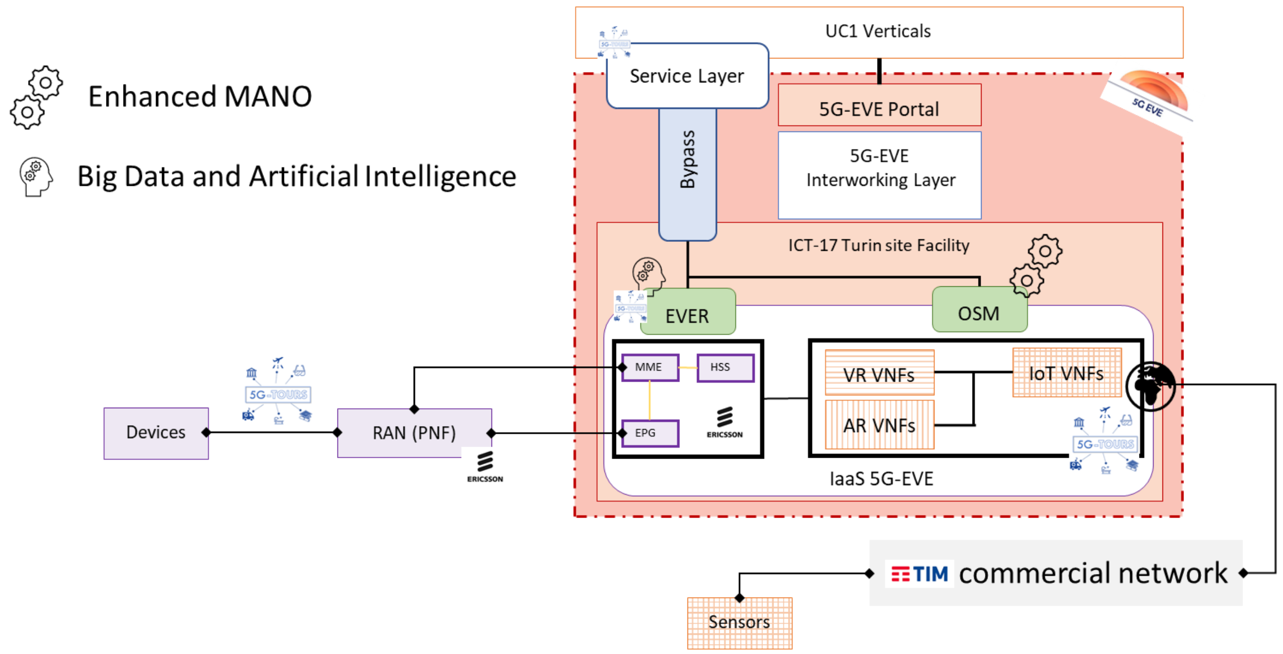


Figure 8. Placement of the novel functionality within the network architecture.

Enhanced MANO solutions will be developed to allow the OSM network orchestrator deployed in Turin to support AI and big data solutions. Specifically, this is aligned with the ongoing WP3 (5G-TOURS, D3.2, 2020) activities related to the development of AI agents and the ETSI ENI PoC (5G-TOURS, D8.1, 2020). While this will not impact the pure performance KPI of the services, it will provide (through the Service Layer directly exposed to vertical) a flexible way of managing network slices from the vertical perspective (the museum, in this case). The AI module will abstract the complexity needed to configure re-orchestration solutions (setting thresholds that may vary according to the considered services) by exposing a “knob” value with high level configuration patterns. For instance, verticals may select between a more conservative (in terms of provisioned infrastructure) but more expensive configuration and a more aggressive (in terms of resource savings) and cheaper ones. The AI algorithms will take care of proactively setting up these thresholds and triggering the needed actions with the orchestration.

So, these thresholds are autonomously managed through the Big Data and Artificial Intelligence algorithms, like the capacity forecasting one explained in (5G-TOURS, D3.2, 2020). Broadcast capabilities are provided through a different infrastructure and are specifically constrained to fulfil the broadcast related UCs.

In the following Table 5. Network innovation for different UCs 1/2/3/4/5., we summarize the deployment of the 5G-TOURS network innovation in a tabular format.

Table 5. Network innovation for different UCs 1/2/3/4/5.

	Network Innovation		
Use case 1	Service layer	Enhanced orchestration	Broadcast
Augmented tourism experience	Exposure of selected AI parameters and continuous KPI monitoring. Onboarding using the 5G-EVE portal.	Implementation of the AI algorithms described in and initially showcased in the ETSI ENI PoC (5G-TOURS, D3.2, 2020)	N/A
Use case 2	Service layer	Enhanced orchestration	Broadcast
Telepresence	N/A	N/A	N/A
Use case 3	Service layer	Enhanced orchestration	Broadcast
Robot-assisted museum guide and monitoring	N/A	N/A	N/A
Use case 4	Service layer	Enhanced orchestration	Broadcast
High quality video services distribution	N/A	N/A	Trial of the Rel 16 HPHT solution and tentative integration of the broadcast solutions into the 5G-EVE IaaS
Use case 5	Service layer	Enhanced orchestration	Broadcast
Remote and distributed video production	Onboarding through the 5G-EVE portal	N/A	Broadcasting, using the HPHT deployed for UC4, of the UC5 produced media

3.3 Technical validation

Appendix A in D2.2 (5G-TOURS, D2.2, 2020) provides a method to translate service requirements into network ones to provide indication about the minimum network KPI values to match expected QoS; network KPI are those defined in (5G-TOURS, D2.2, 2020) par. 4.2 and in (5G-TOURS, D7.1, 2020) par 3.1.

This is completely general approach valid on all UCs across all sites. In the present paragraph, it is reported the result of the evaluation for each UC deployed in Turin site with the indication and explanation about the relevance of each KPI for the specific UC. Moreover, the Architecture of each UC is shown and relevant KPI measurement methods are proposed.

According to the current network deployment time plan, the first tests on commercial 5G network have been shifted as consequence of the covid pandemic and they will be performed in Turin in the first half of 2021. Therefore, some KPIs measurements cannot be available in time for this deliverable for any of the UCs and will be included in next deliverable D7.3; on UC 3 and on UC 5 intermediate validation of KPI measurements has been performed activity description and results are reported in Section 3.4.

Typical tools used to gather measurements in the trials are:

- Ping is a software tool which measures the network layer RTT for messages sent from one machine to another machine.
- IPerf is an open source, multi-platform and freely available tool which is capable of measuring the network bandwidth, jitter and packet loss. It is used to measure the network layer (i.e., DL and UL) throughput.

3.3.1 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, see Table 6. UC 1 Augmented tourism experience network requirements – summary of sub-UCs.

Table 6. UC 1 Augmented tourism experience network requirements – summary of sub-UCs.

5G-Tours - Use Cases: direct specific Technical requirements			Units	UC1: Augmented tourism experience			Priority	Range	
				URLLC	mMTC	eMBB		Min	Max
General Vertical Use cases requirements									
●	1	Latency (in milliseconds) - round trip - Min/Max	msec	20	50	100		20	100
●	2	**RAN** Latency (in milliseconds) - one way	msec	10	25	50		10	50
●	3	Throughput (in Mbps) - Min/MAX - sustained demand	Mbps	40	40	40		15	40
●	4	Reliability (%) - Min/Max	%	99,9999%	99,9999%	99,9999%		99.00%	99,9999%
●	5	Availability (%) - Min/Max	%	99,99%	99,99%	99,99%		99.00%	99,99%
●	6	Mobility (in m/sec or Km/h) - Min/Max	Km/h	10	0	10		0	10
●	7	Broadband Connectivity (peak demand)	Y/N or Gbps	0.08	0.08	0.08		0.04	0.08
●	8	Network Slicing (Y/N) - if Y service deployment time (min	Y/N	50	50	50		10	90
●	9	Security (Y/N) - if Y grade i.e. "Carrier Grade"	Y/N	Y	Y	Y			
●	10	Capacity (Mbps/m^2 or Km^2)	Mbps/m^2	12	12	12		6	12
●	11	Device Density	Dev/Km^2	400	400	400		400	400
●	12	Location Accuracy	m	<1	<0,5	1		0.5	1

● **Non relevant KPIs**

- ➢ **Mobility:** this specific UC is stationary or pedestrian
- ➢ **Security:** UC1 (and all other UCs in Turin do not pose specific requirement
- ➢ **Location accuracy:** A beacon based location service is employed. It is currently not integrated into the 5G network

● **Relevant but not critical KPIs**

- ➢ **Reliability** and **Availability:** As this is not a mission critical UC; the service stability is measured as the ratio between the uptime vs total time. Formally, availability is measured as:

$$Availability = \frac{Uptime}{Uptime+Downtime}$$

where Uptime and Downtime are the times when service stays up (Uptime) or down (Downtime) during the observation time. As, specific probes could not be deployed around each SW/HW component, Reliability is not measured.

● **Difficult to be demonstrated KPIs**

- ➢ **Broadband connectivity:** Due to the low number of devices, the peak capacity could not be fully tested.
- ➢ **Capacity** and **Device density:** Only a low number of devices are involved

● **Relevant KPIs**

- ➢ **Network slicing deployment time:** Although the slice deployment time can be regarded as not relevant for this type of services, as they are not emergency ones, UC1 will be the targeted UC for measuring the slice management performed by the EVER orchestrator in Turin. More precisely, the EVER API will be leveraged to perform measurements related to the slice deployment time. EVER provides APIs for the 6 main functions related to the Network Slice Instance management (Preparation, Commissioning, Instantiation, Modification, De-Activation, and Termination). More specifically, we will measure timings on the /create and /instantiate endpoints of the EVER orchestration framework (5G-EVE, D3.4, 2020).
- ➢ **Latency:** measured at application level by means of ICMP probes.
- ➢ **RAN latency:** measured by ERI-IT on Ericsson RAN. To be noticed that Turin site phase 2 RAN solution is still under discussion inside WP4, different options for RAN latency measurement are under analysis (e.g. use of Ericsson RAN internal performance counters that take in account data packet transit time across RAN or latency difference in lab environment: between wired and 5G wireless

connectivity, between 5G and 4G wireless connectivity, etc.). The final choice how to measure it will be made at a later stage.

- **Throughput:** measured at application level through in-app metrics.

UC 1.a – In the very heart of Turin

This sub-UC purpose is to enhance the experience of Palazzo Madama visitors through an App that provides information about the museum and its surroundings, enable access to specific contents for each room or artwork and the interaction with 3D objects in virtual scenarios; contents can be stored even for an offline fruition.

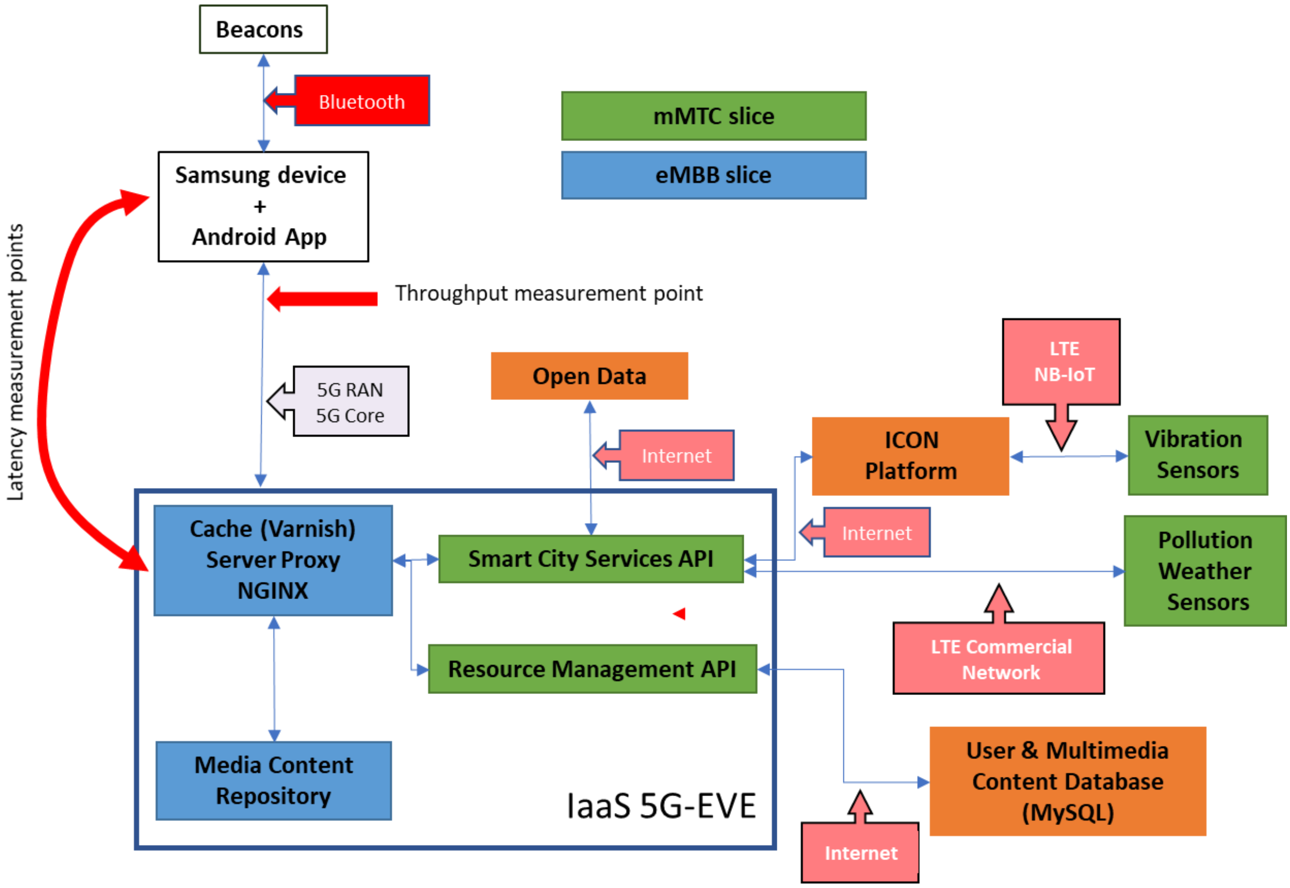


Figure 9. UC 1.a AR architecture

Throughput and latency are the main KPIs addressed by this UC. While latency is measured end to end through ICMP packets sent from the user to the server, the applications can gather the user level throughput for each connection. With respect to RAN latency, more details will be provided once the full phase 2 setup is put into operation.

UC 1.b – Gamification let's play artist

The objective of this sub-UC mixes extended reality and gamification and targets students or families with children allowing them to test directly artwork creation process entering in the life and work of N. De Maria at GAM museum and reproducing his canvas on an interactive wall.

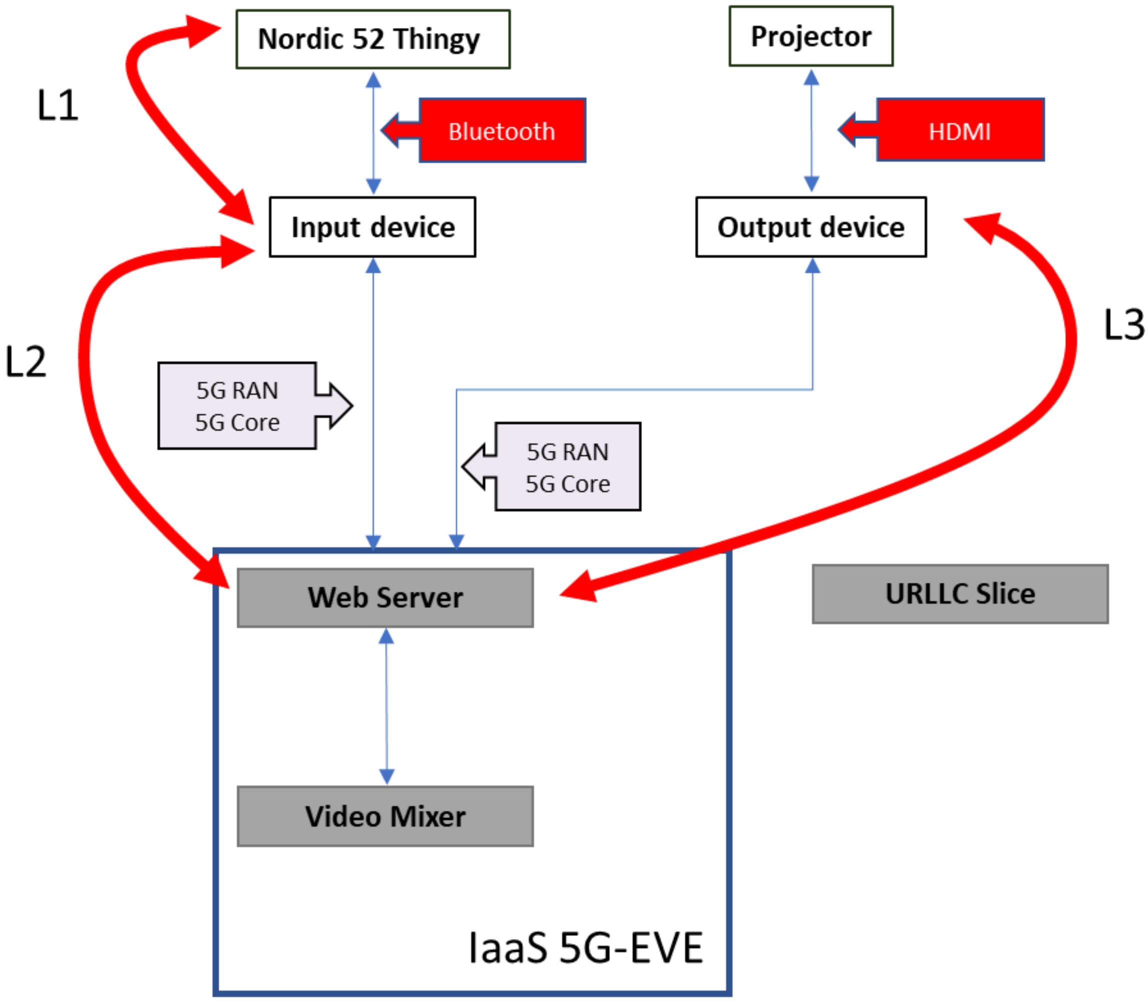


Figure 10. UC 1.b Architecture and measurement probes positioning.

Latency in UC1.b is measured by splitting it into three parts, according to the different segments involved in the communications. L1 is considering the delay between the Nordic 52 device and the server using Bluetooth. L2 and L3 are measuring the 4-way delay between the two machines through the 5G network. All of them are measured through ICMP packets. Throughput is measured via in app probes. For LAN latency, see the description of UC1a.

3.3.2 UC 2 Telepresence

This use case employs a robot located inside the museum, controlling it from remote location. Telepresence robots have the potential to contribute to accessibility and inclusiveness by extending access (e.g. enlarging number of visitors for exhibitions, providing access to school from remote locations) and provide surveillance services.

Table 7. UC 2 Telepresence network requirements.

		5G-Tours - Use Cases: direct specific Technical requirements	Units	UC2 – Telepresence			Priority	Range	
				URLLC	mMTC	eMMB		Min	Max
General Vertical/Use Case Requirement									
●	1	Latency (in milliseconds) - round trip - Min/Max	msec	2			High	1	10
●	2	**RAN** Latency (in milliseconds) - one way	msec	1			high	1	5
●	3	Throughput (in Mbps) - Min/MAX - sustained demand	Mbps	30			High	~10	~30
●	4	Reliability (%) - Min/Max	%	99,9999%				99,000%	99,9999%
●	5	Availability (%) - Min/Max	%	99,9999%				99,000%	99,9999%
●	6	Mobility (in m/sec or Km/h) - Min/Max	Km/h	1				0,1	1
●	7	Broadband Connectivity (peak demand)	Y/N or Gbps	0,1					0,1
●	8	Network Slicing (Y/N) - if Y service deployment time (min)	Y/N	Y (30)					
●	9	Security (Y/N) - if Y grade i.e. "Carrier Grade"	Y/N	Y					
●	10	Capacity (Mbps/m^2 or Km^2)	Mbps/m^2	30				~10	~30
●	11	Device Density	Dev/Km^2	5				1	5
●	12	Location Accuracy	m	0,1				0,1	0,5

● **Non relevant KPIs**

- ➢ **Mobility:** robot speed is close to pedestrian one
- ➢ **Broadband connectivity:** Not enough devices to stress the network
- ➢ **Network slicing deployment time:** As discussed for UC1, we will measure the network slicing deployment time at the EVER orchestration, which will be our reference UC for the network slicing deployment time. As depicted in Figure 11, UCs will largely share the infrastructure, hence we will provide this metric just for UC1.
- ➢ **Capacity** and **Device density:** Only one device (robot) involved
- ➢ **Location accuracy:** Double 3 robot is a teleoperation only system guided from same or remote location

● **Difficult to be demonstrated KPIs**

- ➢ **Security:** See UC1
- ➢ **Reliability** and **Availability:** The duration available to make the measurements is short

● **Relevant KPIs**

- ➢ **Latency** and **Throughput:** see each sub-UC description (paragraphs 0, 0 and 0)
- ➢ **RAN latency:** See UC1

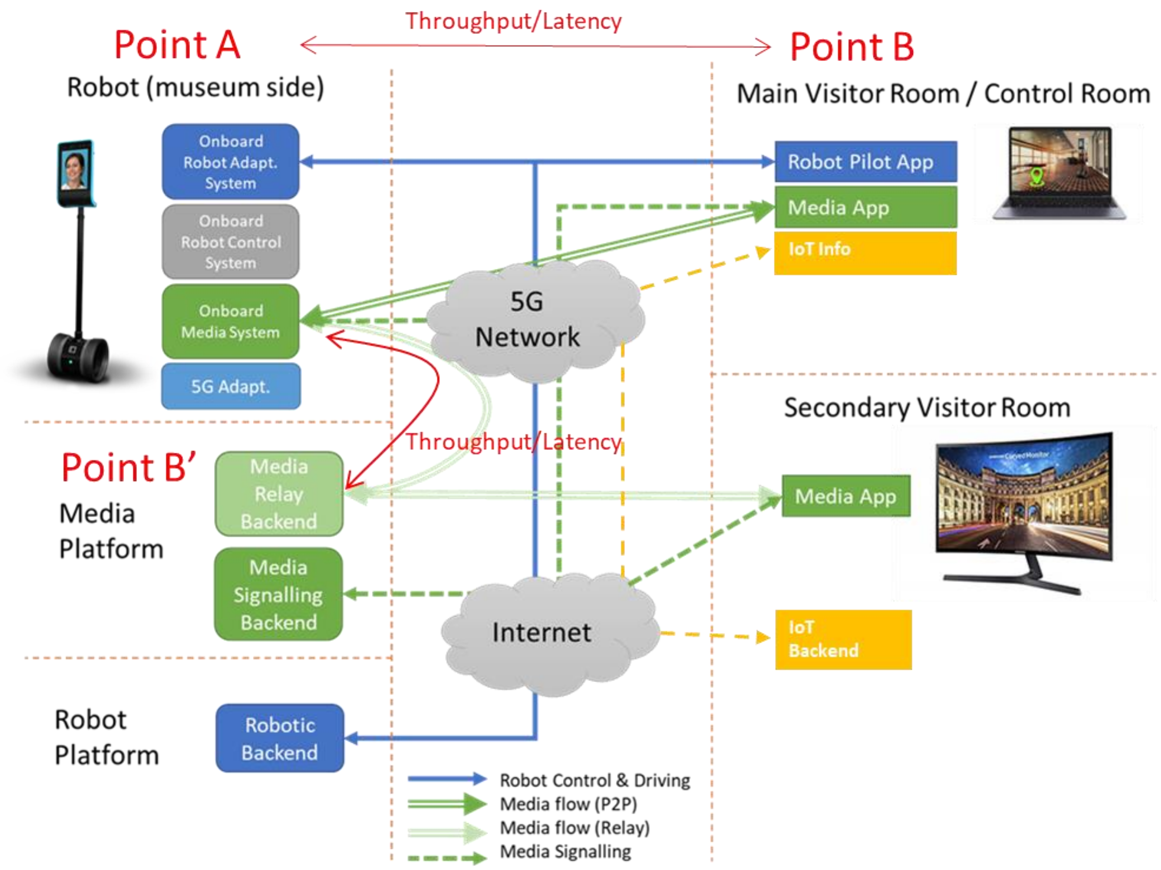


Figure 11. UC 2a, b and c architecture and measurement probes positioning.

UC 2.a

This sub-UC aim is to enlarge the public for selected exhibitions, to make the experience accessible from remote to promote events and attract more tourists.

In Figure 11, the measuring points are indicated, for both throughput and latency, that are located on the robot (point A) and on the driver/control room client (point B).

The tools used are: Ping between the two points A and B and browser based set of tools allow developers to check all the internal parameters and status from the robot firmware for latency and the same browser tool plus embedded quality gauge overlapped to video stream cast by the robot, containing minimal and useful information about the multimedia flow (frame size, frame rate, current bitrate etc.) for throughput measurement.

UC 2.b

This sub-UC is intended to offer enhanced educational activities to students at school remotely connected with Edulab premised with GAM.

In Figure 11, the measuring points are reported. for both throughput and latency, that are located on the robot (point A), on the driver/control room client (point B) and on the Media Relay server (point B').

Tools used for latency and throughput measurements between the points A and B are the same described in 0 for UC 2.a while for measurements between A and B points, ping and media relay control panel are used for latency and throughput respectively.

UC 2.c

In this sub-UC robot is used for tele surveillance of the museum, possible extension is monitoring of social distancing inside the museum.

For UC 2.c measuring points (shown in Figure 11) and tools used for measurements are the same used in UC 2.a and described in 0, for Double 3 robot usage.

On UC 2.c R1 robot usage too is foreseen; in that case measurement probes position and tools are the ones reported in 3.3.3.

3.3.3 UC 3 Robot-assisted museum guide

This UC foresees the use of robotic technology to enhance museum visit experience; R1 robot will interact with visitors assisting them during queuing time at the desk, guiding them through the museum and describing artworks. R1 will perform its activity autonomously with human intervention required only in emergency situations.

Table 8. UC 3 robot-assisted museum guide network requirements

5G-Tours - Use Cases: direct specific Technical requirements			Units	UC3: Robot-assisted museum guide and monitoring			Priority	Range	
				URLLC	mMTC	eMMB		Min	Max
General Vertical/Use Case Requirement									
🟢	1	Latency (in milliseconds) - round trip - Min/Max	msec	2			High	1	10
🟢	2	**RAN** Latency (in milliseconds) - one way	msec	1			high	1	5
🟢	3	Throughput (in Mbps) - Min/MAX - sustained demand	Mbps	30			High	~10	~30
🟢	4	Reliability (%) - Min/Max	%	99,9999%				99,0000%	100,0000%
🟢	5	Availability (%) - Min/Max	%	99,9999%				99,0000%	100,0000%
●	6	Mobility (in m/sec or Km/h) - Min/Max	Km/h	0,5				0,1	0,5
●	7	Broadband Connectivity (peak demand)	Y/N or Gbps	0,1					100Mbps
●	8	Network Slicing (Y/N) - if Y service deployment time (min)	Y/N	Y (30)					
●	9	Security (Y/N) - if Y grade i.e. "Carrier Grade"	Y/N	Y					
●	10	Capacity (Mbps/m^2 or Km^2)	Mbps/m^2	30				~10	~30
●	11	Device Density	Dev/Km^2	1				1	1
●	12	Location Accuracy	m	0,1				0,1	0,5

● **Non relevant KPIs**

- **Mobility:** robot speed is close to pedestrian one
- **Broadband connectivity:** not enough
- **Network slicing deployment time:** Not relevant for this type of services
- **Capacity** and **Device density:** Only one device (R1 robot) involved
- **Location accuracy:** R1 robot relies on beacon system for positioning, not on 5G network

🟢 **Relevant KPIs**

- **RAN latency** see UC1.
- **Latency:** A and B probes positioning I accordance to Figure 12; tool Ping
- **Throughput**: A and B probes positioning I accordance to Figure 12; tool Iperf
- **Availability:** see UC1
- **Reliability:** using the formula

$$Reliability\ (t) = e^{(-t/MTBF)}$$

where Mean Time Before Failure (MTBF) is calculated considering all the network functions involved in service provisioning (HW and SW) and positioned in the network segment between A and B probes (see Figure 12).

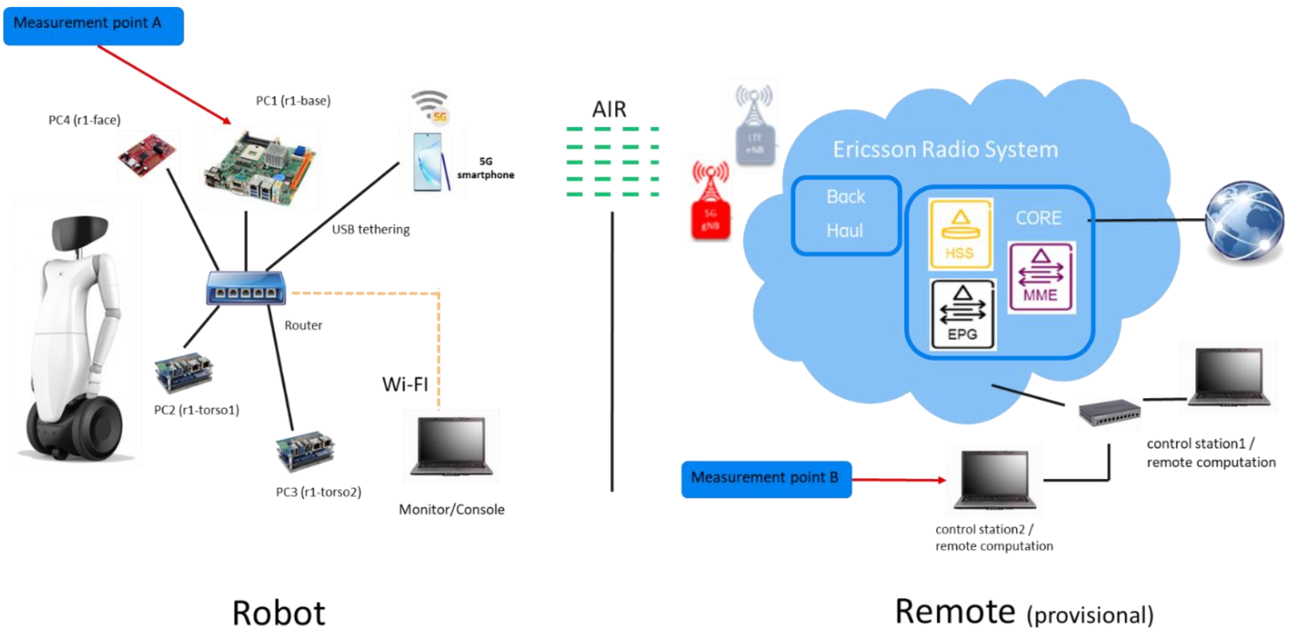


Figure 12. UC 3 Robot-assisted museum guide architecture and probes positioning

3.3.4 UC 4 High Quality video service distribution

UC4 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.

Table 9. UC 4 High Quality video service distribution network requirements.

5G-Tours - Use Cases: direct specific Technical requirements			Units	UC4: High quality video services distribution			Priority	Range	
				URLLC	mMTC	eMMB		Min	Max
General Vertical/Use Case Requirement									
●	1	Latency (in milliseconds) - round trip - Min/Max	msec			10 ms	Medium	10 ms (bi-directional)	None (broadcast)
●	2	**RAN** Latency (in milliseconds) - one way	msec			5 ms	Low		
●	3	Throughput (in Mbps) - Min/MAX - sustained demand	Mbps			25	High	25 Mbps	-
●	4	Reliability (%) - Min/Max	%			99,9999%	High	99,999%	99,9999%
●	5	Availability (%) - Min/Max	%			99,90%	Medium		
●	6	Mobility (in m/sec or Km/h) - Min/Max	Km/h			100	Medium	10	100
●	7	Broadband Connectivity (peak demand)	Y/N or Gbps			0,1	-	0,05	0,1
●	8	Network Slicing (Y/N) - if Y service deployment time (mi	Y/N			Y (60)	Medium	60 min	120 min
●	9	Security (Y/N) - if Y grade i.e. "Carrier Grade"	Y/N			N	-		
●	10	Capacity (Mbps/m^2 or Km^2)	Mbps/m^2			-			
●	11	Device Density	Dev/Km^2			N/A (multicast/broadcast)	Low		
●	12	Location Accuracy	m			-	-		

5G - Broadcast LTE-Based is a technology that does not require communication between the user and node, achieving greater flexibility in the network. For this reason, there are many KPIs that are impossible to demonstrate/measure and validate (or are not relevant for this use case).

- **Non relevant KPIs**
  - **Reliability** and **availability:** Not critical, just multimedia content is broadcasted and there are no critical communication between User and Node.
  - **Mobility:** For use case 4.b, mobility (in terms of reception at high-speed scenarios) will be measured by evaluating throughput KPI at the receiver.
  - **Broadband connectivity:** Not applicable in a 5G Broadcast scenario.
  - **Network slicing deployment time:** This use case will be showcased.
  - **Security:** The user does not require any kind of identification in the network, (Free to air) so no authentication or security protocol is necessary.

- ➢ **Capacity:** Not applicable. There are no limits, in terms of Users connected in 5G-Broadcast, because there is no need of feedback from UE side.
- ➢ **Location accuracy:** Not applicable for this use case.

● **Difficult to be demonstrated KPIs**

- ➢ **Latency:** We will try to measure and validate in the 4.c sub-UC. When dealing just with laboratory trials, simulated users will be available with a software tool (Landslide), we have to analyze how to measure, and if possible, latency with these tools.

● **KPIs whose validation is still in discussion**

- ➢ **RAN latency:** Under discussion if its measurement and validation is possible in the sub-UC 4.b.

● **Relevant KPIs**

- ➢ **Throughput:** see each sub-UC description
- ➢ **Device density:** see each sub-UC description

UC 4.a Mixed unicast/broadcast delivery

Decided to drop after a long study phase, no deployment and validation activities are required and foreseen on this sub-UC.

UC 4.b 5G Broadcast delivery to massive audiences

High quality audio/video contents transmitted via broadcasting network of RAI in downlink-only to all users at once.

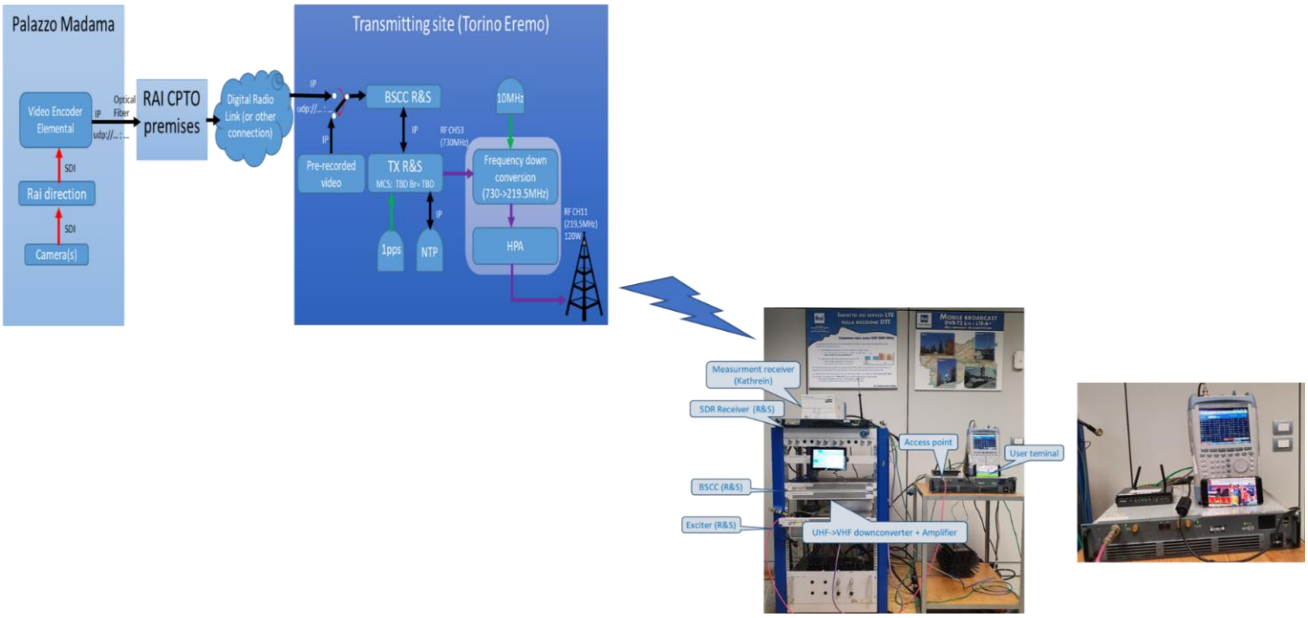


Figure 13. UC 4.b Broadcast delivery to massive audiences, architecture.

On UC 4.b sub-UC the only relevant KPI in plan to be measured is throughput, in order to validate the data rates obtained in 5G Broadcast. 5G Broadcast LTE-Based (Release 16) will be used to transmit multimedia content from Monte Eremo (HPHT distribution) and will be received in Palazzo Madama and also in a car scenario (phase 2); It is envisioned to measure throughput between point A (the end user device, i.e. phone/headset, tablet, etc.) and point B (application server access point). We highlight two possible throughput measures for this sub-UC. On the one hand, the throughput obtained in the field and in the other hand the throughput after the entire protocol stack (Reception). The tool to be used to do field measurements is a measurement receiver from *Kathrein*, connected to SDR receiver (R&S), see Figure 13, and also to the UPV receiver. It is envisioned to use free software iperf to measure throughput after the full stack protocol processing.

UC 4.c 5G Core Multicast

This use case entails the development of a multicast component in the 5G core available in UPV premises. There is no demonstration involved, only sub-UC lab validation.

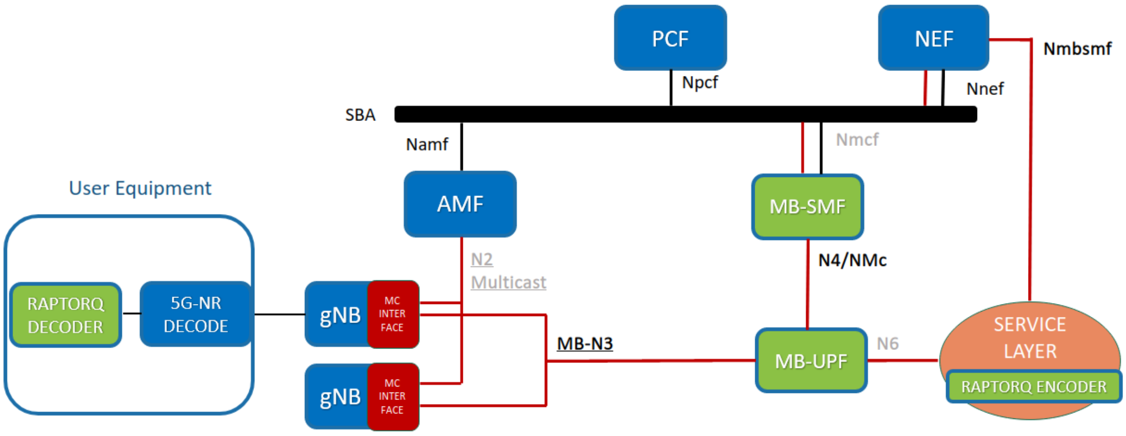


Figure 14. UC 4.c 5G Core Multicast architecture and integration.

On UC 4.c sub-UC the two relevant KPIs are throughput and device density.

Throughput will be measured using Ping and Iperf tools between point A (the end user device, i.e. phone/head-set, tablet, etc.) and point B (application server access point).

Device density will be measured using Landslide (professional network validation tool able to create real life traffic simulating both 4 and 5G RAN with up to 2000 gNB and 4 million UE attached) and counting the number of Landslide simulated user connected to the 5G multicast core. As an additional test, Landslide offers different measures involving throughput that can be used to complement Ping and Iperf measurements.

3.3.5 UC 5 Remote and distributed video production

The main objective of this UC is to exploit the 5G TOURS network features for remote television production, analysing how 5G networks could allow scenarios in which high-quality video and sound is generated in different locations and mixed in a TV studio to produce the content; UL throughput and latency made available by 5G network are the key parameters to allow real time transmission that is essential part of the UC. The implementation of the UC in fact foresees the production of a concert where some musicians are waking towards the hall where the rest of the orchestra is located while playing together.

Table 10. UC 5 Remote and distributed video production network requirements.

5G-Tours - Use Cases: direct specific Technical requirements			Units	UC5 – Distributed video production			Priority	Range	
				URLLC	mMTC	eMMB		Min	Max
General Vertical/Use Case Requirement									
●	1	Latency (in milliseconds) - round trip - Min/Max	msec	10		<50	Med	10	50
●	2	**RAN** Latency (in milliseconds) - one way	msec	1		1	Low	1	5
●	3	Throughput (in Mbps) - Min/MAX - sustained demand	Mbps	180		100	High	50	200
●	4	Reliability (%) - Min/Max	%	99,9999%		99,9999%	High	99,0000%	99,9999%
●	5	Availability (%) - Min/Max	%	99,9999%		99,9999%	Med	98,0000%	99,9999%
●	6	Mobility (in m/sec or Km/h) - Min/Max	Km/h	3		3	Med	0	10
●	7	Broadband Connectivity (peak demand)	Y/N or Gbps	0,25					
●	8	Network Slicing (Y/N) - if Y service deployment time (mi	Y/N	Y (5)		Y	Low	5	15
●	9	Security (Y/N) - if Y grade i.e. "Carrier Grade"	Y/N	Y		Y	Low		
●	10	Capacity (Mbps/m^2 or Km^2)	Mbps/m^2	360		360	Medium	180	900
●	11	Device Density	Dev/Km^2	12		12	hi	12	15
●	12	Location Accuracy	m	n.a.		n.a.	n.a.	n.a.	n.a.

- **Non relevant KPIs**
  - **Mobility:** pedestrian speed for musicians
  - **Broadband connectivity:** almost constant uplink data rate (audio plus video)
  - **Capacity** and **Device density:** Only few devices (orchestra plus max 4 musicians) involved
  - **Location accuracy:** Not relevant precise location of musicians
- **Difficult to be demonstrated KPIs**
  - **Network slicing deployment time:** see UC2
  - **Security:** see UC1
- **Relevant KPIs**
  - **Latency:** UL latency, *Glass-To-Glass latency***,** can be measured with Tektronicx MSO3034 oscilloscope (manually performed with audio as a reference signal)., in the lab, measure point A' is the Camera and measure point B' is the screen (see Figure 15); alternatively, network UL latency estimate value could be provided by LiveU logs, in this case probe A is on Live U backpack and probe B on LiveU server (see Figure 15), estimation between points A and B can be available also during live demo.
  - **RAN Latency:** see UC1
  - **Throughput:** network UL throughput from each backpack can be obtained from LiveU logs, measuring point are the same A and B ones used for latency estimation.
  - **Availability:** see UC1
  - **Reliability:** using formula proposed in UC3

Where Mean Time Before Failure (MTBF) is calculated considering all the network functions involved in service provisioning (HW and SW) and positioned in the network segment measurement points A (A') and B (B') in Figure 15, depending on the considered scenario.

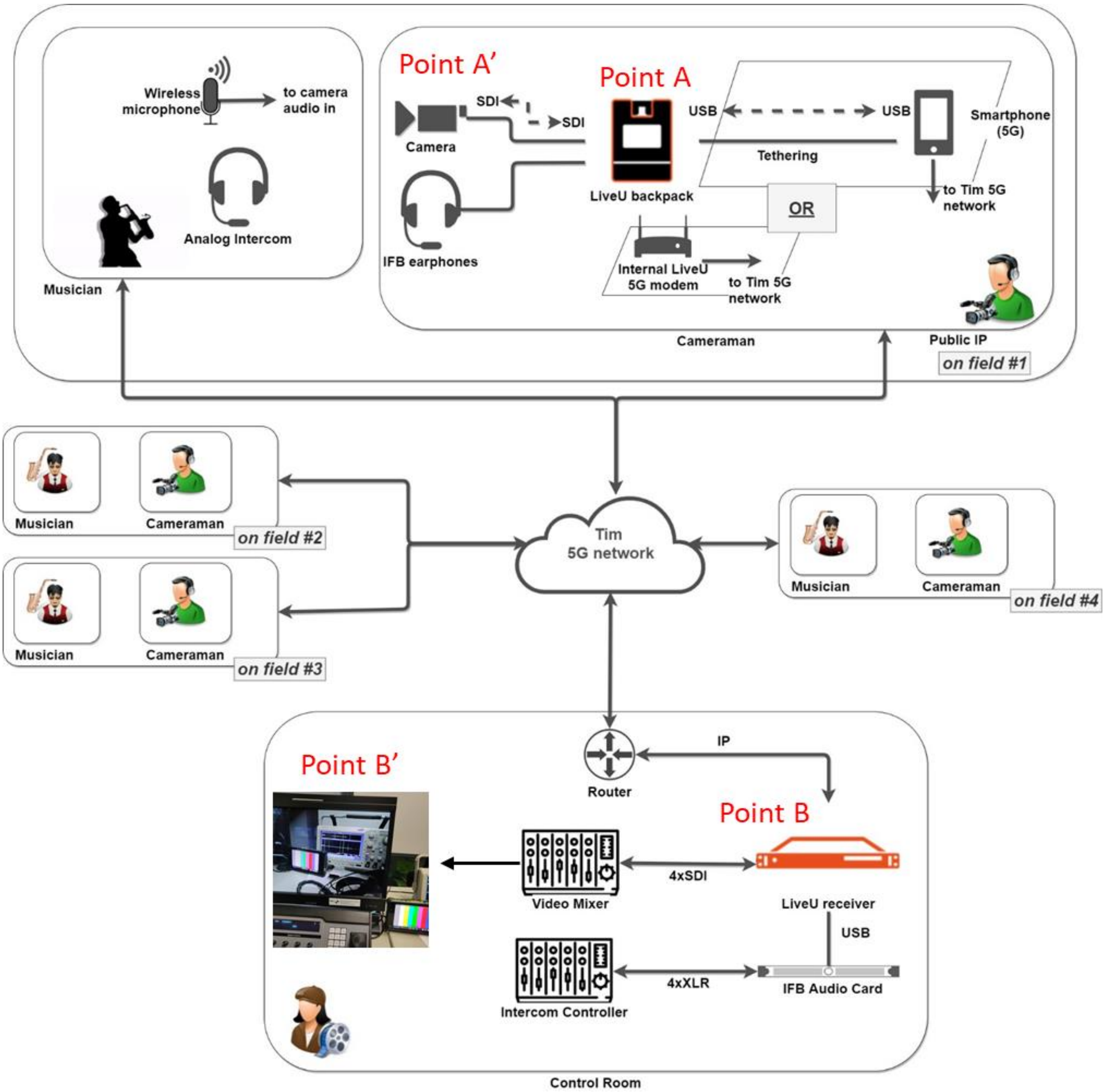


Figure 15. UC 5 Remote and distributed video production architecture and monitoring point position.

3.4 Initial trials and validation results

Initial results for KPI measurement activities are reported in 3.4.1 for UC3 and 3.4.2 for UC5.

3.4.1 UC 3 Robot-assisted museum guide

In this paragraph the latency KPI measurements for the UC3, following the methodology discussed above are presented; measurements were caried on in ERI-IT lab in Genoa.

Main reason of the choice was that UC3 is currently emulated in a controlled environment (ERI-IT lab in Genoa), with control on network performances and less impact from COVID-19 restrictions; ERI-IT and IIT run the test campaign whose aim is primarily to validate test methodology of the latency KPI.

The scenario foreseen for UC3 in Turin museums is currently enacted in ERI-IT premises in Genoa, using networking equipment that closely match those available in Turin:

- The Ericsson 5G site facility is constituted by laboratory-based experimental environments for the evaluations of the 5G features.
- It relies on radio connectivity ensured by equipment provided by Ericsson: 5G Radio R4422 (a 4TX/4RX, 4x40W max output power radio operating in B43 band with 100MHz NR carrier bandwidth for both indoor and outdoor coverage) and Radio R2203 (a 2TX/2RX 2x5W max output power radio operating in B1 with up to 40MHz LTE carrier bandwidth that can be used both for both indoor and outdoor coverage) as LTE Anchor.
- The infrastructure consists in 5G RAN including a CORE NSA solution based on a vEPC, fronthaul and backhaul nodes.

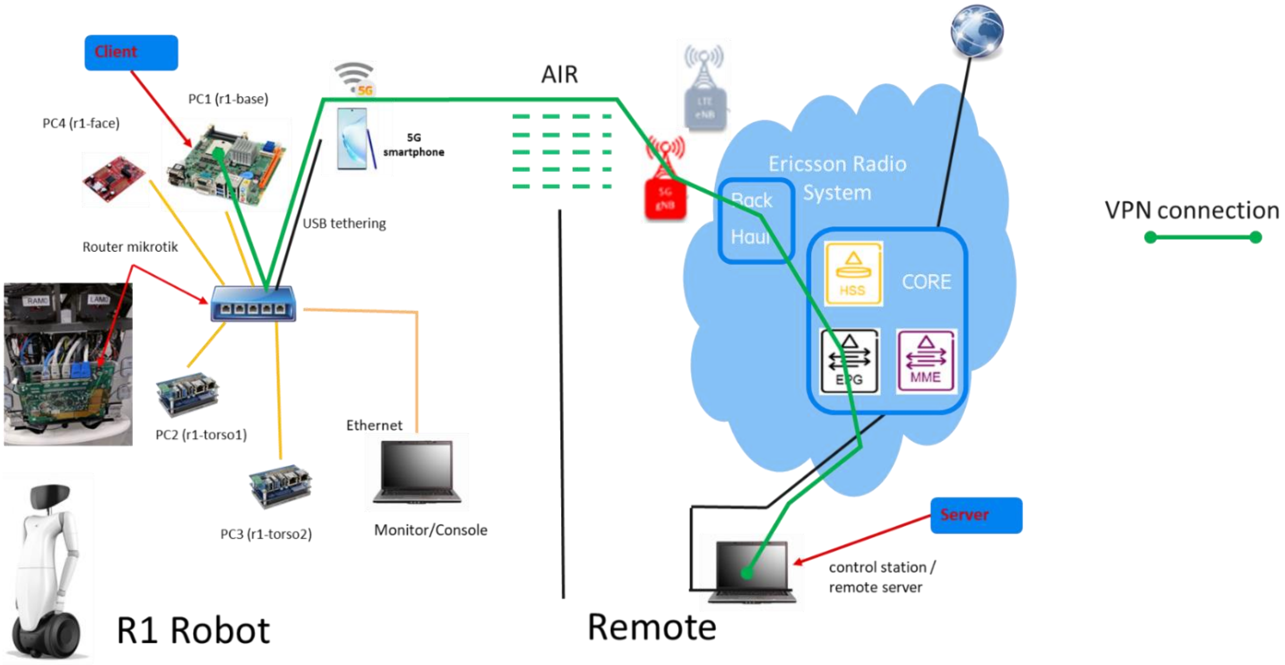
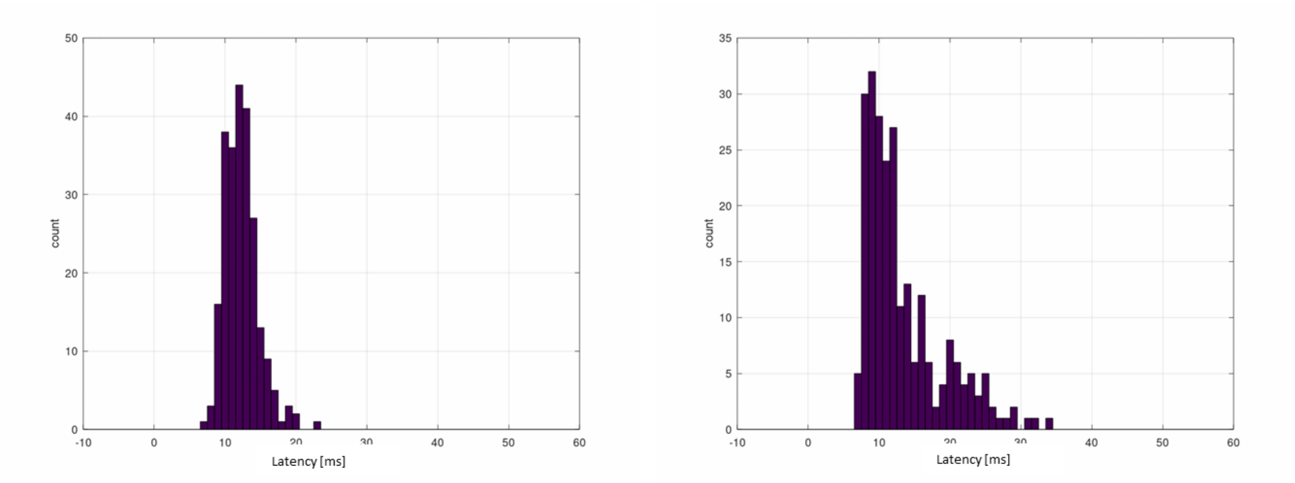


Figure 16. UC 3 setup in ERI-IT lab

Tests performed during December 2020 consisted in:

- Test 1
  Ping client PC1(r1-base) IP address from Server
  Packet dimension 64byte
- Test 2
  Ping Server IP address from console connected to PC1(r1-base)
  Packet dimension 64byte

On both tests air connection to 5G network was ensured by a 5G phone connected to local router via USB tethering and a VPN connection was established between local PC1(r1-base) and remote server.



Test 1
Server to Client
Average=12.24 ms

Test 2
Client to Server
Average= 13.36 ms

Figure 17. UC 3 latency test results.

Latency test results are reported in Figure 17, main considerations to highlight after this initial test campaign are:

- KPI measurement methodology (ping tool, measurement probes positioning, etc.) described in (5G-TOURS, D7.1, 2020) for latency has been successfully verified on UC 3.
- Preliminary test results in current setup are close to targets stated in (5G-TOURS, D2.2, 2020) (≤ 10ms) and reported in Table 8.

Tests were performed on the scenario represented in Figure 16 that includes the VPN as it is the target configuration for application in Turin locations. Further tests are planned to identify margins of improvement:

- To compare the behavior with and without VPN (in lab configuration only, in uplink direction from user to server – Test 2)
- To fine tune VPN configuration parameters
- To verify network segments contributions to end to end latency

3.4.2 UC 5 Remote and distributed video production

UC5 first trial took place in Turin at Palazzo Madama museum, and during this preliminary test it was possible to measure the glass-to-glass latency of the system and the throughput provided by the LiveU 5G LU600 back-packs.

During the trial it was possible to test the network coverage provided by Ericsson and TIM inside Palazzo Madama and at Piazza Castello square, just in front of the building.

The scenario foreseen only two of four remote musicians and a part of fixed orchestra inside Palazzo Madama. Differently from the planned setup the connection between MCR (master control room) and remote musician were provided by a RF analog commercial intercom system (RTS Adam) as shown in Figure 18.

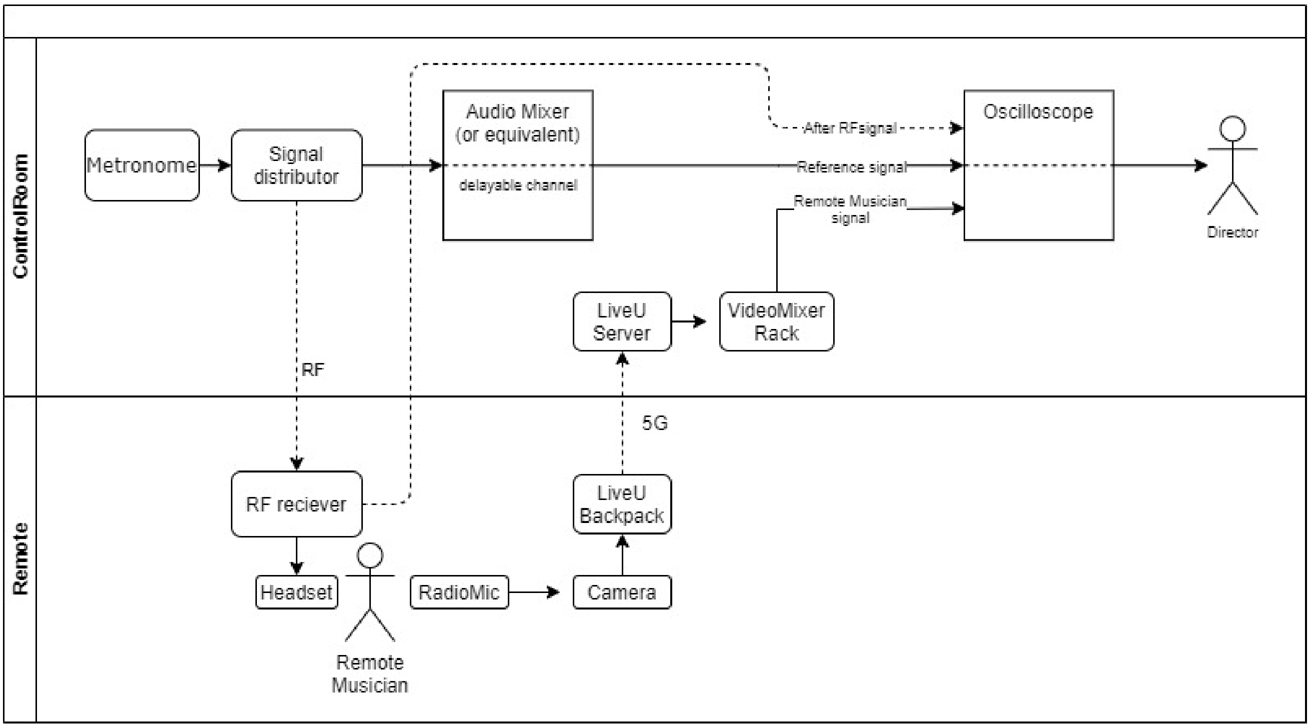


Figure 18. UC 5 glass-to-glass measure setup.

In order to measure the glass-to-glass latency we used a metronome click track as a reference signal and de-embed it from the video signal in order to calculate the latency introduced by the system. This kind of measurement is not only more reliable but grants us a wide range of measurement values. In fact, with audio, we can measure the latency of the overall system, presented in a schematic in Figure 19. An example measurement process: the peak coming from the reference signal (yellow) and the delayed one (lower in amplitude in pink). The device used for the measurements is Tektronix MSO 3034 Mixed Signal Oscilloscope.

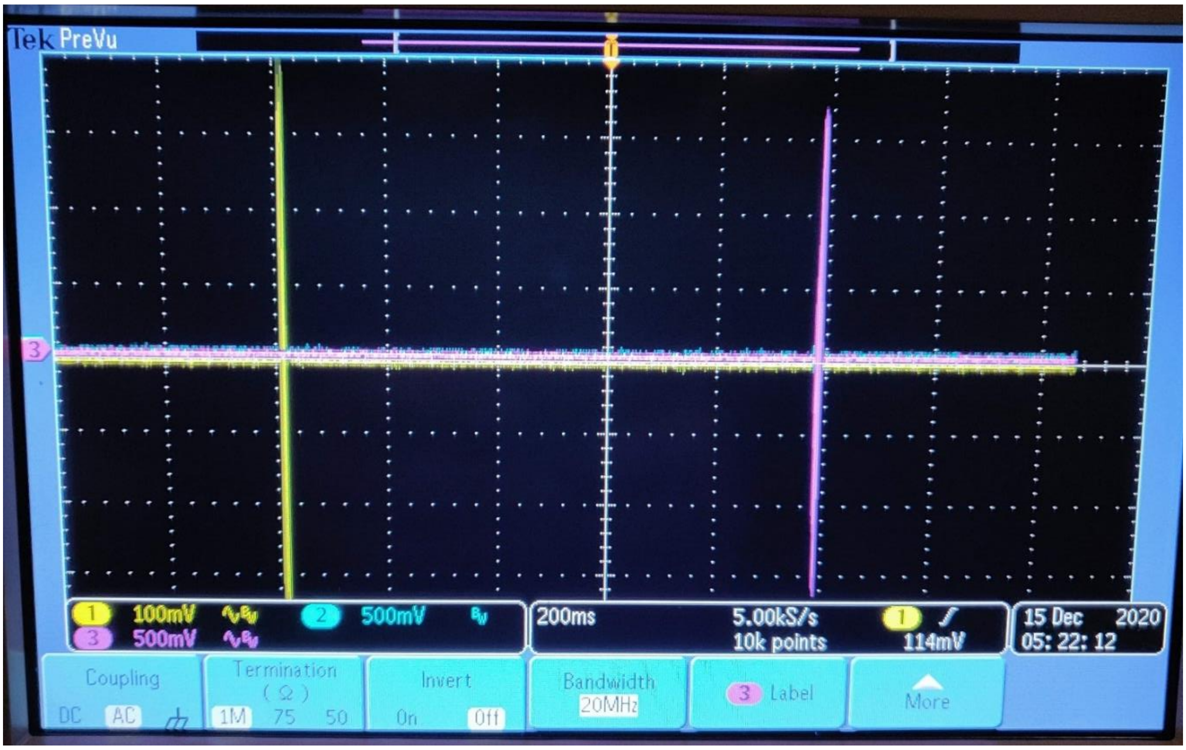


Figure 19. UC 5 oscilloscope measure setup.

During the two days at Palazzo Madama we were able to test multiple times the overall latency of the system, the measured delay compared also with the previous test performed in Tim laboratory tell us that the value is pretty constant in time Table 11.

Table 11. UC5 glass-to-glass measure.

Delay measure	AVG (ms)	MIN (ms)	MAX (ms)	STDEV
Tim lab (sep2020)	900	900	900	-
Trial Palazzo Madama (dec2020)	970	960	980	10

In the second day of testing, we performed a second type of test, with multiple backpacks involved. The main objective here is to check if, and how, the latency involves the backpacks, in particular if it is present some kind of difference between three backpacks. The results of this experiment tell us that we have some offset between backpacks, the reason is partially explained and related to the routing of the UDP streams in the network.

The setup does not involve the same schematic presented in Figure 18, but as we have only 4 inputs in the oscilloscope device, we measured just 4 feedback audio signals as input in the oscilloscope, without the reference signal, in this way we checked the delay between each backpack signal.

Again, in this setup we sent an audio (metronome signal) reference signal in the system, and the result is visible in Figure 20.

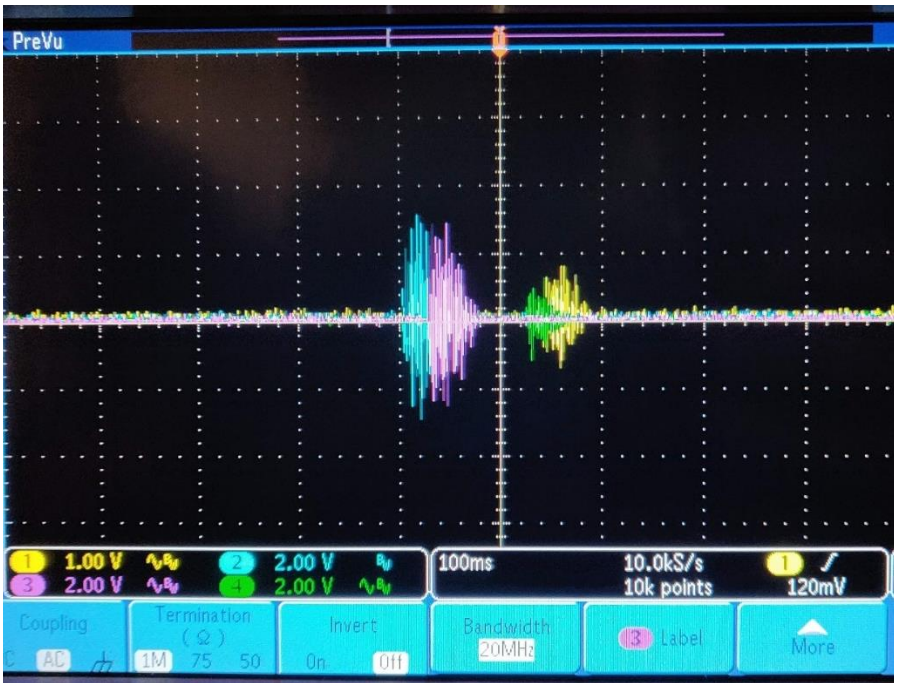


Figure 20. UC5 delay difference between backpacks.

The difference between delays were pretty constant during the tests, the maximum value of this latency offset is around 150ms. In Figure 20 we can see the 4 audio metronome signals coming back from the backpack divided into two couple of signals with a difference around 150ms. It’s important to note that during this test we placed the 4 backpacks on the desk in order to avoid any problems with coverage and connectivity.

Finally, thanks to LiveU logs, it was possible to retrieve information regarding the bandwidth, latency and packet loss rate.

In the following charts we have multiple axis: bandwidth [kbps] uses 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 point (so the total BW at each point is the aggregation of both).

The "extrapolated latency" shown in the graphs is part of the overall 600 (or 800 ms in this case "end-to-end") 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. In Figure 21we can see the chart related to a field unit during the trial.

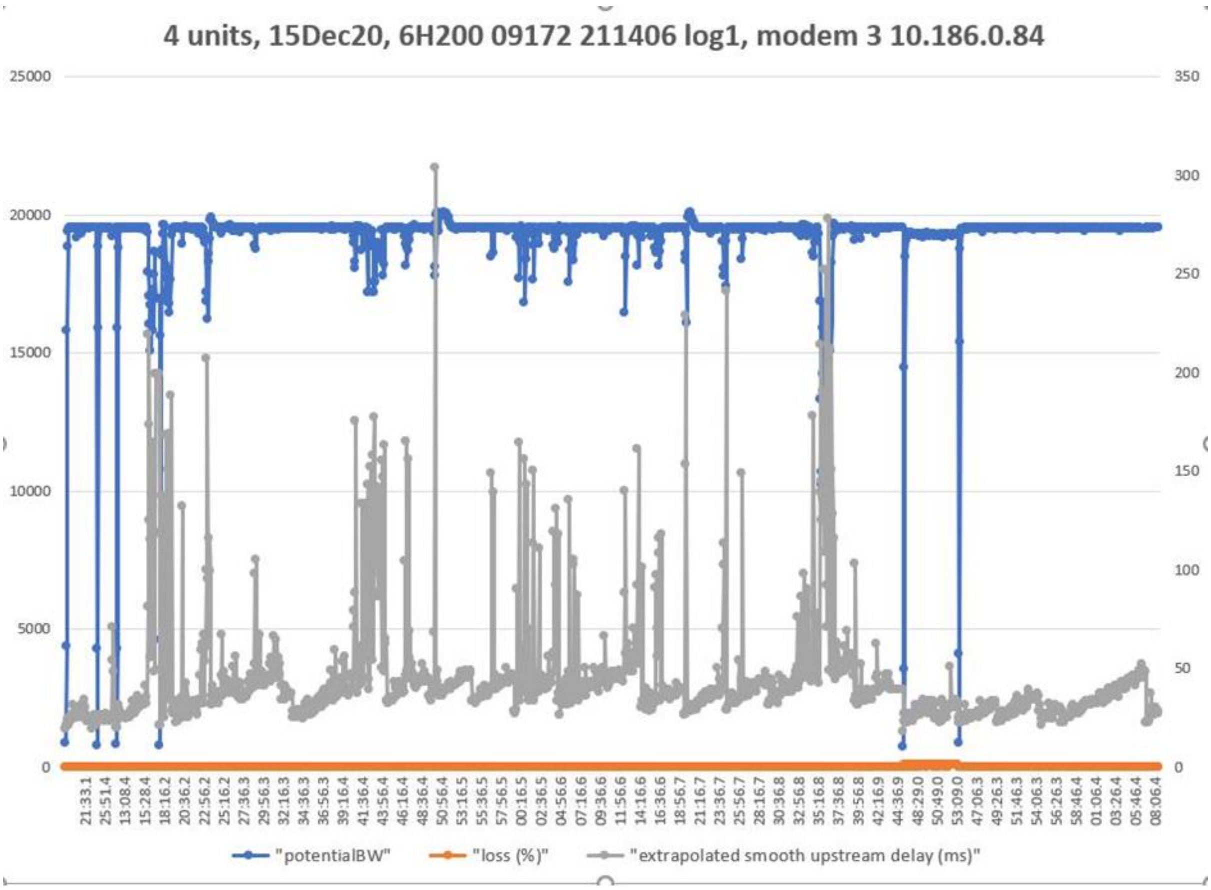


Figure 21. UC5 LiveU LU600 trial statistics.

4 Safe city integrated ecosystem, use case deployment, trial and validation

4.1 General description

One of the main subjects of 5G-TOURS project is the safe-city, including healthcare use cases supported and enhanced by 5G technology. Nowadays, especially in time of COVID-19 epidemic, the health status of patients should be monitored and analysed - wherever and whenever.

As a result of the worsening demographic trends associated with ageing populations in many countries and the consequent upward trends in chronic diseases affecting seniors, traditional medical services involving visits to health clinics are becoming increasingly expensive. The unfolding COVID-19 pandemic is also contributing to the overload on health services, with realistic predictions of its end becoming increasingly difficult. It should also be noted that the bottleneck for many medical procedures is diagnosis, which consumes many health care resources and is time-consuming. One of the most promising methods of overcoming these problems is to move diagnostics from the clinic to the patient's home, analyse the results of these tests and make them available for medical staff.

Four UCs, implemented in French site, enable to achieve such goals. First, IoT UC 6 with real-time monitoring via connected devices can saves lives in event of a medical emergency like heart failure, diabetes, asthma attacks, etc. Secondly, the time of necessary action taken must be as short as possible, and this could be achieved by taking care of the most optimal/shortest travel time consuming route for ambulance (UC9). It should be noticed that in case of emergencies, 5G network slicing can ensure the minimum required quality of service for communicating audio/video and real-time diagnostic such as ultrasound images and ECG between an ambulance and the hospital (UC7). Moreover, each department in the hospital will be provided with the same data with the quality guaranteed by the indoor 5G network. Finally, using indoor 5G connected imaging equipment that automatically connect, synchronize and perform image fusion to support complex image guided interventions in operation rooms, more precious time is saved as well as complicated procedures can be accelerated (UC8).

In summary, the following UCs are being developed within French site:

- UC6: Health monitoring and incident-driven communications prioritization;
- UC7: Teleguidance for diagnostics and intervention support, focused at emergency care:
- UC8: Wireless operating room;
- UC9: Optimal ambulance routing.

The above wellbeing and healthcare UCs are covered by WP5 and D5.2 (5G-TOURS, D5.2, 2020).

UC7 and UC8 will be trialed in Rennes, using mobile network infrastructure of Orange and Nokia. UC6 and UC9 are deployed currently in Greece (demonstrated and validated as stand alone UCs), but during the next period of the project, selected components will be deployed in Rennes in order finally to be demonstrated and validated as cross-site UCs.

Mobile broadband (MBB) communication services are supported by 4G LTE network, while machine type communication (MTC) of IoT devices are supported from the commercial LTE-M mobile network of Orange. For uRLLC use cases (UC 7 and UC 8) an experimental 5G network is being created.

More details on French site deployed network, its architecture and characteristics are available in 5G-TOURS D3.2 (5G-TOURS, D3.2, 2020) and 5G-TOURS D5.2 (5G-TOURS, D5.2, 2020).

4.2 Integrated ecosystem

The “Safe City” use-cases are trialed in Rennes, using the mobile network infrastructure of Orange and Nokia. This infrastructure currently supports a 4G LTE network for MBB communication, as well as a LTE-M network for MTC of IoT devices. For the 5G-TOURS project, an experimental 5G network is being created to be used in URLLC use cases.

The commercial LTE-M mobile network of Orange will be used for UCs 6 and 9, since these use cases rely on IoT sensors and devices (5G-TOURS, D3.2, 2020). This is a temporary solution, because of the lack of a 5G mMTC experimentation network in Rennes. Once this becomes available, i.e. a 3GPP Release-14 or higher compliant 5G mMTC network (5G-TOURS, D2.2, 2020), UCs 6 and 9 will have the capability to use using this network (in addition to the NB IoT network already available in the Athens site).

For other two use-cases (UC 7 and UC 8), we will use eMBB and URLLC features of 5G infrastructure

These use-cases will be deployed in CHU Rennes hospital and B-COM premises. These two sites will be connected to the 5G-EVE infrastructure as depicted in Figure 22.

At the BCOM premises, there will be a 5G base station with a local virtual UPF (User Plane Function), part of the so-called “Wireless Edge Factory” (WEF) (WEF, 2021). Similarly, there will be a WEF UPF at the hospital that connects to the WEF core network hosted in the BCOM datacentre through a dedicated VPN backbone. This will enable the setting of end-to-end network performance KPIs and the prioritization of data traffic between the ambulance and the hospital to guarantee the required quality of service. Furthermore, the WEF Core Network deployed in BCOM datacenter will manage the WEF UPF at the hospital to connect the 5G terminals of the Wireless Operating Room.

In addition, for the non-critical overall network orchestration and automatic deployment of the WEF core network, Orange provides an ONAP orchestrator in Châtillon as part of their 5G EVE infrastructure. ONAP enables the experimenter to deploy and configure the WEF Core Network on demand. It could also be used to deploy the user plane part of the WEF.

The Orange datacenter has already been connected to the BCOM datacenter in the scope of the 5G EVE project.

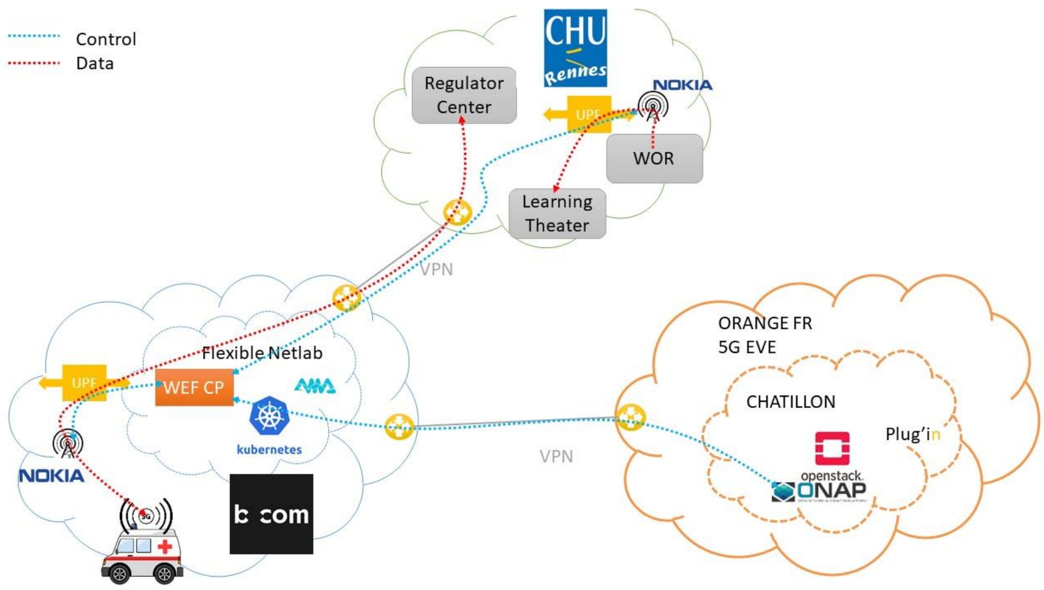


Figure 22. Overall network architecture and physical deployment of network equipment and functions.

In the sequel, we describe the 5G part control plane (CP), user plane (UP), and radio access network (RAN) equipment.

<u>Control plane</u>

The Control Plane is part of the WEF solution developed by BCOM. It is deployed as a set of Docker containers managed by a Kubernetes cluster. This cluster is hosted on the Flexible Netlab platform in the BCOM datacenter

(BCOM, Netlab, 2019). The Control Plane is deployed and orchestrated by an instance of the ONAP orchestrator hosted by Orange.

User plane

The main component is the User Plane Function (UPF) component of the WEF provided by BCOM. Two instances of the UPF will be deployed as part of 5G-TOURS.

The first instance will be a VNF i.e. a purely virtual UPF deployed in BCOM datacenter as a virtual machine hosted on an OpenStack cluster provided by Flexible Netlab (BCOM *Flexible Netlab* is a multi-tenant environment dedicated to technical experimentation from early integration up to field trials. The testbed is operated according to a standard Infrastructure / IaaS / PaaS architecture. It relies on BCOM in- house infrastructure which includes a private cloud, indoor and outdoor radio access networks. Access is provided to 4G LTE and 5G authorized by Arcep, WiFi on 2.4GHz and 5GHz bands, IoT LoRa in the 868MHz ISM band (B-COM, 2021). This virtual machine hosts an OpenVSwitch (OVS) virtual switch that acts as a tunnel endpoint for the GTP tunnels coming from the RAN equipment deployed at BCOM for UC7. The WEF Control Plane manages the virtual switch under control of the OpenDaylight (OpenDaylight) SDN controller that is deployed in the control plane.

The second instance is a PNF i.e. an appliance built from a COTS network switch and a COTS mini-ITX PC. The PC is a KVM (Linux-KVM) hypervisor that hosts an OVS-based virtual machine similar to the one deployed in Flexible Netlab. It will be installed in the technical room of the Rennes CHU and will interconnect the RAN equipment deployed there with the various components required by UC8. The same WEF Control Plane will manage this switch through the VPN established between BCOM and the CHU.

RAN equipment

For 5G-TOURS, Nokia Small Cell technology is used as the basic RAN equipment. Two small cells will be deployed: one at the Rennes CHU to provide coverage for the Wireless Operating Room and one at BCOM premises to cover the outside area for UC7. Both will use the 26GHz/2.6GHz bands in 5G NSA mode. The Nokia RAN at BCOM will be deployed and operated by BCOM while the one at the CHU will be deployed and operated by Nokia. In addition, we conducted the first integration tests for UC8 in the BCOM showroom. These tests are carried out with Amarisoft Classic Callbox RAN equipment (Amarisoft, LTE-callbox, 2021). This equipment uses the 3.5GHz band and is also compatible with 5G Non-Stand Alone (NSA) mode.

4.2.1 Relationship with the 5G EVE project

The integration of 5G-TOURS with 5G EVE is achieved as depicted in Figure 23. The Service Layer interacts with the 5G EVE Portal through a programmable REST API to request the deployment and instantiation of the whole vertical service by the 5G EVE platform.

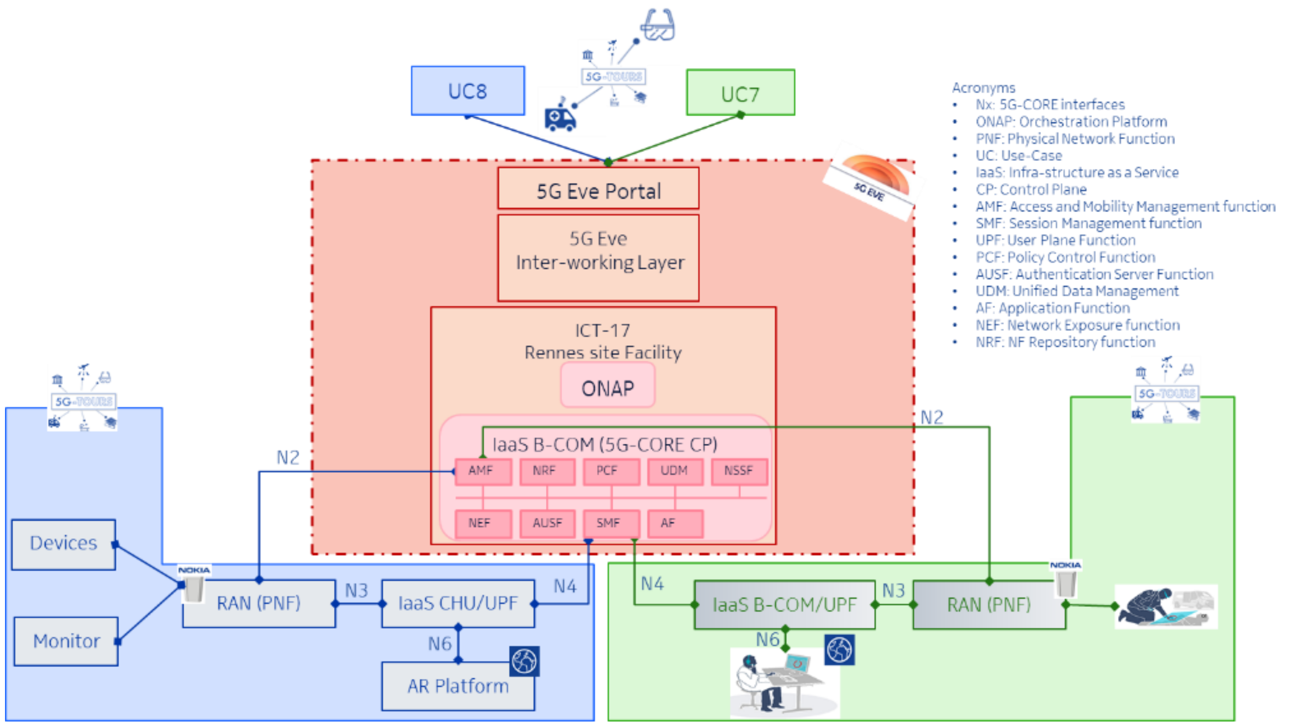


Figure 23. 5G-TOURS integration with 5G EVE.

The 5G EVE Portal API enables a programmable interaction between 5G-TOURS and 5G EVE at the portal level. Such API documentation is available in 5G EVE (D4.2, 2019) which includes the general description and the functionalities of the first version of the portal, and in 5G EVE (D4.3, 2020) which includes the functionality extensions made to the first version. The 5G EVE Portal API supports experiment lifecycle management operations (e.g., instantiation, termination, polling status, etc.), whilst all the experiment design operations are available only through the 5G EVE Portal GUI.

As depicted in Figure 23, the 5G CORE control plane will be part of 5G EVE. The 5G CORE user plane named UPF will be instantiated in the EDGE node deployed in CHU Rennes and in the B-COM datacenter.

In terms of monitoring, the 5G EVE platform will be responsible of providing the collection and visualization functionalities for the monitoring of data of the entire vertical service, provided that the VNFs developed by 5G-TOURS support the required extensions to publish monitoring data into the 5G EVE monitoring platform. The 5G EVE platform supports the visualization of monitoring data through the 5G EVE portal GUI and provides internal functionalities for performance validation and evaluation based on KPIs.

4.2.2 Safe City use-cases Innovation aspects

Table 12 shows the network innovations associated to each of the above use cases in terms of: service layer, enhanched orchestration, Network Performance.

Table 12. Network innovation for different UCs 6/7/8/9.

	Network Innovation		
Use case 6	Service layer	Enhanced orchestration	Service Provider Innovation
Remote health monitoring and emergency situation notification	Active Performance Measurement while the Service is Running (on the Greek node)	Resource allocation, deployment and migration of Network Services in an automatic and optimized way using various metrics (infrastructure, VNFs, Applications, etc) and verticals' requirements.	Correlation of user QoE with Active Service KPIs to identify relation between network performance, Quantitative Service KPIs and QoE.
Use case 7	Service layer	Enhanced orchestration	Other

Teleguidance for diagnostics and intervention support	This use-case will be fully onboarded on 5G-EVE via blueprints	Resource allocation for the medical devices, and priority of the slice compared to the others Core slices.	The use of the 26GHz mmWave frequency for the 5G connected devices
Use case 8	Service layer	Enhanced orchestration	Other
Wireless operating room	This use-case will be onboarded on 5G-EVE via blueprints and integrated with 5G-EVE framework	Network Services Core Network deployment through 5G EVE.	Actual integration and deployment of the Antenna in the University Hospital of Rennes (CHU de Rennes)
Use case 9	Service layer	Enhanced orchestration	Other
Optimal ambulance routing	Active Performance Measurement while the Service is Running (on the Greek node)	Resource allocation, deployment and migration of Network Services in an automatic and optimized way using various metrics (infrastructure, VNFs, Applications, etc.)	Correlation of user QoE with Active Service KPIs to identify relation between network performance, Quantitative Service KPIs and QoE.

4.3 Technical validation

As for the other two TOURS sites, i.e. Turin and Athens, the technical validation of the UC's implemented in Rennes is based on the general methodology found in (5G-TOURS, D7.1, 2020), assuming the possibility to link service requirements to network quality requirements by relating current measurements to KPI threshold values.

The choice of a specific validation path for each UC is determined by its inner characteristics and the possibility to perform selected measurements with a given UC architecture.

Taking into account the characteristics of a given UC, from the general list of KPIs included in (5G-TOURS, D7.1, 2020), the ones that are necessary to ensure the minimum level of QoS within the particular UC are selected and placed in KPI tables assigned to each of them.

In the current phase of the project, only some of the necessary measurements can be realised.

4.3.1 UC6 Health monitoring and incident-driven communications prioritization

This UC addresses solutions for remote health monitoring of people, especially when already diagnosed with a critical disease still compatible with home care (e.g. some form of cardiovascular disease, hypertension, diabetes, etc.). The main features offered by this UC involve:

a) Remote health monitoring services;
b) Quick, reliable notifications to nearby ambulances, medical professionals, and family members in case of a health incident or a health emergency prediction.

The UC leverages wearable devices tracking a tourist's vital signs and having them aggregated inside an IoT based platform named STARLIT (Smart living platform powered by Artificial intelligence & robust IoT connectivity). Figure 24 illustrates the high-level architecture of UC6, in which the different components of the deployment are presented. More information about UC6 can be found in 5G-TOURS D5.2 (5G-TOURS, D5.2, 2020).

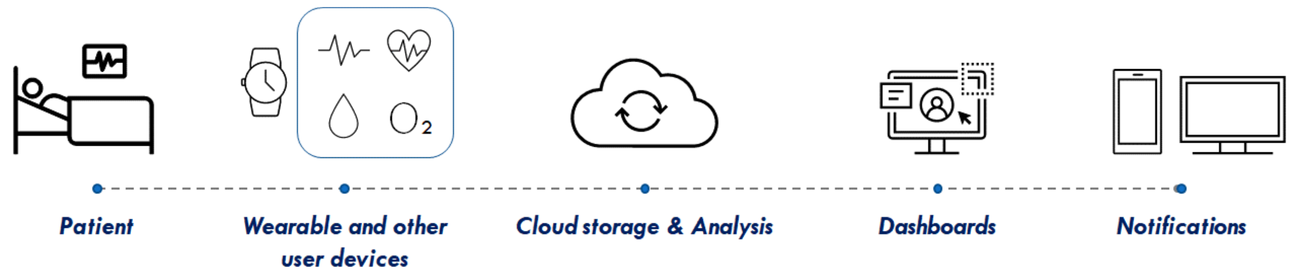


Figure 24. UC6 high level architecture.

In order to generate a clear plan for the UC6 validation approach, the user requirements generated in 5G-TOURS WP2 are used. These user requirements together with their definitions and methodologies of generation are presented in detail in 5G-TOURS D2.2 (5G-TOURS, D2.2, 2020). The analysis included a feasibility study to examine which of the KPIs can be collected, analysed and validated in practice. For each KPI that was characterized as feasible, a technical validation approach was generated. Table 13 illustrates the outcome of this feasibility study. In UC6 application level KPIs will be validated.

In UC6, only application level KPIs will be validated, no network KPIs will be validated. Application level KPIs will be measured on the application level and they will demonstrate the actual application performance. Regarding network KPIs, the reason is that this UC will be validated on an NB-IoT network which is not exposing any measurements capabilities.

Table 13. UC 6 Remote health monitoring network requirements

5G-Tours - Use Cases: direct specific Technical requirements		Units	UC6 –Remote health monitoring and emergency situation notification			Priority	Range	
			URLLC	mMTC	eMMB		Min	Max
General Vertical/Use Case Requirement								
1	Latency (in milliseconds) - round trip - Min/Max	msec	10	10		High	10	50
2	RAN Latency (in milliseconds) - one way	msec	1	1		High	5	10
3	Throughput (in Mbps) - Min/MAX - sustained demand	Mbps				High	10	50
4	Reliability (%) - Min/Max	%	99,9999%	99,9999%		High		
5	Availability (%) - Min/Max	%	99,99%	99,99%		High		
6	Mobility (in m/sec or Km/h) - Min/Max	Km/h				High	5Km/h	100 Km/h
7	Broadband Connectivity (peak demand)	Y/N or Gbps		Y		High	N/A	N/A
8	Network Slicing (Y/N) - if Y service deployment time (mi	Y/N		Y		Medium	N/A	N/A
9	Security (Y/N) - if Y grade i.e. "Carrier Grade"	Y/N		Y		Medium	N/A	N/A
10	Capacity (Mbps/m^2 or Km^2)	Mbps/m^2					N/A	N/A
11	Device Density	Dev/Km^2					N/A	N/A
12	Location Accuracy	m		0,1		High		1m

Extra KPI: power consumption (battery level)

- ● **Non relevant KPIs**
- ● **Relevant KPIs (will be collected and demonstrated)**
- ● **Relevant but not critical KPIs**
- ● **Difficult to be demonstrated KPIs**

Regarding the application level KPIs, the following KPIs will be validated: RTT latency, service reliability, service availability and power consumption (battery level). The power consumption KPI (noted as extra KPI in Table 13) is selected to be collected and validated (although not present in the initial list of requirements) because it is important for UC6 mainly because of the involvement of sensors and wearable devices. In Table 13, the KPIs which are annotated with the black spots are judged as not important for UC6. In detail, mobility is not important for the UC, because of we assume patients are stationary or moving with low speeds. Since, we are referring to mMTC services broadband connectivity is not important. Capacity and device density KPIs cannot be validated with actual trials instead simulations/emulations can be used which generate a very large number of devices. Throughput (UL/DL) will be validated only on IP layer (as described above) while RAN latency is considered as difficult to be validated (to be reconsidered later in the project). The technical validation approaches are described in the following paragraphs.

RTT latency (APP layer)

The positions of the probes are illustrated in Figure 25, while the approach is described below. We discriminate between two paths. The first path (short path) is located between the wearable devices and the server (for publishing the new health values), while the second path (long path) starts from the generation of the health values that triggers an emergency and ends up to the actual notification of an emergency situation.

- Collection in APP layer
    - Short path
        - ADD timestamp to requests. Calculate DIFF in time between request from wearable and response from server.
    - Long path
        - ADD timestamp to requests. Calculate DIFF in time between request from wearable and response from notification.

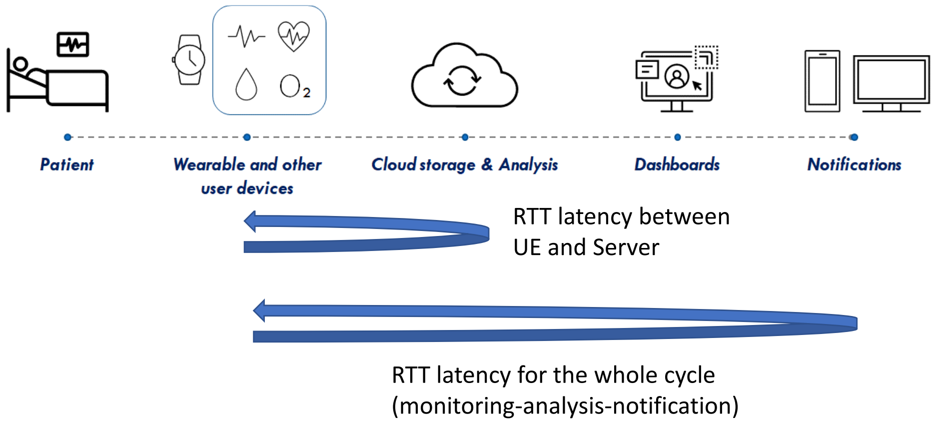


Figure 25. RTT latency.

Service reliability (APP layer)

As explained in section 2.2, in cases of small or medium operational times (days or months), it is preferable to use "service reliability" instead of "network reliability" to validate the reliability of a service. In order to measure and validate service reliability, the definition in ITU-R M.2410 is considered.

Reliability: (ITU-R M.2410) Reliability relates to the capability of transmitting a given amount of traffic within a predetermined time duration with high success probability. Reliability is the success probability of transmitting a layer 2/3 packet within a required maximum time, which is the time it takes to deliver a small data packet from the radio protocol layer 2/3 SDU ingress point to the radio protocol layer 2/3 SDU egress point of the radio interface at a certain channel quality. This requirement is defined for the purpose of evaluation in the URLLC usage scenario.

Validation methodology: The packet error rate at the APP layer (packets that arrive delayed or erroneous are considered as lost packets) will be measured using a set of probes, the positions of which are illustrated in Figure 26.

Service availability (APP layer)

Availability refers to the percentage of time that a system is fully operational. Because of the rates at which the site is being tested and upgraded, it would be impractical (and deceptive) to measure the network availability, this being defined as the ratio of uptime over the total time (uptime plus downtime).

Instead, as already explained in section 2.2, we decided to estimate the service availability as one minus the measured packet error rate during the operation of a service.

Validation methodology: The packet error rate at the APP layer (packets that arrive delayed are considered as arrived packets) will be measured using a set of probes, the positions of which are illustrated in Figure 26.

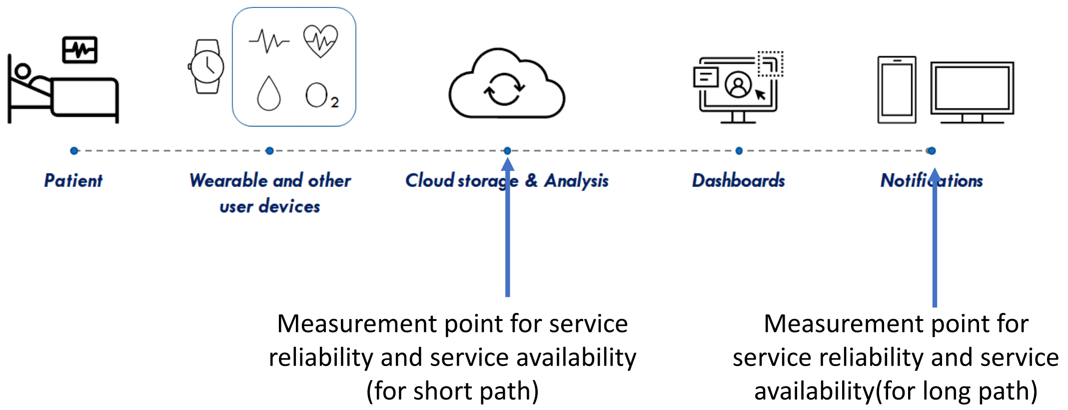


Figure 26. Service reliability and availability.

4.3.2 UC7 Teleguidance for diagnostics and intervention support, focused at emergency care

The goal of the use case is to develop profound understanding on how 5G can be used to improve emergency care, in particular, how it can improve the communication between care givers in the ambulance / near the patient, the medical regulator, remote experts and emergency department staff to save the life of more patients than before. To save lives and improve outcomes for patient, it is essential to realize fast and precise diagnosis of life threatening conditions in order to be able to give patients the necessary lifesaving treatment as quickly as possible.

The solution developed for this use case is built on streaming live video, live ultrasound images, in addition to voice communication, leveraging the capability of new 5G cellular networks to give the high-quality video and reliable medical feeds to the emergency care regulators for best decision making.

The outcomes of the analysis on the user requirements reported in 5G-TOURS D2.2 (5G-TOURS, D2.2, 2020) in order to decide the feasibility to validate a specific KPI as well as the description of the validation process are illustrated in Table 14. Application and network KPI are listed with targeted values for the UC7.

Table 14. UC 7 Connected Ambulance network requirements.

5G-Tours - Use Cases: direct specific Technical requirements		Units	UC7 – Teleguidance for diagnostics and intervention support			Priority	Range	
			URLLC	mMTC	eMMB		Min	Max
General Vertical/Use Case Requirement								
1	Latency (in milliseconds) - round trip - Min/Max	msec	10				10	25
2	RAN Latency (in milliseconds) - one way	msec	2					
3	Throughput (in Mbps) - Min/MAX - sustained demand	Mbps	1000				150	1000
4	Reliability (%) - Min/Max	%	99,999%				99,00%	99,999%
5	Availability (%) - Min/Max	%	99,999%				99,00%	99,999%
6	Mobility (in m/sec or Km/h) - Min/Max	Km/h						
7	Broadband Connectivity (peak demand)	Y/N or Gbps	1,5				1000	1500 Mbps
8	Network Slicing (Y/N) - if Y service deployment time (mi	Y/N	Y(1)				1	5
9	Security (Y/N) - if Y grade i.e. "Carrier Grade"	Y/N						
10	Capacity (Mbps/m² or Km²)	Mbps/m²						
11	Device Density	Dev/Km²						
12	Location Accuracy	m						

- **Non relevant KPIs**
- **Relevant KPIs**
- **Difficult to be demonstrated KPIs**
- **Relevant but not critical KPIs** (The UC will target measuring the service deployment time)

From Table 14 and for the KPI which can be collected, we can consider the following formulae

- For calculating the User Data Rate, the following formula is used:
    - *Cell user throughput = Volume in Mbits / (Accumulated number of users with buffered data (sampled every 1 slots) * 1 slots * Slot duration)*
- For the availability, the following formula is used:
    - *Availability ratio = (number of samples when the cell is available]) / (number of samples when cell availability is checked))*
- Throughput via Iperf tool in different segment of the infrastructure
- Latency
    - Tests through ping methods will be carried out to measure the RTT (Round Trip Time)

In UC7, UL data rate will be one of the KPI we will focus on as a priority, as high volume of data coming from video streams of both AMA smart glasses and Philips Ultra Sound probes should be transmitted to the network in the uplink direction with the lowest latency. Table is pointed out targeted values of latency, tests will be carried out to reach those values, with respect to the quality of the video streams received by the remote operator

The architecture deployment for technical validation for UC7 is shown in Figure 27.

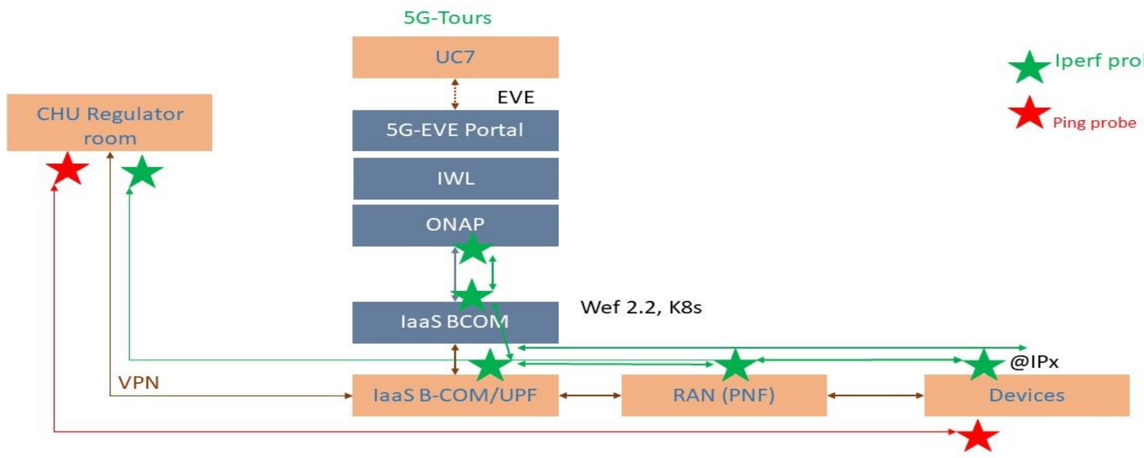


Figure 27. UC7 deployment architecture for technical validation.

4.3.3 UC8 Wireless operating room

The goal of the use case is to demonstrate the impact of 5G inside the operating room. This use case will face very low latency requirements and important amount of video data to be transferred. The scenario for the trial corresponding to this use case considers a situation where a patient has to go under a cardiac intervention procedure based on live, simultaneous X-Ray and ultrasound imaging.

Table 15. UC 8 Wireless Operating Room network requirements.

5G-Tours - Use Cases: direct specific Technical requirements		Units	UC8 – Wireless Operating Room			Priority	Range	
			URLLC	mMTC	eMMB		Min	Max
General Vertical/Use Case Requirement								
1	Latency (in milliseconds) - round trip - Min/Max	msec	20				10	30
2	RAN Latency (in milliseconds) - one way	msec	5				2	7
3	Throughput (in Mbps) - Min/MAX - sustained demand	Mbps	800				600	7000
4	Reliability (%) - Min/Max	%	99,99999%					
5	Availability (%) - Min/Max	%	99,99999%					
6	Mobility (in m/sec or Km/h) - Min/Max	Km/h	0					
7	Broadband Connectivity (peak demand)	Y/N or Gbps	0,8					
8	Network Slicing (Y/N) - if Y service deployment time (min)	Y/N	Y (5)					
9	Security (Y/N) - if Y grade i.e. "Carrier Grade"	Y/N	N					
10	Capacity (Mbps/m² or Km²)	Mbps/m²	N/A					
11	Device Density	Dev/Km²	N/A					
12	Location Accuracy	m	N/A					

- Non relevant KPIs
- Relevant KPIs
- Difficult to be demonstrated KPIs
- Relevant but not critical KPIs (The UC will target measuring the service deployment time)

From Table 15 and for the KPI which can be collected, we can consider the following formulas

- For calculating the User Data Rate, the following formula is used:
  - *Cell user throughput = Volume in Mbits / (Accumulated number of users with buffered data (sampled every 1 slots) * 1 slots * Slot duration)*
- For the availability, the following formula is used:
  - *Availability ratio = (number of samples when the cell is available]) / (number of samples when cell availability is checked))*
- Throughput via iperf tool in different segment of the infrastructure
- Latency
  - From E2E latency from the applications devices (UltraSound) to the Augmented Reality monitor, a dedicated tool will be used in that purpose using a proprietary solution for the needs of such equipment. The tool introduces a black square followed by a white square regularly in the source image and measures the delay to display the square in the final image.
  - Tests through ping methods will be also carried out to measure the RTT (Round Trip Time)

To obtain measurements of throughput and latency, in Figure 28 is depicted the deployment architecture for the technical validation, through the 5G EVE architecture.

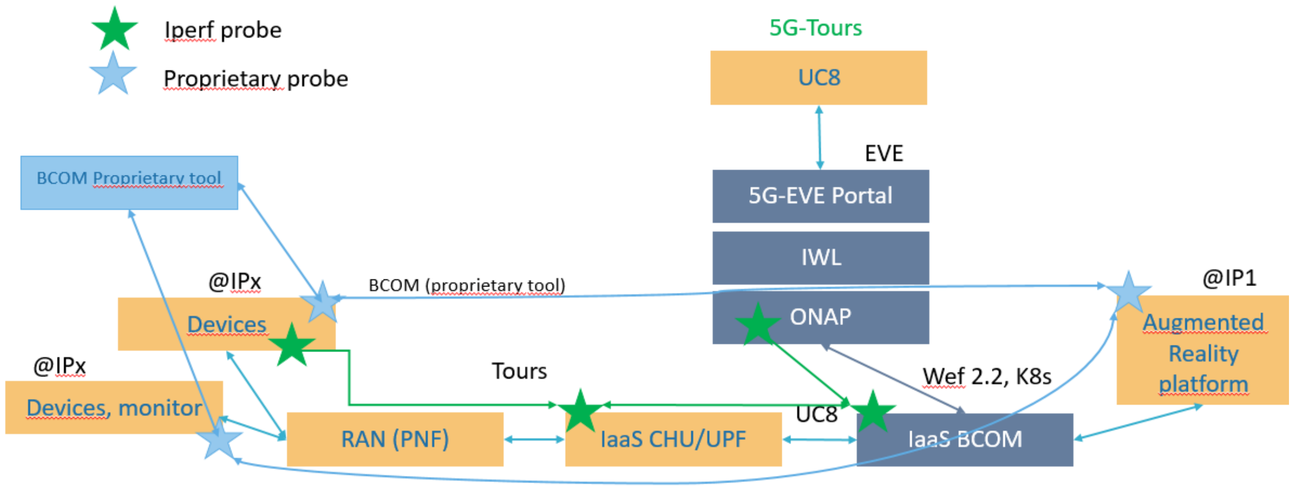


Figure 28. UC8 deployment architecture for technical validation.

- Coverage/Power
    - An independent external company will conduct a thorough audit of the 5G deployment with regards to health and regulations. Aim is at measuring the power radiated inside the hospital Operating room and to validate that those measurements are with respects of the regulations.

Results are automatically collected through the monitoring databases and tools in place in Paris Chatillon, which are built within 5G EVE project. Kafka broker, Prometheus or any reporting through Excel or others reporting methods will be used to that purpose to monitor for instance the KPI of availability.

4.3.4 UC9 Optimal ambulance routing

This use case shows how city sources can be exploited towards real-time vehicle navigation, taking into consideration the network coverage and type (LTE or 5G) in a specified path toward the hospital. This use case addresses real time navigation of the ambulance, both to the site of the emergency, to ensure that medical help will be provided as quickly as possible, as well as from the site of emergency to the hospital, as soon as possible once the patient has been stabilized on site, i.e. on emergency location. Figure 29 illustrates the UC9 high level architecture, in which the different components of the deployment are presented. More information about UC9 can be found in 5G-TOURS D5.2 (5G-TOURS, D5.2, 2020).

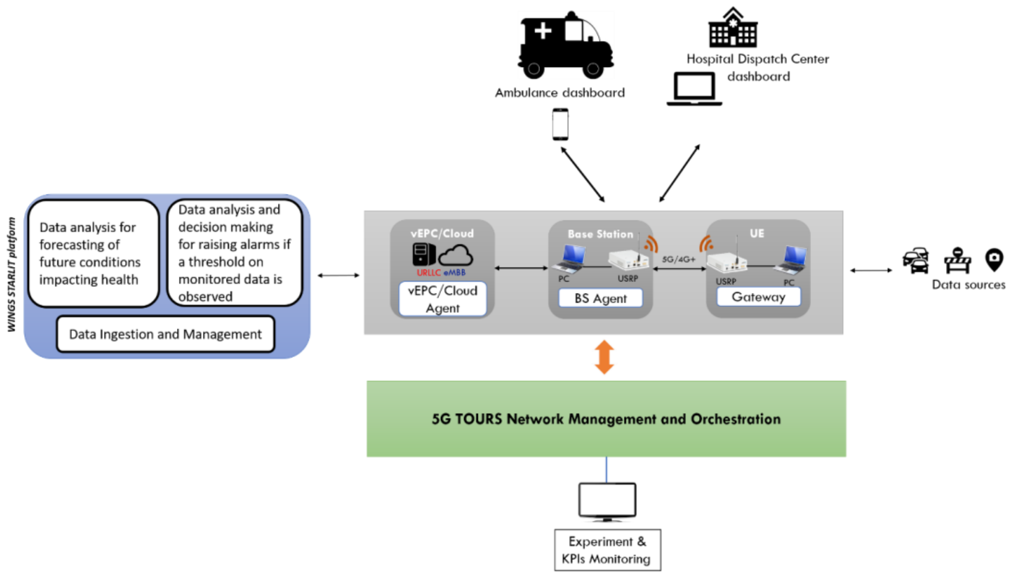


Figure 29. UC9 high level architecture.

The outcomes of the analysis on the user requirements reported in 5G-TOURS D2.2 (5G-TOURS, D2.2, 2020) in order to decide the feasibility to validate a specific KPI as well as the description of the validation process are illustrated in Table 16. In UC9, similar to UC6, two types of KPIs will be validated: network KPIs and application level KPIs.

Table 16. UC 9 Optimal ambulance routing network requirements

		5G-Tours - Use Cases: direct specific Technical requirements	Units	UC9 – Optimal Ambulance Routing			Priority	Range	
				URLLC	mMTC	eMMB		Min	Max
General Vertical/Use Case Requirement									
1	🟢	Latency (in milliseconds) - round trip - Min/Max	msec		10		High	10	50
2	🔴	RAN Latency (in milliseconds) - one way	msec		1		High	5	10
3	⚫	Throughput (in Mbps) - Min/MAX - sustained demand	Mbps		50		High	10	50
4	🟢	Reliability (%) - Min/Max	%		99,9999%		High		
5	🟢	Availability (%) - Min/Max	%		99,99%		High		
6	🟠	Mobility (in m/sec or Km/h) - Min/Max	Km/h		>=100Km/h		High		
7	🔴	Broadband Connectivity (peak demand)	Y/N or Gbps		Y (1)		High		
8	⚫	Network Slicing (Y/N) - if Y service deployment time (mi	Y/N		Y (1)				
9	⚫	Security (Y/N) - if Y grade i.e. "Carrier Grade"	Y/N		Y		Medium		
10	⚫	Capacity (Mbps/m^2 or Km^2)	Mbps/m^2		n/a				
11	⚫	Device Density	Dev/Km^2		n/a				
12	🟠	Location Accuracy	m		0,1		High		

⚫ **Non relevant KPIs**

🟢 **Relevant KPIs (will be collected and demonstrated)**

🟠 **Relevant but not critical KPIs**

🔴 **Difficult to be demonstrated KPIs**

Regarding network KPIs, RTT latency will be validated. RTT latency will be measured using ping tool on the end nodes (UEs, sensors, Application Server). Regarding the application level KPIs, the following KPIs will be validated: RTT latency, service reliability and service availability. The technical validation approaches are described in the following paragraphs. The KPI which are noted with the black spots are judged as not important for UC9, while RAN latency and peak throughput are considered as not feasible to be practically validated, while mobility and location accuracy are still under consideration.

<u>RTT latency (IP and APP layer)</u>

Regarding latency, the latency of three paths of the service will be validated:

a. latency between UE in the ambulance and the Server
b. latency between UE at the hospital and the Server
c. latency (not so critical) between the data sources and the Server

The positions of the probes for the three different service paths are illustrated in Figure 30, while the approach is described below.

- Collection in APP and IP layer
  - IP layer
    - Ping from UE to server
- App layer
  - ADD timestamp to requests. Calculate DIFF in time between request and response

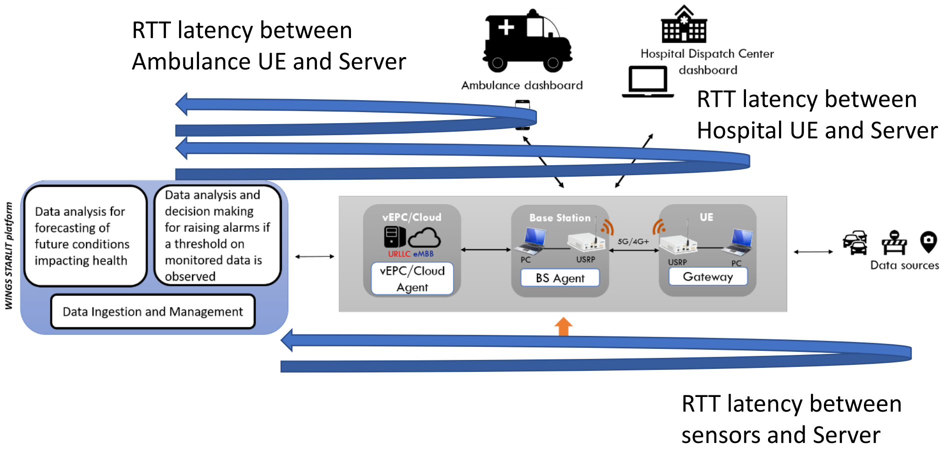


Figure 30. RTT latency.

<u>Service reliability (APP layer)</u>

In order to measure and validate service reliability, the definition in ITU-R M.2410 is considered similar to UC6, therefore the same methodology is used.

Validation methodology: The packet error rate at the APP layer (packets that arrive delayed or erroneous are considered as lost packets) will be measured using a set of probes, the positions of which are illustrated in Figure 31.

<u>Service availability (APP layer)</u>

Similar to UC6, the service availability will be measured as one minus the measured packet error rate during the operation of a service.

Validation methodology: The packet error rate at the APP layer (packets that arrive delayed are considered as arrived packets) will be measured using a set of probes, the positions of which are illustrated in Figure 31.

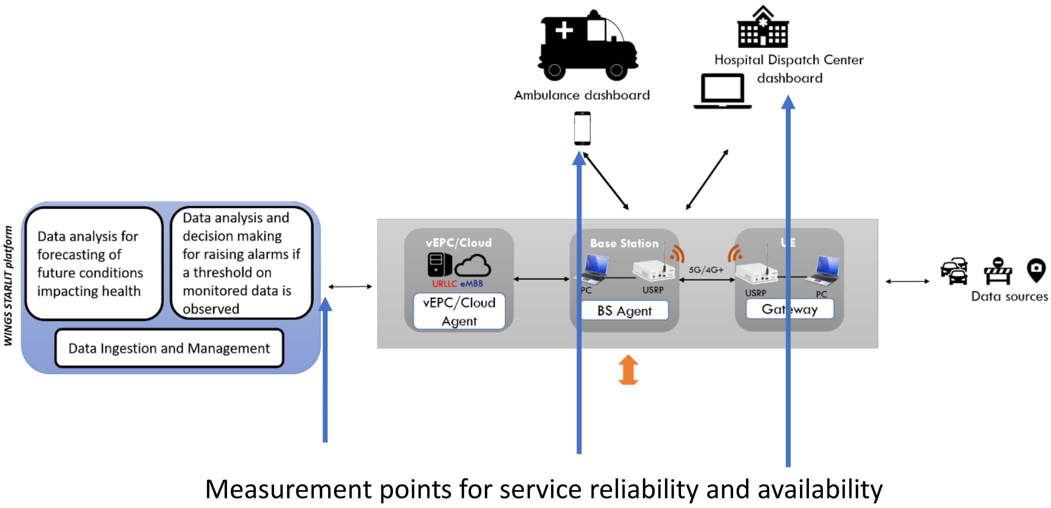


Figure 31. Service reliability and availability.

4.4 Initial trials and validation results

4.4.1 Initial trials of UC7 and UC8

These trials were conducted in the BCOM show room in October 2020.

The interfaces between the different devices are presented in Figure 32. Video signal is retrieved and displayed using DVI or SDI connectors and transferred over IP thanks to the DICOM-RTV standard. DICOM-RTV is a new standard based on the recent video over IP standards, SMPTE 2110, and enables the transfer of metadata, related to the video, such as patient information, device in use or tools' position. Dedicated encoder and decoder boxes are used to compress the video signal to 30 Mbps.

For the lab test phase, all user components of the use case were located in the BCOM showroom. The UPF and WEF Control Plane were also located in the showroom. Each was hosted on a dedicated mini-ITX PC. The UPF used a 1Gbps switch and network interfaces on the PC. The gNodeB (gNB) component was an Amarisoft Call-box Classic (Amarisoft, LTE-callbox, 2021). AMARI Callbox Classic is supporting 4x4 MIMO and carrier aggregation and it is used for testing up to CAT10 LTE UEs. It is also suitable for handover and reselection testing thanks to multiple cells configuration. It also supports 5G NR NSA mode (Amarisoft, LTE-callbox, 2021). It supports up to 600Mbps DL and 150Mbps AL as well as a 10m range when used at full power. During the testing phase, the power settings of the Amarisoft Callbox Classic were set to minimal, so the bit rate and range were lower. The architecture of the test setup to show case UC8, is shown in Figure 33.

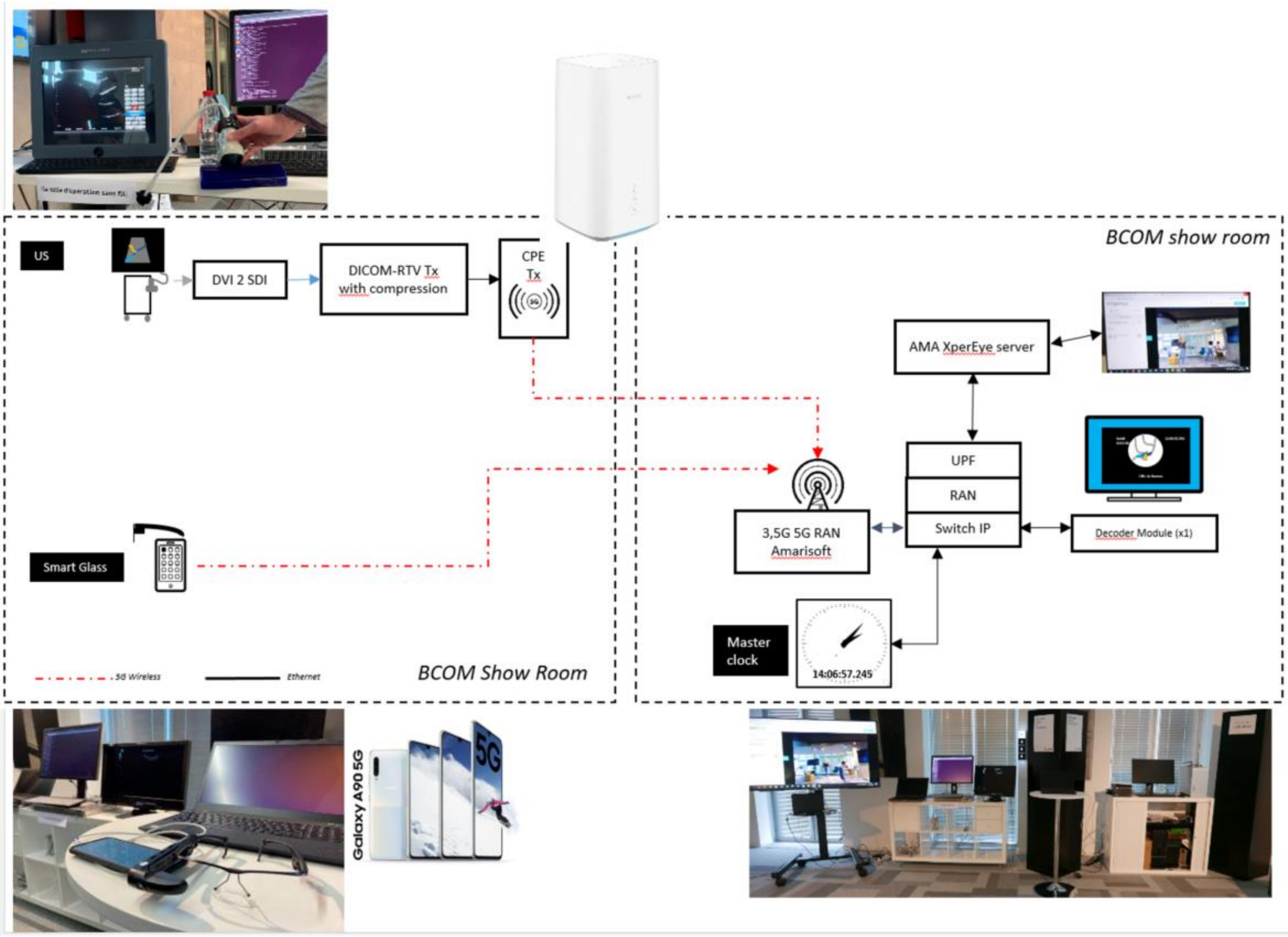


Figure 32. Test in lab architecture.

The first tests in lab consisted of two uplink 5G transmissions, one for the ultrasound stream and one for the **AMA XpertEye** solution, see Figure 32.

The ultrasound was using the DICOM-RTV Tx module to compress the video signal to 30Mbps. The output of the compression module was then connected to the 5G CPE Router.

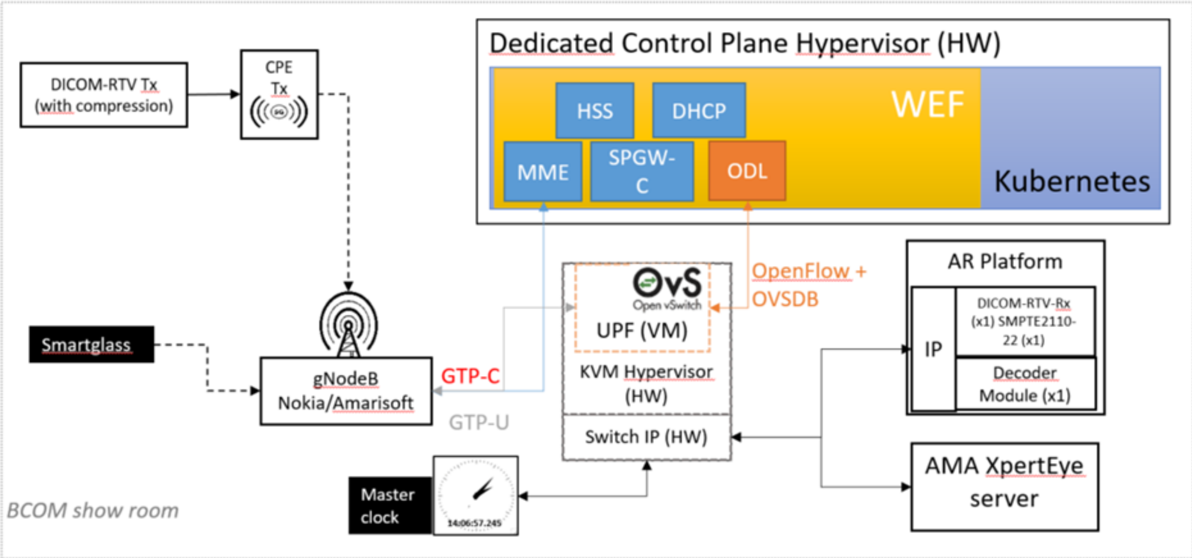


Figure 33. UC8 Network architecture (Demo target).

Initially, the network components were tested in separation to determine the bit rate supported by our experimental 5G networks and then we ran functional tests that involved a first version of the AR use case and the smart glasses provided by AMA.

Networking tests

In terms of bit rate, we achieved an average downlink rate of 100 Mbps and an average uplink rate of 43 Mbps with the Huawei CPE set 5m from the RAN antenna**.** With the CPE set 1m from the antenna, we reached 180 Mbps DL and 70 Mbps UL. It is important to remember that these were done with the RAN set to its minimal power output, which explains the relatively low bit rate.

We also tested the network latency and found that it varied greatly. We used the ping tool to evaluate the round-trip-time between a laptop connected to the Huawei CPE through a wired connection and the UPF component.

Finally, we tested the end-to-end latency between the ultra sound probe and the remote monitor using a proprietary tool provided by Harmonics. These tests include the 5G NSA network as well as the video encoder and decoder and lasted 9 hours. The results were as follows:

- Latency for the video coder/decoder: 30ms each
    - Total of 60ms
- Latency of the 5G network:
    - Between 57ms and 73ms

Functional tests

For the functional tests, the setup described in section 5.3.1 was used. The DICOM-RTV TX component was configured to encode its video flow at a bit rate of 30Mbps. The tests showed that the flow could be transmitted to DICOM-RTV decoder through the 5G network successfully for several hours without interruption.

On the reception side, the output of the decoder module was connected to a monitor to visualize the ultrasound and estimate the latency in the UL transmission. After some measurements, the overall latency was estimated around 120ms, 60ms for coding and decoding the video signal, and 60ms for the 5G operations. Knowing the processed video signal will need to be transferred back to the operating room, we will investigate to find ways to reduce this latency, so that the surgeon can perform his intervention in good conditions. Tests are currently carried out to identify the minimum value of latency to retrieve a video and images with the best quality to allow analysis and diagnosis.

Finally, tests were conducted with the smart glasses provided by AMA to test whether it was possible to transport the video stream from the smart glasses to another phone connected on the 5G network while simultaneously streaming the video encoded by the DICOM-RTV module. The test was successful and showed that there was enough bandwidth for both video streams to be transmitted at the same time.

4.4.2 Initial validation results of UC6

As described in section 4.3.1, in UC6 metrics will be collected and validated both in network and application layer. Regarding network metrics, RTT latency and throughput (UL/DL) will be validated. Regarding the application layer, RTT latency, throughput (uplink/downlink), service reliability and service availability will be collected and validated. During the initial phase of the trials, we selected as initial KPI the RTT latency in APP layer. For simplicity we started by collecting RTT latency metrics on the short path (located between the wearable devices and the server) as illustrated in Figure 34.

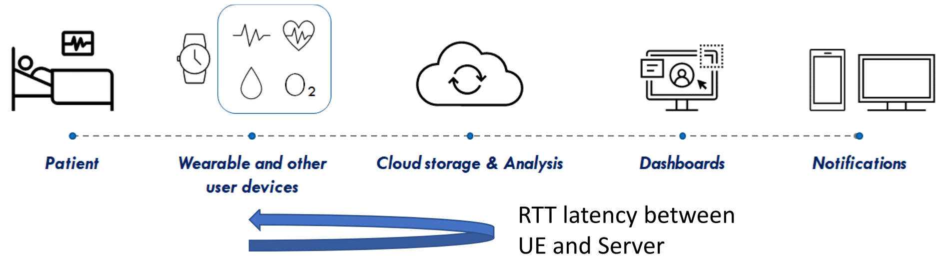


Figure 34. UC6 RRT latency metric collection.

The collection of RTT latency was realised by adding timestamps on all requests departed from the sensors. Then, the Server was responsible to duplicate this timestamp on the relative responses sent back to the sensors. Then, sensors calculate the RTT latency by subtracting this timestamp from the current timestamp of the system. Then, the results were propagated to the server by adding the results on the next application request.

During the initial trials of UC6, RTT latency metrics were collected from 7 consecutive days (21/01/2021 to 27/01/2021). In total, 5300 samples (RTT latency results) were collected and analysed as illustrated in Figure 35. The average value of app layer RTT latency is around 113ms. In addition, from the figure it becomes obvious that the app layer latency is relatively stable with small fluctuations of 10ms.

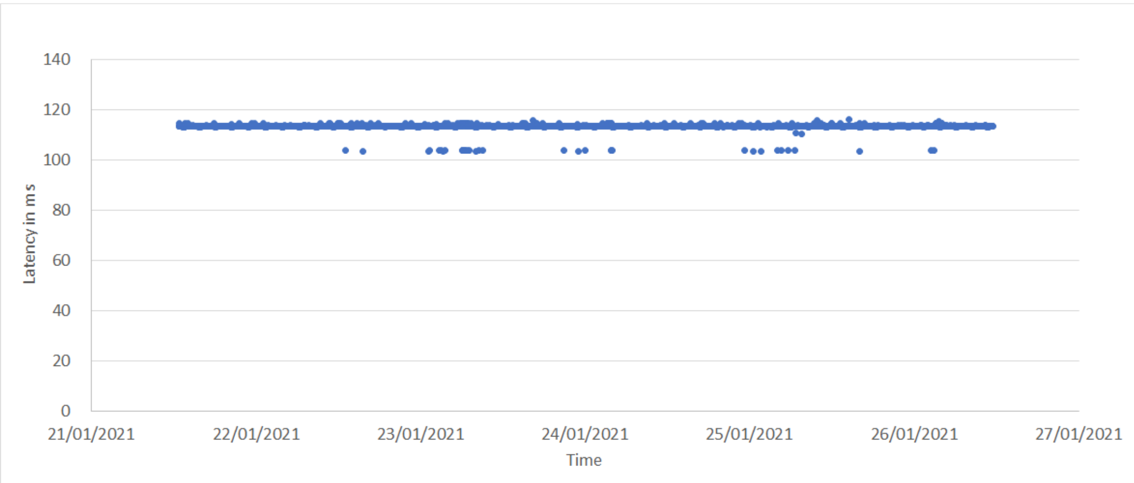


Figure 35. UC6: Initial results on RRT latency.

In order to further improve the initial results, we will collect additional metrics in the direction to examine if this latency is mainly due to the latency on the network or because of processes (mem/cpu locks) on the app layer.

5 Mobility-efficient city integrated ecosystem, use case deployment, trial and validation

5.1 General description

One of the three main themes addressed by the 5G-TOURS project is the mobility-efficient city, which aims at implementing a set of use cases that improve mobility-related experiences from various perspectives. These use cases revolve around the 5G EVE Athens site, including an extension to the Athens International Airport (AIA).

More specifically, the four use cases concerning the mobility-efficient city are:

a) **UC10. Smart airport parking management:** This is a solution that relies on the mMTC functionality provided by 5G. Around 100 parking sensors, installed at each parking position, will help keep track of available and occupied spots in real time, facilitating the parking process within an airport, as well as in any other controlled parking area.
b) **UC11. Video-enhanced follow-me moving vehicles:** Follow-me vehicles, which lead aircrafts to parking positions, monitor and oversee the activity at the airport airside area, and attend to incidents, emergencies and critical events. 5G-TOURS will develop a solution to equip mobile units of the airport with high definition cameras, sending multiple live feeds to the Airport Operations Centers (AOCs) and other stakeholders.
c) **UC12. Emergency airport evacuation:** This UC will monitor the location of the different users and provide them with instructions for evacuation in a real life setting inside the AIA satellite terminal based on AR. The incorporation of AR technology in this particular use case will be useful for training and simulation exercises to be held in the airport. Furthermore, this use case focuses on the location accuracy part of 5G technology.
d) **UC13. Excursion on AR/VR-enhanced bus:** Applications based on AR or VR can easily attract and retain students' attention and help them focus on valuable informative sessions on the road during excursions, as well as at the places they visit; such applications were not feasible before 5G.

To support the needs of 5G-TOURS project and the implementation of the four UCs at the AIA premises to extend the existing 5G EVE Greek site node, the following additional equipment has been installed:

- 2 outdoor and 4 indoor pair antennas with radio units, (4G/5G) utilizing band 3.5-3.6 GHz, while the 4G antennas the 2.5 GHz.
- All the antennas will be connected through fiber optics to NOKIA's BBUs (2 x BBUs) at the airport. Then, the data will be forwarded through an OTE switch which is connected to the OTE IP Core, using a 10 Gbit line, to interconnect to the 5G-EVE Greek site infrastructure at OTE Labs in Psalidi.
- For the needs of implementation of the four UCs, smart devices are used (mobiles, tablets, AR/VR headsets, cameras, chipsets, sensors, etc.) and specific innovative applications are under development (smart parking app, 4K UHD video transmission, evacuation app, AR/VR apps).
- Moreover, probe server and s/w probes are installed at 5G-EVE infrastructure as well as at AIA extended NOKIA's network. These probes are used for measuring metrics in real time in order to validate the KPIs of the network.

Refer for more details to deliverable (5G-TOURS, D6.2, 2020) which describes the progress in terms of implementation of the 4 UCs of the mobility-efficient city.

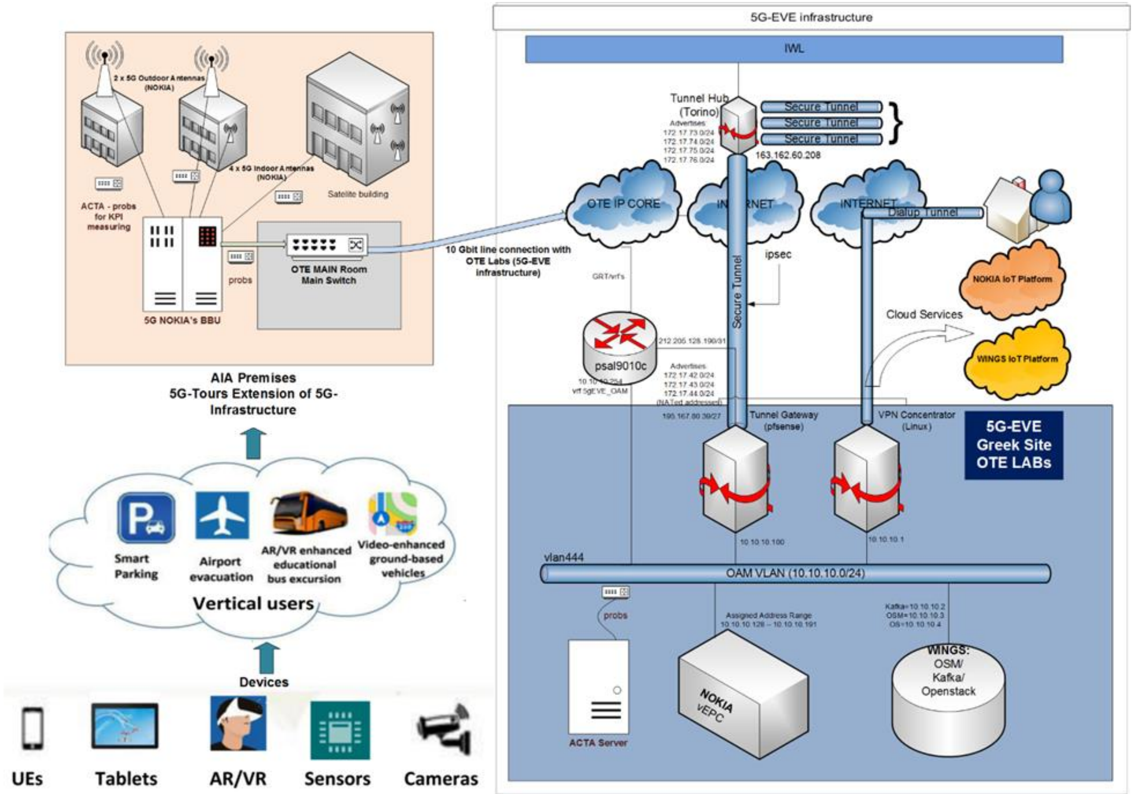


Figure 36. 5G-TOURS Greek site/Athens node infrastructure.

5.2 Integrated ecosystem

OTE, NOKIA-GR and WINGS are responsible to drive the upgrade of the 5G-EVE Greek site infrastructure and ensure that the corresponding deployments will be in place on time. The final architecture will be capable of dealing with the following use cases that will be demoed in the surrounding area of AIA:

- UC10: Smart airport parking management
- UC11: Video-enhanced ground-based moving vehicles
- UC12: Emergency airport evacuation
- UC13: Excursion on an Augmented Reality (AR)/Virtual Reality (VR)-enhanced bus

The architectural extensions that will be developed in the context of 5G-TOURS will integrate smoothly with existing 5G-EVE infrastructure that covers a region of northern Athens around the R&D site of OTE. The network enhancements and extensions are better illustrated in Figure 37 below.

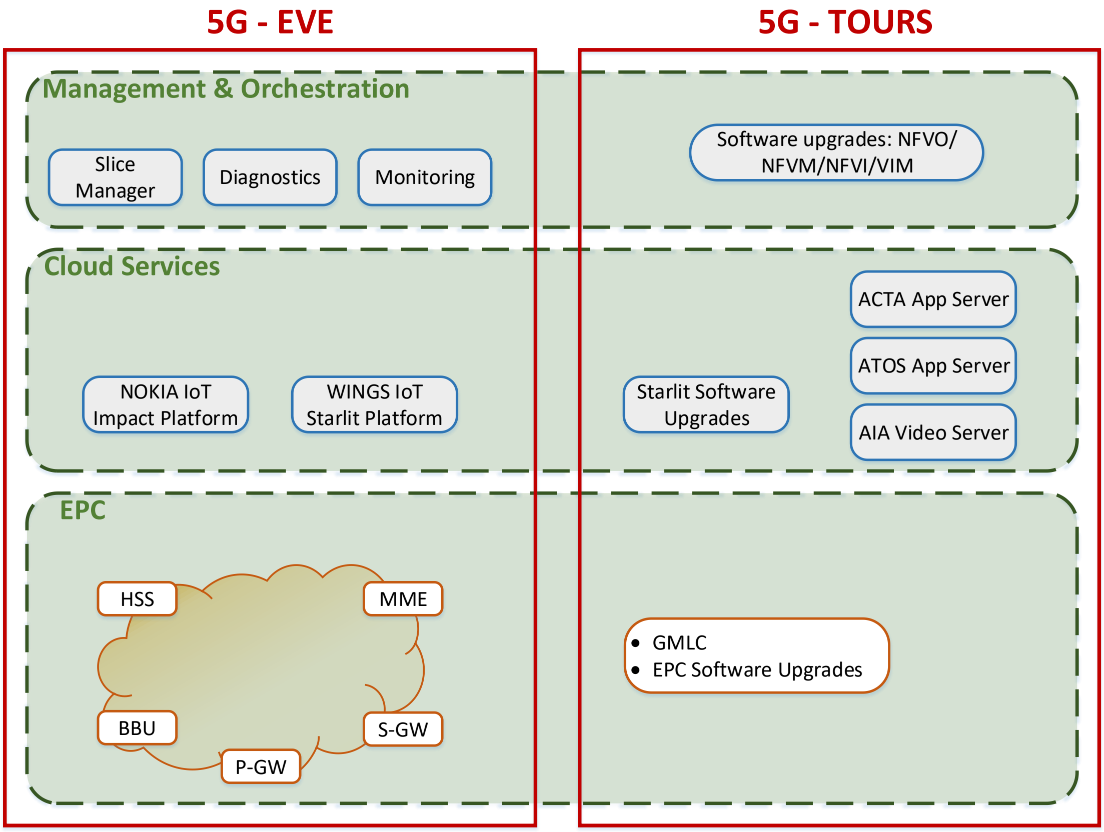


Figure 37. Network Extensions and Enhancements brought by 5G-TOURS.

A quantitative representation of the existing 5G-EVE infrastructure covers the logical layers of management-orchestration, cloud services and networking that cooperatively aim to satisfy demanding technical objectives, e.g. network slicing and orchestration mechanisms. Relying on this robust architecture, 5G-TOURS manages to provide necessary software upgrades of existing components and to extend with new ones in order to support the required verticals. In a nutshell, the major add-ons are summarized as follows:

- NFVO, NFVM, VNFI, VIM software upgrades
- EPC software upgrades
- STARLIT application server upgrades to support the respective use cases/verticals
- A brand-new Gateway Mobile Location Centre (GMLC) that will serve UC12
- New application servers (ACTA app server for network monitoring and performance evaluation, ATOS app server for AR/VR content delivery and AIA video streaming server)

Figure 38 depicts a brief overview of RAN solution that will be deployed at AIA's demo areas. NOKIA-GR will provide Airscale product family that enables support for Non-Standalone (NSA) 5G NR technology and suits both to indoor and outdoor coverage. E-UTRAN New Radio Dual Connectivity (EN-DC) option 3/3x will be used to enable 5G radio connectivity, as also highlighted in the figure above.

A detailed description of all the above is beyond the scope of this document and is presented adequately in D6.2 (5G-TOURS, D6.2, 2020). To be able to support all Athens use cases, 5G-TOURS infrastructure extensions can operate with all three basic service types, i.e. eMBB, mMTC, URLLC and combinations. Figure 39 shows a high-level concentrated snapshot of the deployment at AIA surrounding area, emphasizing on the network segments that participate in each use case. Focusing on the RAN, Figure 40 shows an indicative deployment for UC13, which from the implementation perspective is the most complex as it requires both indoor and outdoor setup.

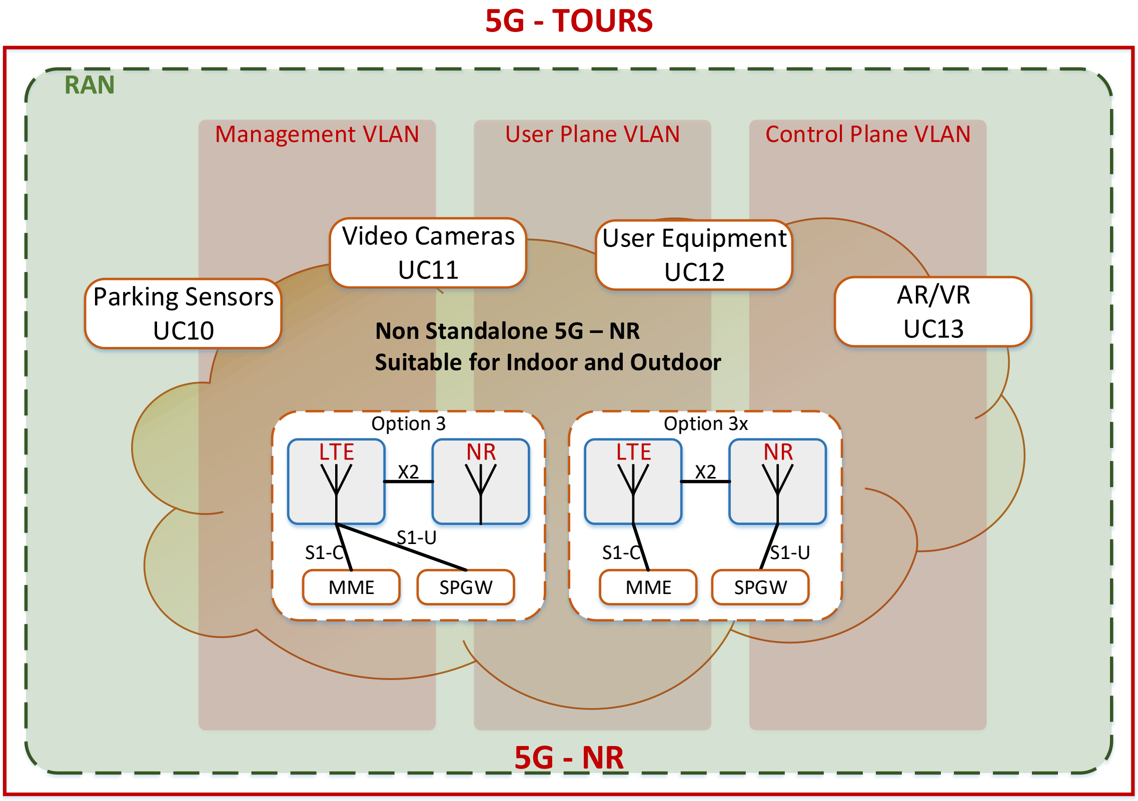


Figure 38. Overview of RAN Deployment at AIA.

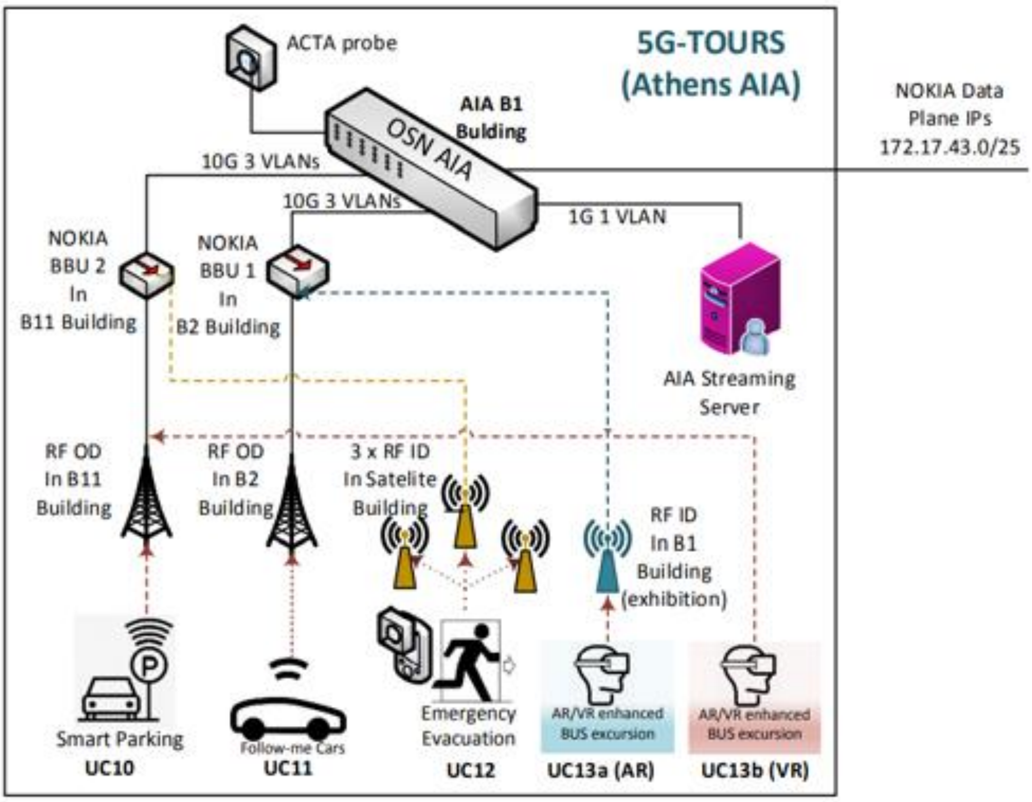


Figure 39. High-Level AIA Infrastructure.

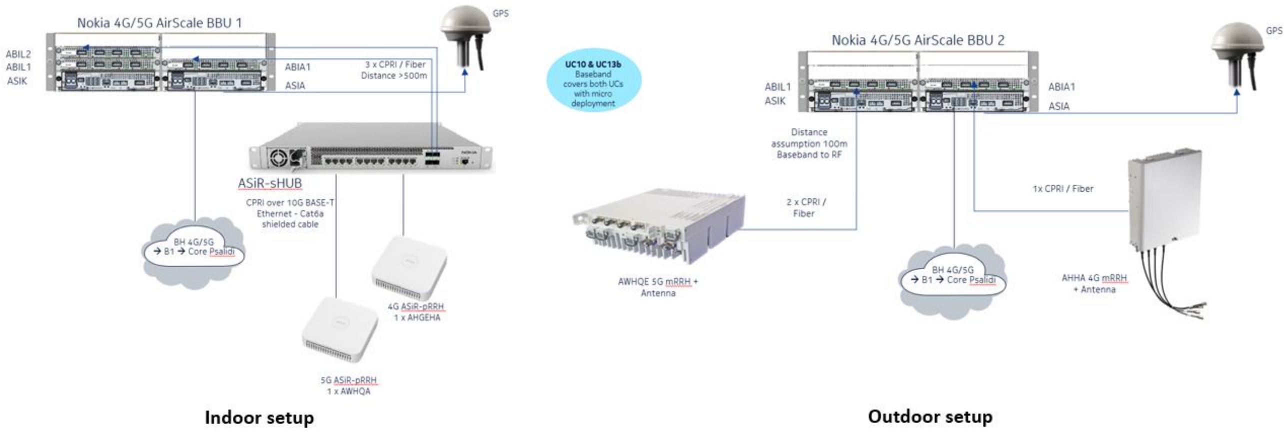


Figure 40. Indicative RAN Hardware Setup for UC13.

Based on the overall architecture, the diverse use cases that will be showcased in Athens site can be explained via conceptual flow diagrams as referred below:

UC10: Smart airport parking management

This use case aims to validate 5G capabilities to support reliable massive machine type communications. As shown in Figure 41, parking sensors will use the public EPC network for refreshing their state at STARLIT WINGS application server, while the client application running at users' mobile phones will require updates via the 5G-TOURS network infrastructure. Traffic between AIA network and 5G EVE EPC network will be established via backhauling.

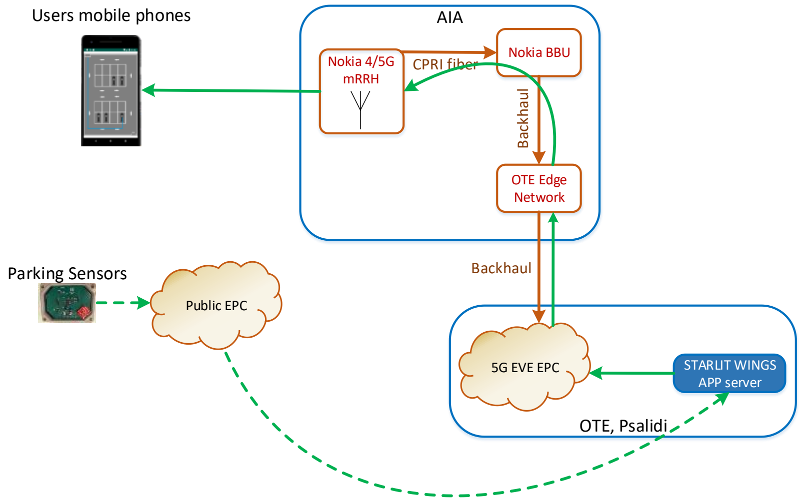


Figure 41. UC10 Conceptual Flow Diagram.

UC11: Video-enhanced ground-based moving vehicles

This use case aims to demonstrate the potential of 5G technology to high bandwidth and fast network response for live streaming of camera feeds. To achieve this, Figure 42 shows that video captured by moving vehicles will be forwarded via 4G/5G Wi-Fi routers to AIA's RAN. The streaming will reach 5G EVE EPC network at OTE Psalidi area and will return to video server installed in AIA's control room for real time inspection.

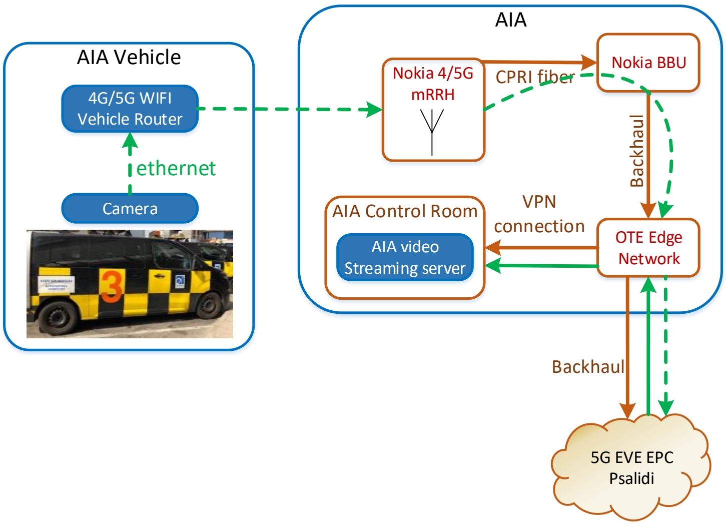


Figure 42. UC11 Conceptual Flow Diagram

UC12: Emergency airport evacuation

This use case aims to prove that 5G technology enables low-latency and high-reliability communications to a big number of users concentrated to an indoor area. To achieve this, the use case demonstrates the quick and organized evacuation of people with the aid of 5G enabled solutions.

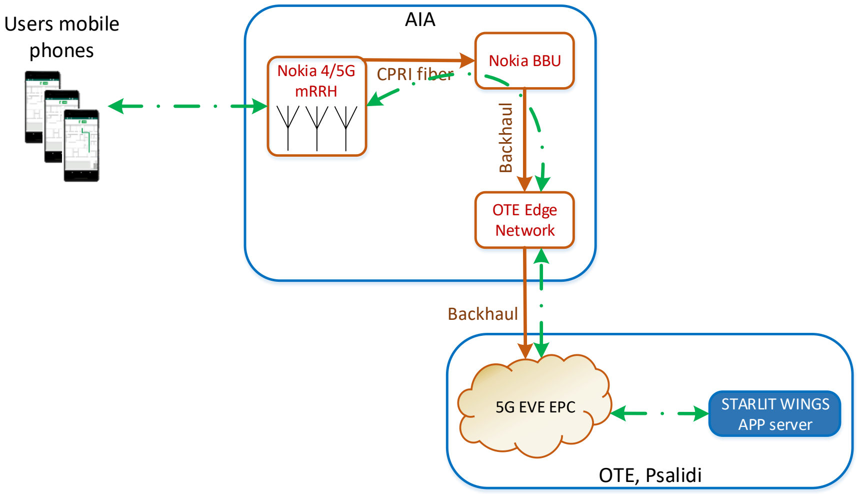


Figure 43. UC12 Conceptual Flow Diagram

Indoor micro cells provided by NOKIA-GR will be installed in appropriate places in a selected Gate area in AIA, thus allowing WINGS application deployed on STARLIT server to estimate accurately all users' position via triangulation. The result of this processing will return to WINGS mobile application that eventually draws the user a personalized and optimized evacuation path. As shown in Figure 43, the same network flow is used for both directions.

UC13: Excursion on an Augmented Reality (AR)/Virtual Reality (VR)-enhanced bus

This use case aims to demonstrate the capability of 5G technology to provide fast and reliable connectivity that support smooth streaming of online content to a group of users that move at moderate speed. This use case is split in two parts. The first part concern students that are transferred to AIA, while they are presented with rich informational and educational content via VR technologies and 5G-enabled headsets.

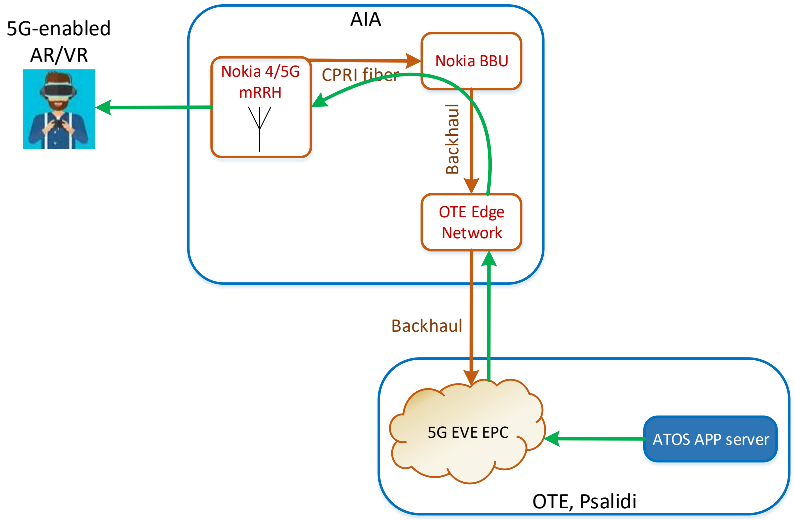


Figure 44. UC13 Conceptual Flow Diagram.

The second part of the use case begins when students visit an exhibit area at AIA, and they interact with digital content. The use case requires the development of the respective AR and VR applications. This will be carried out by ATOS in collaboration with EA, based on technological development and deployment offered by ATOS and educational and 3D digital content offered by EA. Figure 44 illustrates the path from the ATOS server to AR/VR headsets, where the digital content is displayed.

5.2.1 Mobility-efficient city use-cases Innovation aspects

The network innovations associated the Mobility-efficient city use cases are shown in Table 17 (5G-TOURS, Periodic Report Part B).

A) To add smartness AI-enhanced MANO to OSM (5G-EVE orchestrator) and diagnostics module (by WINGS). The use cases to showcase this innovation are UC10 and UC12.

B) B) To implement Real-time (Active or Service Performance) measurements while the 5G-TOURS Use Cases are active and running (by ACTA). The use cases to showcase this innovation are UC11 and UC13.

Table 17. Network innovation for different use cases for work WP6.

	5G-TOURS WP6 Network Innovations			
Use case	**Service layer**	**Enhanced orchestration**	**AI-based data analytics**	**Service Provider Innovation**
UC10 Smart Parking Managment	N/A	Resource allocation, deployment and migration of Network Services in an automatic and optimized way using various metrics (infrastructure, VNFs, Applications, etc) and verticals' requirements. (5G-EVE OSM upgrade)	Network monitoring for anomaly detection, performance degradation and root cause analysis of these problems; will be provided by the diagnostic component of the AI-enhanced MANO.	The end-user (driver) will be informed in real-time about the parking facility status as well as find a parking spot and be routed to it based on the parking facility status, other concurrent requests aiming to minimize the unnecessary driving that leads to fuel costs, and increases emissions. The end-user (parking facility staff) will be able to monitor the condition of the facility in real time as well as view the occupancy trends. This can lead to the optimal management of the parking facility as well as schedule maintenance proactively through the platform's real-time notifications.

Use case	Service layer	Enhanced orchestration	AI-based data analytics	Service Provider Innovation
UC11 Video enhanced ground-based vehicles	Active Performance Measurement while the Service is Running	N/A	Real time feed of KPI values, for better AI-based decision making	The end user (follow-me car driver and the control center personnel) will increase their situation awareness, have better and more interactive collaboration among themselves and pre-emptively address irregular or harmful conditions that might happen.
Use case	**Service layer**	**Enhanced orchestration**	**AI-based data analytics**	**Service Provider Innovation**
UC12 Airport Evacuation	N/A	Resource allocation, deployment and migration of Network Services in an automatic and optimized way using various metrics (infrastructure, VNFs, Applications, etc) and verticals' requirements. (5G-EVE OSM upgrade)	Network monitoring for anomaly detection, performance degradation and root cause analysis of these problems; will be provided by the diagnostic component of the AI-enhanced MANO.	The end-user (evacuee) will be guided towards the nearest exit via an intuitive interface rather than a set of instructions that maybe confusing for the user under stress. Also the location accuracy that will be provided from the network in conjunction with the 3 indoor cell will provide the users location precisely. Thus, the accuracy will be better than the one provided by current mobile networks.
Use case	**Service layer**	**Enhanced orchestration**	**AI-based data analytics**	**Service Provider Innovation**
UC13 AR/VR Students Bus Excursion	Active Performance Measurement while the Service is Running	N/A	Real time feed of KPI values, for better AI-based decision making	Service delivery will be improved by analyzing the correlation of user QoE (WP7) with Active Service KPIs to identify relation between network performance, Quantitative Service KPIs and QoE.

5.3 Technical validation

5.3.1 Methods for KPIs measurements

Concerning the 5G-TOURS KPIs measurements, two testbed measurement methods have been proposed for the Turin and Rennes trial sites, based on measuring the collected results from

a) "ping"
b) "iperf" commands.

In addition to these methods, for the Athens trial site, "probes" are used for the measurement network KPIs. Probes can be installed between antennas, BBUs and central servers. Continuous real time measurements of the network KPIs are performed, which are valuable as UC10 and UC12 provide the end user services for a long duration. Also, the real time feed of KPI values support better AI based decision making. Then, data and measurements will be collected for a certain period (6 months or 1 year) and using the corresponding analysis of data, the Reliability KPI for the Athens node 5G network will be measured.

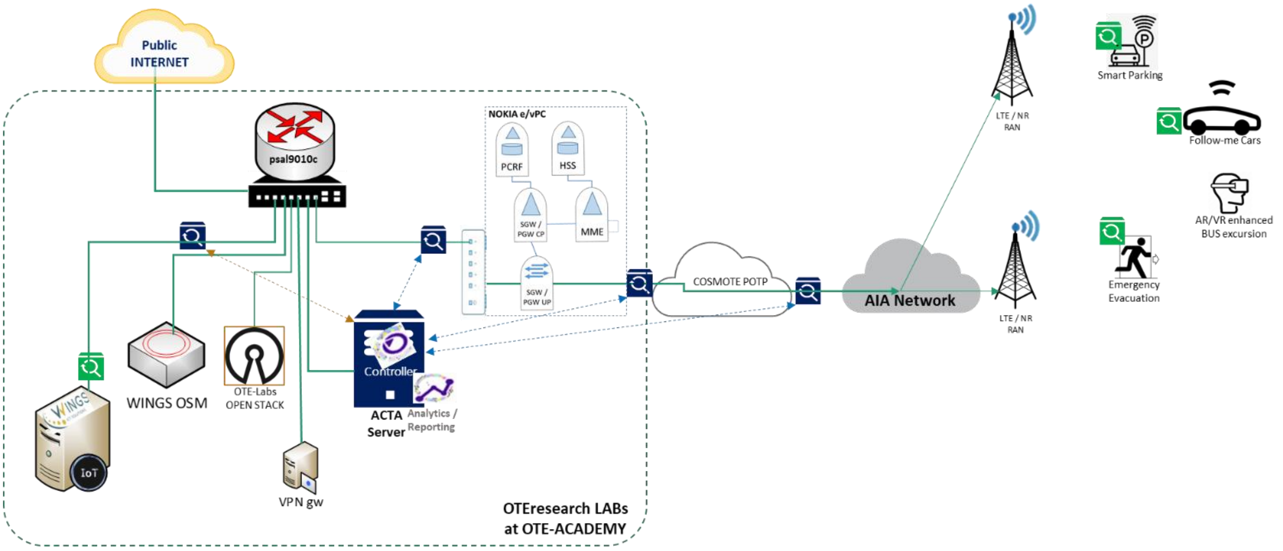


Figure 45. The Athens site general diagram indicating also the 4 Use Cases (all in the Athens International Airport – AIA).

The color code for the probes (depicted with boxes and a magnifying glass icon) in the diagram of Figure 45 above is as follows:

- *Blue probes (Network KPIs) – the ones that are in VLAN 445 (control plane VLAN) and are L2 to L4*
- *Green probes (Service Layer KPIs – L3 and above) – end to end*

<u>Probes</u>

Network Probes are devices or software plug-ins inserted at key junctures on the network in order to monitor certain parameters, either passively (i.e., non-intrusively) or actively (i.e., intrusively), by generating small amounts of traffic that simulate user traffic.

These network probes generally fall in two categories:

a) Hardware probes that are devices/equipment placed close to network elements (e.g., routers, switches and server), or even on them (e.g., small form-factor pluggable (SFP) modules) to monitor certain performance parameters.
b) Software probes that are in the form of software plug-ins that are built-in or installed separately on the network elements, or even on the end user devices, e.g., user equipment (UE).

A. Multiple probe based, layer 2 & 3, active & passive KPIs continuous measurement (monitoring) platform.

- Pass through probes, GE/10GE, connected at selected points of the network.
- End Probes for each use case site, next, just after the terminal device or even integrated in the UE (when possible): camera, IoT sensor or IoT gateway, 5G modem, etc.
- Close to the interface between the 5G antenna Base Station (BS) and BBU and before the backhauling transport network equipment.
- Between the EPC and the IP Core router.
- Close to or even integrated (software Probe) in the application servers (after the IP core router).

B. Single Probe based, layer 3 & 4, passive KPIs continuous measurement (monitoring) platform.

- A platform (Viavi, 2019) will be connected at an interface (GE/10GE) in the core of the 5G network (perhaps through a mirror or a span port). This is an interface where all the network traffic is passing through. It will provide recording of the layer 3 & 4 (and above) signals using hardware and software filters. Accurate timestamping of the recorded signals will be performed.

- Network Segmentation: An effort will be made to deploy as many probes as possible along the full E2E network, in order to evaluate separately the performance of all distinguished network segments (e.g. access, backhaul, aggregation, core, etc.).
- We will combine the aforementioned metrics with the metrics collected by 5G-EVE probes.

In each site, the measurement results are collected from all UCs.

Analysis of the results

The results for each type of KPI (latency, reliability, etc.) is processed and compared to the required or target value. Two types of analysis will be conducted:

- KPI target–based analysis
- Deep analysis Further analysis, as part of QoE evaluation

5.3.2 Two-Way-Active-Measurement Protocol (TWAMP)

Additional measurements are considered and have been successfully tried in the Lab at a WAN environment. These involve the use of Two-Way-Active-Measurement Protocol (TWAMP) on end user devices (Figure 47). The TWAMP protocol is used by Network equipment manufacturers (CISCO, HUAWEI, ERICSSON, Juniper etc.) and is often build in in the OS that controls their equipment.

The official RFC5357 can be found in the IETF repository here (IETF, 2008). It is based on the One Way Active Measurement Protocol (OWAMP), that is described in IETFs RFC4656 (TWAMP, 2015).

```
Microsoft Windows [Version 6.3.9600]
(c) 2013 Microsoft Corporation. Με επιφύλαξη κάθε νόμιμου δικαιώματος.

C:\Users\User>cd Desktop

C:\Users\User\Desktop>PYTHON twampy_new.py sender 172.16.18.50:8022
===============================================================================
Direction         Min         Max         Avg          Jitter     Loss
-------------------------------------------------------------------------------
  Outbound:           0us         0us         0us         0us      2.0%
  Inbound:       882.97ms    985.01ms    894.81ms     13.12ms      7.0%
  Roundtrip:          0us    125.00ms     18.30ms     30.63ms      9.0%
-------------------------------------------------------------------------------
                                                 Jitter Algorithm [RFC1889]
===============================================================================

C:\Users\User\Desktop>PYTHON twampy_new.py sender 172.16.18.50:8022
===============================================================================
Direction         Min         Max         Avg          Jitter     Loss
-------------------------------------------------------------------------------
  Outbound:           0us    232.03ms      4.28ms      7.95ms      0.0%
  Inbound:       890.76ms    980.39ms    906.64ms      7.07ms      1.0%
  Roundtrip:          0us      1.19sec   171.14ms    119.55ms      1.0%
-------------------------------------------------------------------------------
                                                 Jitter Algorithm [RFC1889]
===============================================================================

C:\Users\User\Desktop>PYTHON twampy_new.py sender 172.16.18.50:8022
===============================================================================
Direction         Min         Max         Avg          Jitter     Loss
-------------------------------------------------------------------------------
  Outbound:           0us         0us         0us         0us      1.0%
  Inbound:       887.51ms      1.02sec   900.57ms      6.04ms      7.0%
  Roundtrip:          0us    204.00ms     30.53ms     23.79ms      8.0%
-------------------------------------------------------------------------------
                                                 Jitter Algorithm [RFC1889]
===============================================================================

C:\Users\User\Desktop>PYTHON twampy_new.py sender 172.16.18.50:8022
===============================================================================
Direction         Min         Max         Avg          Jitter     Loss
-------------------------------------------------------------------------------
  Outbound:           0us         0us         0us         0us      1.0%
  Inbound:       879.51ms      1.03sec   899.89ms     13.97ms      6.0%
  Roundtrip:          0us    438.00ms     46.52ms     45.79ms      7.0%
-------------------------------------------------------------------------------
                                                 Jitter Algorithm [RFC1889]
===============================================================================
```

Figure 46. TWAMP measurements in lab environment.

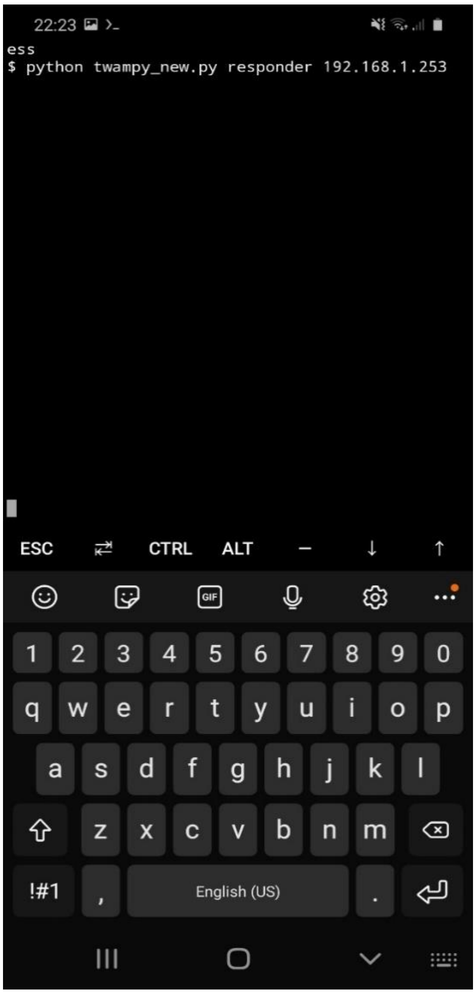


Figure 47. The TWAMP Server output on a Win10 PC when the responder is a Samsung S20 Pro Smartphone

The improved TWAMP performance and accuracy compared to the ICMP protocol was measured by Zaim * Kocak in their 2016 article (Kahraman Zaim, 2016).

A brief table overview of the comparison between PING and TWAM is shown in the table below.

Open Source Python Code is available and in order execute ("run") it in different platforms (like Windows, Linux, Mac and/or Android) modifications were applied.

Table 18. TWAMP vs. PING comparison for time based measurements.

Capability	TWAMP	ICMP echo (ping)
Original Scope	Performance monitoring across IP networks	Connectivity check, Crude round-trip delay capability
Monitoring of existing Infrastructure	Available in certain routers, NIDs, probes	Yes (almost universal support in every NE, Operating System)
Transparency through network elements allowing generic, robust, predictable test methodology	Yes (UDP traffic based test, passes through network)	In some installations, routers block or rate limit ICMP
Round Trip Delay KPI	Yes	Insufficient accuracy due to slow ICMP processing in network elements
1-way Loss KPI	Yes	No
1-way Delay KPI	Yes	No
1-way delay variation (PDV) KPI	Yes	No

5.3.3 Initial results on network KPI validation

The Integrated KPI validation Platform

Measurements have taken place from the two blue probes depicted in Figure 48, relating to the Athens Use Cases.

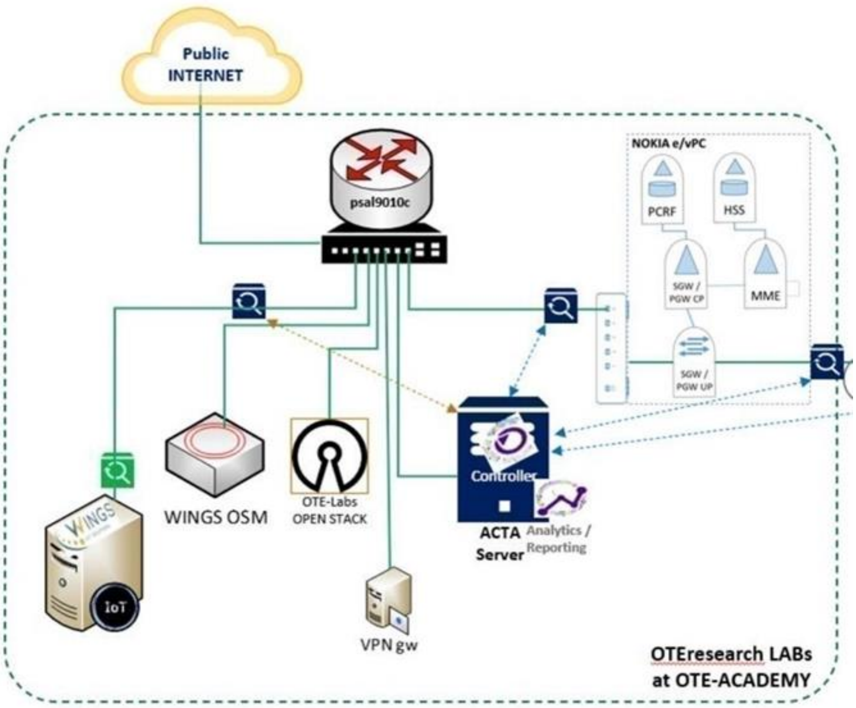


Figure 48. KPI Validation Platform at the OTE Research Labs for all Athens UCs.

Preliminary data of traffic measurement and frame delay measurements (using TWAMP) are shown in the screenshot here (Figure 49). These measurements are made on the OTE Core Network. Three data flows between probes ❷ and❸, representing Video, Data and Voice traffic, are initiated and the roundtrip delay for each direction are provided.

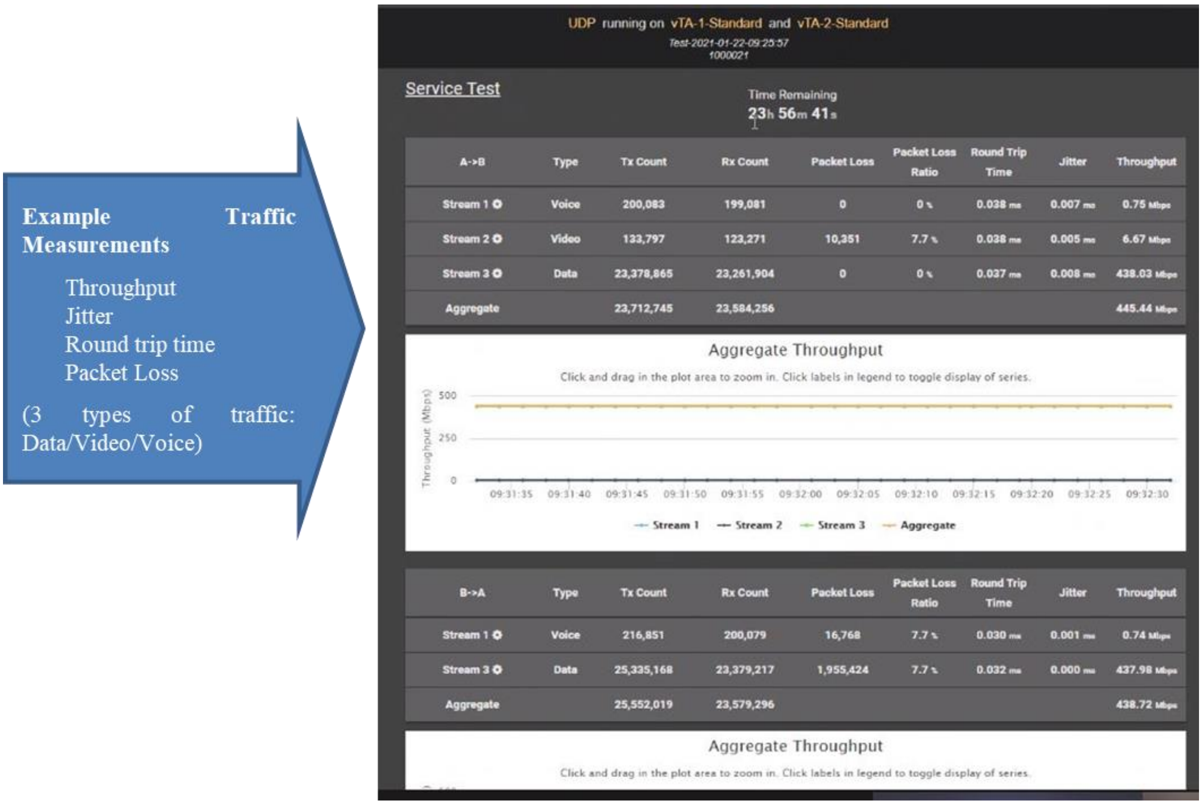


Figure 49. Preliminary data of traffic measurement.

The Integrated KPI validation Platform

- The front and back side pictures of ACTA's hypervisor and probe installations are shown in Figure 50.
- Red cables: Control / Management Plane of the KVaP platform (VLAN 445)
- Green Cables: WAN interface for Internet Access and Remote Management/Configuration
- Yellow (optical) Cables: Data Plane / User traffic (VLAN 443)

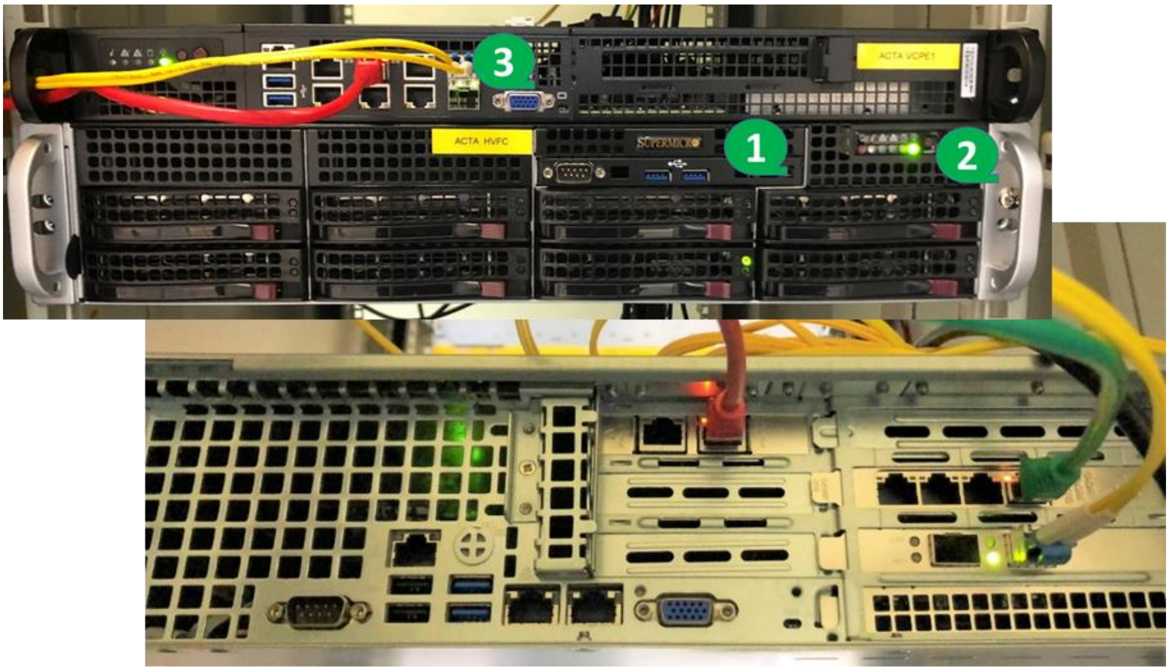


Figure 50. The front and back side pictures of ACTA's hypervisor and probe installations.

Preliminary Example Results

- Preliminary Aggregate Throughput, Packet Loss & Round-trip time (delay) measurements are shown in Figure 51.
- Three data flows between probes ❷ and ❸, representing Video, Data and Voice traffic, are initiated.
- The Aggregate Traffic approached 500 Mbps (0.5 Gbps).
- Packet loss was 0 (only the OTE switch and BNG (Broadband Network Gateway) router were involved).
- The Round Trip Latency was measured to be approximately 0.25 ms (sub-millisecond, as expected).

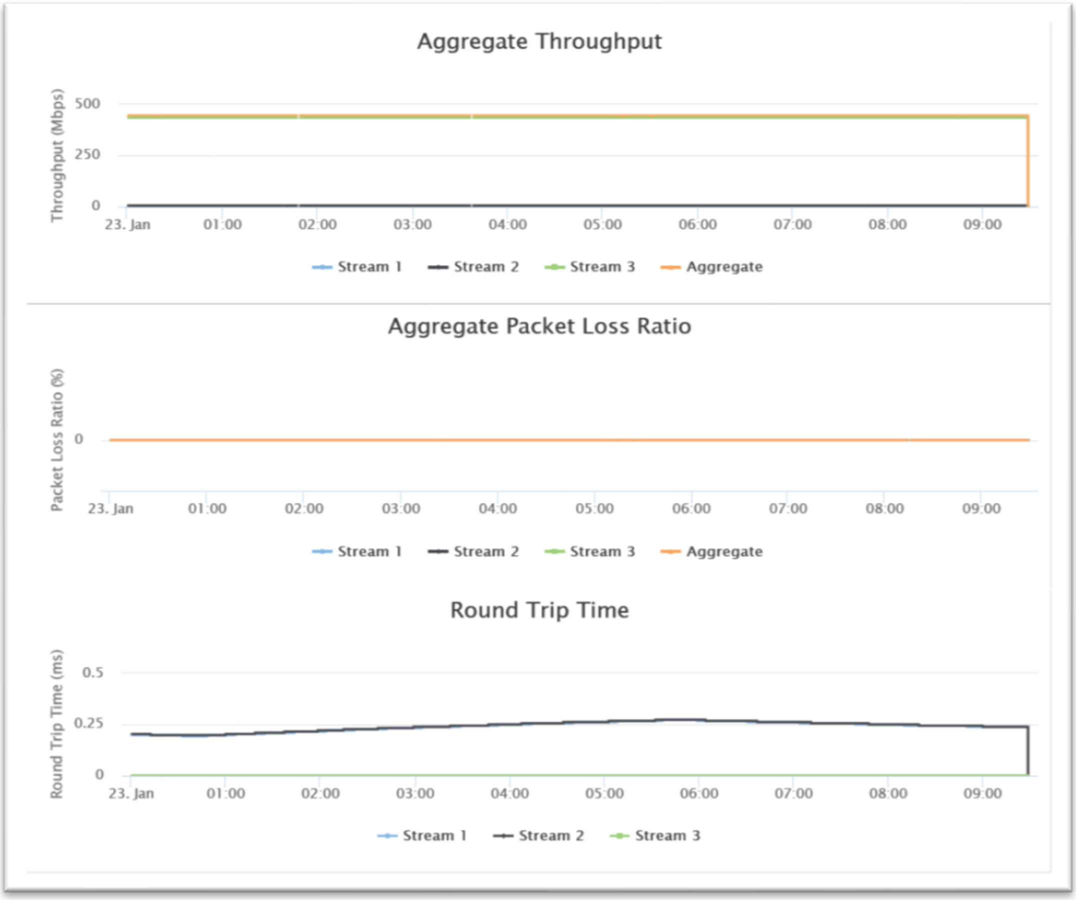


Figure 51. Preliminary results.

Jitter is also measured for the 3 data streams, as shown in Figure 52. This is the variation of the packet delay (per stream) and it is again bellow 1ms (as expected).

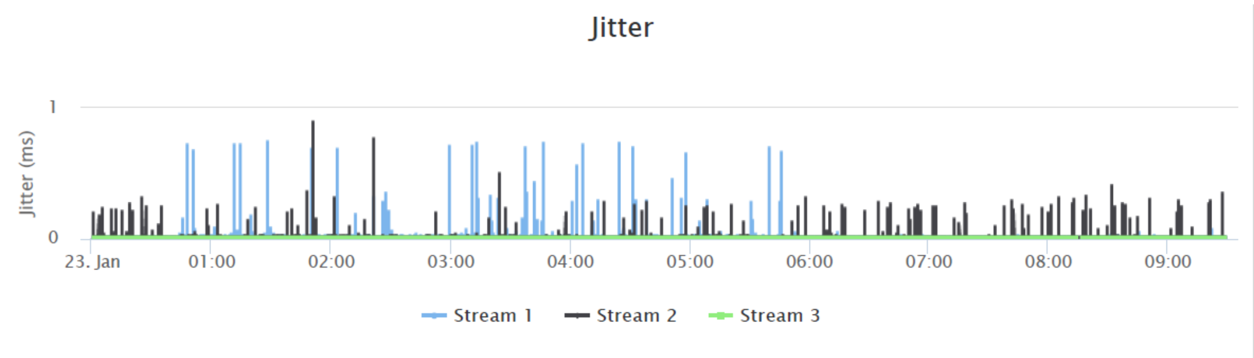
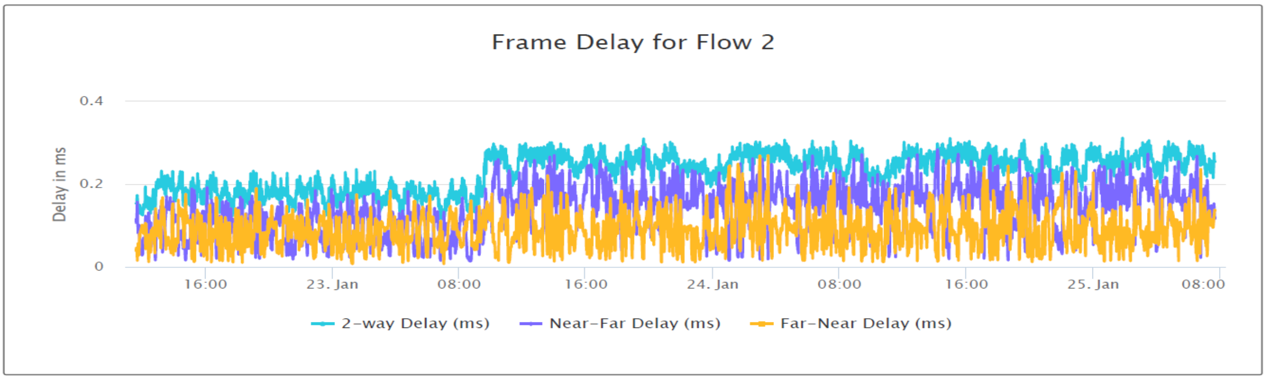


Figure 52. Jitter results.

Using TWAP, time measurements can be acquired for the three (3) streams and the results are more accurate as shown below in Figure 53.



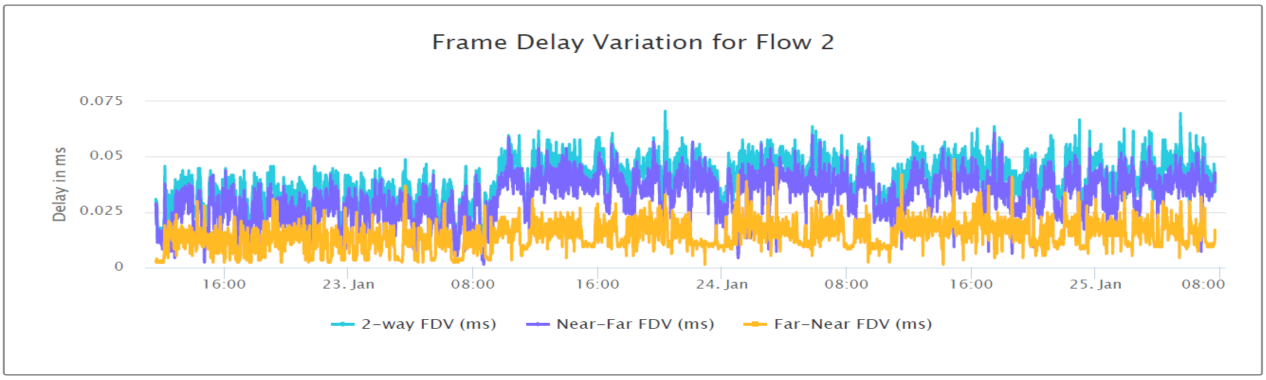


Figure 53. Frame delay results.

5.3.4 UC 10 Smart airport parking management

Smart airport parking management use case targets in validating the 5G capabilities to support smart parking application including both mMTC services for the support of the sensors-server communication as well as eMBB services for the support of UE APP-server communication. Figure 41 illustrates the UC10 high level architecture, in which the parking sensors (WINGSPARK Sensors) are pushing their measurements (parking slot occupancy) across the NB-IoT network and toward the parking management server (WINGSPARK Server), while the driver application (WINGS Smart Parking App) is communicating with the server for retrieving parking related information and guidelines. Also see the general architecture in Figure 45 at the beginning of the Section.

The actual deployment on the AIA and OTE premises is illustrated in Figure 55. 5G network paths between the sensors and driver UEs (located in AIA) and Server (located in OTE) are established.

In order to generate a clear plan for the UC10 validation approach, the user requirements generated in WP2 and reported in D2.2 were analysed. The analysis includes a feasibility study to examine which of the KPIs can be validated in practice, while for the selected KPIs a technical validation approach was generated. Table 19 illustrates the outcome of this feasibility study. In UC10, two types of KPIs will be validated:

a) Network KPIs: which will be measured and validated and will demonstrate the network performance.
b) Application level KPIs: which will be measured on the application level, on the sensors/server/UEs and they will demonstrate the actual application performance.

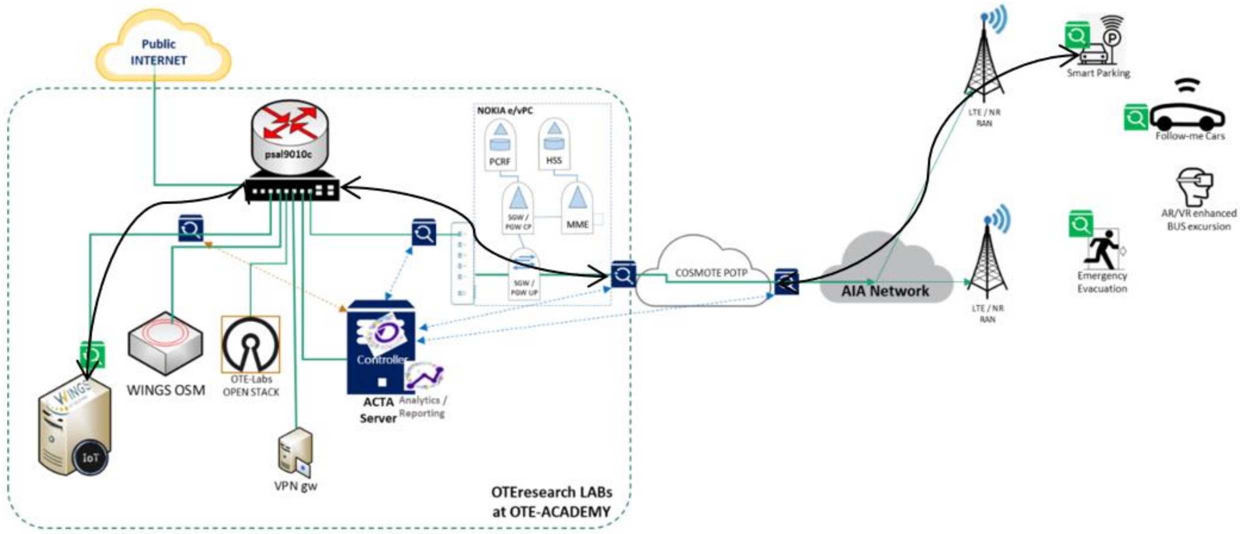


Figure 54. The participating components for UC10.

The KPIs are to be measured and validated along the data path indicated in the diagram of Figure 54, overlaid on the Athens site network architecture.

Regarding network KPIs, latency, throughput (UL/DL) and peak throughput will be validated. The technical validation methodologies of the aforementioned KPIs apply to all the UCs of the Athens node and therefore are described in detail in section 5.3.

Table 19. UC 10 Smart airport parking management network requirements

	5G-Tours - Use Cases: direct specific Technical requirements	Units	UC 10 – Smart parking management			Priority	Range	
			URLLC	mMTC	eMBB		Min	Max
General Vertical Use cases requirements								
1	Latency (in milliseconds) - round trip - Min/Max	msec		10		High	10	50
2	RAN Latency (in milliseconds) - one way	msec		5		High	5	10
3	Throughput (in Mbps) - Min/MAX - sustained demand	Mbps		50		High	10	50
4	Reliability (%) - Min/Max	%		99,9999		High	99,9990	99,9999
5	Availability (%) - Min/Max	%		99,99		High	99,99	99,99
6	Mobility (in m/sec or Km/h) - Min/Max	Km/h		30		High	5	30
7	Broadband Connectivity (peak demand)	Y/N or Gbps		1		High	0,01	0,1
8	Network Slicing (Y/N) - if Y service deployment time (m	Y/N		Y		Medium	1	3
9	Security (Y/N) - if Y grade i.e. "Carrier Grade"	Y/N		Y		medium		
10	Capacity (Mbps/m^2 or Km^2)	Mbps/m^2		0,1			0,1	0,1
11	Device Density	Dev/Km^2		100K		High	1K	100K*
12	Location Accuracy	m		<0,5		High	0,5	1
(*) 1 parking space = 10m^2 => 1 Km^2 = 100.000 parking spaces								

● **Non relevant KPIs**

● **Difficult to be demonstrated KPIs**

● **Relevant KPIs**

Regarding the application level KPIs, the following KPIs will be validated: RTT latency, throughput (UL/DL), service reliability, service availability, peak throughput and location accuracy. The technical validation approaches are described in the following paragraphs. The KPIs which are related with capacity, security and network slicing are judged as not important for UC10, while mobility and device density are considered not feasible to be practically validated. Mobility cannot be validated because of the slow car velocities during parking procedures, while device density requires an extremely large number of UEs/sensors. The validation of device density will be realised analytically and using simulation studies.

RTT latency (APP layer)

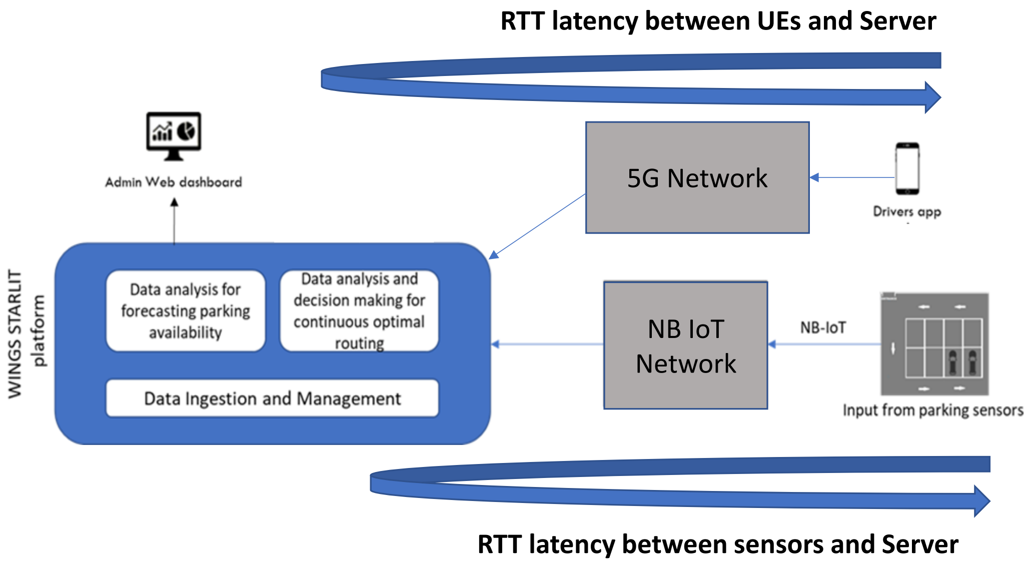


Figure 55. RTT latency.

- Collection in APP and IP layer
    - App layer
        - ADD timestamp to request. Calculate DIFF in time between request and response.
- IP layer
    - Ping from sensor to server
    - We will combine the aforementioned metrics with the metrics collected by ACTA probes

<u>Latency (network/IP layer)</u>

In the following Figure 56, the probe locations and approach of positioning them is depicted on the overall architecture diagram. Blue coloured probes are hardware ones and green are software probes.

End to end latency

- Subject to proper placement on the probes
    a) Inside the vehicle at the source of the video traffic
    b) At the AIA site next to the Video Server / Control Center
    c) At the OTE-lab site (close to the NOKIA ePC)
- The end-to-end latency between the “end-user” and the “central App Server at AIA” are measured.
- Subject to proper placement of the other probes the traffic statistics can also be measured for various network segments (Cosmote PoTP / Core link between AIA and OTE-Labs, between the end-point and the Core network that will very closely approximate the RAN latency, etc.).

<u>Throughput, probe based measurements</u>

- The Throughput between two points can also be measured (subject to traffic isolation among other traffic (i.e. via different VLAN, IP tunnel, slice or other mechanism).
- The Throughput will be bidirectional:
    a) From the end-point to the App Server (mainly video and voice traffic)
    b) From the App Server to the end-point (mainly control and voice traffic)
- The Throughput between the end-user (camera inside the vehicle) and the NOKIA’s ePC (located at OTE-labs premises can be monitored).
- The Throughput between NOKIA’s ePC and the Application Server (located at AIA premises) will be monitored (subject to availability of the statistics – i.e. if no encryption or some privacy encoding allows it).

Service reliability (APP layer)

In order to measure and validate service reliability, the definition in ITU-R M.2410 is considered, similar to UC6 (section 4.3.1) and UC9 (section 4.3.4). Therefore, the same validation methodology will be used.

Validation methodology: The packet error rate at the APP layer (packets that arrive delayed or erroneous are considered as lost packets) will be measured using a set of probes, the positions of which are illustrated in Figure 56.

Service availability (APP layer)

Availability refers to the percentage of time that a system is fully operational. Because of the rates at which the site is being tested and upgraded, it would be impractical (and deceptive) to measure the network availability, this being defined as the ratio of uptime over the total time (uptime plus downtime).

Instead, we decided to estimate the service availability as one minus the measured packet error rate during the operation of a service.

Validation methodology: The packet error rate at the APP layer (packets that arrive delayed are considered as arrived packets) will be measured using a set of probes, the positions of which are illustrated in Figure 56.

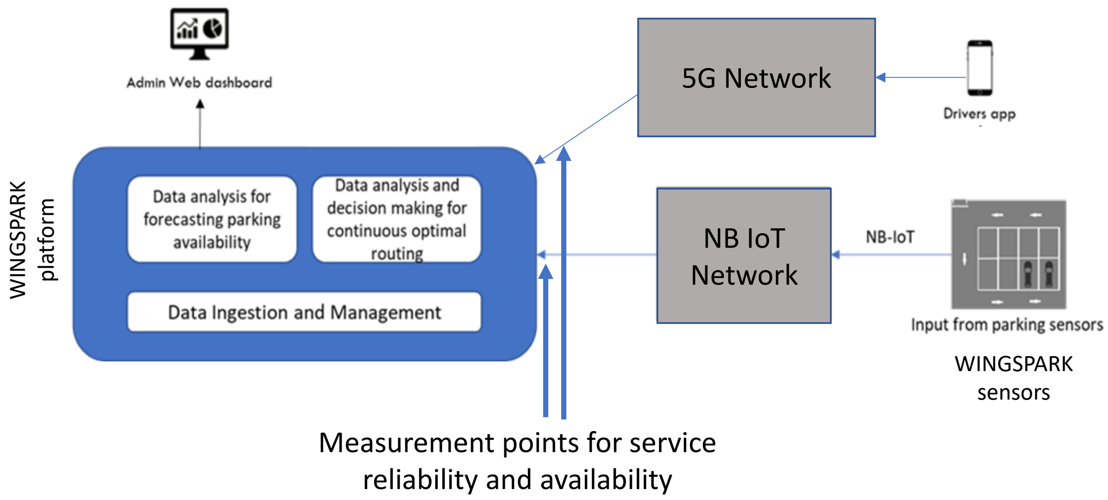


Figure 56. Service reliability / availability.

Location accuracy

Location Accuracy refers to the "degree closeness" of a measured end-user device location (by means of the communication network infrastructure/technologies) to the real location of the device at the time of the measurement.

Validation methodology: In order to validate location accuracy, the location of a specific UE will be provided by the 5G network. Since in UC10, only one 5G cell will be used in the network deployment, we may acquire a lower location accuracy. On the other hand, in UC12, three 5G cells will be used in the network deployment, providing higher accuracy.

Then, this collected location (from 5G network) will be compared against the “real location”. “Real location” is defined as follow:

- “Real location” in outdoor: Measurements coming from GNSS (GPS, Galileo) and/or relative position (e.g. laser telemeter) from known spots.
- “Real location” in indoor: Relative position (e.g. laser telemeter) from known spots.

5.3.5 UC 11 Video-enhanced follow-me moving vehicles

The goal of this UC is to demonstrate the impact of 5G on video that is transmitted from the UE (in this case AIA's ground based vehicle) to a Server located closer to the Core Network. The direction of the Video Transmission is Upstream (as opposed to the usual downstream direction from the Server to the Access and UE). It is more frequent to expect that the End-User will receive High-Definition Video but in this case the End-Use transmits High-Definition Video. Therefore, since also it is a Real-time service (the Video Feed is to be real-time and stored and forwarded on demand) the Upstream direction of the 5G Mobile Access Network is being stressed. Furthermore, the one-way upstream latency (from UE to the Server) is of higher importance than downstream one.

For this use case, Latency, Throughput, Availability, Broadband connectivity, and Location Accuracy will be measured, as depicted in Table 20 below. More importantly, as mention above, the Latency from the UE (vehicle terminal) to the Server and the Throughput in the same direction are the most important KPIs to validate. Also since Broadband connectivity is to be measured, high volume traffic should be generated from the UE towards the Video Streaming Server.

These are the KPIs that are relevant and important here and are possible to be measured, with the existing measurement setup. Latency refers to the Latency between the end user equipment (in follow me vehicle) and the AIA video Streaming Server. Throughput will be measured at the interconnection of two points e.g. between the e/VPC and Cosmote Packet Optical Transport (POTP). Network availability is measured as a percentage and is monitored to ensure that the service being offered continues to operate for end-users. Broadband connectivity (peak demand) will be measured via Speed test at the video Streaming Server. For Location Accuracy the location of a specific UE will be provided by the 5G network.

The participating components for UC11 are shown in Figure 57. The KPIs to be measured and validated along the data path are indicated in the diagram overlaid on the Athens site network architecture. For Latency, probes will be installed in the follow-me car in AIA, at the NOKIA ePC, and next to the video server, to allow us to measure latency from the source video traffic up to the video server. This distribution of the probes will provide latency data at segments of the network, as well as the end-to-end Latency.

For Throughput, a probe will be installed among the e/VPC and Cosmote POTP. Also, probes will be installed in other locations to measure Throughput at specific points of the network i.e. at the end points.

The probes will gather locally network metrics data. This data will be collected centrally for analysis and reporting. If metrics values are worse than the expected 5G network values, feedback will be given to the network providers, to study and identify if issues can be resolved.

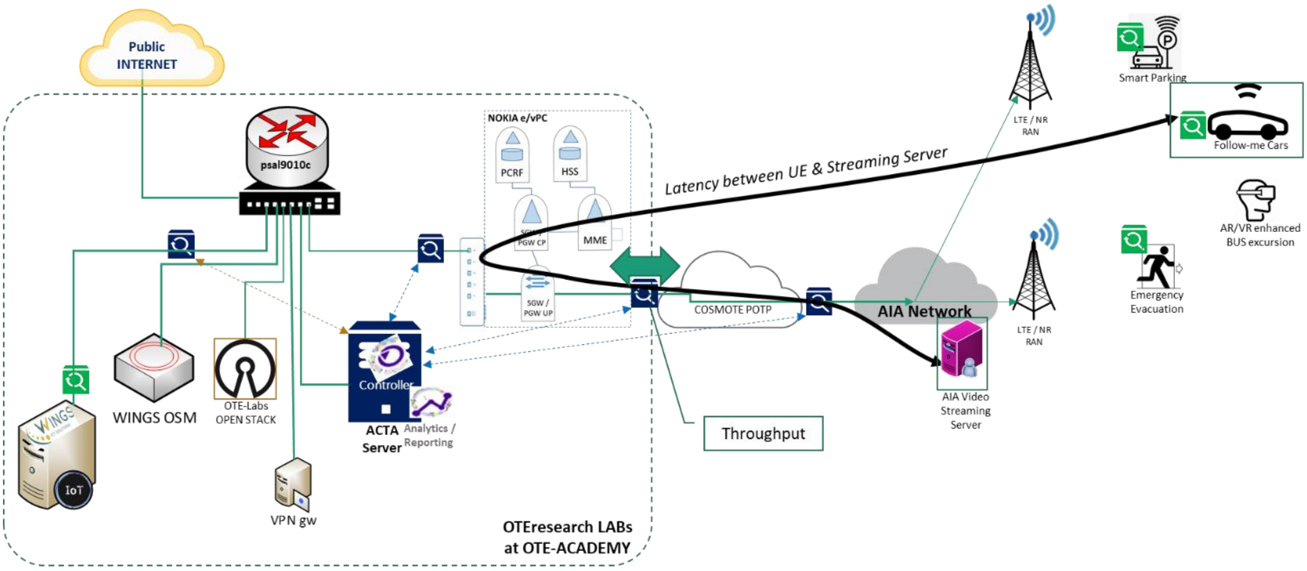


Figure 57. The participating components for UC11.

The KPIs are to be measured and validated along the data path indicated in the diagram overlaid on the Athens site network architecture.

Table 20. UC 11 Video-enhanced ground-based moving vehicles network requirements

5G-Tours - Use Cases: direct specific Technical requirements		Units	UC 11 - Video-enhanced ground-based moving vehicles			Priority	Range	
			URLLC	mMTC	eMBB		Min	Max
General Vertical Use cases requirements								
● 1	Latency (in milliseconds) - round trip - Min/Max	msec			100		100	500
● 2	RAN Latency (in milliseconds) - one way	msec			50		50	100
● 3	Throughput (in Mbps) - Min/MAX - sustained demand	Mbps			50		10	50*
● 4	Reliability (%) - Min/Max	%			99,99		99,9	99,99
● 5	Availability (%) - Min/Max	%			99,999		99,99	99,999
● 6	Mobility (in m/sec or Km/h) - Min/Max	Km/h			150		80	150
● 7	Broadband Connectivity (peak demand)	Y/N or Gbps			0,25		25 Mbps	250 Mbps
● 8	Network Slicing (Y/N) - if Y service deployment time (min)	Y/N			30		60	30
● 9	Security (Y/N) - if Y grade i.e. "Carrier Grade"	Y/N			Y		Y	
● 10	Capacity (Mbps/m^2 or Km^2)	Mbps/m^2			0.00256		1 Gbps/Km^2	2,5 Gbps/Km^2 **
● 11	Device Density	Dev/Km^2			50		5	50 ***
● 12	Location Accuracy	m			1		5	1

(*) per vehicle 50 Mbps video stream is transmitted

(**) assume 50 vehicles at 50 Mbps/vehicle in one Km^2 = 2,5Gbps/Km2 = 0,00256Mbps/m^2

(***) 50 vehicles

● **Non relevant KPIs**

● **Difficult to be demonstrated KPIs**

● **Relevant KPIs**

End to end latency

- Subject to proper placement on the probes
  a) Inside the vehicle at the source of the video traffic
  b) At the AIA site next to the Video Server / Control Center
  c) At the OTE-lab site (close to the NOKIA ePC)
- The end-to-end latency between the "end-user" and the "central App Server at AIA" can be measured.
- Optimally, 3 components of the Latency should be measured. From UE→ Server, Server → UE and Round Trip initiated from the UE (that is the source of the data traffic).
- Subject to proper placement of the other probes the traffic statistics can also be measure for various network segments (Cosmote PoTP / Core link between AIA and OTE-Labs, between the end-point and the Core network that will very closely approximate the RAN latency, etc.).

Throughput

- The Throughput between two points can also be measured (subject to traffic isolation among other traffic (i.e. via different VLAN, IP tunnel, slice or other mechanism)).
- The Throughput will have two components (two directions),
  a) From the end-point to the App Server (mainly HD video and voice traffic)
  b) From the App Server to the end-point (mainly control and voice traffic)
- The Throughput between the end-user (camera inside the vehicle) and the NOKIA's ePC (located at OTE-labs premises can be monitored).
- The Throughput between NOKIA's ePC and the Application Server (located at AIA premises) will be monitored (subject to availability of the statistics – i.e. if no encryption or some privacy encoding allows it).

5.3.6 UC 12 Emergency airport evacuation

The key aspects on this UC is the transmission of Location Information (and direction using the gyroscope) per UE with High-Accuracy and Low one-way Latency in the Upstream Direction and Transmission of guidance information from the Server towards the UE. Therefore Location Accuracy and Latencies (UE→ Server and Server → UE) are important. Since there might be involvement of a large number of UEs the total Throughput (and not the Throughput per UE) is also important. Finally, since this UC deals with an Emergency Situation Availability and Reliability are the most important parameters.

The airport evacuation system comprises of:

- **An AR-mobile application** for easy-to-perceive guidance
- **Intelligence** for:
  - Suggestion of optimal evacuation route
  - Providing personalized guidance based on:
    - Closeness to the exit
    - Ongoing requests to split the users uniformly among the available exits

For this use case, RTT Latency, Throughput, Reliability, Availability, and Location Accuracy will be measured, as depicted in Table 21 below. These are the KPIs that are relevant and important in this case and are possible to be measured, with the existing measurement setup. RTT Latency refers to the Latency between the end user equipment (at an emergency situation) and the WINGS Starlit Platform and back to the end user. Throughput will be measured at the interconnection of two points e.g. between the Starlit Platform and the 5G Network and between end users and the network. Network availability is measured as a percentage and is monitored to ensure that the service being offered continues to operate for end-users. For Location Accuracy, the location of a specific UE will be provided by the 5G network.

For Latency, software probes will be used on the end user mobile phones, probe at the NOKIA ePC, and next to the Starlit Platform. This distribution of the probes will provide latency data at segments of the network, as well as the end to end Latency.

For Throughput, a probe will be installed among the e/VPC and Cosmote POTP and also in other locations to measure throughput at specific points of the network i.e. at the end points.

The probes will gather locally network metrics data. This data will be collected centrally for analysis and reporting. If metrics values are worse than the expected 5G network values, feedback will be given to the network providers, to study and identify if issues can be resolved.

The components that implement UC12 in the Athens site and their relative placement are shown in the Figure 58. The KPIs to be measured and validated along with the data path are indicated in the diagram, overlaid on the Athens site network diagram. The data path, over which the KPIs are to be measured and validated, is indicated in Figure 59.

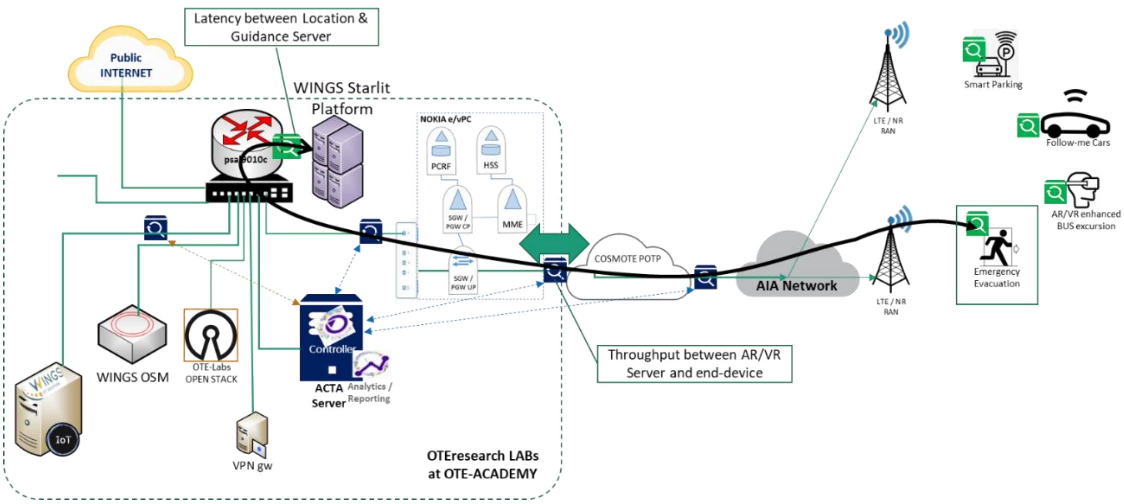


Figure 58. UC12 Emergency Evacuation.

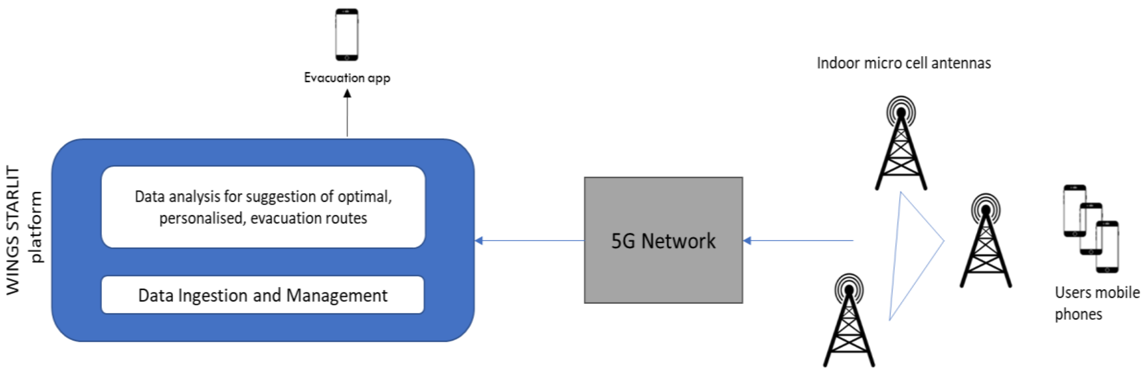


Figure 59. Data path of UC12.

Table 21. UC 12 Emergency airport evacuation network requirements.

	5G-Tours - Use Cases: direct specific Technical requirements	Units	UC 12 - Emergency airport evacuation			Priority	Range	
			URLLC	mMTC	eMBB		Min	Max
General Vertical Use cases requirements								
1	Latency (in milliseconds) - round trip - Min/Max	msec	15	25			15	100
2	RAN Latency (in milliseconds) - one way	msec	10	10			10	20
3	Throughput (in Mbps) - Min/MAX - sustained demand	Mbps	500	100			100	500 *
4	Reliability (%) - Min/Max	%	99,9999	99,9999			99,999	99,9999
5	Availability (%) - Min/Max	%	99,99	99,99			99,99	99,99
6	Mobility (in m/sec or Km/h) - Min/Max	Km/h	10	0			0	10**
7	Broadband Connectivity (peak demand)	Y/N or Gbps	10	10			1	10
8	Network Slicing (Y/N) - if Y service deployment time (min)	Y/N	1	1			1	1
9	Security (Y/N) - if Y grade i.e. "Carrier Grade"	Y/N	Y	Y			Y	
10	Capacity (Mbps/m^2 or Km^2)	Mbps/m^2	20	20			2	20***
11	Device Density	Dev/Km^2	1000K	1000K			1000K	1000K*****
12	Location Accuracy	m	<1	<1			1	0,3

(*) Total per UE
(**) 10 km/h running speed of a peson evacuating
(***) 2 persons per m^2 at 10 Mbps/person
(*****) 1 or 2 persons per m^2

- **Non relevant KPIs**
- **Difficult to be demonstrated KPIs**
- **Relevant KPIs**

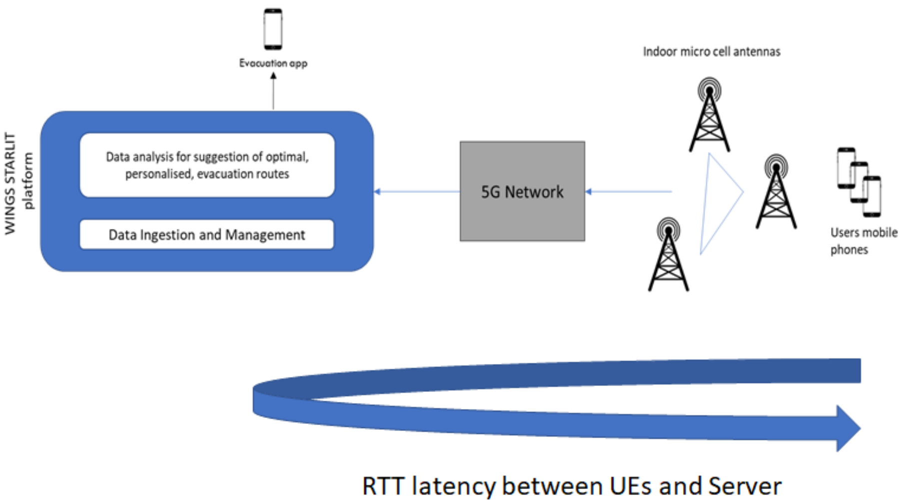


Figure 60. Data path for RTT latency.

RTT latency (Figure 60)

- Collection in IP layer
    - Ping from UE to server located in the remote WINGS platform

Throughput (Figure 61)

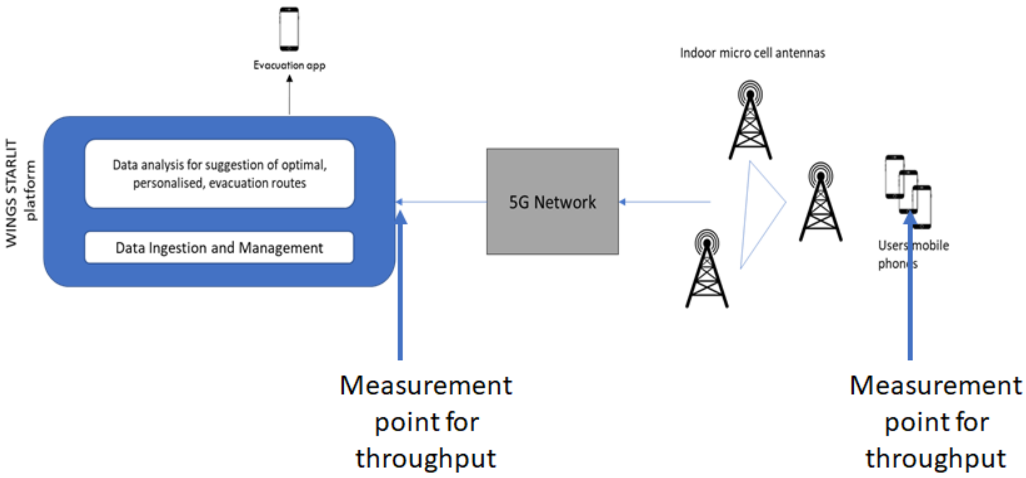


Figure 61. Location of Throughput measurement

- Collection in IP layer
    - IP layer
        - Measure the throughput on the UE egress interface
        - Measure the throughput on the Server ingress interface
- We will combine the aforementioned metrics with the metrics collected by ACTA probes

Location accuracy

Location Accuracy refers to the "degree closeness" of a measured end-user device location (by means of the communication network infrastructure/technologies) to the real location of the device at the time of the measurement.

Validation methodology:

In order to validate location accuracy, the location of a specific UE will be provided by the 5G network. In UC12, three 5G cells will be used in the network deployment, providing high accuracy. We will use the same validation methodology already described in UC10 (section 5.3.3. Therefore, the collected location (from 5G network) will be compared against the "real location".

5.3.7 UC 13 Excursion on AR/VR-enhanced bus

The goal of this use case is to demonstrate the impact of 5G on AR/VR-enhanced applications. Contrary to the UC10 the Video/Audio information is transmitted from the Core Network Server (located at OTElabs) towards the UE. The downstream throughput is thus more important in this UC. Furthermore, since there is high interactivity in this UC (the end-user view direction and location should be sent to the server in order to stream the correct content) the Upstream as well the Downstream One-way Latencies are also very important. Finally, since the content that is streamed to the UE is dependent on the user viewing angle and placement in space, location information should also be provided and transmitted with low latency (in the upstream direction) to the AR/VR Server.

For this use case, Latency, Throughput, Availability, Mobility, Broadband connectivity, and Location Accuracy will be measured, as depicted in Table 22 below. These are the KPIs that are relevant, important in this case and are possible to be measured, with the existing measurement setup. Latency refers to the Latency between the end user (AR/VR user) and the AR/VR Server. Throughput will be measured at the interconnection of two points e.g. between AR/VR server and end-devices. Network availability is measured as a percentage and is monitored to ensure that the service being offered continues to operate for end-users. Mobility is still under consideration. Broadband connectivity (peak demand) will be measured via Speed test at the AR/VR Server. For Location Accuracy, the location of a specific UE will be provided by the 5G network

The participating components for UC13 are shown in Figure 62. The KPIs to be measured and validated along the data path are indicated in the diagram overlaid on the Athens site network architecture. For Latency, probes will be installed at the AR/VR server and at the end devices, as well as in between positions. This distribution of the probes will provide latency data at segments of the network, as well as the end to end Latency.

For Throughput, a probe will be installed among the AR/VR server and end-devices. Moreover, probes will be installed in other locations to measure Throughput at specific points of the network, i.e. at the end points.

The probes will gather locally network metrics data. This data will be collected centrally for analysis and reporting. If metrics values are worse than the expected 5G network values, feedback will be given to the network providers, to study and identify if issues can be resolved.

Table 22. UC 13 Excursion on an AR/VR-enhanced bus network requirements.

	5G-Tours - Use Cases: direct specific Technical requirements	Units	Use case 13 – Excursion on an AR/VR-enhanced bus			Priority	Range	
			URLLC	mMTC	eMBB		Min	Max
General Vertical Use cases requirements								
● 1	Latency (in milliseconds) - round trip - Min/Max	msec			100		100	500
● 2	**RAN** Latency (in milliseconds) - one way	msec			25		25	50
● 3	Throughput (in Mbps) - Min/MAX - sustained demand	Mbps			120		80	120
● 4	Reliability (%) - Min/Max	%			99,99		99,9	99,99
● 5	Availability (%) - Min/Max	%			99,99		99,9	99,99
● 6	Mobility (in m/sec or Km/h) - Min/Max	Km/h			100		4	100
● 7	Broadband Connectivity (peak demand)	Y/N or Gbps			0,01		2	10 *
● 8	Network Slicing (Y/N) - if Y service deployment time (mir	Y/N			Y		30	5
● 9	Security (Y/N) - if Y grade i.e. "Carrier Grade"	Y/N			N			
● 10	Capacity (Mbps/m² or Km²)	Mbps/m²			10		1	10 **
● 11	Device Density	Dev/Km²			1000		10K	1000K***
● 12	Location Accuracy	m			>=1		<4	>=1
(*) 10 Mbps per VR device downstream = 0,01 Gbps								
(**) 1 device per m²								
(***) 1 or 2 students per m² = 1000K devices (AR/VR gogles) per Km²								

● **Non relevant KPIs**

● **Difficult to be demonstrated KPIs**

● **Relevant KPIs**

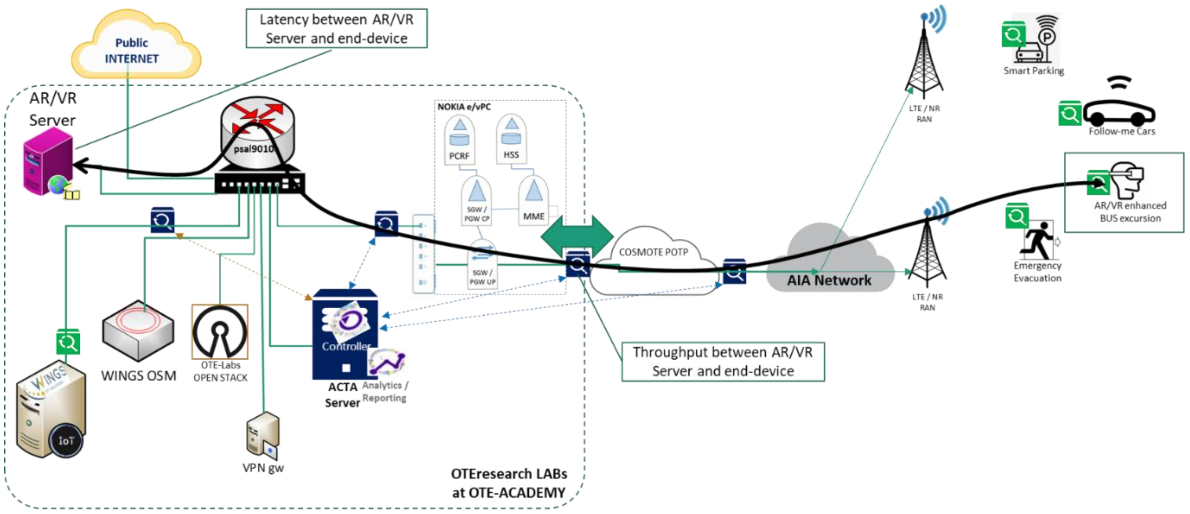


Figure 62. The participating components and their location for the KPI measurement of UC13.

End to end latency

- In order to measure end-to-end latency between the AR/VR Server at OTE-Labs and the AR/VR headsets a probe should be placed (hardware and/or software) close to the end-device
- In between probes will provide data concerning segment of the network
- The round-trip latency will be measured since the orientation/location of the end-device should be sent to the server and the corresponding "appropriate" video/audio information will be feed down to the AR/VR headset

Throughput

- The traffic between the AR/VR headsets and the corresponding Server (at OTE-Labs) will be measured by a probe placed next to the Server
- The traffic will be measured in a non-intrusive manner
- Depending on the traffic segregation /isolation mechanism that each AR/VR Headset is utilizing, individual traffic or total traffic will be measured
- The other probes can provide information about the traffic throughput that corresponds to the other segments of the network (COSMOTE Core IP network, AIA, network, etc.)

5.4 Initial trials and validation results

In this section initial validation results from UC10 are presented.

5.4.1 Initial validation results of UC10

During the initial phase of the trials, we selected as initial KPI the RTT latency in APP layer. For simplicity, we started by collecting RTT latency metrics on one of the two network paths (between the parking sensors and the parking server), which is illustrated on the bottom part of Figure 63.

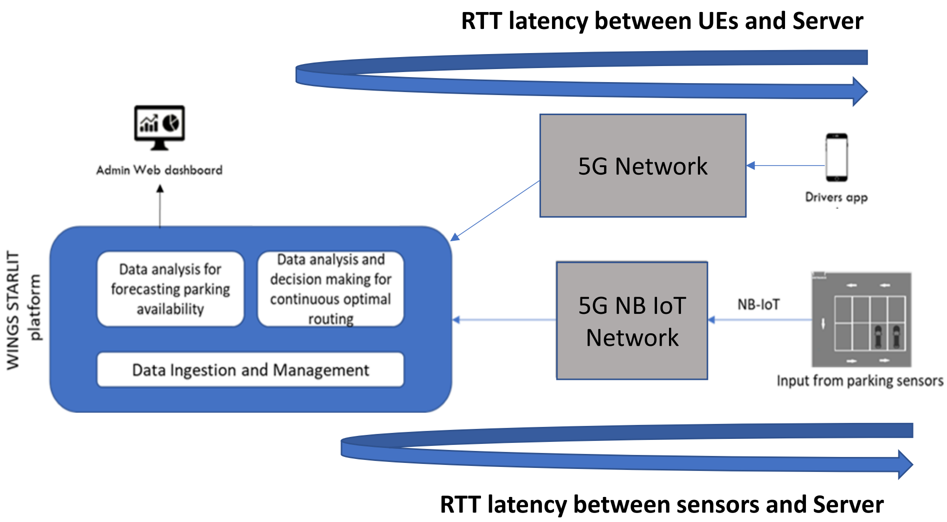
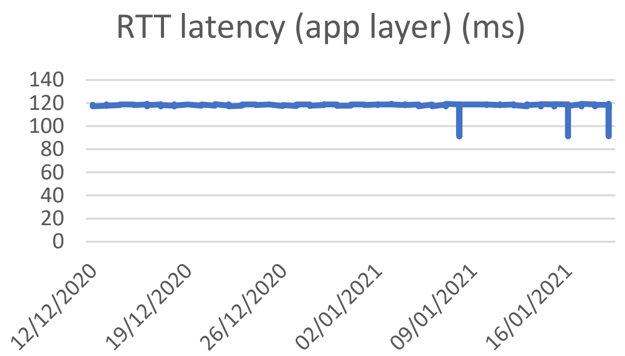


Figure 63. UC10: RRT latency metric collection.

The collection of RTT latency was realised by adding timestamps on all requests departed from the parking sensors. Then, the Server was responsible to duplicate this timestamp on the relative responses sent back to the parking sensors. Following, parking sensors calculated the RTT latency by subtracting this timestamp by the current timestamp of the system. Lastly, the results were propagated to the server by adding the results on the next sensor request.

During the initial trials of UC10, RTT latency metrics were collected from 36 consecutive days (12/12/2020 to 17/01/2021). In total, 300 samples (RTT latency results) were collected and analysed as illustrated in Figure 64. The average value of app layer RTT latency is around 117ms, while the minimum and maximum are 91ms and

119ms. In addition, from Figure 64 is obvious that the app layer latency is relative stable with some drops at ~90ms.



RRT latency	Value (ms)
Average	117
Min	91
Max	119

Figure 64. UC10: Initial results on RRT latency.

6 Conclusions

In the current document the initial 5G-TOURS ecosystem was presented together with the final 5G-TOURS evaluation methodology and technical validation plan.

Regarding the integration activities, the first outcome of the integration activities which ensure the smooth deployment of the UCs are presented for all three sites including the integration of 5G EVE platform, 5G-TOURS innovations and UC components. The progress in both WP3 and WP7 is presented, since WP3 is focused on the hardware aspects (e.g. infrastructure), while WP7 on the software aspects (e.g. platform).

Regarding validation, the presented 5G-TOURS evaluation methodology includes the validation of QoS, QoE and end-users and vertical players satisfaction. The two phases of 5G-TOURS evaluation methodology are presented in detail. The first phase is realized during the trials execution and collects both the QoS metrics, automatically collected from the infrastructure, and the QoE metrics (and vertical satisfaction) collected using appropriate questionnaires. The second phase is realized after the trials executions and by using correlation-regression analysis tries to create a model for QoS-QoE correlation.

In addition, a detailed plan for the technical validation of the use cases is presented (in a per use case and KPI manner) including all the required guidelines to the technical WPs (WP4/5/6) in order to collect the required metrics including a) probe positions in the network; b) probe positions in the protocol layers; c) trial details when possible (e.g. duration, sampling period, collection method); d) any assumptions during collection.

The next steps toward the integration and validation activities are:

- Regarding the integration activities, the finalisation of the integration of the software components required in each UC and the integration of the 5G-TOURS innovations. The outcome of these activities will provide the second version of 5G-TOURS ecosystem.
- To orchestrate the overall trials and validation processes and accelerate where needed in order to also compensate for the slow start due to the covid pandemic.
- To continue the technical validation activities, in the sense of:
    - providing updates on the technical validation approach, based on feedback during the first trials.
    - examine for each UC the “difficult to be demonstrated KPIs”. In the case that the KPI is important for the specific UC, other approaches of validation (simulation, emulation, analytical) will be examined and adopted.
- To continue with the analysis of the validation results in order to provide validation outcomes compared with the KPI targets defined in D2.2, 5G PPP KPI targets and comparison with legacy technologies (e.g. 4G). In addition to provide some initial validation findings on QoE and first QoE-QoS correlations.
- The preparation of the 5G-EVE platform maintenance process, as the 5G-EVE project will be completed by M24 and 5G-TOURS will continue for one year after that.

The outcome of the aforementioned next activities will be reported in detail in D7.3 (next WP7 deliverable).

7 Appendix

7.1 Questionnaires for all UCs

Table 23 shows the questionnaire per UC. Theses questionnaires will be used during the trial process as a metric for QoE. By responding to this list of questions, the end users describe the quality of his experience.

Table 23. Questionnaires per UC

UC #	UC name	Questionnaires
UC1	Augmented tourism experience	How pleasant was the user experience in terms of intuitiveness of the service? *Excellent, Good, Fair, Poor, Very Poor* How pleasant was the user experience in terms of usefulness of the service? *Excellent, Good, Fair, Poor, Very Poor* How do you rate the time taken by the application to download the 3D model? *Excellent, Good, Fair, Poor, Very Poor* How was the quality of the video streaming experienced during the visit? *Excellent, Good, Fair, Poor, Very Poor* Please state how much you agree with the following statement: I would like to pay an extra fee for the usage of the augmented tourism experience *Strongly agree, agree, neutral, disagree, Strongly Disagree* Please state how much you agree with the following statement: Your interaction with the museum contents has been inspiring and you felt involved in the artistic context more than traditional one *Strongly agree, agree, neutral, disagree, Strongly Disagree* Please state how much you agree with the following statement: the weather, environmental and logistic information (smartcity services) are clear and useful to feel comfortable in my touristic experience *Strongly agree, agree, neutral, disagree, Strongly Disagree* How many contents did you enjoy during the visit? *'Open question'* If you like, please provide your open feedback on your experience during the Museum visit *'Open comment'*
UC2	Telepresence	**Questionnaire for visitors:** Please state how much you agree with the following statement: the telepresence guide is better than the traditional audio guide *Strongly agree, agree, neutral, disagree, Strongly Disagree* How pleasant was the user experience in terms of responsiveness of the service? *Excellent, Good, Fair, Poor, Very Poor* How pleasant was the user experience in terms of intuitiveness of the service? *Excellent, Good, Fair, Poor, Very Poor* How pleasant was the user experience in terms of usefulness of the service? *Excellent, Good, Fair, Poor, Very Poor* How do you rate the overall interaction with the robot? *Excellent, Good, Fair, Poor, Very Poor*

		Please state how much you agree with the following statement: I would like to pay an extra fee for the usage of the augmented tourism experience *Strongly agree, agree, neutral, disagree, Strongly Disagree* Please state how much you agree with the following statement: Your interaction with the museum contents has been stimulated and you felt deeply involved in the artistic context. *Strongly agree, agree, neutral, disagree, Strongly Disagree* How do you rate the educational value of the experience? *Excellent, Good, Fair, Poor, Very Poor* Please state how much you agree with the following statement: You would love to repeat the experience *Strongly agree, agree, neutral, disagree, Strongly Disagree* If you like, please provide your open feedback on your experience during the Museum visit *'Open comment'* **Questionnaire for Museum Operators:** How pleasant was the user experience in terms of responsiveness of the additional functionalities? *Excellent, Good, Fair, Poor, Very Poor* How pleasant was the user experience in terms of intuitiveness of the additional functionalities? *Excellent, Good, Fair, Poor, Very Poor* How pleasant was the user experience in terms of usefulness of the additional functionalities? *Excellent, Good, Fair, Poor, Very Poor* Please state how much you agree with the following statement: Your interaction with the additional surveillance functionalities helped you to do better your job? *Strongly agree, agree, neutral, disagree, Strongly Disagree* Please state how much you agree with the following statement: the fires and structural failures information (smartcity services) are clear and useful to monitor critical events *Strongly agree, agree, neutral, disagree, Strongly Disagree* If you like, please provide your open feedback on your experience during the Museum visit 'Open comment'
UC3	Robot assisted museum guide and monitoring	**Questionnaire for Visitors** Please state how much you agree with the following statement: the telepresence guide is better than the traditional audio guide *Strongly agree, agree, neutral, disagree, Strongly Disagree* How pleasant was the user experience in terms of responsiveness of the service? *Excellent, Good, Fair, Poor, Very Poor* How pleasant was the user experience in terms of intuitiveness of the service? *Excellent, Good, Fair, Poor, Very Poor* How pleasant was the user experience in terms of usefulness of the service? *Excellent, Good, Fair, Poor, Very Poor* Please state how much you agree with the following statement: I feel comfortable interacting with and close to the robot during my visit in the museum

		Strongly agree, agree, neutral, disagree, Strongly Disagree Please state how much you agree with the following statement: I would like to pay an extra fee for the usage of the augmented tourism experience *Strongly agree, agree, neutral, disagree, Strongly Disagree* Please state how much you agree with the following statement: Your interaction with the museum contents has been stimulated and you felt deeply involved in the artistic context. *Strongly agree, agree, neutral, disagree, Strongly Disagree* If you like, please provide your open feedback on your experience during the Museum visit *'Open comment'* **Questionnaire for Museum Operators:** How pleasant was the user experience in terms of responsiveness of the additional functionalities? *Excellent, Good, Fair, Poor, Very Poor* How pleasant was the user experience in terms of intuitiveness of the additional functionalities? *Excellent, Good, Fair, Poor, Very Poor* How pleasant was the user experience in terms of usefulness of the additional functionalities? *Excellent, Good, Fair, Poor, Very Poor* Please state how much you agree with the following statement: Your interaction with the additional surveillance functionalities helped you to do better your job? *Strongly agree, agree, neutral, disagree, Strongly Disagree* If you like, please provide your open feedback on your experience during the Museum visit *'Open comment'*
UC4	High quality video services distribution	How do you rate the overall experience? *Excellent, Good, Fair, Poor, Very Poor* Please rate the audio quality (e.g. no crackling or choppy audio) *Far above the expectation, above the expectation, meets the expectation, below the expectation, far below the expectation* Please rate the video quality (e.g. choppy video) *Far above the expectation, above the expectation, meets the expectation, below the expectation, far below the expectation* How many times did the video stop during transmission? *Never, rarely, sometimes, often, always* Please state how much you agree with the following statement: The experience is as satisfactory as traditional live TV *Strongly agree, agree, neutral, disagree, Strongly Disagree* Would you be willing to hire an additional fee in order to enjoy the eMBMS service? *Strongly agree, agree, neutral, disagree, Strongly Disagree* Please state how much you agree with the following statement: I would pay an extra fee for the use of immersive TV services *Strongly agree, agree, neutral, disagree, Strongly Disagree* If you like, how much will you be willing to pay for using this service (in €)? *'Open comment'* If you like, please provide your open impressions of the experience

<table>
<tr><td></td><td></td><td>'Open comment'</td></tr>
<tr><td>UC5</td><td>Distributed video production</td><td>How experienced are you with transmitting or producing live video?
This is the first time I use a live video production service
I am familiar with using live video production service
I am a frequent user of live video production service

Please state your past/current profession, if relevant:
…

Please rate the following statements on a scale of 1 to 5, with 5 being “strongly agree” and 1 being “strongly disagree”.
The Demonstrated 5G Production is very important in order to succeed in my job
1 2 3 4 5
The Demonstrated 5G Production brings important benefits to standard production workflows
1 2 3 4 5
The Demonstrated 5G Production brings important benefits to a News cast environment
1 2 3 4 5
The Demonstrated 5G Production brings important benefits to a live event production
1 2 3 4 5
The Demonstrated 5G Production brings important benefits to a live Tier 1 Sports production (such as Premier soccer, big marathons etc)
1 2 3 4 5
The Demonstrated 5G Production brings important benefits to a live Tier 2-3 Sports production (such as lower soccer leagues, local sports etc)
1 2 3 4 5
I think the Demonstrated 5G Production can be also useful in:
.....
The production in this Demonstrated 5G Production offers new possibilities over the traditional live production
1 2 3 4 5
The production in this Demonstrated 5G Production meets my needs very well
1 2 3 4 5

Which of the following is more important to you/your company in such productions?
Cost is the most significant factor
Cost is more significant than quality
Quality is more significant than cost
Quality is the most significant factor

The production using single 5G transmission seems to have the same risk or lower risk as
Single 4G cellular transmission
Bonded 4G cellular transmission
Satellite based transmission
Fiber based transmission

The Demonstrated 5G Production impact on current satellite-based Outdoor production:
More than 25%
10% - 25% more
More or less the same
10% - 25% less
More than 25% lower

According to this Demonstrated 5G Production over the designated, empty Private Network, I expect that a single 5G modem (without cellular bonding) will be enough for such live professional productions in:
90%-100% of all cases
70% - 90% of cases
50% to 70% of the cases
20% to 50% of the cases</td></tr>
</table>

		less than 20% of the cases According to this Demonstrated 5G Production over the designated, empty Private Network, I expect that in public commercial network of an operator, a single 5G modem (without cellular bonding) will be enough for such live professional productions in: *90%-100% of all cases* *70% - 90% of cases* *50% to 70% of the cases* *20% to 50% of the cases* *less than 20% of the cases* **Quality of Demonstrated 5G Production (QoE)** **In the following questions, the scale is: 1: unacceptable; 2: poor; 3: fair; 4: very good; 5: excellent.** How do you evaluate the video quality? *1 2 3 4 5* How do you evaluate the audio quality? *1 2 3 4 5* How is the video quality compared to current live street concert production? *1 2 3 4 5* How is the audio compared to a street concert production audio? *1 2 3 4 5* The given battery is sufficient for such broadcasts? *1 2 3 4 5* The 5G signal was stable (bars in the UI) *1 2 3 4 5* How do you evaluate the impact of the breaks in the video/audio (1: no breaks; 2: slightly impacting my Demonstrated 5G Production; 3: impacting my Demonstrated 5G Production; 4: strongly impacting my Demonstrated 5G Production; 5: I wanted to stop watching)? *1 2 3 4 5* How is the impact of the pixels and other artifacts (1: no impact; 2: slightly discernible; 3: impacting my Demonstrated 5G Production; 4: strongly impacting my Demonstrated 5G Production; 5: Not usable for my needs)? *1 2 3 4 5* How does the impact of dis-harmonies and/or lip-syncs between audio and video or between the players and the orchestra impact (1: no impact; 2: slightly discernible; 3: impacting my Demonstrated 5G Production; 4: strongly impacting my Demonstrated 5G Production; 5: Not usable for my needs)? *1 2 3 4 5* **System Usability Scale (SUS)** I think that I would like to use this live 5G video production service in my professional activity frequently *1 2 3 4 5* I thought the fact that this live 5G video production service was easy to deploy *1 2 3 4 5* I think that I would need the support of a technical persons to be able to significantly exploit this live 5G video production service in my company *1 2 3 4 5* I found this live 5G video production service complex *1 2 3 4 5* Which of the following words would you say best describes the Demonstrated 5G Production potential for live production? *Revolutionary* *Improvement in the workflow* *Same* *Reduced service* *Wouldn't touch it*

		Please tell us what else you think on the Demonstrated 5G Production and/or the future potential for 5G-based remote and distributed production:
UC6	Remote health monitoring and emergency situation notification	**Questionnaire for Patient** How do you asses your experience in terms of intuitiveness of the service? *Excellent, Good, Fair, Poor, Very Poor* How do you assess your experience in terms of usefulness of the service? *Excellent, Good, Fair, Poor, Very Poor* How do you asses your experience in terms of responsiveness of the service? *Excellent, Good, Fair, Poor, Very Poor* How do you assess the delays of displaying measurements results from the wearable devices by web dashboard? *Very big, significant, perceptible, acceptable, no delays* How do you assess the reaction time (i.e. ambulance arrive) in case of emergency notification by system? *Excellent, Good, Fair, Poor, Very Poor* Were situations when false alarm raised? *Very often, often, rarely, never* Were there situations when no alarm was raised even though measurement results should trigger it? *Very often, often, rarely, never* Please rate the statement: I found the system unnecessarily complex. *Strongly agree, agree, neutral, disagree, strongly disagree* Please rate the statement: I would imagine that most people would learn to use this system very quickly. *Strongly agree, agree, neutral, disagree, strongly disagree* How this technology was important to increase your sense of health security? *Extremely important, important, moderately important, slightly important, not at all important* How do you rate the user experience in terms of the quality and promptness of the service? *Excellent, Good, Fair, Poor, Very Poor* How ready are you to use this technology as part of your daily routine? *Extremely ready, slightly ready, ready, not ready* Please state how much you agree with the following statement: the technology is ready to be used in an operational environment *Strongly agree, agree, neutral, disagree, Strongly Disagree* Do you think that the cost to your health protection will be lower thanks to this technology? *Strongly agree, agree, neutral, disagree, Strongly Disagree* How likely do you feel that this technology might improve your overall health? *Strongly agree, agree, neutral, disagree, Strongly Disagree* In case when there were many people around with the same health monitoring services, was the service stable with no quality problem? *Very often, often, rarely, never* If you like please provide your open feedback on your experienced during this use case:

		Questionnaire for Doctor Have you noticed any monitoring imperfections, such as interruptions, delays or misrepresentation? *Very often, often, rarely, never* How likely do you feel that this technology might improve your medical treatment of patient? *Strongly agree, agree, neutral, disagree, Strongly Disagree* How do you assess your experience in terms of intuitiveness of the service? *Excellent, Good, Fair, Poor, Very Poor* Please rate the following statements: I need to learn a lot of new things before I could get going with the system. *Strongly agree, agree, neutral, disagree, Strongly Disagree* How do you assess your experience in terms of usefulness of the service? *Excellent, Good, Fair, Poor, Very Poor* How do you assess your experience in terms of responsiveness of the service? *Excellent, Good, Fair, Poor, Very Poor* How ready are you to use this technology as part of treatment? *Extremely ready, slightly ready, ready, not ready* Please state how much you agree with the following statement: the technology is ready to be used in an operational environment *Strongly agree, agree, neutral, disagree, Strongly Disagree* If you like please provide your open feedback on your experienced during this use case: **Questionnaire for hospital** Please state how much you agree with the following statement: this technology will lower our overall costs of patient treatment. *Strongly agree, agree, neutral, disagree, Strongly Disagree* Please state how much you agree with statement: this technology will reduce the number of patients on ER in hospital. *Strongly agree, agree, neutral, disagree, Strongly Disagree* This technology will reduce the number of patients with complications treated in hospital. *Strongly agree, agree, neutral, disagree, Strongly Disagree* If you like please provide your open feedback on your experienced during this use case:
UC7	Teleguidance for diagnostics and intervention support	**Questionnaire for ambulance crews** To what extent does the service allow you to secure patient care? *Perfectly, Well, Honestly, Weakly, Very Weakly* To what extent does this service allow you to do your work more serenely? *Perfectly, Well, Honestly, Weakly, Very Weakly* To what extent do you think the proposed technology will improve diagnosis? *Perfectly, Well, Honestly, Weakly, Very Weakly* To what extent does the proposed technology improve patient care before hospital admission? *Perfectly, Well, Honestly, Weakly, Very Weakly* How do you evaluate your experience in terms of intuitiveness of the overall service? *Perfectly, Well, Honestly, Weakly, Very Weakly*

		How much you agree with the following statement: the technology is ready for use in an operational environment *I definitely agree, I agree, neutrally, I disagree, I definitely disagree* If you like, please provide your open feedback on your experienced during this use case: **Questionnaire for the emergency regulators** To what extent do you think the proposed technology will improve diagnosis? *Perfectly, Well, Honestly, Weakly, Very Weakly* To what extent does the proposed technology improve patient care before hospital admission? *Perfectly, Well, Honestly, Weakly, Very Weakly* How do you rate the importance of this technology in your routine? *Extremely important, important, moderately important, slightly important, not at all important* How do you rate the user experience in terms of reliability of the service? *Excellent, Good, Fair, Poor, Very Poor* How much you agree with the following statement: the technology is ready for use in an operational environment *I definitely agree, I agree, neutrally, I disagree, I definitely disagree* If you like please provide your open feedback on your experienced during this use case: **Questionnaire for the medical expert at the hospital** To what extent do you think the proposed technology will improve diagnosis? *Perfectly, Well, Honestly, Weakly, Very Weakly* To what extent does the proposed technology improve patient care before hospital admission? *Perfectly, Well, Honestly, Weakly, Very Weakly* How do you rate the user experience in terms of reliability of the service? *Excellent, Good, Fair, Poor, Very Poor* How do you rate the user experience in terms of the precision and promptness of the service? *Excellent, Good, Fair, Poor, Very Poor* Please state how much you agree with the following statement: the technology is ready to be used in an operational environment *Strongly agree, agree, neutral, disagree, Strongly Disagree* If you like please provide your open feedback on your experienced during this use case …
UC8	Wireless operating room	**Questionnaire for Doctor in WOR** Have you noticed any imperfections, such as interruptions, delays or jitter in the Mosaic Display system? *Very often, often, rarely, never* How do you assess your experience in terms of quality of the pictures? *Excellent, Good, Fair, Poor, Very Poor* By comparison with the wire system, how do you assess your experience with wireless system? *Excellent, Good, Fair, Poor, Very Poor* How likely do you feel that this 5G connectivity with medical devices might improve your surgical operations? *Strongly agree, agree, neutral, disagree, Strongly Disagree*

		For remote doctors, how do you assess your experiences supporting remotely surgeons in the WOR? *Excellent, Good, Fair, Poor, Very Poor* Have you noticed any imperfections, such as interruptions, delays in the remote connection? *Very often, often, rarely, never* If you like please provide your open feedback on your experienced during this use case: **Questionnaire for hospital staff** How do you assess your experience in terms of usefulness of the service, such as moving US equipment from room to room and with automatic detection? *Excellent, Good, Fair, Poor, Very Poor* How do you assess your experience in terms of responsiveness of the service? *Excellent, Good, Fair, Poor, Very Poor* If you like please provide your open feedback on your experienced during this use case: …
UC9	Optimal ambulance routing	**Questionnaire for ambulance crews** Have you noticed any shortcomings in the ambulance management system, such as loss of service, misdirection, delays in issuing commands? *Very often, often, rarely, never* To what extent does the proposed technology improve patient transport? *Perfectly, Well, Honestly, Weakly, Very Weakly* How do you evaluate your experience in terms of intuitiveness of the service? *Perfectly, Well, Honestly, Weakly, Very Weakly* How do you evaluate your experience in terms of service utility? *Perfectly, well, honestly, poor, very poor* How do you evaluate your experience in terms of the speed of service response? *Perfectly, well, honestly, poor, very poor* How much you agree with the following statement: the technology is ready for use in an operational environment *I definitely agree, I agree, neutrally, I disagree, I definitely disagree* **Questionnaire for the routing system operator (probably a hospital)** How do you rate the importance of this technology in your routine? *Extremely important, important, moderately important, slightly important, not at all important* How do you rate the user experience in terms of reliability of the service? *Excellent, Good, Fair, Poor, Very Poor* How do you rate the user experience in terms of the precision and promptness of the service? *Excellent, Good, Fair, Poor, Very Poor* Please state how much you agree with the following statement: the technology is ready to be used in an operational environment *Strongly agree, agree, neutral, disagree, Strongly Disagree*
UC10	Smart airport parking management	How much do you agree with the following: There are seldom (or no) cases that you pass by the parking spot because of the delay of the parking application? *Strongly agree, agree, neutral, disagree, Strongly Disagree* How much do you agree with the following: There are seldom (or no) cases that you find a parking place on your own other than of what is proposed by the parking application? *Strongly agree, agree, neutral, disagree, Strongly Disagree*

		How much do you agree with the following: have you observed an empty parking spot that is shown on a different status in the mobile application and vice versa? *Strongly agree, agree, neutral, disagree, Strongly Disagree* How much do you agree with the following: are the updates for the change of status of the parking spot transmitted in a timely manner? *Strongly agree, agree, neutral, disagree, Strongly Disagree* **How much do you agree with the following:** would you be willing to pay for a service that would allow you to reserve a preferred car parking space and a way finding service that would allow you to find this space in the most efficient manner? *Strongly agree, agree, neutral, disagree, Strongly Disagree*
UC11	Video-enhanced ground-based moving vehicles	How much do you agree with the following: There are seldom (or no) perceptible delays in video. *Strongly agree, agree, neutral, disagree, Strongly Disagree* How much do you agree with the following: There are seldom (or no) perceptible delays in audio. *Strongly agree, agree, neutral, disagree, Strongly Disagree* How much do you agree with the following: There are seldom (or no) quality problems such as crackling audio and choppy audio/video. *Strongly agree, agree, neutral, disagree, Strongly Disagree* How much do you agree with the following: There are seldom (or no) choppy or frozen audio/video. *Strongly agree, agree, neutral, disagree, Strongly Disagree* How much do you agree with the following: Connection remains stable and with no quality problems independent of the amount of sources the videos are coming from *Strongly agree, agree, neutral, disagree* How do you rate the user experience in terms of precision? *Excellent, Good, Fair, Poor, Very Poor* Please state how much you agree with the following statement: the technology is ready to be used in an operational environment *Strongly agree, agree, neutral, disagree, Strongly Disagree* How much do you agree with the following: have you experienced loss or reduced transmission service when the follow-me cars are traveling with high speeds? *Strongly agree, agree, neutral, disagree, Strongly Disagree* How much do you agree with the following: have you experienced disconnections or problems with video transmission when selecting different or all video sources on the media platform? *Strongly agree, agree, neutral, disagree, Strongly Disagree*
UC12	Emergency airport evacuation	How much do you agree with the following: My location on the map is depicted with high accuracy no matter how many people are in the same area with me. *Strongly agree, agree, neutral, disagree, Strongly Disagree* How much do you agree with the following: My location on the map is accurately updated towards the direction I move without delay, no matter how many people I see evacuating the area with me? *Strongly agree, agree, neutral, disagree, Strongly Disagree* How much do you agree with the following: My location on the map is depicted with high accuracy in all of the areas under test. *Strongly agree, agree, neutral, disagree, Strongly Disagree*

		How much do you agree with the following: There is no difference in how accurate my location on the map is depicted between open and closed spaces. *Strongly agree, agree, neutral, disagree, Strongly Disagree* How much do you agree with the following: Connection remains stable and with no quality problem no matter how many people are evacuating the area with me. *Strongly agree, agree, neutral, disagree, Strongly Disagree* How do you rate the user experience in terms of precision? *Excellent, Good, Fair, Poor, Very Poor* Please state how much you agree with the following statement: the technology is ready to be used in an operational environment *Strongly agree, agree, neutral, disagree, Strongly Disagree*
UC13	Augmented Reality (AR) and Virtual Reality (VR)-enhanced excursion	How do you rate the time you had to wait to download content? *Excellent (not at all long), Good (not very long), Fair (bearable), Poor (too long), Very Poor (much too long)* How was the quality of video and audio? *Excellent, Good, Fair, Poor, Very Poor* How often did you experience problems such as delays, interruptions, bad video and audio? *Never, Rarely, Sometimes, Often, Very often* Please state how much you agree with the following statement: I feel comfortable interacting with the AR and VR content. *Strongly agree, Agree, Neutral, Disagree, Strongly Disagree* How do you rate the overall VR experience on the bus? *Excellent, Good, Fair, Poor, Very Poor* Please state how much you agree with the following statement: During the bus journey, my interest in the learning aims of the excursion has been stimulated through the use of VR and I felt deeply involved *Strongly agree, Agree, Neutral, Disagree, Strongly Disagree* How do you rate the overall interaction with the exhibit through the AR application? *Excellent, Good, Fair, Poor, Very Poor* Please state how much you agree with the following statement: My interaction with the exhibit has been stimulated through the use of AR and I felt deeply involved in the experience. *Strongly agree, Agree, Neutral, Disagree, Strongly Disagree* Please state how much you agree with the following statement: The AR and VR experiences have made this a better school excursion than the usual school excursion. *Strongly agree, agree, neutral, disagree, Strongly Disagree* If you wish, please provide your feedback on your AR and VR experiences during the excursion in your own words: …

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