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

D7.4

Final integrated 5G-TOURS ecosystem and technical validation results

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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
5QI	5G QoS Identifier
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
COTS	Commercial Off-The-Shelf
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
GTP	GPRS Tunnelling Protocol
gNB	gNodeB
GUI	Graphical User Interface
HD	High Definition
HPHT	High-Power High-Tower
IoT	Internet of Things
IP	Internet Protocol
IT	Information Technology
ITU	International Telecommunication Union
KPI	Key Performance Indicator
KQI	Key Quality 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
OVS	Open vSwitch
PNF	Physical Network Function
PSM	Power Saving Mode
QCI	QoS Class Indicator
QoE	Quality of Experience
QoS	Quality of Service
RAN	Radio Access Network
RTT	Round-Trip Time
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
TC	Translation Component
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
USIM	Universal Subscriber Identity Module
vEPC	virtual Evolved Packet Core
VNF	Virtual Network Function
VPN	Virtual Private Network

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) have been deployed. The ultimate goal of this approach was to trial the use cases in real environments to continuously collecting network, service and vertical KPIs and then to 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 would allow for the realisation of the pilots in all three sites and drive the evaluation of the results of the trials. This deliverable is the final document produced by WP7 and presents: a) the final version of the 5G-TOURS integrated ecosystem; b) the final validation results from the execution of the trials; c) the results from the application of 5G-TOURS QoS/QoE model.

Regarding the 5G-TOURS ecosystem, a first version was introduced in the previous deliverable D7.2 [6]. In this deliverable, its final version of the ecosystem is presented, which includes: a) the site infrastructure, b) the 5G-TOURS platform and 5G-TOURS innovations, c) the hardware and software components of the verticals and, in general, d) all the required functionalities which were required for the smooth and successful execution and evaluation of the 5G-TOURS trials. This deliverable acts complementary to deliverables D4.4 [3], D5.4 [4] and D6.4 [5], in which the final sites infrastructure, the hardware and software components deployment and the preparation and execution of the trials were presented for each of the three sites respectively.

Regarding the validation results, in D7.2 [6] a feasibility study was realised for each use case to identify which of the KPIs could be technically validated. For the KPIs that were characterised as feasible, a technical validation plan was generated. In this deliverable, the realisation of the validation plan is described for each use case, as well as the process of collecting the metrics, analysing the metrics, calculating the KPIs and, finally, validating the KPIs against the latest use case requirements presented in D2.3 [1]. In this deliverable, in addition to the selected KPIs for each use case, the details behind the validation process are presented including: a) the scenario details using a scenario template; b) the probe positions in the network; b) the probe positions in the protocol layers; c) the trial details (e.g., duration, sampling period, collection method); d) the methodology used during the analysis and validation and; e) any assumptions made during the collection/analysis/validation process.

Regarding the 5G-TOURS QoS/QoE model, in the previous deliverable D7.2 [6], the final 5G-TOURS evaluation methodology, which covers QoS, QoE and vertical satisfaction aspects, was introduced. In this deliverable, the results from the application of such QoS/QoE methodology on the use cases are presented. By following the 5G-TOURS QoS/QoE methodology, the level of satisfaction of end-users and verticals' players in the use cases were measured and evaluated. This evaluation included users' QoE as well as the feedback from the vertical players on how the technology provided can improve their business operations. The final 5G-TOURS evaluation methodology was followed in the trial execution of all use cases. Initially, during the actual trial execution, both the QoS metrics, automatically obtained from the infrastructure, and the QoE metrics (and vertical satisfaction), were collected using appropriate questionnaires, Then, all the collected metrics were analysed and the KPIs calculated and validated against the predefined targets. In addition, insights were provided in the case of successful validation results, while a justification in case of not fulfilled KPIs. Besides, in selected use cases, models for QoS/QoE correlation were created by using correlation-regression analysis.

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 sites: Turin, Rennes and Athens.

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

In this deliverable, which is the last deliverable of WP7, the final version of the 5G-TOURS integrated ecosystem is presented. In addition, the final validation results from the execution of the trials are presented and explained. For each use case trial, the following is included: a) the trial scenario deployment details; b) the details regarding the metrics collected (e.g., the probe positions in the network, the probe positions in the protocol layers, duration, sampling period, collection method); c) the methodology and tools used for the analysis and the calculation of the KPI values; d) the validation process, including the comparison against the latest use case requirements presented in D2.3 [1].

Finally, for this deliverable, the level of satisfaction of end-users and verticals' players in the use cases were measured and evaluated. For this, for each use case, a set of questionnaires were delivered to the users, filled, collected, analysed, and then validated; the results are also included here. In addition, for some selected use cases (UC1 and UC4), models for QoS/QoE correlation were created by using correlation-regression analysis and are also reported here.

1.1 Summary of 5G-TOURS validation results

In order to be more comfortable for the reader to explore the validation results of all the 13 Use Cases, the summary of the validation results of the trials executed in 5G-TOURS nodes is presented in Table 1. Table 1 initially reports, for each Use Case, the trial scenario or trial scenarios executed. Then, it discriminates between QoS and QoE.

QoS values illustrates the performance of the network and applications as validated using the metrics/KPIs collected during the trial execution. These metrics includes both network metrics (measured using network probes and tools) as well as applications metrics (measured using app layer probes). In the QoS case, Table 1 presents, for each trial scenario: a) the metrics/KPIs that were collected, analysed and finally validated during the trials; b) the outcome of the validation process, which includes the calculation of the KPIs from the collected metrics and the comparison of the KPI values against the vertical requirements and targets reported in D2.3; c) the section in this document in which the trial scenarios and results of the specific use case are described in detail.

QoE values illustrates the level of satisfaction of end-users and verticals' players involved in the use cases, also capturing the different roles the end-users may have (e.g., visitor, staff, administrator etc.). In Table 1, the methodology followed is reported and also the validation results expressed as the average score after the collection and analysis of the questionnaires. In addition, it is mentioned the related section in the document in which the methodology, the questionnaires used (per user role), the score per question in the questionnaires are presented and explained in detail.

Table 1. Summary of 5G-TOURS validation results.

Use Case	Scenario	QoS results (Network and application performance)			QoE results (User experience)		
		KPIs collected, analysed, and validated	Validation results	Section	Methodology	Validation results (average score)	Section
UC1	Augmented tourism experience	RTT latency, RAN latency, Throughput, Reliability, Availability	PASSED	3.3	Questionnaires and QoS/QoE modelling	PASSED (scores inside section)	3.4.1, 3.5.1

UC2	Telepresence	RTT latency, RAN latency, Throughput, Reliability, Availability	PASSED	3.3	Questionnaires	PASSED (scores inside section)	3.4.2
UC3	Robot-assisted Museum guide	RTT latency, RAN latency, Throughput, Reliability, Availability	PASSED	3.3	Questionnaires	PASSED (scores inside section)	3.4.3
UC4	High-quality video services distribution	RTT latency, RAN latency, Throughput, Reliability, Availability	PASSED	3.3	QoS/QoE modelling	PASSED (scores inside section)	3.5
UC5	Remote and distributed video production	RTT latency, RAN latency, Throughput, Reliability, Availability	PASSED	3.3	Questionnaires	PASSED (scores inside section)	3.4.4
UC6	Health monitoring and incident-driven communications prioritization	RTT latency, Throughput DL/UL, Service Availability, Service Reliability, App layer RTT latency	PASSED: mMTC, eMBB, URLLC FAILED: Only RTT latency (URLLC case)	4.3.1	Questionnaires	PASSED (3.44)	4.3.1.5
UC7	Smart glasses and ultrasound Android application with XpertEye webrtc screen sharing	Latency, Data rate, Frame drops	PASSED	4.3.2	Questionnaires	PASSED (4.8)	4.3.2.4
	Multi-stream digital ultrasound data transfer	Latency, Data rate, Frame drops	PASSED (Edge) FAILED (Core)	4.3.2	Questionnaires	PASSED (4.8)	4.3.2.4
	3D telepresence	Data rate	PASSED	4.3.2	Questionnaires	PASSED (4.0)	4.3.2.4
UC8	Wireless operating room	Latency, Throughput DL/UL	PASSED	4.3.3	Questionnaires	PASSED (4.2)	4.3.3.3
UC9	Optimal ambulance routing.	RTT latency, Throughput DL/UL, Service Availability, Service Reliability, App layer RTT latency	PASSED: eMBB, URLLC FAILED: Only RTT latency (URLLC case)	4.3.4	Questionnaires	PASSED (3.67)	4.3.4.5
UC10	Smart airport parking management	RTT latency, Throughput DL/UL, Network Availability, Network Reliability, Service Availability, Service Reliability, App layer RTT latency	PASSED	5.3.1	Questionnaires	PASSED (4.05)	5.3.1.5
UC11	Video-enhanced follow-me moving vehicles	RTT latency, Throughput DL/UL, Network Availability, Network Reliability	PASSED	5.3.2	Questionnaires	PASSED (4.1)	5.3.2.5

UC12	Emergency airport evacuation	RTT latency, Throughput DL/UL, Network Availability, Network Reliability, Service Availability, Service Reliability, App layer RTT latency, Location accuracy	PASSED: Network Availability, Network Reliability, Service Availability, Throughput UL FAILED: RTT latency, Throughput DL, Service Reliability, Location accuracy	5.3.3	Questionnaires	PASSED (3.32)	5.3.3.5
UC13	Excursion on AR/VR-enhanced bus	RTT latency, Throughput DL/UL, Network Availability, Network Reliability	PASSED FAILED: Only VR case (Throughput DL, Network Reliability)	5.3.4	Questionnaires	PASSED (3.76)	5.3.4.4

From the summarised results in Table 1, it becomes clear that, regarding the QoS validation results, these are successful for the vast majority of the Use Cases, meaning that the trials proves that the use of 5G was successful in fulfilling even the strict requirements of the verticals (D2.3 [1]). In only two scenarios (UC7 – Scenario "Multi-stream digital ultrasound data transfer" and UC12 – "Scenario Emergency airport evacuation"), we identified that the validation results cannot support some KPIs. In the first case, because the service was deployed in the core, the KPI failed, and when the service was migrated to the edge, the trials were successful; while, in the second case, the reason is the extremely strict requirement combined with some limitations of the trial deployment (e.g. 50MHz available bandwidth instead of 100MHz which is available commercially). The details of the trials together with the appropriate justification are presented in the related section of the document (mentioned in Table 1). In addition, even in the cases that only some KPIs are not successful under specific cases, justification is also provided in the related sections (e.g.: UC6 and UC9 – RTT latency in URLLC and UC13 – VR case).

Regarding QoE validation results, Table 1 illustrates that, in all scenarios, the average score is above the defined threshold of 3.0 (following the Likert scale and threshold [33]). This practically means that in all Use Cases, even in the Use Cases that some of the KPIs failed to fulfil the targets, the measured level of user satisfaction is high, and the end-users are happy with the use of the application. In the related sections, the reader can find very interesting details about the questions that hit the highest score and the questions that just passed the threshold. Regarding the questionnaires, all the questionnaires that were used are reported in Annex B of the document and the reader can refer to them.

1.2 Document structure

The content of this deliverable is structured as follows:

- Section 2 presents an extended version of 5G-TOURS QoS/QoE evaluation approach. In the previous deliverable D7.2 [6], the final 5G-TOURS evaluation methodology was reported, which covers QoS, QoE and vertical satisfaction aspects. In this document, this version is further enhanced with an extension for assessment in a large-scale network. In addition, the results from the application of the QoS/QoE methodology on the use cases are also presented in this document. These results are not presented in Section 2, but in Sections 3,4 and 5 and in the related UC subsections.
- Section 3 presents the touristic city integrated ecosystem. In particular, an overview of the ecosystem, the technical validation, and the integration part are presented. Then the final validation results are presented capturing both the QoS and QoE (user satisfaction) aspects. Details are provided for the trial scenario deployment (scenario template), metrics and KPIs collected during the trials, the methodology

and tools used for the collection, analysis and validation of the KPIs. In addition, justifications are provided in the cases that the validation results failed to fulfil the requirements set in D2.3 [1].

- Section 4, similarly to the previous section, presents the safe city integrated ecosystem. The final version of the ecosystem is presented, explaining all the details including innovations, hardware and software components and the infrastructure. The trial scenarios are presented, together with the relative methodology and tools for the analysis and validation process and finally the validation results are presented, explained and justified.
- In Section 5, the mobility-efficient city integrated ecosystem is presented. Again, similarly to the previous sections, all the details related with the collection, analysis and validation of both QoS and QoE metrics are presented and explained in detail, while justifications are provided when needed.
- Section 6 concludes the document and summarizes the integrated ecosystem and the final validation results.
- Finally, two Annexes are present in the document. In Annex A, some extra graphs from the collection of metrics/KPIs during the trials are presented, while in Annex B, the final version of the questionnaires used in each UC for the validation of user satisfaction (QoE) are included for completeness.

2 5G-TOURS QoE/QoS evaluation approach

In this section, we describe the overall methodology that was followed for the realisation and the evaluation of the trials executed in the pilot sites. We reuse information from 5G EVE testing and validation methodology and 5G-MoNArch aspects and explain how these methodologies are updated to meet the requirements of the 5G-TOURS pilot sites.

2.1 QoE evaluation methodology

QoE evaluation methodology was developed in WP7, and the high-level illustration of this methodology is presented in Figure 1.

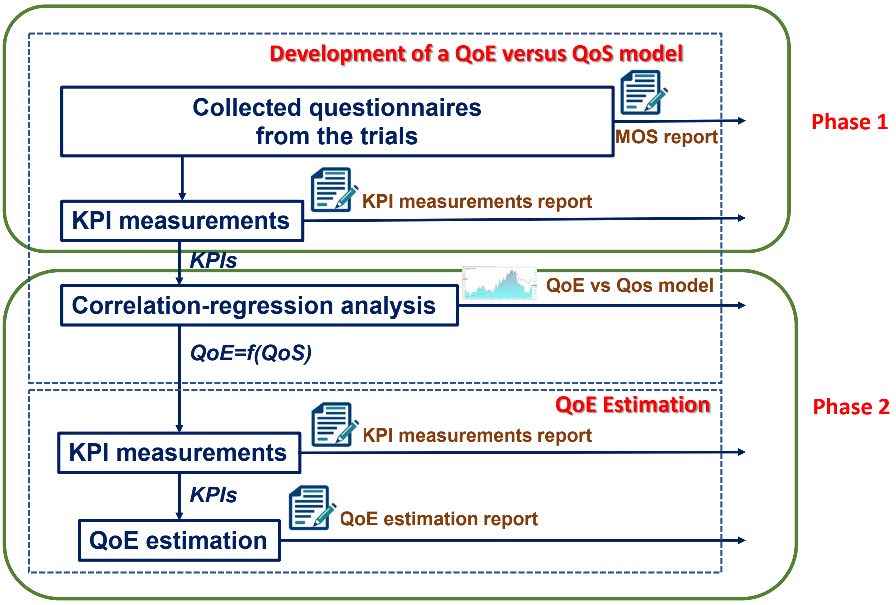


Figure 1. General approach for evaluation methodology.

The final 5G-TOURS developed methodology (Step 1 – Step 7) is presented below in more details. During Step 1 to 3, the preparations phases are realised. In Steps 4 to 7 the actual methodology is realised which is illustrated Figure 1. According to the methodology, based on the description and targets of each UC, the most relevant KPIs to be measured and demonstrated were defined (Section 3.3 of D7.2 [6]).

Step 1 – Definition of the most relevant KPIs for each UC using the following template:

Table 2. Most relevant for the UC KPIs.

KPI_1	KPI_2	…	KPI_n

Step 2 – Definition of the most relevant QoE parameters and weight coefficients for each QoE parameter and UC.

Table 3. The most relevant for the UC QoE parameters.

	QoE_1	QoE_2	…	QoE_m
Weight coefficient (*K*)	K_1	K_2	…	K_m

Step 3 – Development of the appropriate questionnaires for each UC (Section 7.1 from [D.7.2]).

After these preparations, 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.

Step 4 – KPI measurements according to pre-defined methodology presented in D7.1 [7].

Step 5 – Collection of the QoE questionnaires. The example of QoE related part of the developed questionnaire is represented in Figure 2.

Quality of Demonstrated 5G Production (QoE)

In the following questions, the scale is: 1: unacceptable; 2: poor; 3: fair; 4: very good; 5: excellent.

17. How do you evaluate the video quality?	1	2	3	4	5
18. How do you evaluate the audio quality?	1	2	3	4	5
19. How is the video quality compared to current live street concert production?	1	2	3	4	5
20. How is the audio compared to a street concert production audio?	1	2	3	4	5
21. The given battery is sufficient for such broadcasts?	1	2	3	4	5
22. ` The 5G signal was stable (bars in the UI)	1	2	3	4	5

Figure 2. QoE questionnaires.

The second phase is realized after the trials executions and by using regression analysis (in details described in Section 2.3), which aims to create a model for QoS to QoE mapping.

Step 6 – Estimation of the weighted QoE for each QoE/QoS measurements iteration:

$$QoE = K_1 \cdot QoE_1 + K_2 \cdot QoE_2 ... + K_n \cdot QoE_n,$$

where $K_1 + K_2 ... + K_n = 1$ and $K_1, K_2, ..., K_n > 0$.

Step 7 – Processing of the obtained experimental data (QoE and QoS). It is better to present this data in table form (Table 4).

Table 4. Collected during trials QoE and QoS values.

QoE	**QoS parameters**			
	KPI$_1$	*KPI*$_2$	…	*KPI*$_N$

Collected data should be processed according to the algorithms represented in the Section 2.3.

2.1.1 Specific approach of a QoS/QoE assessment in a large-scale network

In this subsection, we introduce a specific approach for QoS/QoE assessment from a real live network prospective where results from questionnaires are not available, since it is not feasible to have questionnaires all the times in real life and large-scale network. It is important at this stage to plan and take into consideration the challenges of QoS/QoE from a real live network prospective and this goes a step beyond the trials analysed in 5G-TOURS.

Successful 5G performance management will require combined views of both the network underlay QoS, and the applications/services overlay QoE. The ultimate performance metric will be the end-user experience, which necessitates granular management and measuring at the application layer. Accurate KPI measurements from the underlay network, combined with service-level quality metrics, will enable wireless service providers to deliver end-to-end quality of experience for 5G users, particularly for private networks and those using enterprise apps. In Figure 3, the QoS/QoE pyramid illustrates a high-level relationship between classical network KPIs used to derive the end-to-end network QoS, the KQIs measured for every application and the final resulting QoE perceived by the user.

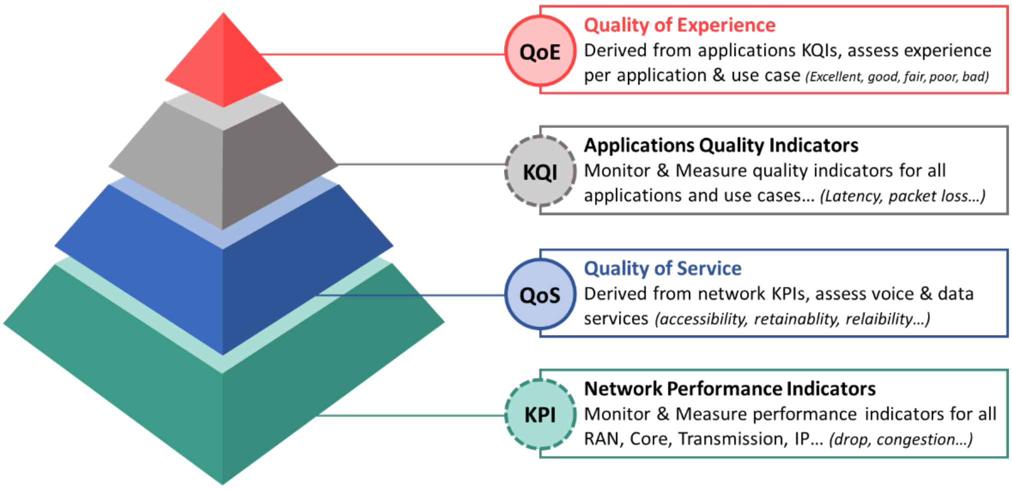


Figure 3. The QoS/QoE Pyramid.

The traditional network KPIs will develop further in 5G to measure the performance across all entities, interfaces, systems and new specific 5G components related to MIMO, mmWave, O-RAN, etc. These measured KPIs will result in generating a massive amount of data to analyze the global network quality of service that is critical for modelling and securing optimum QoE for various use cases.

For 5G services, it’s crucial to understand the network topology and architecture, the specific configurations associated to the spectrum band, MIMO, bandwidth, uplink and downlink traffic paths, 4G-5G interworking, core setup SA-NSA, O-RAN, backhaul, midhaul, fronthaul, network slicing and MEC availability, in order to build the right performance measurement setup for efficient QoS monitoring. Generic performance management systems provide valuable reports and correlated data from all interfaces to troubleshoot connectivity throughout all connection phases.

The end-to-end statistical monitoring presented for the various network entities and interfaces in Figure 4 should cover but not be limited to:

1. **RAN KPIs** for instance describing coverage, signal quality, interference, available capacity, bandwidth utilization, licenses usage, connection establishment, mobility, session drop, retransmission rate, RF latency, availability, user throughput.
2. **Transport KPIs** for instance evaluating transmission capacity, utilization, packet loss, delay, jitter, modulation scheme usage, interference, routers and switches performance, packet drops, processing delay, port utilization, optical network performance.
3. **Packet Core KPIs** for example for data session management, rejection rate, mobility, gateway traffic usage, discarded frames.

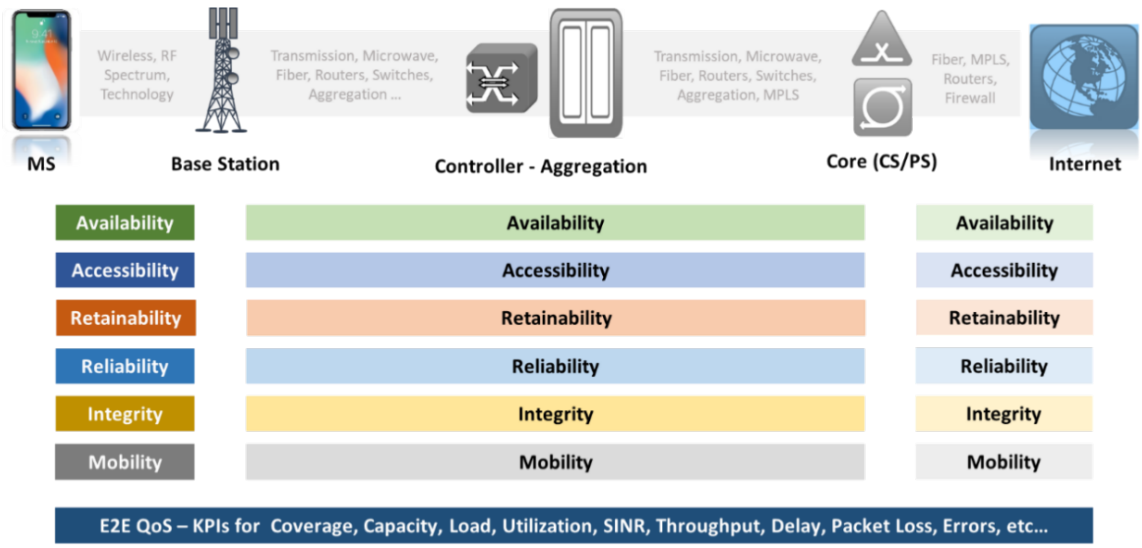


Figure 4. End-to-end network QoS management.

Moreover, traditional performance management includes other useful tools to monitor and analyse essential quality measurements in critical areas like:

- **Call trace** – to understand the individual user performance issues.
- **Field benchmarking** – to evaluate the performance variation between different networks, vendors, or regions. It also gives insights about dissimilar configurations and their impact on QoS/QoE.
- **Scanners** – to examine the spectrum cleanness and possible existence of interference.

In turn, the growing complexity of applications in 5G creates a dilemma for service and network management. The root of the challenge is the fact that traffic for diverse applications behaves differently as application demands vary significantly. For instance, touristic city use cases combine different applications involving advanced technological requirements such as AR/VR, IoT, UHD video and Robotics, each one associated with its unique slices and network requirements as illustrated in Figure 5 for the touristic smart city ([8]).

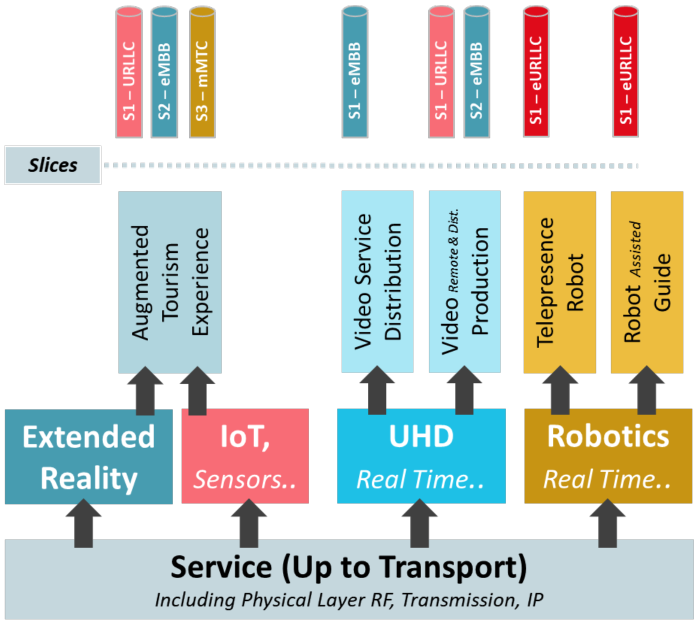


Figure 5. Smart Touristic City different use cases and slices requirements.

Clearly and with the expected data increase in real live network, wireless service providers need better tools with new levels of insight. Legacy network and service performance management solutions are no longer effective. Pre-5G QoS/QoE management approach will create significant challenges that need to be tackled in order to manage and deliver the promised 5G experience, which can be summarized by the following [10]:

1. **Lack of end-to-end visibility** – Traditional management tools and protocols are designed for monitoring separate network components and analyzing their bandwidth (traffic) performance and utilization. But, these legacy tools do not provide a complete index for measuring what really matters: the quality of experience (QoE), i.e. "how well the service is performing for the end user". Having visibility and a consistent monitoring layer, end-to-end, is necessary to manage quality of experience (QoE) over these discontinuous domains.
2. **Best Effort QoE Assurance** – While best-effort QoE assurance has been the accepted standard for internet applications and services, it's no longer good enough for today's growing digital services. Customers are no longer tolerant of services being "okay" rather than "excellent." Understanding the QoE level for the various use cases is crucial and it can impact customers' perception of network quality and lead to churn [11].
3. **Understanding the relationship between QoS and QoE** – Service providers are still more comfortable monitoring QoS than QoE, a leftover from traditional telephony performance monitoring. The problem is that the end user experience is largely driven by QoE and not QoS. Thus, it's crucial to recognize the associated network QoS requirements per use case, then define the appropriate performance management methodlogy for efficient network monitoring and testing and also creating a specific QoE model per use case.

2.2 QoE/QoS Model

International Telecommunication Union (ITU) defines QoE as the overall acceptability of an application or service. As perceived subjectively by the end-user. 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.

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 6 [12].

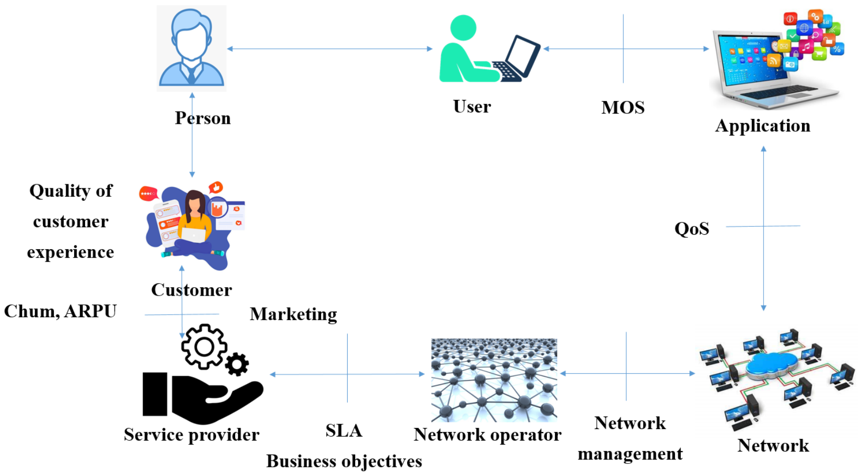


Figure 6. QoE model.

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

To implement this approach, a set of UC scenarios was introduced that should be analysed:

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

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

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

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

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

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

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

At the second stage, QoS and QoE indicators are selected S_{ijp} , using multi-factor correlation-regression analysis. To construct a generalized 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, namely the analytic expression that best reflects the relationship of factor characteristics with the resultant, that is, the choice of function:

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

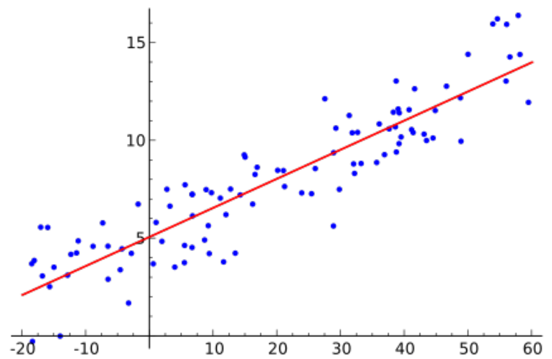
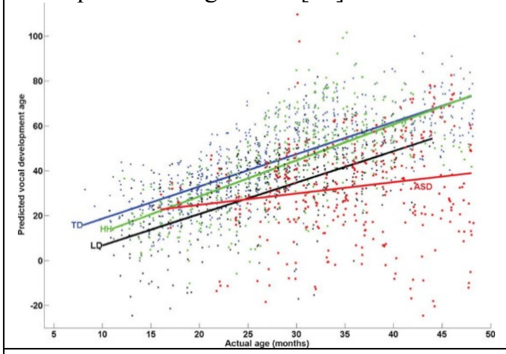
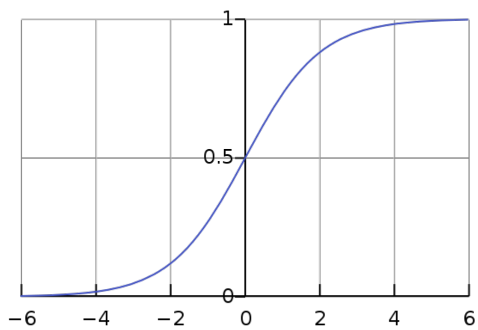
where $\hat{Y}$ – effective sign-function; $x_1, x_2, x_3, ..., x_n$ – factor signs.

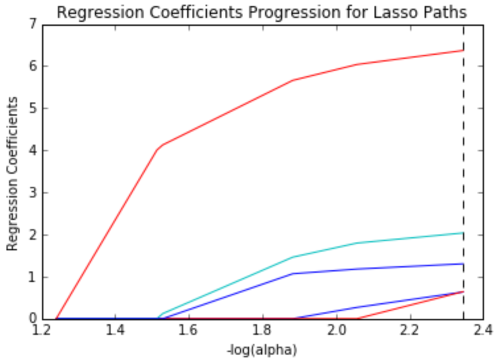
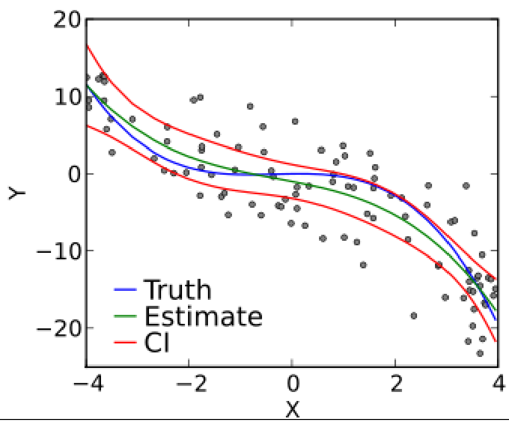
Regression analysis mathematically describes the relationship between a set of independent variables and a dependent variable. There are numerous types of regression models that you can use. This choice often depends on the kind of available data for the dependent variable and the type of model that provides the best fit. In this section, we cover the more common types of regression models and how to decide which one is right for existing data.

As analysed, there are many types of regression analysis techniques, and their usage varies according to the nature of the data involved. That is why it was decided to create the special bank of regression models for the needs of the project.

The Table 5 summarises the different types of regression models, and under what condition each of them can be used for QoE and QoS dependencies estimation.

Table 5. Bank of 5G-TOURS regression models.

Model name / Graph model	Mathematical model (expression)
Linear regression [13] 	$Y = a + b \cdot X + \varepsilon$, where: X is the explanatory variable; Y is the dependent variable; b is the slope of the line; c is an intercept; ε is a model error.
Multiple linear regression [14] 	$Y = \beta_0 + \beta_1 \cdot x_1 + \beta_2 \cdot x_2 + ... + \beta_p \cdot x_p + \varepsilon$, where: Y is the predicted value; β_0 is the Y-intercept (value of y when all other parameters are set to 0); β_p is the regression coefficient of the independent variable x_p ; p is the number of independent variables; ε is a model error.
Logistic Regression [15] 	$Y = \frac{1}{1+e^{-(\beta_0+\beta_1 \cdot x)}}$, where: Y is the predicted value; β_0 is the Y-intercept; β_1 is the regression coefficient of the variable x .

<table>
<tr>
<td>Lasso Regression [16]

</td>
<td>$$\sum_{i=1}^{n}\left(y_i-\sum_{j}x_{ij}\cdot\beta_j\right)^2+\lambda\cdot\sum_{j=1}^{p}\left|\beta_j\right|,$$
where:
y_i is the predicted value;
β_j is the regression coefficient of the independent variable x;
λ denotes the amount of shrinkage.</td>
</tr>
<tr>
<td>Polynomial Regression [17]

</td>
<td>$$Y=\beta_0+\beta_1\cdot x+\beta_2\cdot x^2+\ldots+\beta_p\cdot x^p,$$
where:
Y is the predicted value;
β_0 is the Y-intercept;
β_p is the regression coefficient of the independent variable x;
p is the power of a variable x.</td>
</tr>
</table>

Choosing the correct regression model can be difficult. Trying to model it with only a sample does not make it any easier. It applies when a researcher wants to mathematically describe the relationship between some predictors and the response variable. The research team tasked to investigate typically measures many variables but includes only some of them in the model. The analysts try to eliminate the variables that are not related and include only those with a true relationship. Along the way, the analysts consider many possible models. They strive to achieve a Goldilocks balance with the number of predictors they include.

- **Too few**: An underspecified model tends to produce biased estimates.
- **Too many**: An overspecified model tends to have less precise estimates.
- **Just right**: A model with the correct terms has no bias and the most precise estimates.

To choose the best appropriate regression model, it is better to include the variables that are specifically testing along with other variables that affect the response in order to avoid biased results. There are statistical measures and procedures that help to specify regression model [18].

Adjusted R-squared and Predicted R-squared: R-squared is a statistical measure that represents the proportion of the variance for a dependent variable that's explained by an independent variable or variables in a regression model. This model has higher adjusted and predicted R-squared values. These statistics are designed to avoid a key problem with regular R-squared—it increases *every* time a predictor is added and can trick the engineer into specifying an overly complex model.

- The adjusted R-squared increases only if the new term improves the model more than would be expected by chance and it can also decrease with poor quality predictors.
- The predicted R-squared is a form of cross-validation and it can also decrease. Cross-validation determines how well your model generalizes to other data sets by partitioning your data.

P-values for the predictors: A p-value measures the probability of obtaining the observed results, assuming that the null hypothesis is true. In regression, low p-values indicate terms that are statistically significant. “Reducing the model” refers to the practice of including all candidate predictors in the model, and then systematically removing the term with the highest p-value one-by-one until you are left with only significant predictors.

Stepwise regression and Best subsets regression: These are two automated procedures that can identify useful predictors during the exploratory stages of model building.

Figure 7 below shows the schematic flow of the method selection and subsequent model generation.

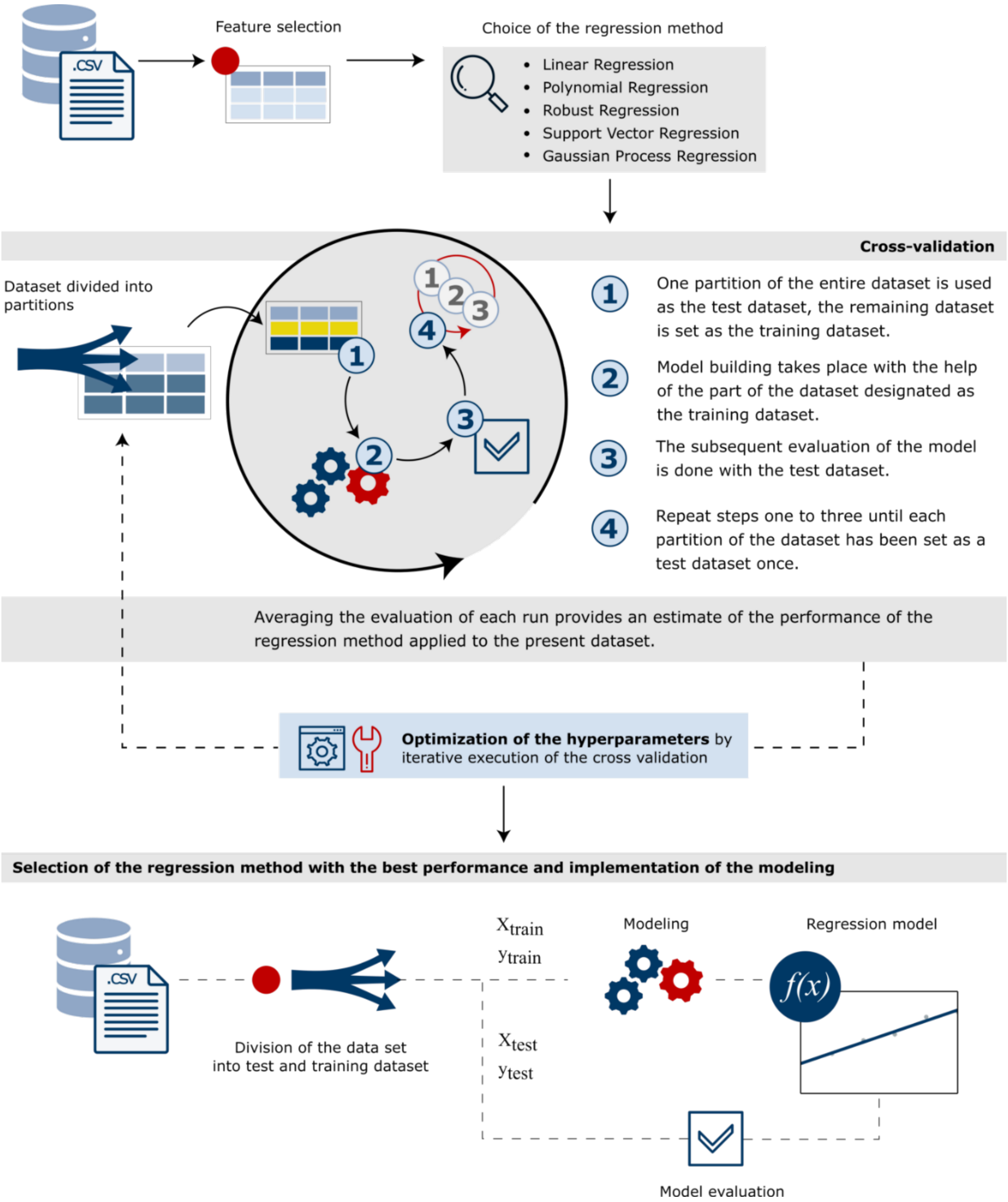


Figure 7. Regression method selection and subsequent QoE-to-QoS model generation [19].

The feature selection already takes place before the model building and defines the input attributes of the later regression model. The datasets were already structured during the creation in such a way that they only contain relevant attributes.

The regression methods are suitable for different problems, differently well. For evaluation, the dataset is split into training and test dataset before model building. This step is automatically performed iteratively during *cross-validation*.

Hyperparameter optimization through repetitive cross-validation with different hyperparameter settings:

The result of the *cross-validation* represents a list with the values of the selected scoring parameters. Since the evaluation is performed after each run, if the dataset is divided into five partitions, there is also a list with five evaluation values. An averaging of these values allows an assessment of the performance of the regression procedure. Since most regression methods allow an adjustment of the model complexity via one or more hyperparameters, an adjustment of the hyperparameters is necessary for a meaningful comparison of the regression methods. The finding of these optimal hyperparameter settings is done by iterative model building. The *cross-validation* is performed repeatedly for different hyperparameter settings. Finally, the parameter settings are chosen which showed the best model accuracy during the evaluation. This process is performed by loops which automatically change the hyperparameters within certain limits and store the evaluation values. The selection of the optimal settings is then done by manual or automated search for the best evaluation results.

2.2.1 Specific approach for a QoS/QoE model in a large-scale network

As 5G networks become virtual, programmable and software-defined, performance assurance has to operate at new levels of automation and speed. New 5G business-critical applications require complete core-to-edge control of service performance. Consequently, performance assurance has to be a mandatory component of 5G service definition and design ([20]).

2.2.1.1 Statistical Visibility Everywhere with Granular Performance Data

A full comprehensive visibility about network performance, applications and subscribers' behaviour will become the source of all network decisions. How the network and applications work together will derive the end user experience. Traditional statistical information will continue to be used for generic 5G core-to-edge performance evaluation and analysis. Nevertheless, it's important to ensure that all systems, entities, nodes and interfaces are tightly synchronized and generating the required metrics and KPIs for proper end to end correlation. Figure 8 describes all the domains of the wireless network requiring full visibility.

Figure 8. The full network visibility for all domains.

Data granularity [21] is another important aspect of full visibility that must be considered while evolving toward mission critical services and real-time interactive data sessions. It describes the degree of accuracy about what's really happening in the network at any specific interval, and it clarifies its criticality. More granular data means it's easier to gain accurate insights where precise actions can be taken directly, resulting in improved problems resolution efficiency and better performance optimization. For example, Figure 9 illustrates how sampling frequency can make a huge difference in revealing the real performance and expose the origin of invisible significant performance issue related to actual bandwidth utilization.

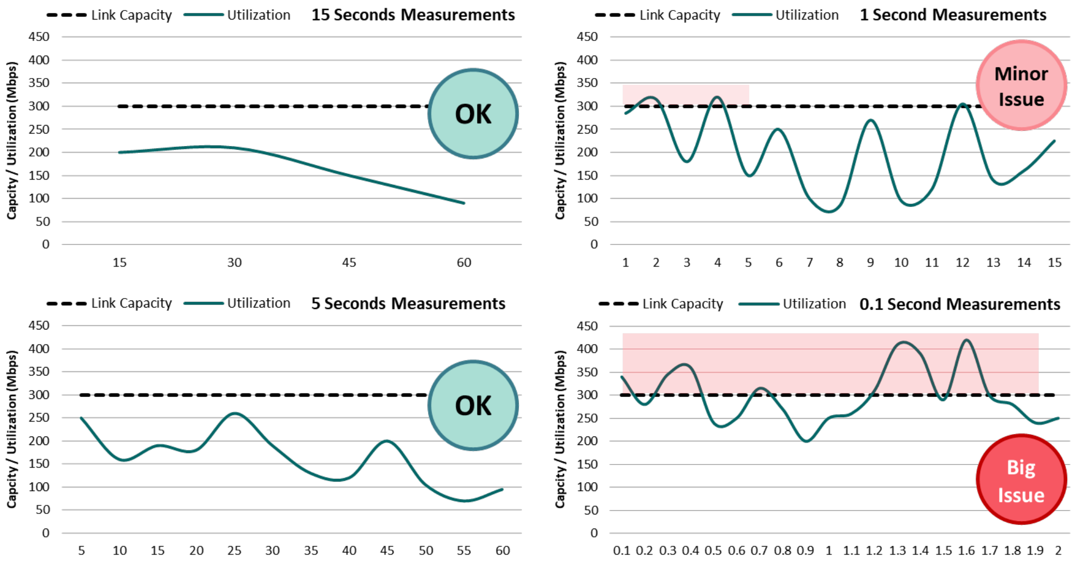


Figure 9. Example of actual BW utilization averaged for different statistical measurement intervals.

While "15" and "5" seconds statistical measurement intervals showed a normal trend without hitting the maximum limit of the link capacity, it's obvious that the link suffered from congestion when using more precise measurement intervals with "1" and "0.1" second.

2.2.1.2 5G Service Experience-Based Modelling

With the evolution of the 5G technology and services, mobile networks need to be transformed from the traditional telecoms service-based network structure model to the service experience-based network construction model that meets the new digital service experience requirements. This will help predicting the quality before a service is deployed [22].

Generally, the QoE of individual use cases is highly influenced by 3 main dimensions of the underlying bearers, which are [11]:

- End-to-end throughput capacity (Bit Rate)
- End-to-end duration (Latency)
- End-to-end seamless continuity (Packet Loss)

Figure 10 illustrates the required bit rate, latency and packet loss for 3 use cases with different slices requirements ([6], [11]), where the 3 main dimensions were linked proportionally together in the triangle chart based on the importance of each dimension. Higher grade (10) indicates the criticality of the KPI for the mentioned UC, while lower grade designates less importance relatively. Note that continuity and latency are crucial for real-time interactive applications.

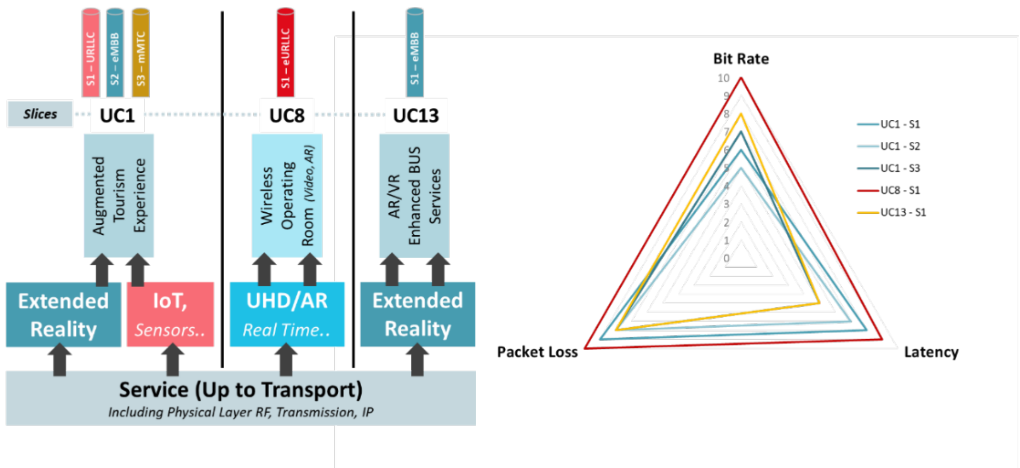


Figure 10. The three main dimension affecting QoE.

It's important to mention that the reference unit for application throughput measurement is variable and follows the application traffic characteristics [23], while latency and packet loss measurements references are similar for all types of applications. In addition, degradation in the throughput requirements will result in further delays and packet drops [24]. Hence, QoE evaluation methodologies and formulas can be based on latency and packet loss variations, while network throughput capacity can be considered separately as a possible root cause of QoE degradation.

$$\boldsymbol{UC_X QoE_{model}} = Function\{Weight_{XT,} * Throughput_{E2E} + Weight_{XL} * Latency_{E2E} + Weight_{XPL,} * PacketLoss_{E2E}\}$$

- *XT – Throughput Weight for use case X*
- *XL – Latency Weight for use case X*
- *XPL – Packet Loss Weight for use case X*

As illustrated in Figure 11, 5G generic QoE models are derived for all use cases and applications, depending on the associated transport expectations and requirements. However, the E2E core KPIs and technical parameters are the same; the difference is how they are weighted in a QoE model.

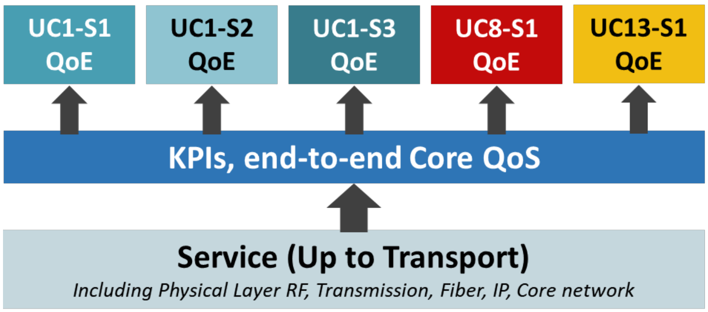


Figure 11. Modelling QoE based on network KPIs.

The below chart in Figure 12 is an example of possible weights for the main E2E KPI assuming UC8 was selected as reference. QoE KPIs total index reflects a combined score of E2E technical requirements.

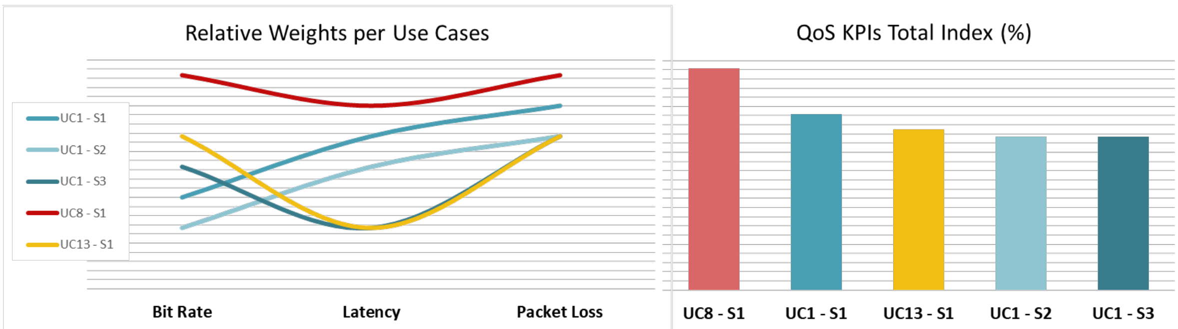


Figure 12. Example, relative weights of different UC slices.

Optimum QoE modelling requires a unified planning across all network domains to ensure effective cross-domain collaboration and domain-based design. The requirements of user experience on the network are mapped to the baseline requirements, such as the E2E throughput, delay, and packet loss rate. Consequently, the E2E planning of service experience–based network structure uses the unified core quality of service (QoS) parameters (throughput, delay, and packet loss rate) as the baseline, and the planning of the wireless network, bearer network, and cloud core network are associated with each other to implement unified planning and domain-based design of the E2E throughput, delay, and packet loss rate.

3 Touristic city integrated ecosystem, trials and validation

3.1 General description

The 5G-TOURS touristic city implemented 5 different UCs (as presented in detail in D4.4 [3]) related to the augmented tourism and media, as follows:

- UC 1 - Augmented tourism experience
- UC 2 - Telepresence
- UC 3 - Robot-assisted Museum guide
- UC 4 - High-quality video services distribution
- UC 5 - Remote and distributed video production

The trials took place in different locations of the city of Turin: while the central points were the museums Palazzo Madama and GAM, other locations such as the EduLab were involved. Also, for the broadcast UCs (4,5), itinerant setups were provided as well as a remote branch connected to the UPV premises.

3.2 Integrated ecosystem

In the context of the activities related to the integration of the 5G-TOURS use cases on the 5G EVE infrastructure, as already reported in D4.4 [3], UC1 and UC4.c have been successfully implemented by onboarding the related backends over the NFV infrastructure of 5G EVE, including the on-field trial phase over the 5G commercial network. According to the phased approach defined in the context of WP4, experimental activities related to the introduction and test of new functionalities would have been addressed based on the 5G EVE NSA laboratory network. In this context, 5G-TOURS worked to extend the 5G EVE orchestrator (EVER) in order to introduce slicing management functionalities with the objective to enable RAN network slice profiling, matching the network behavior with the service requirements for the different use cases.

The support of the three different slices (eMBB, URLLC and mMTC) has been implemented at the RAN level by 5G-TOURS. Those slices can be concurrently instantiated and used according to the service type requests coming from the mobile devices. Furthermore, EVER orchestrator allows to monitor some parameters such as latency, received and transmitted packets that can support the network analysis, as well as QoS profile tuning.

3.2.1 RAN slicing management

EVER is a Network Service orchestrator based on ETSI MANO NFV specifications [26]. Its main goal is to manage the vertical network service in an automatic way, providing the required resources in order to satisfy the SLA service and managing all the lifecycle of the service (i.e., providing the procedures to instantiate, terminate, and modify the service).

EVER implements different features and the description is reported in 5G EVE project [27]. This section details the RAN network slicing support that has been introduced by 5G-TOURS. RAN network slicing is a key element introduced in the fifth-generation mobile networks (5G) to handle, in a flexible way, multiple services sharing the radio infrastructure. RAN slicing is shown in Figure 13 and provides a “slice” or a partition of radio resources to each service. The slice is shown to the user as a logical network isolated from other slices that shares the same radio infrastructure.

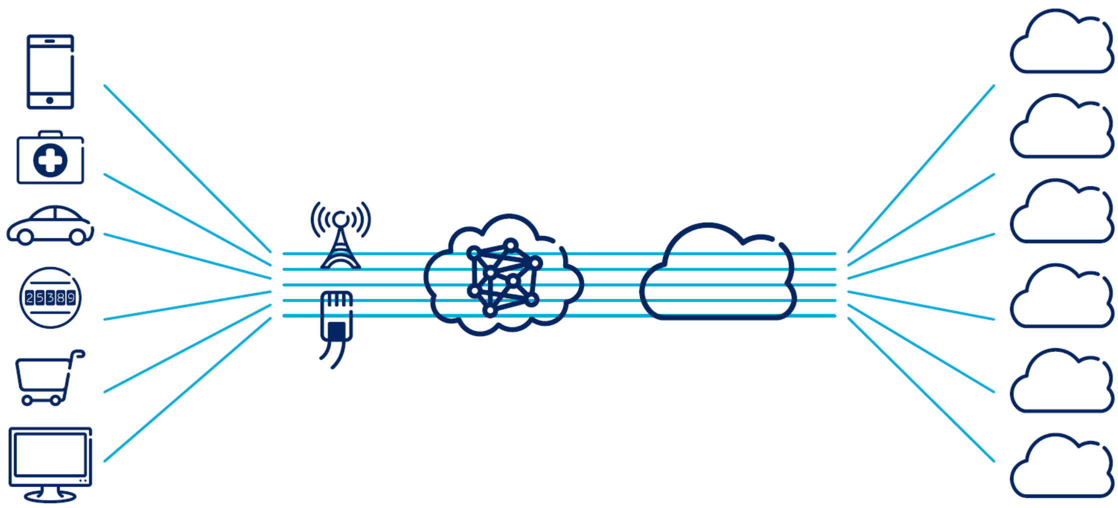


Figure 13. RAN Network slicing.

RAN slicing implementation follows the 3GPP specifications, both in terms of architecture 3GPP TS 28.530 [28] and the information model 3GPP TS 28.540 [29] and 3GPP TS 28.541[30]. Figure 14 shows the management aspects of a RAN slicing service as described in 3GPP.

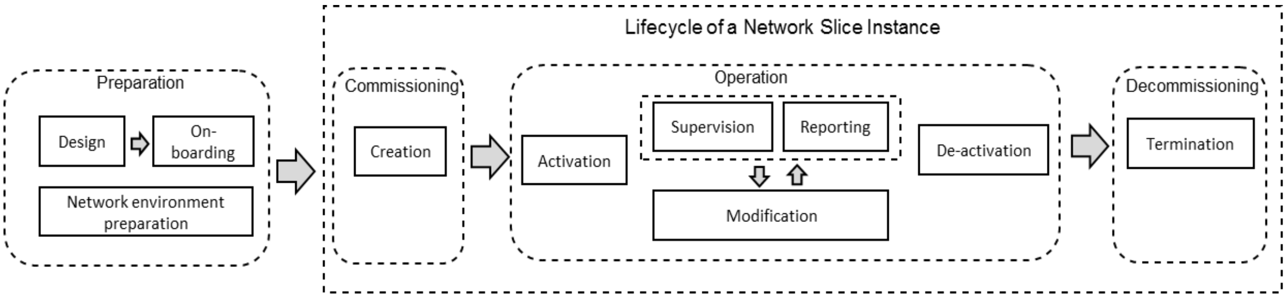


Figure 14. Management of a RAN slicing service.

In order for the network service to be ready to be used inside the EVER orchestrator, an offline preparation phase is required. The preparation phase is formed by a set of descriptor files (json or yaml file). The files are:

- Network Slice Template (NST), that defines the RAN slicing properties. GSMA NG.116 [31] defines the list of parameters that is possible to use.
- Network Service Descriptor (NSD), that describes the logic composition of the service as a Network Function Forwarding Graph (NFFG). The syntax is defined in ETSI MANO IFA 014 [34].
- Network Function Description, that describes the network function composing the NSD that could be virtual or physical (usually refer as VNFD or PNFD). The syntax is defined in ETSI MANO IFA 011 [ref]. A separate file is used for each network function included in the NSD.
- Virtual Link Description (VLD), that describes the connections of NF. The syntax is defined in ETSI MANO IFA 011 [ref] and usually is included inside the NSD file.

Once created on the preparation phase, these files are packaged and onboarded inside the EVER orchestrator. For onboarding, EVER loaded the services packages at bootstrap.

The service package is used by EVER as input to handle instances of the service. Specifically, EVER provides specific REST API to create, activate, modify, deactivate, terminate slice instance of the service.

In the creation process, a new instance is created inside EVER orchestrator with a specific ID. In the activation process, EVER provides the radio resources to the instance satisfying the SLA service requirement (bandwidth, E2E latency, jitter, etc) and creating the slice and its isolation. In the modification process, the created slice can be modified according to certain criteria (not used in the experimentation). In the deactivation process, the radio resources are freed and the slice for the instance is deleted. In the termination phase, the slice instance is deleted inside EVER orchestrator.

Activation and deactivation process are performed using the radio access part of the infrastructure. For such reason, specific plugins have been developed to translate EVER orchestrator commands in the proper radio access configurations. On the radio access domain, Radio Priority mechanisms for the optimization of the Radio Scheduler behavior and fulfilling the QoS requirements of the mobile devices have been introduced by the implementation of the two features “Relative priority and minimum bit rate” and “Advance Subscriber Group Handling” described hereafter.

3.2.1.1 Relative priority and minimum bit rate

As part of the operator-defined profile characteristics, the feature “Relative Priority and minimum bit rate” allows to configure some parameters in term of scheduling algorithm and bit rate. Feature description is detailed hereafter:

Operator defined QCI/5QI

— When a UE needs to set up new bearers at UE initial connection setup, at connection setup for handover, or during connected mode, if one of the requested bearers has associated QCI/5QI profile that is operator-defined, that bearer is only possible to set up with the requested QCI/5QI profile if the following conditions are fulfilled:

- The Operator Defined QCI/5QI feature is operable.
- The requested QCI/5QI value has a corresponding QCI profile configured in the eNodeB/gNodeB.

— Similar conditions apply when a bearer QCI/5QI modification is requested and the new QCI/5QI has a value in the interval 10–255.

Minimum Rate Proportional Fair Scheduler

— The feature allows selecting a preferred scheduling algorithm per QCI in 4G or 5QI in 5G.

— The feature also includes setting a minimum bit rate for QCIs/5QIs that are configured for one of the Proportional Fair scheduling algorithms. The minimum bit rate for Uplink (UL) and Downlink (DL) can be set independently and are configured for each QCI/5QI by the operator.

Relative priority scheduling

— The feature allows the operator to control the bitrate proportions that services using a specific Quality of QCI/5QI would get with respect to services using other QCIs/5Qis.

— The Relative Priority Scheduling feature provides the specified bit rate ratios only when either the radio conditions are ignored (Rate Proportional Fair (PFS) equal rate) or when all User Equipment have similar radio conditions.

— Otherwise, the resulting bit rate proportions will be influenced also by the difference in experienced radio conditions.

3.2.1.2 Advanced Subscriber Group Handling (ASGH)

As a subscriber group is the subset of all RRC Connected UEs in a node, the advanced Subscriber Group Handling framework feature introduces a new framework for operators to define advanced subscriber groups which classify subscribers. Feature description is detailed hereafter:

— A user can only be part of zero or one subscriber groups.

— If a user does not belong to a subscriber group, legacy behavior is maintained.

— A Subscriber Group Profile is the parameterization of a detection criteria as well as the specification of the attributes that are unique to the subscriber group.

— Using advanced subscriber groups means that different system configurations can be applied to them.

— The Advanced Subscriber Group Handling (ASGH) Framework feature introduces a new framework for operators to define advanced subscriber groups which classify subscribers. Using advanced subscriber groups means that different system configurations can be applied to them.

— Trigger to map users onto ASG based on SPID (Subscriber Profile ID) and/or QCI.

— Each Advanced Subscriber Group profile includes four bearer offsets to map the standardized QCI6~QCI9 into the range of operator defined QCIs.

In the implemented design, the differentiation of the users into a specific Group is based on different QCIs and SPIDs that are defined based on the service type. Based on this, the Radio Scheduler is able to serve the different UEs according to their services by means of the features: schedulingAlgorithm, relativePriority and ul/dlMinBitRate.

3.2.2 Integration and tests

The test environment is illustrated in Figure 15. The end-to-end infrastructure based on the 5G EVE NSA node that was installed in TIM premises and consists of two Base Band units: BB6630 for 5G Node and BB5216 for 4G Node (bottom part in Figure 15). Each Base Band unit is connected to the related Antenna System and to the Core Network. The Core Network has then access to the 5G EVE NFV infrastructure running the service application's backends.

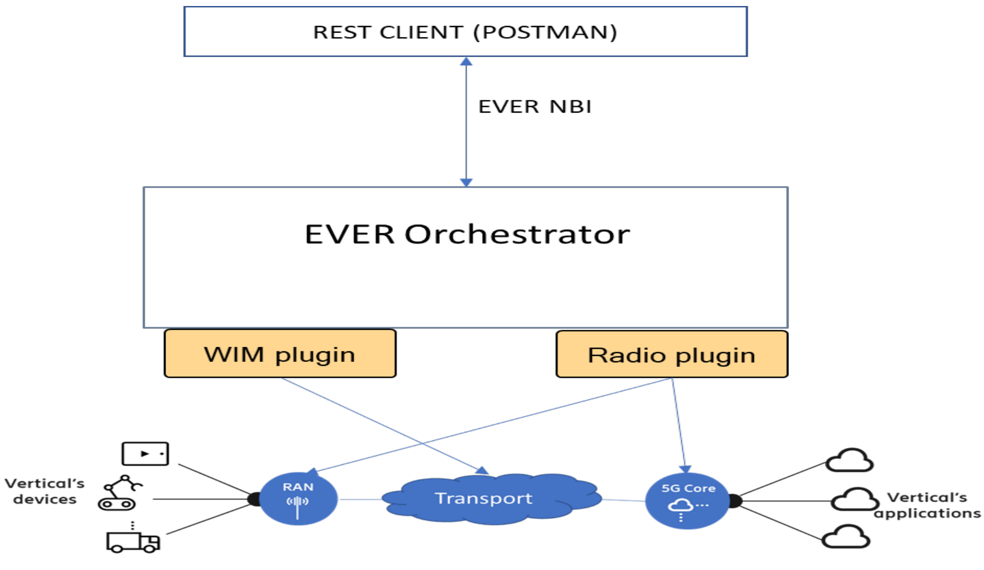


Figure 15. Integration and test environment.

EVER orchestrator runs in a dedicated Linux Virtual Machine and is configured inserting the developed plugin and the reachability information for the infrastructure. Moreover, three service types are created and three service packages are prepared and onboarded on EVER. The services have different types and different SLA:

- **Low_latency service**. It represents a mission critical application compliant to 3GPP URLLC specs.
- **High_traffic service.** It represents a high capacity, high density traffic compliant to 3GPP eMBB specs.
- **High_number service.** It represents an application formed by many devices with low power and low traffic per device compliant to 3GPP mMTC specs.

An open-source Rest Client called PostMan [32] is used to trigger the creation, modification, termination of service instances using the provided REST API made available by EVER orchestrator.

Preliminary tests were successfully performed in which the different services were created, modified and terminated with the allocation of the proper resources on the radio access part. Due to overlaps with the trials activity on filed, it was not possible to perform the tests with mobile devices. Nevertheless, the integrated platform is going to remain available for future activities related to RAN slicing management in the context of research domain.

3.3 Technical validation results (QoS)

As discussed previously, in contrast to what happened with the UCs trialed by other WPs which involved the physical instantiation of different network instances, the WP4 UCs were trialed using the commercial network, that is hence yielding similar performance for all of them. Thus, we take as reference for the latency and bandwidth the ones obtained for UC1. The results are obtained using the Samsung phones available for the visitors.

Throughput

We measured the downlink throughput by capturing the traffic between the UE and the VR Server implementing the UC1a application (i.e., the one allowing people at the museum visiting the artifacts), effectively measuring the bandwidth available in the 5G-EVE infrastructure. While the performance obtained with Iperf tests directly measured at the core network yielded a total downlink bandwidth of 1.2 Gbps, we discuss here the results obtained with the real conditions used for the UCs measured during the download of a 3D asset from the server.

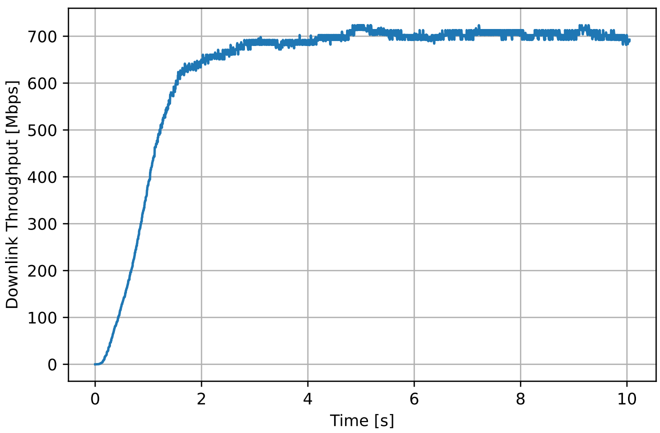


Figure 16. The UC1 downlink throughput.

Figure 16 depicts the achieved results. After the slow start and the additive increase phase, the network can provide a sustained performance of around 700 Mbps that, as we discuss later, is fulfilling the requirements for all the UCs. Leveraging the same infrastructure, we also measured the uplink bandwidth, this time stressing the network through an Iperf. The results are shown in Figure 17.

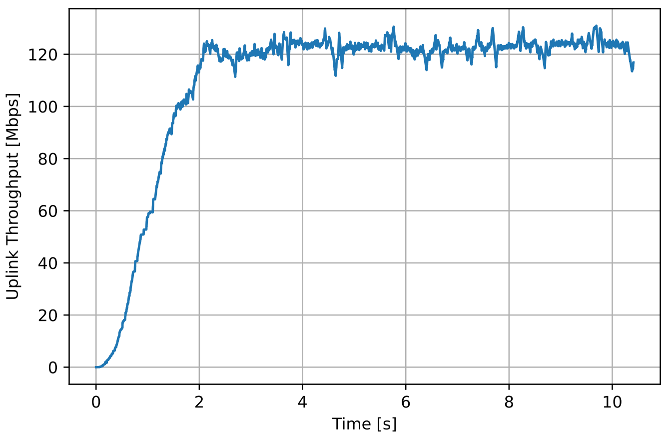


Figure 17. The UC1 uplink throughput.

The network provides uplink throughput of around 120 Mbps, which again, fulfills the requirements of all the UCs. This is also in line with the configuration of the used cells, that are a TDD with a 7-downlink / 2-uplink pattern.

The final reported measurement is the one related to the end-to-end latency, which we measured with ICMP packets with 1000 bytes of payload to mimic a frame size that could be used by e.g., video applications. ICMP packets are sent every 500ms. The timeseries is depicted in Figure 18.

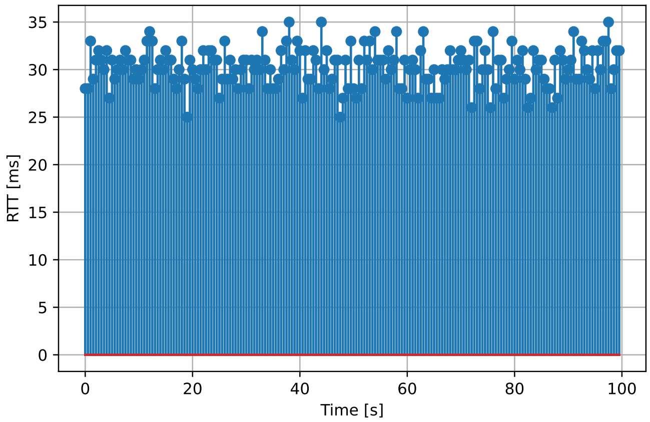


Figure 18. The UC1 latency.

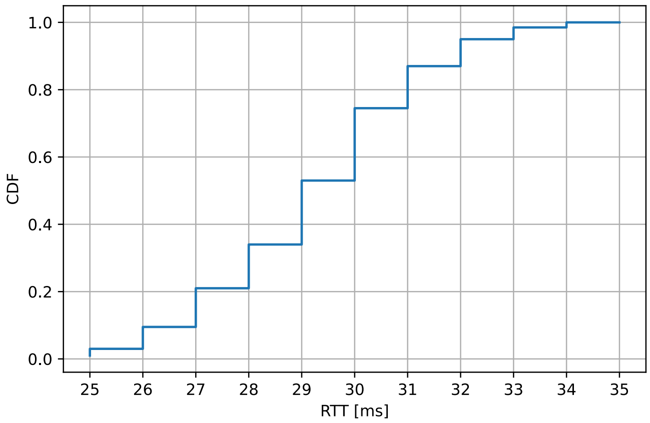


Figure 19. The UC1 latency CDF.

The RTT latency towards the 5G-EVE infrastructure is averaging around 30ms (30.2ms in the period) and, during the 100s run, the RTT never exceeds 35ms (Figure 19). In the following Table 6, we summarize the obtained KPIs, analyzing them UC by UC.

Table 6. KPI Summary.

KPI	UC1	UC2	UC3	UC4	UC5
RTT Latency [ms]	20 (URLLC) 100 (eMBB)	50-100	30-35	10	10 (URLLC) 50 (eMBB)
RAN Latency [ms]	10	10	12.5	5	N/A
Throughput [Mbps]	40-600Mbps	30Mbps	40Mbps	25Mbps	180 Mbps

Reliability/ Availability	99.999%	99.999%	99.999%	99.999%	99.999%

The Throughput requirements are always fulfilled by the network, even in the most extreme case (actually, the measures are obtained from the UC1 campaign). Most of these considerations apply for the RTT latency, which is enough to support the eMBB services. For other cases (e.g., the Augmented Reality part of UC1 and UC4/5), the measured results are slightly above the one obtained in our measurement campaign. This is reflected by some impairments in the AR part of UC1 (see D4.4 [3]), while for the UC4, the latency part is less relevant as the broadcast network was used. Also, UC5 was not onboarded on the 5G EVE infrastructure, and the latency obtained was enough to support the services. Finally, we did not experience any issues related to reliability and availability, as we could perform all our UCs without any interruption. In the next subsection, we analyze the QoE assessment UC by UC, studying the responses obtained by the questionnaires.

3.4 User satisfaction results (QoE)

As discussed in D7.1, in 5G-TOURS we assess the Quality of Experience through questionnaires. For the touristic city, we collected more than 400 questionnaires from the people involved in the UCs, getting valuable feedback from the end user on both the applications and the quality of the network. In the following, we discuss the results obtained from the UCs.

3.4.1 UC1

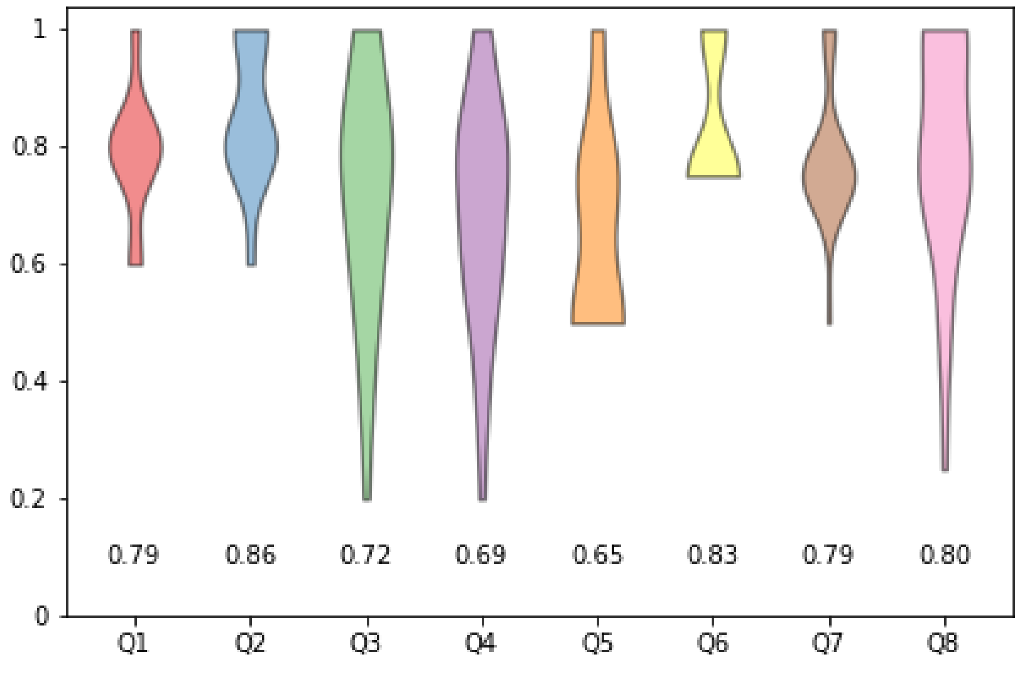


Figure 20. QoE for the UC1a.

Figure 20 above shows the distribution of the answers to the questionnaires for the UC1a, the application. As some of them had a score from 1 to 4 and other from 1 to 5, here and in the following we discuss the normalized marks between 0 and 1. In the bottom row of each figure, we show the average grade obtained by the questions.

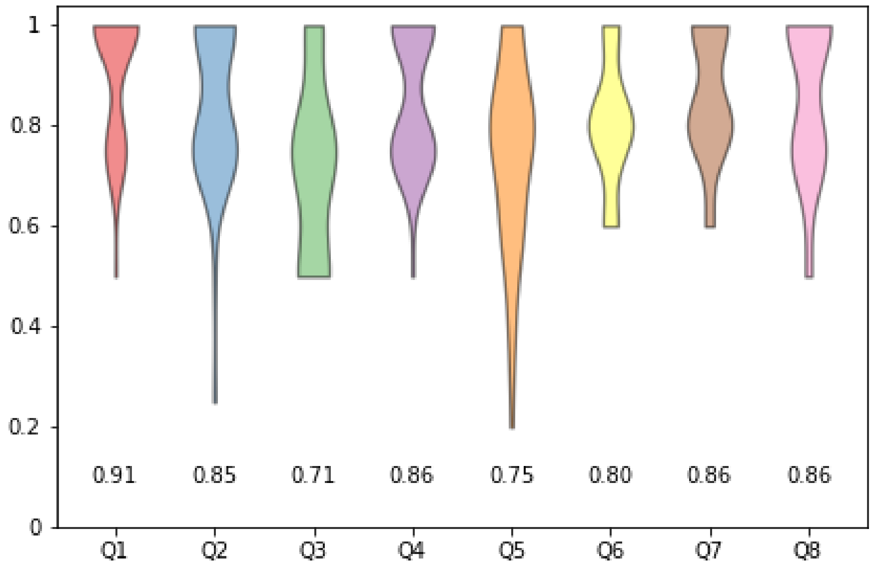


Figure 21. QoE for the UC1b.

Figure 21 above shows the QoE results for the UC1b, involving the VR. We can see that most of the questions that were asked obtained a score above 80% of the highest mark, corroborating the fact that the 5G Network deployed in the museum could provide sustainable performance.

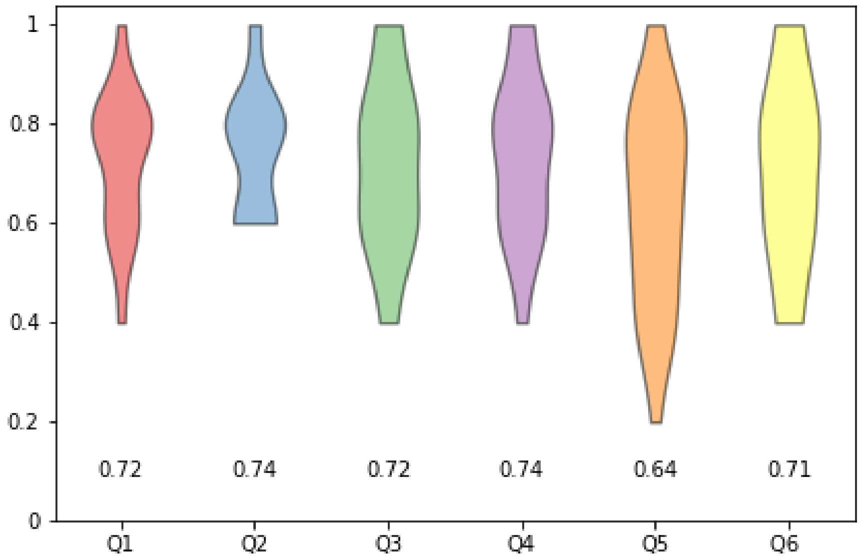


Figure 22. QoE for the UC1c.

Similar consideration applies for the UC1c (the interactive wall), with a slightly lower achievement in each of the questions.

3.4.2 UC2

For UC2 we collected questionnaires for two different cohorts of participant: adults at the museum, that are visiting the basement using the robot, and children remotely piloting the robots from EduLab. Results are depicted below (Figure 23 and Figure 24).

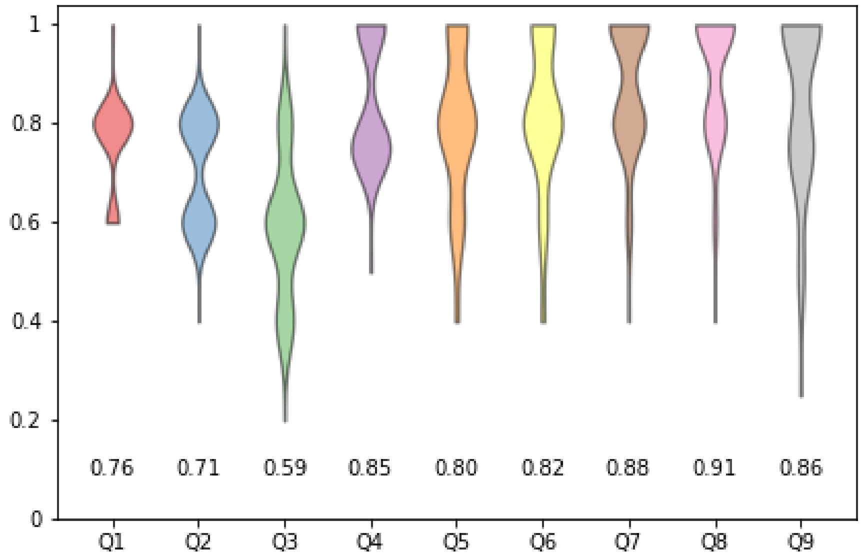


Figure 23. QoE for UC2, adults.

While almost all the questions obtain very high scores, Q3 (the one that measures the willingness to pay), just score a 0.59 in average, showing how a non-negligible share of the users are not convinced about the service with an additional fee.

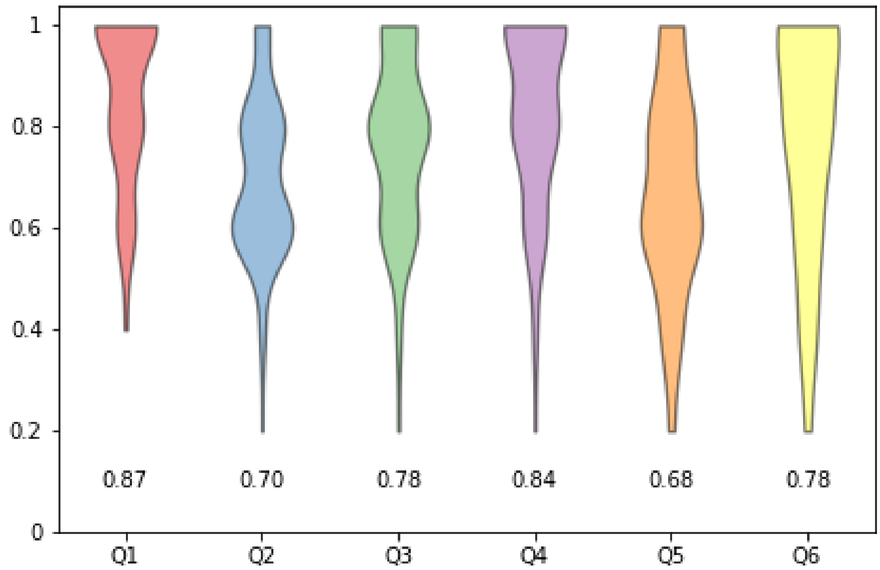


Figure 24. QoE for UC2, children.

We provided a simplified version of the questionnaires for children (Figure 24), were aspects such as the willingness to pay are omitted. Also, in this case the users show how the 5G network can support the needed quality of experience for the UC.

3.4.3 UC3

The UC3 involved the robot R1 obtained and got feedback from more than 100 people during the showcases performed in GAM and Palazzo Madama. The results are depicted in Figure 25.

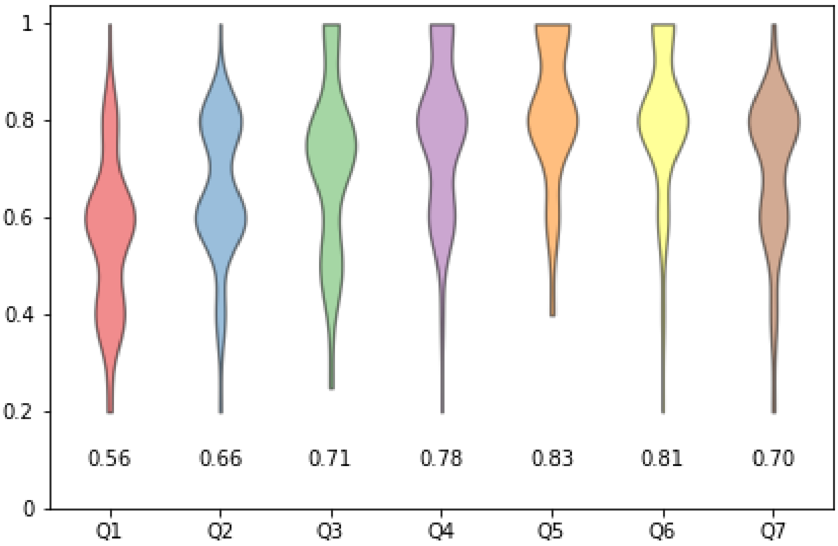


Figure 25. QoE results for UC3.

The only question that shows results that are a bit below the rest is Q1, that is related to the fluidness of the experience. However, this aspect is affected by several factors that go beyond the pure network performance, that range from the ability of the final user to some technical limitation of the robot itself.

3.4.4 UC5

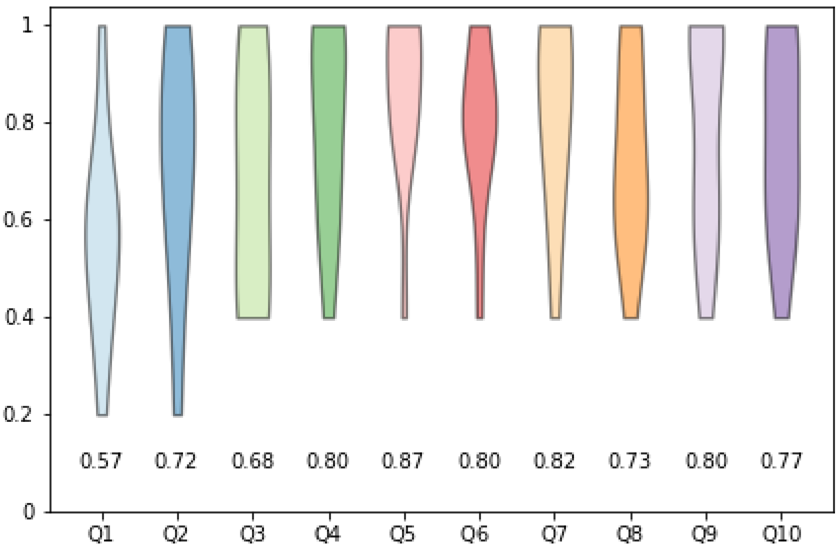


Figure 26. QoE results for UC5.

UC5 has been the first one being showcased, in 2021. Hence, due to the restrictions that were applied back then, we had a lower number of answers for our questionnaires. Results are depicted in Figure 26. In spite of the reduced number of answers, the quality of the 5G coverage and the application has been appreciated by the user. The only value that is below excellence is the first one, related to the video production, thus more on the application per-se rather than the network coverage, that has been positively evaluated.

3.5 Results from application of QoE/QoS approach

To apply our proposed QoE evaluation methodology for all the use cases of the project needs a lot of effort, additional testing tools and testing procedures. That is why it was decided to apply the developed approach only to one use case in which it was possible to collect all the required data. Thus, UC4 “High quality video service distribution” was under study to ensure the applicability of the developed approach. All the experiments were conducted in Turin, in a specially equipped car, which was moving with regular speed. During the trials, QoE and QoS data were collected for further analysis. The routes of the vehicle are shown in Figure 27. There were 18 different locations for the data collection. For each location, the following values were collected: Video OK level, Location, Frequency band, Speed of the vehicle, Date, Time, Signal Power. The Video OK level was considered as a binary QoE parameter and is the result of the observations of just one person:

$$Video\ OK\ level = \begin{cases} 0, & video\ errors\ visibility\ and\ /\ or\ audio\ impairments, \\ 1, & no\ video\ errors\ visibility\ and\ /\ or\ audio\ impairments. \end{cases}$$

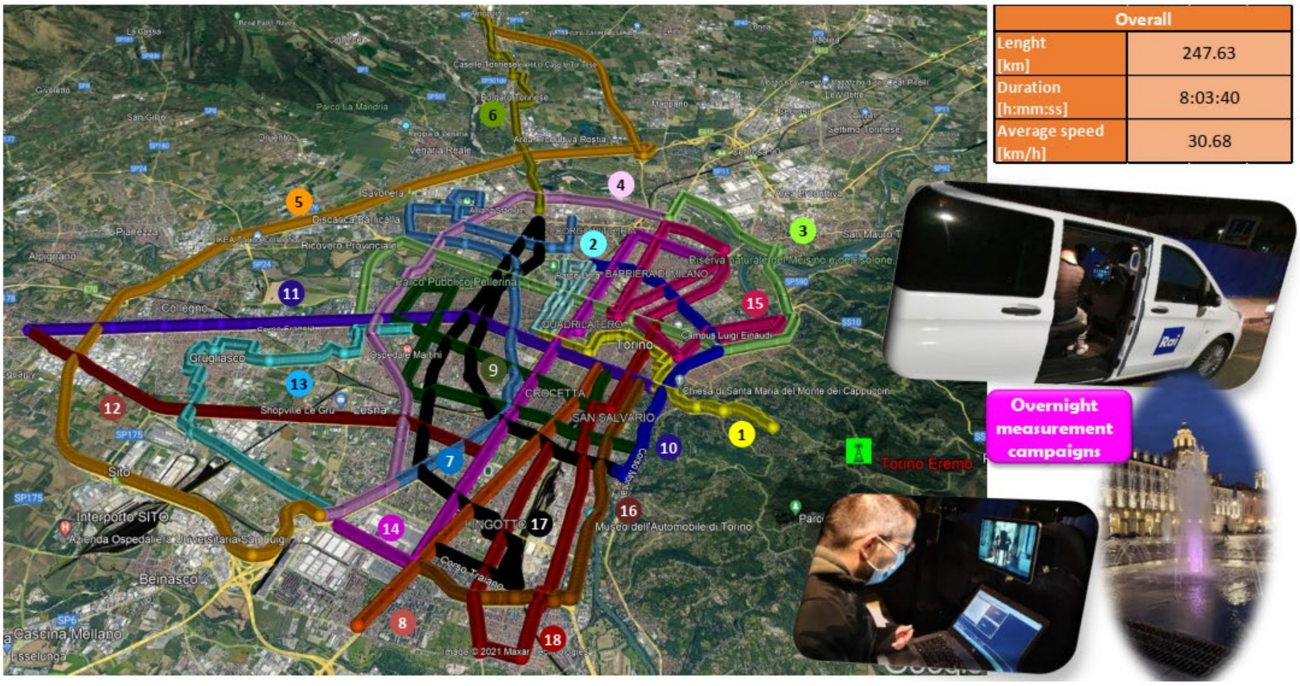


Figure 27. Torino’s 5G subway – the routes.

The analysis started for the location “Colina Cavalli”. Parameters for this location are presented in Table 20 below.

Route 1	
5G profile	BW=5MHz, MCS12, SCS=2.5kHz, CAS Rel. 16
Lenght [km]	6.82
Duration	0:26:03
Average speed [km/h]	16
Type	Urban
File name	01_Collina_Cavalli

Figure 28. “Colina Cavalli” parameters.

During the data analysis, the next KPIs were considered: Power [dBm] and Approx. speed [Km/h]. Graphical representation of conducted measurements of Signal Power [dBm], Video Ok level [0;1], and Speed [Km/h] is shown in Figure 29.

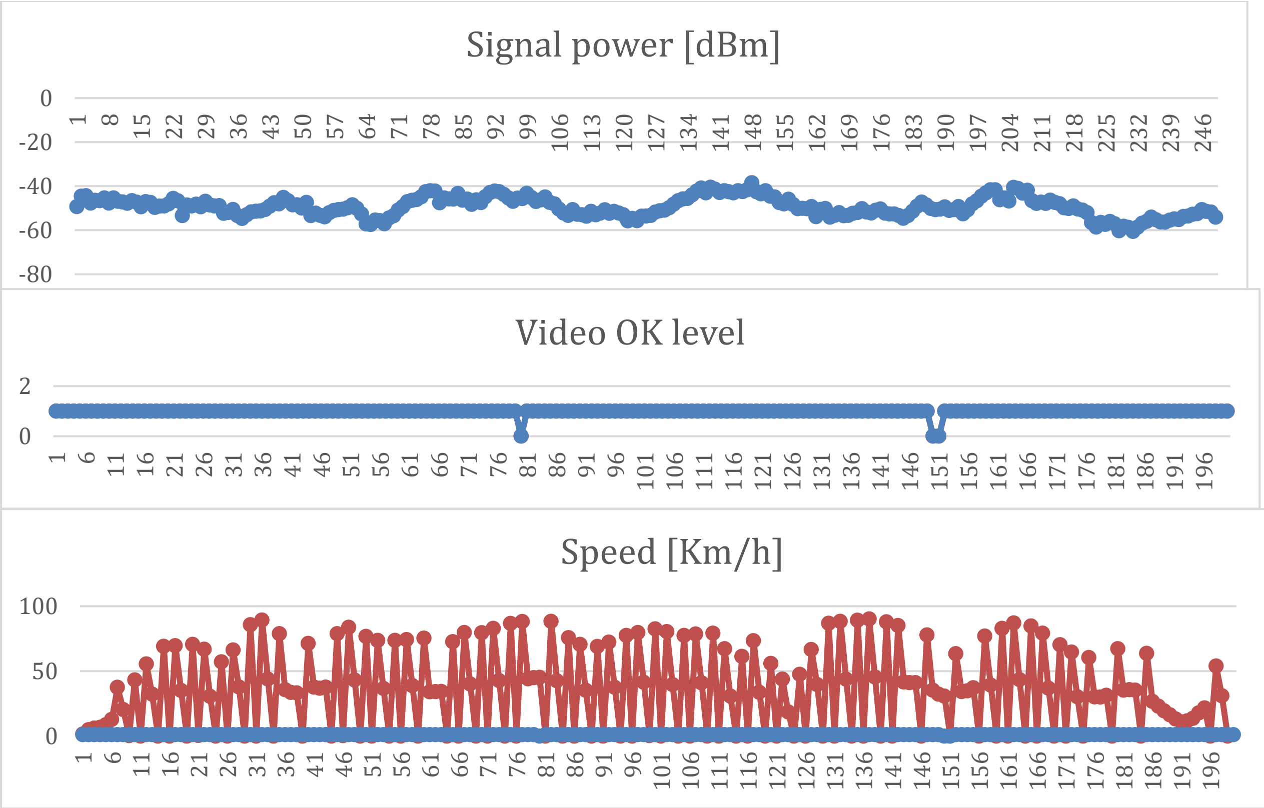


Figure 29. Graphical representation of conducted measurements.

The correlation coefficients were estimated for each the considered parameter:

- For Signal Power [dBm]: Correl[FS] = 0,201735

- For Approx. speed [Km/h]: Correl[S] = -0,02378

According to the received values, the conclusion was that the strength of the relationship by the correlation coefficient is quite low. Figure 30 and Figure 31 prove this. There is no visible correlation between studied variables.

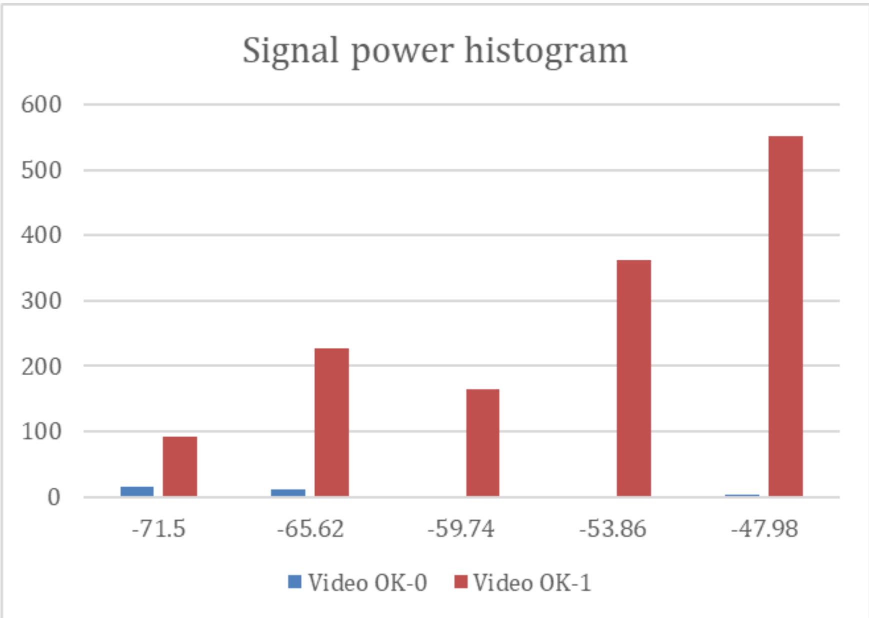


Figure 30. Signal power histogram for Vide Ok level.

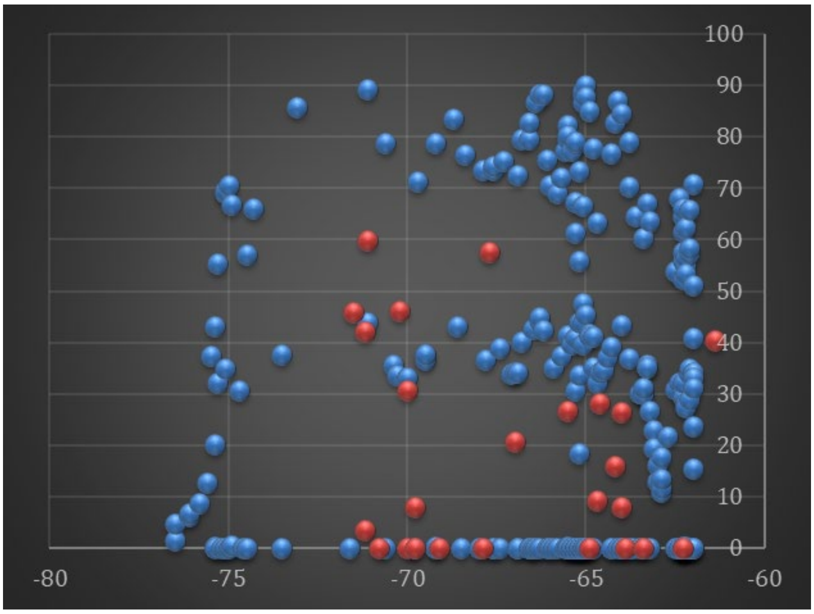


Figure 31. Video Ok level (“1” – blue; “0” – red) representation depending on Signal power [dBm] and Speed [Km/h].

Thus, data analysis allowed to determine that there are no clear dependencies between QoE (Video Ok level) and Signal power [dBm] and Speed [Km/h] for the first location “Colina Cavalli”. This can be explained by the characteristics of the environment in which the trial was realised: inside city with tall buildings and long durations with non-line-of-sight communication between the moving UEs and the cells. That is why, according to the results of experimental measurements, it was not possible to develop any mathematical model of QoE and QoS mapping for this UC. After this, was decided to estimate correlation coefficients between Video OK level and Signal Power [dBm] for the other locations. These values are represented in Table 7 and Figure 32 accordingly.

Table 7. Correlation coefficients for different locations.

Location	Correlation coefficient
101_Collina_Cavalli	0,201735
102_Cavalli_Cavalli	0,518915537
103_Marche_Derna	0,258327277
104_Oxilia_Reni	0,361996861
105_Tangenziale_Caselle	0,550029228
106_Caselle_Borgaro_Torino	0,466348575
107_Casteldelfino_Orbassano	0,184980435
108_Unione_Sacchi	0,359804918
109_Nizza_Dante	0,410781062
110_Zara_Baldissera	0,650058881
111_Vittorio_Francia	0,061480642
112_Allamano_Sebastopoli	0,09455433
113_Grugliasco_Portone	0,317073055
114_Settembrini_Sempione	0,517934714
115_Botticelli_Antonelli	0,416661055
116_Massimo_Vigliani	0,626251366
117_Traiano_Zara	0,395813642
118_Bruno_PioVII	0,477388663

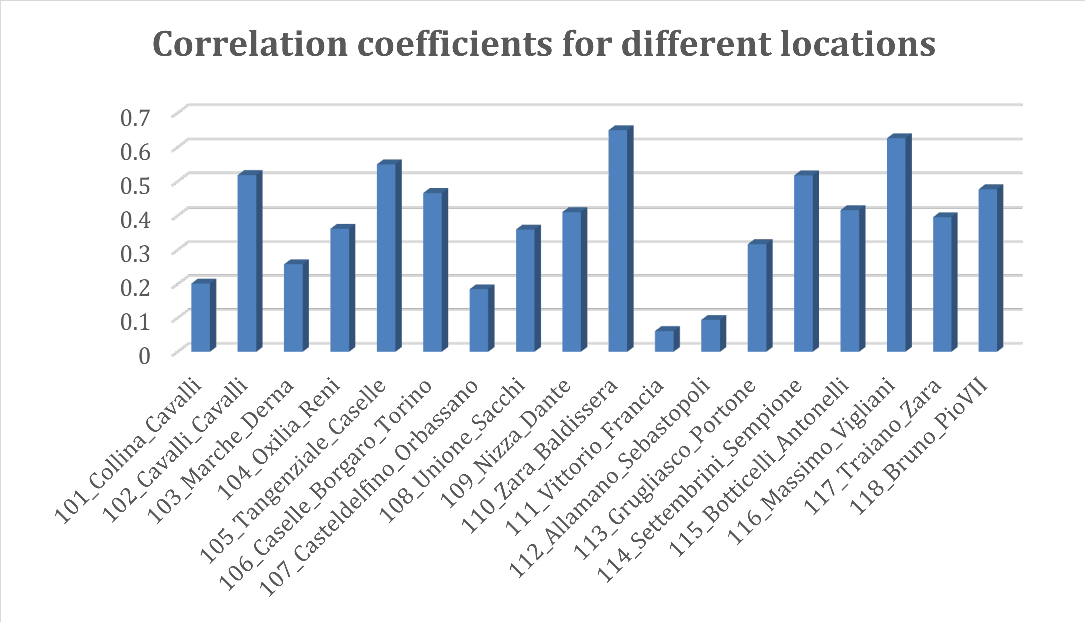


Figure 32. Graphical representation of correlation coefficients for different locations.

As it is obvious from the Table 7 and Figure 32, the most powerful dependence is for the location Zara Baldissera. That is why it was decided to apply the data analysis especially for this location. Results are presented below.

Route 10	
5G profile	BW=5MHz, MCS12, SCS=2.5kHz, CAS Rel. 16
Lenght [km]	8.02
Duration	0:14:51
Average speed [km/h]	32
Type	Urban
File name	10_Zara_Baldissera

Figure 33. Location: Zara Baldissera

During the data analysis, the following KPIs were considered: Power [dBm] and Approx. speed [Km/h]. Graphical representation of conducted measurements of Signal Power [dBm], Video Ok level [0;1], and Speed [Km/h] is shown in Figure 34.

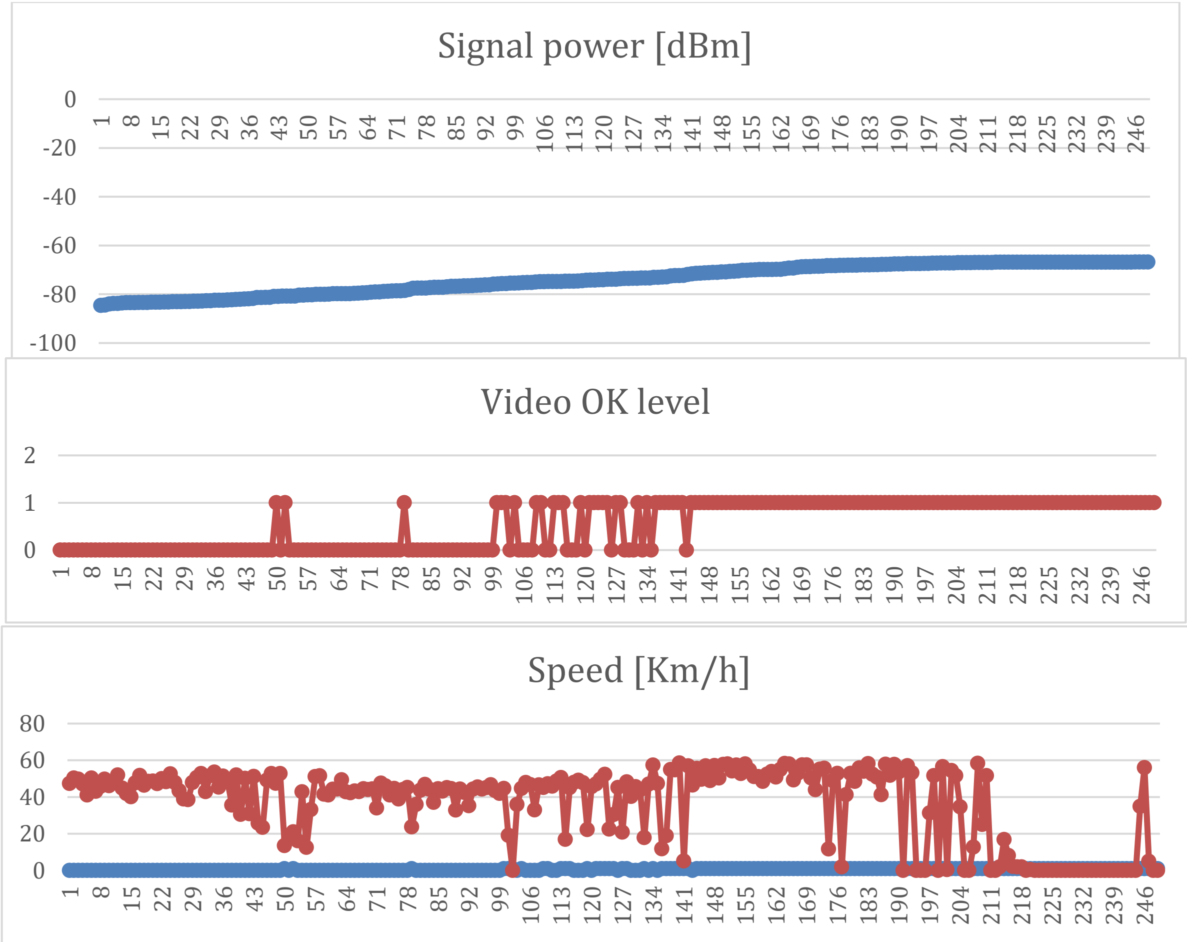


Figure 34. Graphical representation of conducted measurements.

The correlation coefficients were estimated for each of the considered parameter:

- For Signal Power [dBm]: Correl[FS] = 0,65 (0,84 – for first 250 values in the structured dataset)

- For Approx. speed [Km/h]: Correl[S] = -0,19

According to the received values, the conclusion was that the strength of the relationship by the correlation coefficient is quite high. Figure 34 proves this. There is no visible correlation between studied variables.

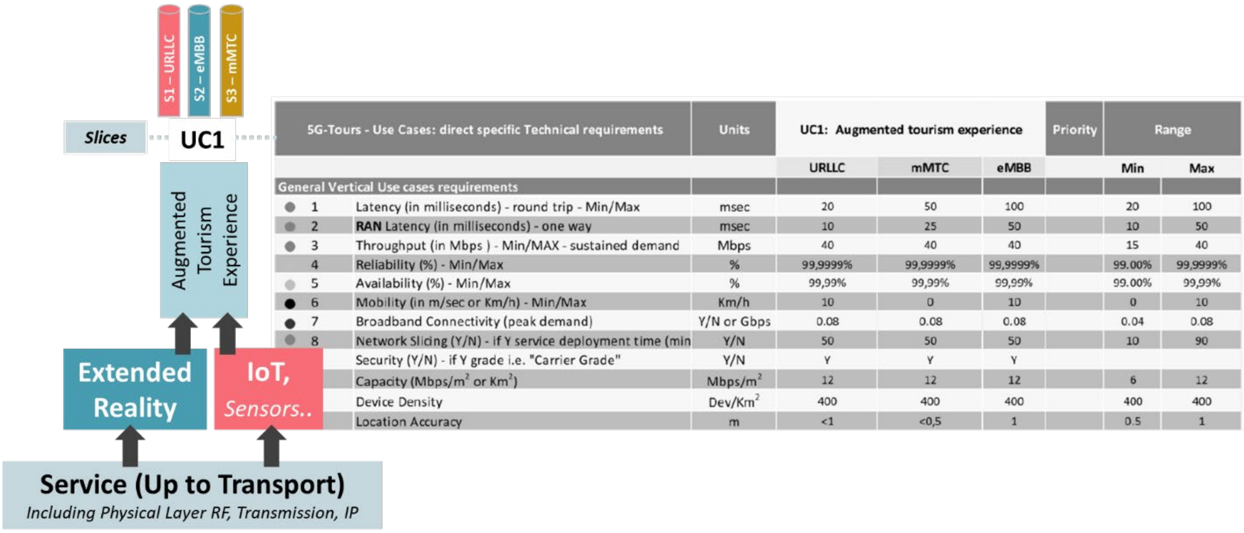
Thus, for this case, data analysis allowed to determine that there is a dependency between QoE (Video Ok level) and Signal power [dBm], but not with Speed [Km/h]. For this case, can be used a threshold of Signal Power [dBm] – Psignal_tresh= – 73 dBm can be used. That is why QoE function can be represented as a binary function in the following way:

$$QoE\_VideoOK\_level(P_{signal}) = \begin{cases} 1, & P_{signal} > -73[dBm], \\ 0, & P_{signal} \le -73[dBm]. \end{cases}$$

In a Gaussian channel for MCS 12, we can expect a threshold of about -84 dBm. On mobile channel, there is a loss of about 10-12 dB. Hence, in the condition we carried out the test, an estimated threshold of -73 dBm sounds correct.

3.5.1 Specific results analysis of UC1 Relative-QoE in a large-scale network

UC1, the augmented tourism experience use case, consists of 3 distinct slices, each one with different technical requirements as illustrated in Figure 35.



#	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
	Security (Y/N) - if Y grade i.e. "Carrier Grade"	Y/N	Y	Y	Y			
	Capacity (Mbps/m^2 or Km^2)	Mbps/m^2	12	12	12		6	12
	Device Density	Dev/Km^2	400	400	400		400	400
	Location Accuracy	m	<1	<0,5	1		0.5	1

Figure 35. UC1 Slices and Requirements.

The initial QoE analysis is generic, focusing only on the latency increase with respect to the criticality of each slice versus different constant retransmission rate patterns. Required latencies can be summarized by the following:

- S1, 20ms E2E Latency
- S2, 100ms E2E Latency
- S3, 50ms E2E Latency

The table in Figure 36 represents the selected Latency thresholds for every slice to be used in the analysis. Excellent thresholds were set to meet the E2E defined requirements.

Slice	Bad	Poor	Fair	Good	Excellent
	[1 – 3.5]	]3.5 – 5.5]	]5.5 – 7]	]7 – 8.5]	]8.5 – 10]
S1 RTT	]60-50[	[50-40[	[40-30[	[30-20[	[20-0]
S3 RTT	]150-125[	[125-100[	[100-75[	[75-50[	[50-0]
S2 RTT	]300-250[	[250-200[	[200-150[	[150-100[	[100-0]

Figure 36. UC1 Slices QoE Score Ranges vs. Latency (ms) Thresholds.

The graphs in Figure 37 summarize the results of the analysis made for the 3 slices with respect to each other's and at 4 different retransmission rates: 0%, 0.35%, 0.85% and 1.5%. S1 QoE score values drop faster with the latency increase, since the service is much more sensitive to any delay increase comparing to S2 and S3. Also, the increase in retransmission rate is clearly affecting the QoE scores and causes shifting to lower QoE grades even at low latency values. For example, S1 cannot operate with 1.5% ReTx rate, since the QoE value drops directly to the poor QoE category, even at low latency figures.

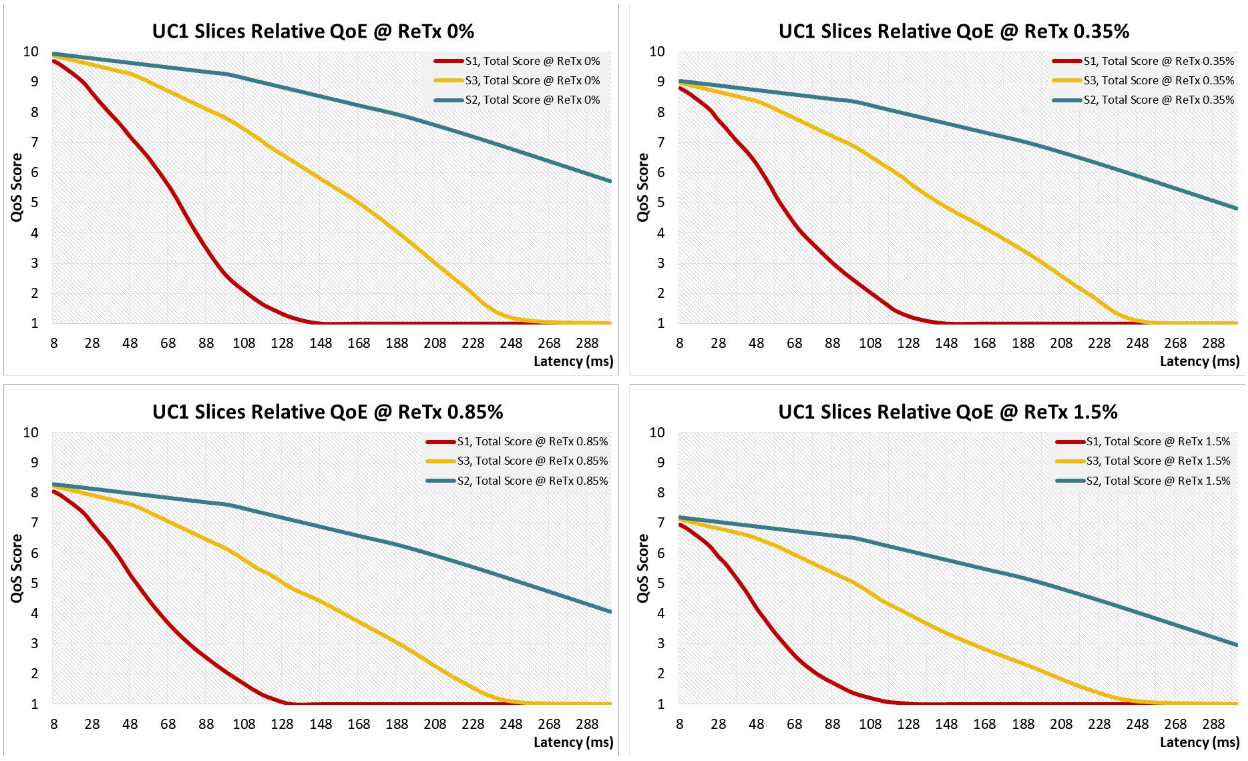


Figure 37. UC1 Slices QoE Scores variation with Latency increase and at different constant Retransmission Rates.

Note that, in the above analysis, the range of thresholds for the retransmission rate was fixed for all slices, which means that the impact of ReTx variation was considered the same for S1, S2 and S3.

To provide better reliable and practical QoE analysis, the second study was performed using particular variable thresholds for both latency and retransmission. Different ReTx sets were defined reflecting the severity of the slice aligned with the latency E2E requirements as illustrated in Figure 38.

Slice	Bad	Poor	Fair	Good	Excellent
	[1 – 3.5]	]3.5 – 5.5]	]5.5 – 7]	]7 – 8.5]	]8.5 – 10]
S1 ReTx	]0.45-0.40[	[0.40-0.35[	[0.35-0.30[	[0.30-0.25[	[0.25-0]
S3 ReTx	]0.55-0.50[	[0.50-0.45[	[0.45-0.40[	[0.40-0.35[	[0.35-0]
S2 ReTx	]0.65-0.60[	[0.60-0.55[	[0.55-0.50[	[0.50-0.45[	[0.45-0]

Figure 38. UC1 Slices QoE Score Ranges vs. Retransmission Rate (%) Thresholds.

Figure 39 demonstrates the achieved results with the curves showing different slopes. They started at high QoE scores resulting from excellent RTT and ReTx values, then they started dropping sharply with the deterioration of both KQIs. S2 and S3 have better tolerance and can accommodate traffic at relatively lower values in their service paths while maintaining higher relative QoE scores.

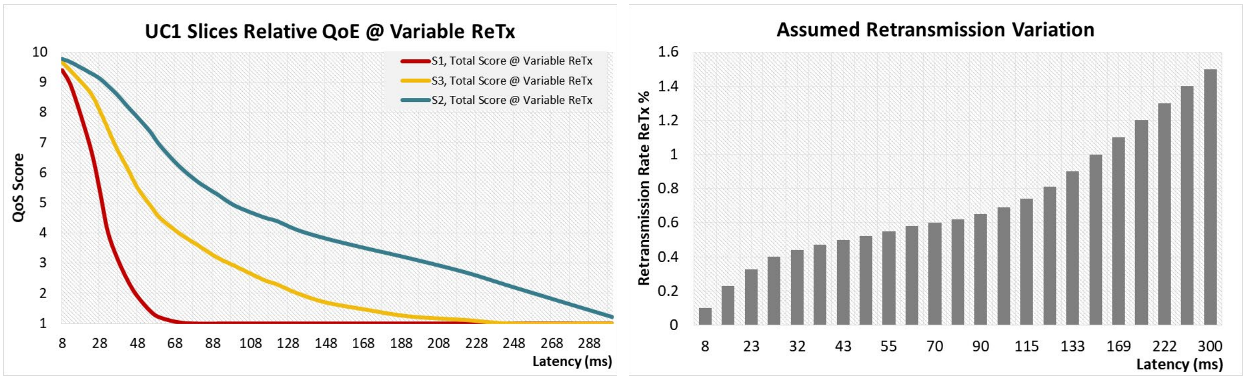


Figure 39. UC1 Slices QoE Scores variation with Latency at variable Retransmission Rate.

In wireless networks, the quality of the coverage is the main reason behind increased delay and packed loss. The distance from the base station, capacity at the busy period, signal to noise ratio, and interference affect directly the QoE score. In addition, the transport capacity and reliability, routers and switches performance, and packet core capacity will also impact QoE results when either saturation exists or if traffic is passing through interfaces with limited processing capability. Also, latency can be influenced by other network devices like application load balancers, security devices and firewalls. Sometimes, the end-user device itself with low memory and limited CPU cycles can cause high RTT being unable to respond in a reasonable timeframe. Obviously, malfunctioning hardware, software bugs, applications servers' performance and specific internet routes can contribute to the deterioration of the service experience.

4 Safe city integrated ecosystem, trials, and validation

4.1 General description

The wellbeing and healthcare use cases of 5G technology are covered by a part of 5G-TOURS project called Safe-city, elaborated in work package 5 (WP5).

Particularly, during the COVID-19 epidemic, it was imperative to be able to analyse patients' health status in real time, independently of their location. Traditional health care, relying on clinic visits, is becoming increasingly expensive as a result of unfavourable demographic trends associated with aging populations in many countries and an associated upward trend in chronic diseases affecting seniors.

It is worth noting that the bottleneck of many medical procedures is diagnostics, consuming time and healthcare resources. Additionally, the COVID-19 pandemic has contributed to health care overload. One of the most promising methods to overcome resource shortages is to move diagnostics from the clinic to the patient's home, analyse the results of these tests, and make them available to medical staff.

The following UCs are being developed under WP5:

- 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 detailed description of the above use cases, their requirements and the network infrastructure used by them is given in D5.4.

Use cases in the "Safe City" work package (WP5) were trialled in 2 locations:

1. **Rennes**, using the mobile network infrastructure of Orange and Nokia at BCOM's and CHU premises. This is applicable to use cases 7 and 8.

2. **Athens**, using the mobile network infrastructure deployed in the WP6 at OTE premises. This location hosted use cases 6 and 9.

4.2 Integrated ecosystem

The "Safe City" use-cases were trialled in two locations: Rennes and Athens.

The first location is supporting UC7 ("Teleguidance for diagnostics and intervention support, focused on emergency care"); and UC8 ("Wireless operating room"), thanks to the mobile network infrastructure of Orange and Nokia at BCOM's and CHU premises.

The second one hosted UC6 ("Health monitoring and incident-driven communications prioritization") and UC9 ("Optimal ambulance routing"), using the mobile network infrastructure deployed by WP6 at OTE premises.

UC7 and UC8 have used URRLC features of 5G infrastructure, being their main requirement is low latency in the testbed.

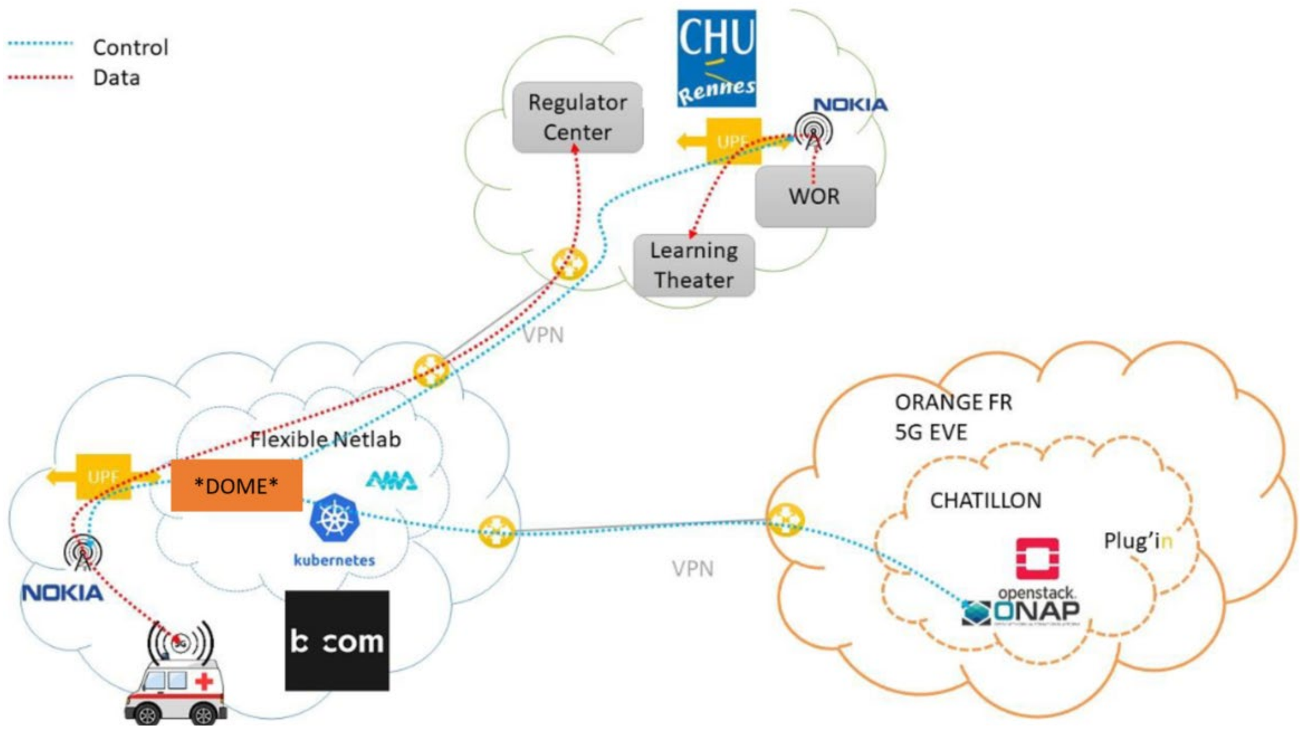


Figure 40. Overall network architecture and physical deployment of network equipment and functions in Rennes location.

The overall network architecture consists of three datacentres as shown in the Figure 40. At the top, it is CHU localization in Rennes; on the left-hand side, the BCOM datacentre in Rennes; and on the right-hand side, the Orange datacentre in Chatillon. In the cloud, the ONAP orchestrator is deployed on a k8s cluster. The Orange datacentre in Chatillon had already been connected to the BCOM datacentre in the scope of the 5G EVE project using VPNs. Connections between the other clouds were established in 5G-TOURS project.

In the sequel, we describe the 5G RAN equipment, user plane and control plane in Rennes.

RAN equipment in Rennes

Nokia devices are used as the basic RAN equipment for 5G-TOURS. The Nokia 5G NR antenna has been installed on the roof of the BCOM building, using primarily the 26 GHz frequency band for data transmission and 2.6 GHz as the anchor frequency band. This deployment covers the outside area for UC7. Moreover, Nokia devices are used indoor at the Wireless Operating Room at CHU Rennes for UC8. They provide high-speed, low-latency wireless access for medical imaging equipment, using 26 GHz for data transmission and 2.6 GHz as the anchor frequency band. In a real operating room, i.e.: ThérA-image room for experimental activities as well as surgery with real patients, Nokia RAN and 4G/5G antennas have been deployed.

Two uses cases can be supported by E2E 5G NSA network. During 5G-TOURS project, successful tests were performed with the NOKIA 5G RAN using the required frequencies (n257 band for 5G and B38/41 band for 4G, which are allowed by the French regulator (ARCEP)) with the BCOM DOME core network.

The same type of BBU (Base Band Unit) on each site is connected to one Core network deployed in BCOM datacentre.

An android smartphone connects the medical devices (i.e.: ultrasound probes from Philips) with the CPE Askey. The RAN solution, composed by RRH (Remote Radio Head) and BBU, is depicted in Figure 41.

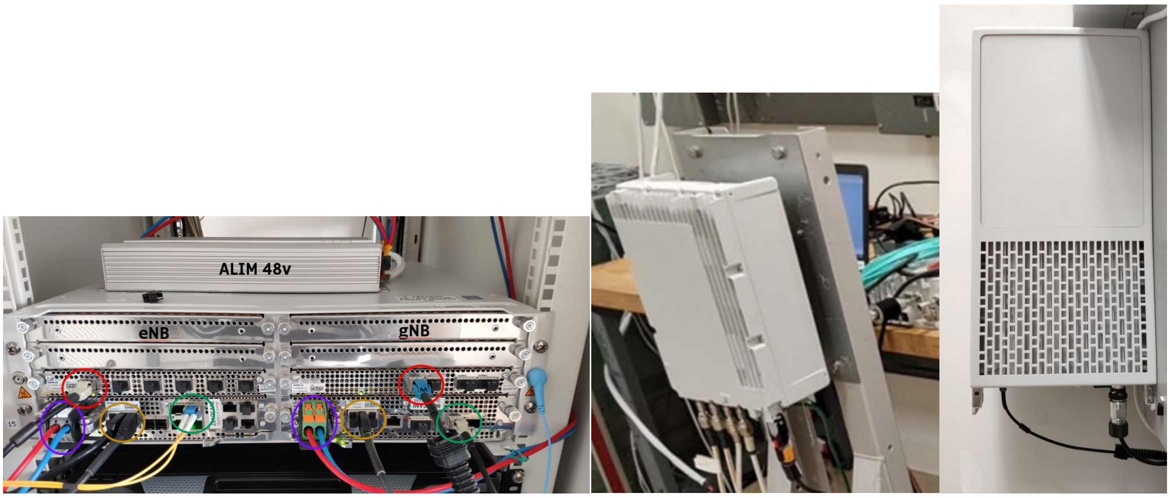


Figure 41. BBU, RRH 4G and RRH 5G used for the experimentations.

Figure 42 shows the installation of the 5G antenna inside the operating room.

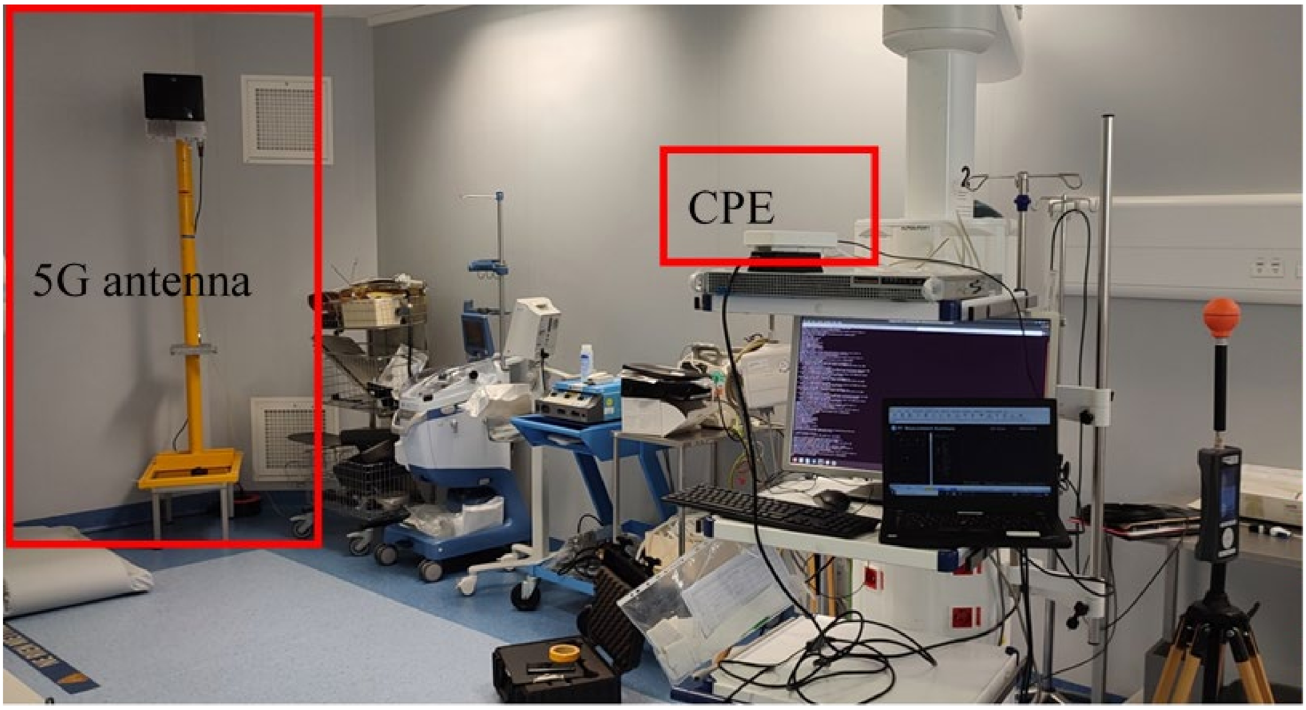


Figure 42. 5G Antenna and CPE deployed in the ThérA-image room in Rennes hospital.

User plane in Rennes

The user plane equipment provides connectivity between the RAN equipment and the data network (Internet). The user plane in Rennes includes two instances of UPF of the DOME provided by BCOM.

The first instance is a VNF deployed in BCOM data centre as virtual machine hosted on an Openstack cluster provided by Flexible Netlab. It is a OVS virtual switch – tunnel endpoint for GTP tunnels coming from the RAN equipment for UC7. At the BCOM premises, the 5G base station with a local virtual UPF, part of the so-called "DOME", has been integrated for UC7.

The second one is a PNF – a device built from a COTS network switch and COTS 1U server. It is installed in the technical room of the Rennes CHU and interconnects the RAN equipment with various tools required by UC8. This DOME UPF is connected to the DOME core network hosted in the BCOM datacentre through a dedicated VPN backbone. This is shown in Figure 42. This enables 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.

Control plane in Rennes

UC7 and UC8 are supported by the DOME Core Network deployed in BCOM datacentre. It manages the DOME UPF at the hospital to connect the 5G terminals of the Wireless Operating Room. Besides, it supports control plane also for "Teleguidance for diagnostics and intervention support, focused on emergency care" use case.

Orange provides the ONAP (Open Network Automation Platform) orchestrator in their Châtillon datacentre as part of their 5G EVE infrastructure. Users are able to orchestrate DOME Core Network as CNF in the BCOM k8s cluster and configure it on demand. ONAP is an open-source solution that gives the comprehension platform for real-time, policy-driven service-orchestration. ONAP orchestrates successfully the 5G core WEF2.2 as well as the newest DOME (WEF 5.0) as CNF. From ONAP perspective, there is no difference in orchestration of both core network: the same type "dummy heat" is chosen. Both are treated as one VNF module – one helm chart (delivered by BCOM) is used for deployment entire network. The difference is in the onboarding package created by ORA-PL for ONAP to know how it should deploy helm charts in k8s cluster in the BCOM data center. These differences are related with the helm charts for DOME and the configuration of some parameters. The configuration of CNF during instantiation process by overriding some parameters' values are done in the same way. Special profile mapping is declared in onboarding package in CBA file and appropriate values are defined in the file outside the package in vnf_parameters.yaml. Thanks to this, the user is able to customized the 5G core instance on demand during instantiation process without changing the entire onboarding package.

The architecture of ONAP integration with 5G-EVE Interworking layer by Translation component (NS-Instance server) is shown in Figure 43 below.

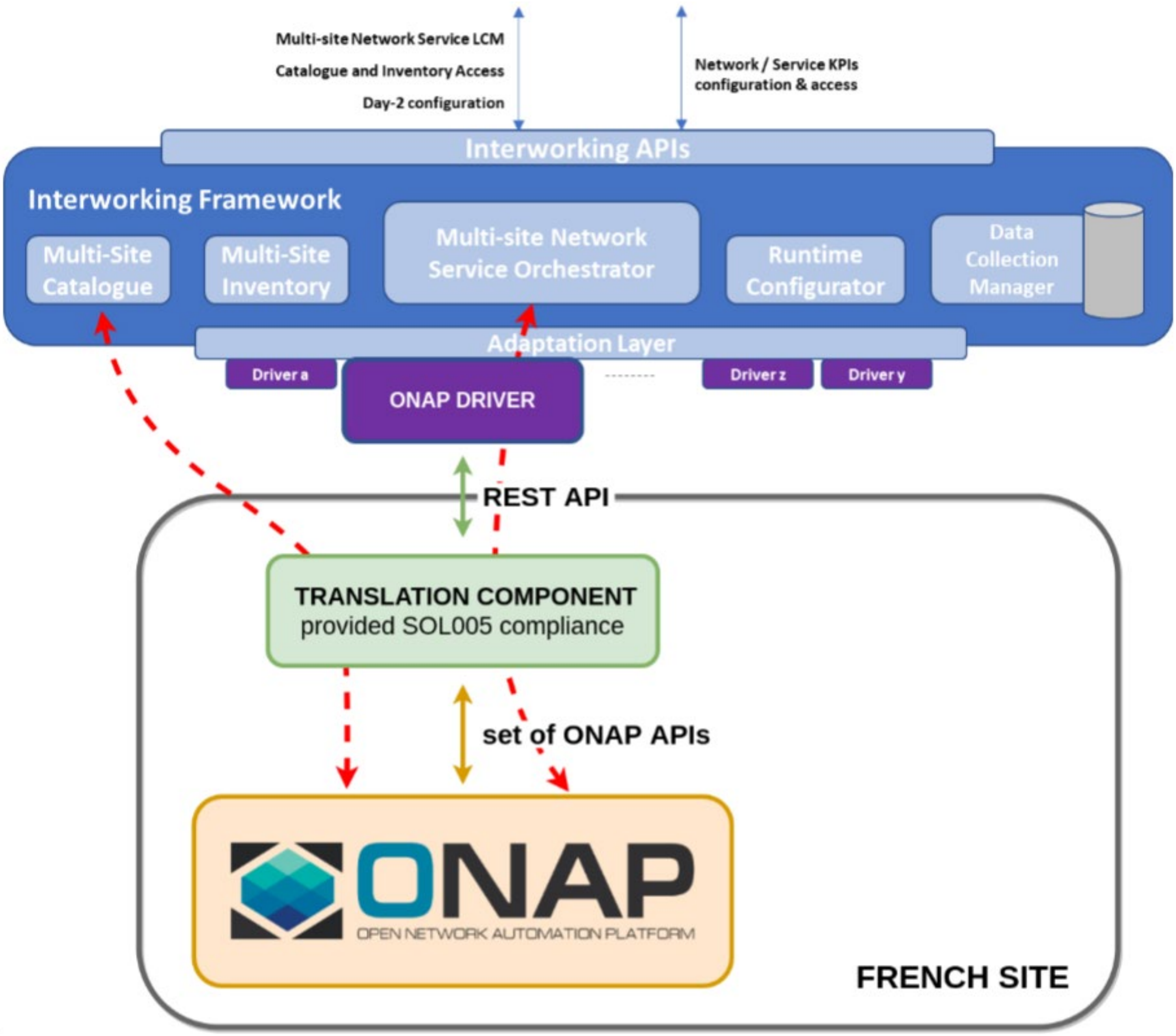


Figure 43. Integration of ONAP to 5G-EVE interworking layer in the French Site.

In the Figure 43, it is presented ONAP orchestrator integrated with 5G-EVE platform by Translation Component. It is an application deployed on docker containers on a virtual machine created on Openstack in Chatillon datacentre. TC was developed by ORA-PL team in 5G-EVE project and in 5G-TOURS project was extended to support CNF instantiation for newer ONAP release (Istanbul).

TC exposes REST API as external interface for communication with ONAP driver and IWL (Interworking Layer of 5G-EVE platform). TC triggers proper action using onapsdk [25] python package to interact with ONAP APIs to manage the life cycle of NS instances.

Main responsibility of TC is to automate deployment process of network services (NS) and provide ONAP a communication compliance with ETSI NFV SOL005 standard.

More detailed information about TC component is included in D3.4 131[2].

4.3 Technical validation results

4.3.1 UC6 Health monitoring and incident-driven communications prioritization

4.3.1.1 UC6 Description

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 and 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 44 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 D5.3 [4].

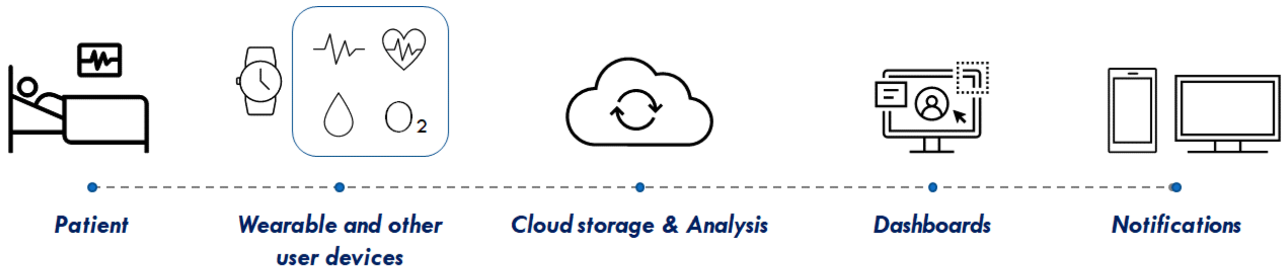


Figure 44. UC6 high level architecture.

4.3.1.2 Relevant KPIs

In Table 8, the full list of UC6 KPIs are presented together with their target values, as defined in D2.3 [1]. The relevant KPIs of UC6 are marked with green colour.

Table 8. UC 6 Remote health monitoring network requirements.

5G-Tours - Use Cases: direct specific Technical requirements			Units	(reviewed) - 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	100	100	High	10	100
2	🔴	**RAN** Latency (in milliseconds) - one way	msec	5	10	10	High	5	10
3	🟠	Throughput (in Mbps) - Min/MAX - sustained demand	Mbps		1<	50	High	1	50
4	🟢	Reliability (%) - Min/Max	%	99,99%	99,99%	99,99%	High		
5	🟢	Availability (%) - Min/Max	%	99,99%	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		No	0,1	High	0,1	0,1
8	⚫	Network Slicing (Y/N) - if Y service deployment time (min)	Y/N		Y	Y	Medium	1	1
9	⚫	Security (Y/N) - if Y grade i.e. "Carrier Grade"	Y/N		Y (baseline)	Y	Medium	N/A	N/A
10	⚫	Capacity (Mbps/m^2 or Km^2)	Mbps/m^2			12			12
11	⚫	Device density	Dev/Km^2					N/A	N/A
12	⚫	Location Accuracy	m		5	5	High	5	5

- 🟢 **Relevant KPIs**
- ⚫ **Non relevant KPIs**
- 🟠 **Relevant but not critical KPIs**
- 🔴 **Difficult to be demonstrated KPIs**

The KPIs that were collected and validated during the trials are in line with the above table and includes: RTT Latency, Throughput, Service Availability and Service Reliability.

4.3.1.3 Trial scenarios

The details of the trial scenarios (infrastructure, environment, deployment) are presented in Table 9 using the Testing Scenario Template. In addition, in Table 10, the metrics collected during the trials are presented, while in Table 11, the KPIs are presented together with details for their analysis methodology.

Table 9. UC6 Testing Scenario.

Parameter group	Test scenarios parameter	Parameter value
3GPP standard	3GPP Release	Rel.15
	3GPP Architecture option	NSA
RAN	Band	3.5 GHz
	Bandwidth	50 MHz
	Carrier aggregation	16
	UL/DL pattern	TDD
	Modulation	DL:256QAM, UL:64QAM
	MIMO	DL:4x2 MIMO, UL:2x2 MIMO
Core	Deployment	Central
UE	Category	CAT 7
	MIMO	DL:4x2 MIMO UL:2x2 MIMO
Service	Deployment	Central
	Service type	eMBB/URLLC/mMTC
Environment	Indoor/Outdoor	Indoor
	Number of UEs	5
	Number of cells	3

	Device density	-
	Mobility	Stationary
	Background traffic	No

Table 10. UC6 Metrics.

Metric parameters	Metrics			
Metric name	RTT latency	Packet loss	Throughput	APP RTT latency
Unit	ms	%	Mbps	ms
Probe position (network)	UE	UE	UE/Server	UE
Probe position (layer)	IP	IP	IP	APP
Sampling rate	1min	1min	30min	Every app request
Tool	Ping tool	Ping tool	VIAVI Speedtest tool	Inhouse tool

Table 11. UC6 KPIs.

KPI parameters	KPIs			
KPI name	RTT latency	Throughput	Service availability	Service reliability
Unit	ms	Mbps	%	%
Criteria	based on D2.3	based on D2.3	based on D2.3	based on D2.3
Analysis methodology	Average of RRT latency metrics	Average of throughput metrics	Calculated based on packet losses metric	Calculated based on packet losses metric and RTT latency metrics

4.3.1.4 QoS validation results

The next tables present the validation results for all three different service type requirements. Justification is provided in case that specific KPIs failed to reach the desired target value.

Table 12. UC6 (mMTC) validation results.

KPI	Measurements	WP2 requirements	Validation results	Justification
Latency (ms)	18.7	100	PASS	
Throughput DL (Mbps)	134.6	1	PASS	
Throughput UL (Mbps)	37.8		PASS	
Service Availability (%)	100	99.99	PASS	
Service Reliability (%)	99.994	99.99	PASS	.
App layer Latency (ms)	27.2		PASS	

Table 13. UC6 (eMBB) validation results.

KPI	Measurements	WP2 requirements	Validation results	Justification
Latency (ms)	18.7	100	PASS	
Throughput DL (Mbps)	134.6	50	PASS	

Throughput UL (Mbps)	37.8		PASS	
Service Availability (%)	100	99.99	PASS	
Service Reliability (%)	99.994	99.99	PASS	
App layer Latency (ms)	27.2		PASS	

Table 14. UC6 (URLLC) validation results.

KPI	Measurements	WP2 requirements	Validation results	Justification
Latency (ms)	18.7	10	**FAIL**	Very strict requirement. Only 2.4% of the measured values are below 10ms.
Throughput DL (Mbps)	134.6	1	PASS	
Throughput UL (Mbps)	37.8		PASS	
Service Availability (%)	100	99.99	PASS	
Service Reliability (%)	99.994	99.99	PASS	
App layer Latency (ms)	27.2		PASS	

From the above tables, it becomes obvious that only for the very strict requirement of RTT latency in the URLLC case, the measured values failed to meet the criteria. In such a case, network prioritizing functionalities should be used in order to meet the target of 10ms. In practice, the measured latency values do not affect the quality of the service and the user satisfaction as illustrated in the next subsection, but it is rather an overestimation during the requirement analysis phase.

4.3.1.5 QoE validation results

In Figure 45, the QoE results, as collected from the questionnaires, are illustrated. The figure presents the average score per question, as well as the total average score for all the questions.

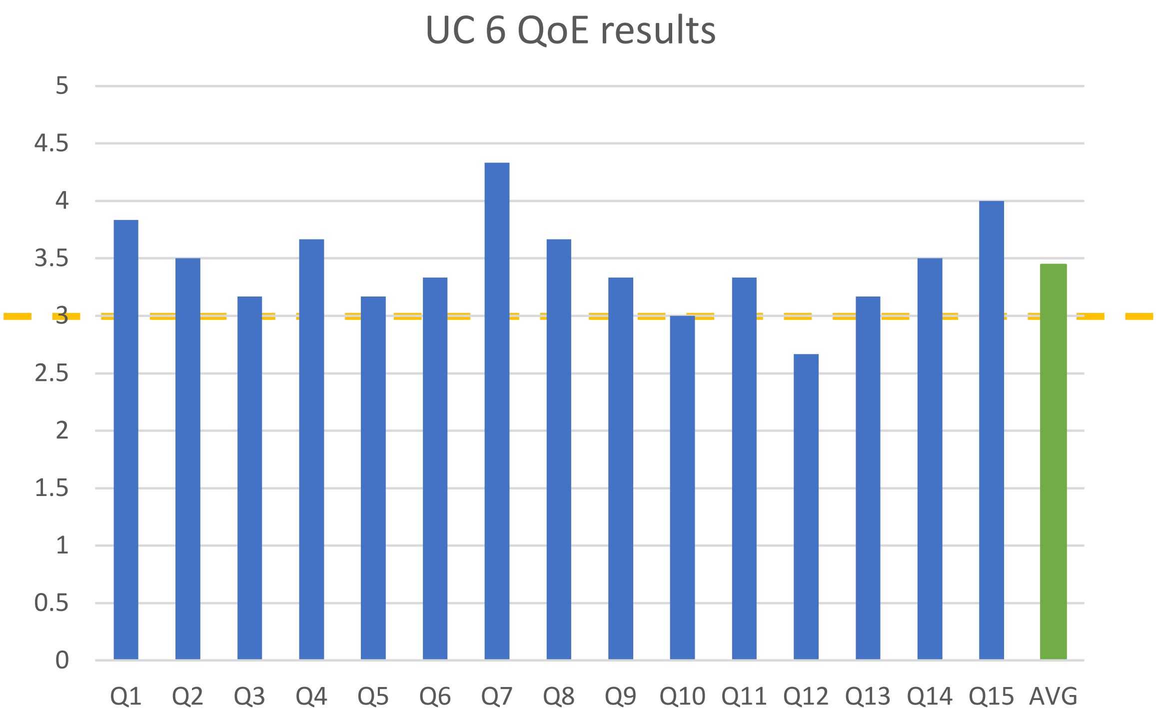


Figure 45. UC6 QoE validation results.

In UC6, we measure an average score of 3.44, which is above the targeted values of 3.0.

The only question that is below the threshold is:

- Q12: (Value: 2.67): How ready are you to use this technology as part of your daily routine?

This is an action that need to be taken from the stakeholders and not an issue with the network performance.

The question that has the highest score is:

- Q7: (Value: 4.33): Were situations when no alarm was raised even though measurement results should trigger it?

This means that the application ran smoothly and efficient.

4.3.1.6 Additional lab tests

A realistic NB-IoT communication module power model has been developed and validated with evaluations from tests with Sequans prototype devices to assess battery lifetime capability of cellular-IoT compatible sensor devices involving mMTC requirements as reported in D5.4 [4].

Two application scenarios were considered with the following assumed communication traffic and battery characteristics:

a) Wearable medical patch
   - Traffic: One transaction per 90 seconds. 85/18 Tx/Rx bytes per transaction.
   - Energy supply: One CR2032-like battery of 235mAh.

b) Portable environmental sensor
   - Traffic: One transaction per 1 hour. 100/100 Tx/Rx bytes per transaction.
   - Energy supply: Two AA-like batteries of 3500mAh each.

Furthermore, different coverage conditions (Outdoor or Indoor) and device behaviours (Power-off or Sleep, using eDRX or PSM features, after sending modem originated UDP data) were considered to help understand the consumption from differently configured use cases. Commonly used NB-IoT network configuration parameters were considered for eDRX (20.48 sec eDRX cycle, 2.56 sec PTW) and PSM (2.56 DRX cycle, 10 sec T3324 active timer) features.

Finally, two device types were considered, termed as “basic” and “optimized”, with the former representing a simpler legacy NB-IoT solution while the latter represents a more advanced solution employing power consumption optimisation features and techniques, such as faster resynchronization implementations and support of standardized energy reduction features such as RRC Connection Release Acknowledgment and Release Early Indication. Figure 46 and Figure 47 depict the difference of the two considered device types in terms of power consumption profile and the summary of the energy spent into different modem states (e.g., wake-up, data communication, etc.), during a PSM-based data session.

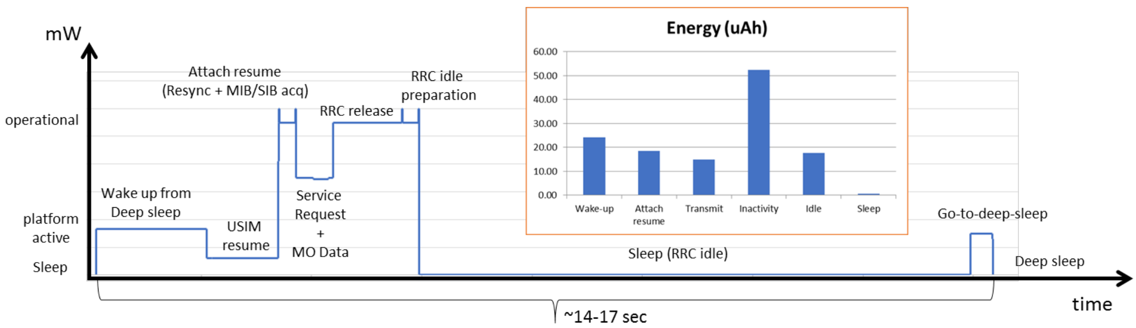


Figure 46. Energy usage profile during PSM-based modem originated data session – “Basic” device.

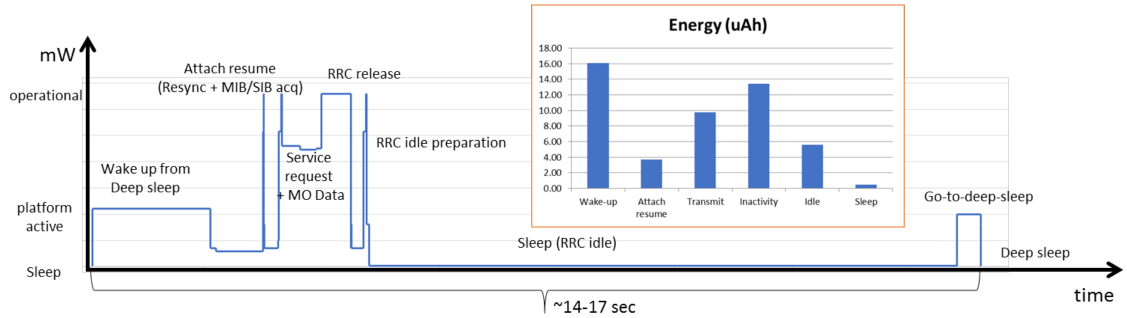


Figure 47. Energy usage profile during PSM-based modem originated data session – "Optimized" device.

Table 15 summarizes the battery lifetime results from the power model evaluations.

Table 15. Cellular-IoT based medical patch and environmental sensor battery lifetime evaluation results.

Scenario	Device	Coverage	Device mode	Evaluation*	Target***	Validation result
Medical patch	Basic	Indoor	Power-off	0.6 days	> 3 days	FAIL
		Outdoor		0.8 days		FAIL
		Indoor	Sleep (eDRX)	1.7 days		FAIL
		Outdoor		2.6 days		FAIL
	Optimized	Indoor	Power-off	2.0 days		FAIL
		Outdoor		3.0 days		PASS
		Indoor	Sleep (eDRX)	3.5 days		PASS
		Outdoor		5.0 days		PASS
Environment Sensor	Basic	Indoor	Power-off	1.8 years **	> 5 years	FAIL
		Outdoor		2.3 years **		FAIL
		Indoor	Sleep (PSM)	3.4 years **		FAIL
		Outdoor		5.0 years **		PASS
	Optimized	Indoor	Power-off	5.2 years **		PASS
		Outdoor		6.9 years **		PASS
		Indoor	Sleep (PSM)	7.1 years **		PASS
		Outdoor		8.3 years **		PASS

** Assuming that communication device dominates the energy usage of the sensor device.*
*** Assuming 3% per year battery self-discharge rate.*
**** Target selected based on current market expectations*

We observe that the optimized device can have significantly reduced energy consumption in several traditionally consuming states. In "Attach resume" state (from USIM resume to System Information acquisition and decoding) a ~75% reduction can be achieved mainly due to efficient synchronization techniques. In "Inactivity" state, covering the receipt of RRC connection release message from the network and its lower layers acknowledgment from the device, a ~75% reduction can be achieved from employing fast release after last transmitted data. In 'Idle" state (from RRC idle preparation to the point where device saves key information in flash memory and prepares to go to deep sleep), a ~60% reduction can be achieved mainly due to optimized techniques for System Information acquisition.

These reductions allow such optimized device to generally support the respective battery lifetime targets for both scenarios, i.e., medical patch and environmental sensor, in both device modes: either if device is using PSM feature (or eDRX, considered in case of medical patch, in order for device to be reachable by the network) to be in deep sleep mode when not needed to transmit/receive; or even in case of complete Power-off mode where the device will need to consume some significant effort/energy to perform a cold boot and more robust synchronization steps. The only case the target is not achievable is in Power-off mode and Indoor environment where there is the additional significant toll of several retransmissions to achieve synchronization and exchange of data. On the other hand, the basic device generally fails to achieve the set targets; however, it still manages to achieve the case of outdoor environmental sensor, when PSM feature is employed.

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

4.3.2.1 UC summary

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 three complementary setups, leveraging the capability of new 5G cellular networks, in particular high throughput, low latency, and ultra-reliability, to enable best decision support to emergency care regulators:

1. Live high-quality audio/video, live ultrasound images, in addition to voice communication.
2. Digital ultrasound data streaming, concerning the transfer of multiple streams of digital high quality medical ultrasound images and associated metadata.
3. 3D scene capture, transfer and rendering in real-time to enable virtual presence to remote emergency care regulators and medical experts, including the transfer of a virtual ultrasound probe back from the remote expert to the local doctor to support optimal probe positioning.

4.3.2.2 Relevant KPIs

The outcomes of the analysis on the user requirements reported in 5G-TOURS D2.3 [1] are used to decide on the feasibility of a specific KPI. Targeted application and network KPIs for UC7 are listed in D2.3 [1] for the combination of all three UC7 setups. In particular, the 3D scene transfer setup is challenging in terms of bandwidth, with moderate requirements for latency, while the Digital ultrasound streaming setup requires low latency with moderate bandwidth.

Therefore, this table is best split-up in three different tables, showing the KPIs for each of the setups shown in Figure 49, Figure 50 and Figure 52.

Table 16. 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/m^2 or Km^2)	Mbps/m^2						
11	Device Density	Dev/Km^2						
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)

Table 17. UC 7 requirements for smart glasses and ultrasound Android application with XpertEye WebRTC screen sharing setup.

5G-Tours - Use Cases: direct specific Technical requirements		Units	UC7 – Teleguidance for diagnostics			Priority	Range	
			URLLC	mMTC	eMMB		Min	Max
General Vertical/Use Case Requirement								
1	Latency (in milliseconds) - round trip - Min/Max	msec			100		10	25
2	**RAN** Latency (in milliseconds) - one way	msec			10			
3	Throughput (in Mbps) - Min/MAX - sustained demar	Mbps			10		150	1000
4	Reliability (%) - Min/Max	%			99,990%		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			130		0	130
7	Broadband Connectivity (peak demand)	Y/N or Gbps			0.1		0,01	1
8	Network Slicing (Y/N) - if Y service deployment time	Y/N			Y(1)		1	5
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			6		1	10
11	Device Density	Dev/Km^2			30		5	30
12	Location Accuracy	m			1		1	25

Table 18. UC 7 requirements for live multi-stream digital ultrasound transfer setup.

5G-Tours - Use Cases: direct specific Technical requirements		Units	UC7 – Teleguidance for diagnostics			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 demar	Mbps	100				50	200
4	Reliability (%) - Min/Max	%	99,990%				99,90%	99,999%
5	Availability (%) - Min/Max	%	99,990%				99,00%	99,999%
6	Mobility (in m/sec or Km/h) - Min/Max	Km/h	120				0	130
7	Broadband Connectivity (peak demand)	Y/N or Gbps	0,5				0,01	1
8	Network Slicing (Y/N) - if Y service deployment time	Y/N	Y(1)				1	5
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	6				1	10
11	Device Density	Dev/Km^2	30				5	30
12	Location Accuracy	m	1				1	25

Table 19. UC 7 requirements for real-time 3D scene transfer and rendering setup.

5G-Tours - Use Cases: direct specific Technical requirements		Units	UC7 – Teleguidance for diagnostics			Priority	Range	
			URLLC	mMTC	eMMB		Min	Max
General Vertical/Use Case Requirement								
1	Latency (in milliseconds) - round trip - Min/Max	msec			100		10	25
2	**RAN** Latency (in milliseconds) - one way	msec			10			
3	Throughput (in Mbps) - Min/MAX - sustained demar	Mbps			1000		600	1500
4	Reliability (%) - Min/Max	%			99,990%		99,00%	99,999%
5	Availability (%) - Min/Max	%			99,990%		99,00%	99,999%
6	Mobility (in m/sec or Km/h) - Min/Max	Km/h			130		0	130
7	Broadband Connectivity (peak demand)	Y/N or Gbps			2		0,6	4
8	Network Slicing (Y/N) - if Y service deployment time	Y/N			Y(1)		1	5
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			6		1	10
11	Device Density	Dev/Km^2			30		5	30
12	Location Accuracy	m			1		1	25

From the above tables and with respect to the KPIs that 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:
    - Measured? 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 KPIs we will focus on as a priority for all three setups, as high volume should be transmitted to the network in the uplink direction with the lowest latency. The Tables 16 to19 are pointing 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 48.

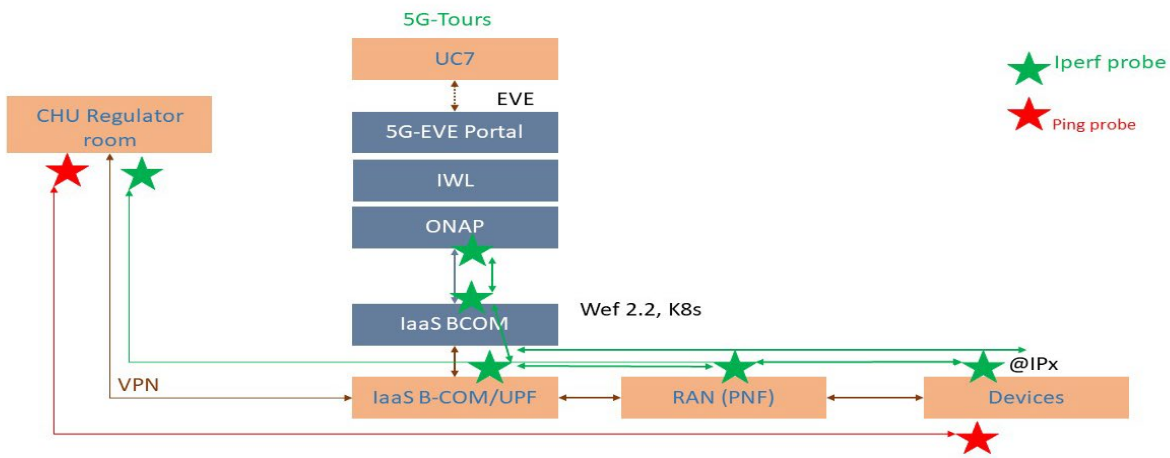


Figure 48. UC7 deployment architecture for technical validation.

4.3.2.3 Test / Trial scenarios and results

For each of the UC7 setups, different test / trial setups were used. These are described in the following subsections.

Several test setups are made, see D5.4 [4].

Test setup with smart glasses and ultrasound Android application with XpertEye webrtc screen sharing

Test case description

This test case is composed of two Android 5G 26GHz mobiles both USB connected to smart glasses and ultrasound probe. Quality of 5G private radio network, webrtc transmission and video and audio streams being shared from emergency ambulance crew to remote medical experts are validated.

Key performance indicators measured

The test case measures the data rates & latency at both sides and webrtc metrics (video/audio quality values) at receiving side.

Methodology and setup

The test cases involve:

- 2 mobiles in ambulance (sending side) with Android applications.
- 1 application computer in regulator room (receiving side) running applications in web browser.
- Internet access on both sides for data rate performance testing (nperf.com).

Both mobiles are connected in 5G 26 GHz to the network. The application computer is connected via an Ethernet cable to the network. This test setup is illustrated in Figure 49.

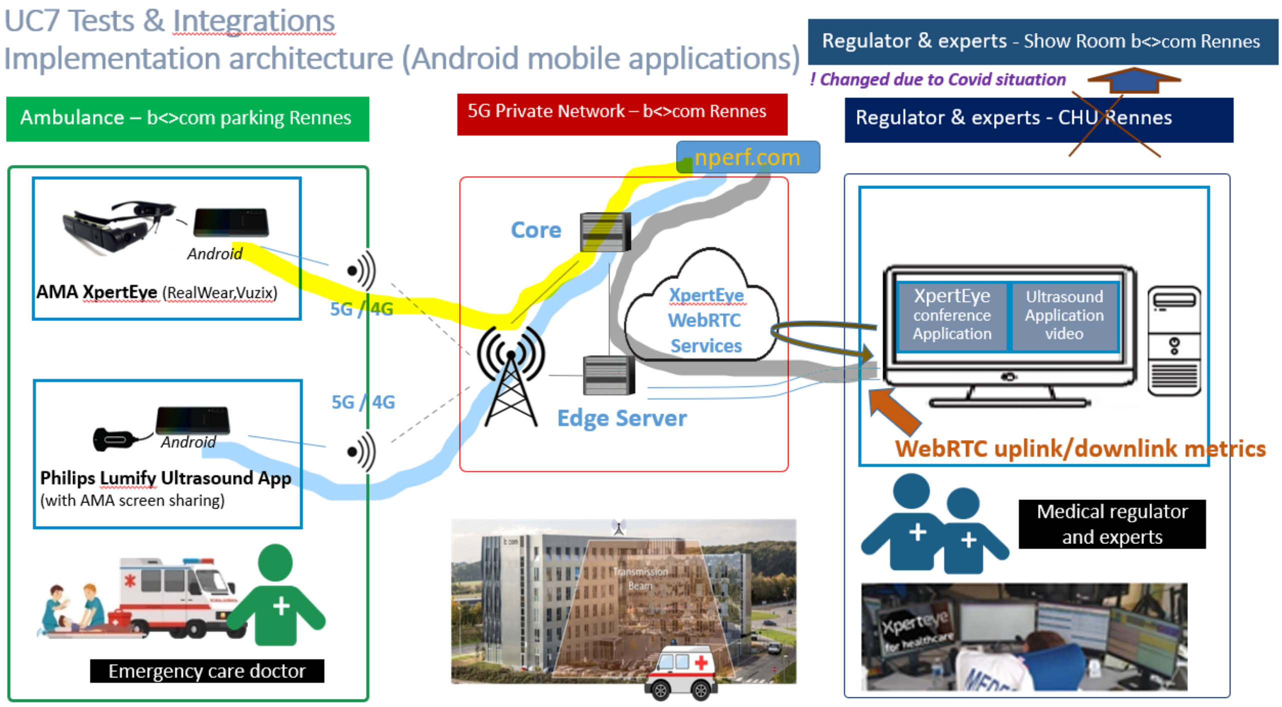


Figure 49. UC7 – smart glasses + ultrasound test setup.

From WebRTC uplink and downlink metrics collected on the application computer at regulator side (called receiving side), main measurements values are obtained.

Some complementary nperf measurements are done from Android mobiles and application computer using internet access requests to nperf.com site.

Results

Network measurements results are presented in this table:

Table 20. QoS and QoE validation results.

KPI	Measured with nperf.com	Expected value for application	Measured value in Application	Validation Result
End to end latency	Min: 10ms, Max: 40ms	60 ms	40 ms	Passed
Data rate	65Mbps UL 320Mbps DL	4 Mbps UL 16 Mbps DL	3Mbps UL 10Mbps DL	Passed
Frame drops	0%	5%	2%	Passed

These results confirm the very good quality of experience regarding this setup that was reported in the questionnaire (Figure 53).

Test setup for multi-stream digital ultrasound data transfer

Test case description

This test case examines the communication of digital multi-stream ultrasound data via WebRTC data channels over the SA 5G wireless network in Groningen (Netherlands). It should validate that a WebRTC data channel solution deployed on a 5G network is able to transfer multiple digital ultrasound streams in real-time at sufficient low latency and with minimal frame drops.

Key performance indicators measured

The test case measures the data rate, latency and frame rates / drops between the ultrasound sender and ultrasound receivers. The scenario requires data rates up to 60Mbps for upload and 30Mbps download for each receiver. Because of the used communication method, where the reception of each received digital ultrasound frame must be acknowledged by each receiver before a next frame is sent by the ultrasound sender, latency must be lower than 10ms and upload bandwidth 100Mbps or higher.

Methodology and setup

The test cases involve multiple laptop computers, each of them running WebRTC client software that is able to send and receive digital ultrasound data. The WebRTC services that are involved in setting up the connection – and possibly relaying some of the traffic – are running on an Amazon server in Ireland. The ultrasound sending laptop also runs a simulator that does playback of prerecorded digital ultrasound test streams. The software on all laptops displays the outgoing/incoming digital ultrasound streams in real-time, i.e.: a video window per ultrasound image stream, a table showing live image metadata that includes the current frame number and frame rate, and the time elapsed between sending a frame and receiving acknowledgement of reception.

The ultrasound sending laptop is connected via an Ethernet cable to a Netgear 5G wireless CPE that is wirelessly connected to the 5G base station. The digital ultrasound receiving laptops are directly connected via ethernet cables to the Edge computer of the 5G base station. The setup is illustrated in Figure 50.

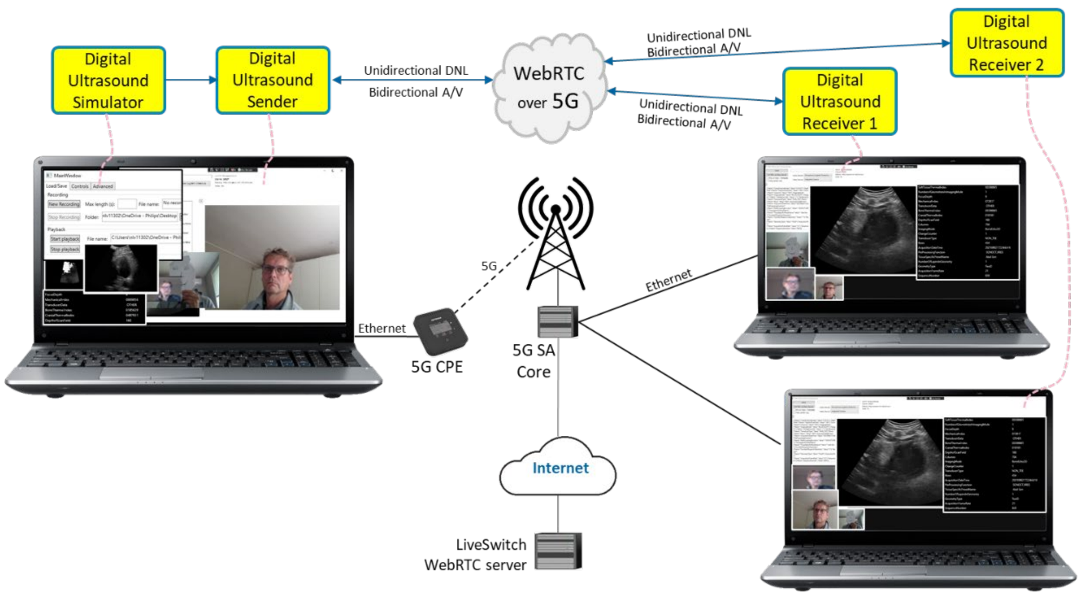


Figure 50. Setup of digital ultrasound communication over WebRTC data channels and 5G.

Results

When executing the experiment with all laptops wirelessly connected to the 5G base station, low bandwidth and high latency is experienced. The reason for this is that the Netgear CPEs only support outgoing traffic, which means that incoming traffic needs to be relayed by the WebRTC services that were running in Ireland during the time of the experiment.

However, it is more realistic that only the ultrasound source will be 5G wirelessly connected (user is the paramedic in the field), while the receivers will be directly connected to the Core / Edge (users are the remote experts in the hospital). Therefore, only measurements are collected for the setup where receivers are directly connected via Ethernet to the 5G Edge. In this case, outgoing traffic from the ultrasound sender will directly go to the receiving laptops that are connected to the Edge and no relaying is needed. In this case, the following measurements are obtained:

Table 21. QoS and QoE validation results at TNO Groningen.

KPI	Measured with speed test	Expected value for application	Measured value in Application	Validation Result
End to end latency	Min: 10ms, Max: 40ms	10 ms	40 ms	Failed
Data rate	70Mbps UL	60 Mbps UL	50Mbps UL	Failed
Frame drops	0%	10%	18%	Failed

The quality of experience is degraded because of the high percentage of frame drops.

Further optimization is possible by deploying also the WebRTC services in the Edge, to avoid all traffic relaying to remote WebRTC services. Such experiments have been carried out in Rennes on May 31 and June 1, 2022, in the 5G network at BCOM with WebRTC services on the Edge of AMA. The test setup has been simplified, see Figure 51.

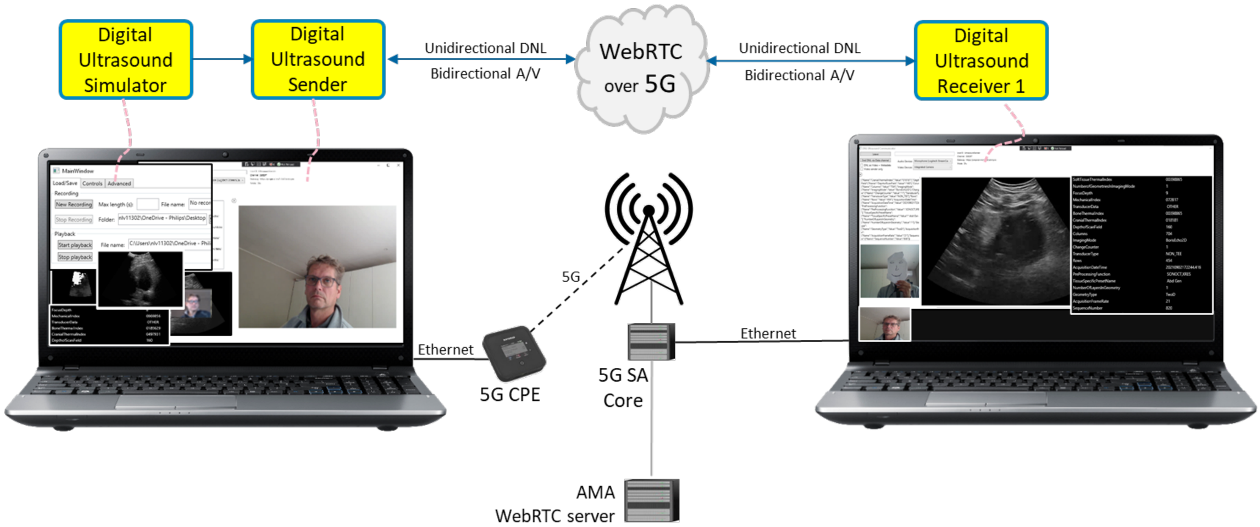


Figure 51. Test setup for digital ultrasound transfer at BCOM on May 31 and June 1, 2022.

When both the sender and receiver are attached to the core, a peer-2-peer connection can be established. When the sender is connected to the RAN and the receiver is connected to the core, such thing is not possible. Instead, a WebRTC relay must be used, which is the AMA WebRTC service deployed on the edge. In case of the peer-2-peer connection, both low latency and high bandwidth can be achieved, resulting good overall QoE.

However, in case that relaying is done, lower performance and QoE is achieved, very similar to the results achieved in Groningen. See results in Table 22 and Table 23.

Table 22. QoS and QoE validation results at BCOM Rennes / Peer-2-Peer on Core.

KPI	Measured with speed test	Expected value for application	Measured value in Application	Validation Result
End to end latency	Max: 5ms	10 ms	5 ms	Passed
Data rate	> 100Mbps	27 Mbps UL	28 Mbps UL	Passed
Frame drops	0%	10%	1%	Passed

Table 23. QoS and QoE validation results at BCOM Rennes / via RAN & relay service on edge. Two different data test sequences used.

KPI	Measured with speed test	Expected value for application	Measured value in Application	Validation Result
End to end latency	-	10 ms	100	Failed
Data rate	Mbps	27 Mbps UL 16 Mbps UL	19 Mbps UL 14 Mbps UL	Failed Failed
Frame drops	0%	10%	30% 12%	Failed

It is, therefore, expected that the limiting factor is the WebRTC data channel protocol stack in case of relaying, not the 5G network. Unfortunately, it was not possible to repeat this test in peer-2-peer mode.

Test setup for 3D telepresence

The 3D telepresence setup tests focused on performance and user experience. The various setups are described in D5.4 [4]. In particular, the setup shown in Figure 52 was tested.

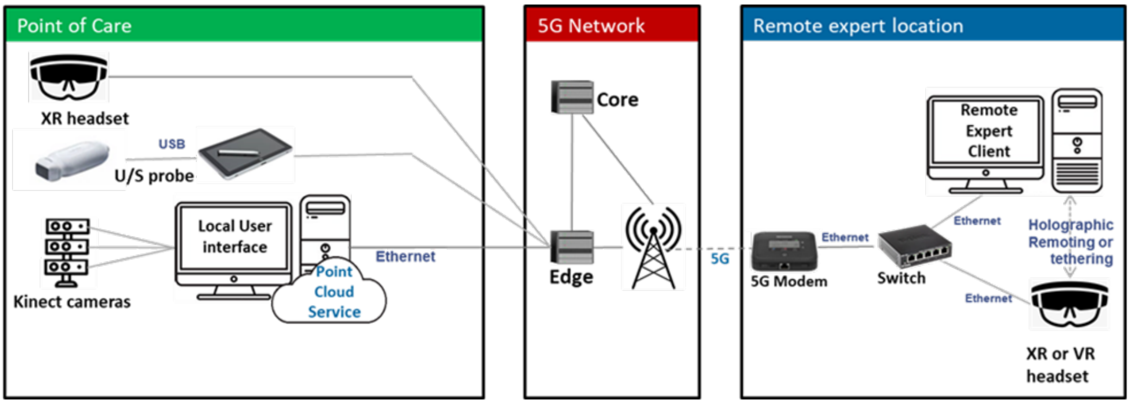


Figure 52. Test setup for 3D telepresence.

Test case description

The test case covers a remote expert giving guidance to the local user. After the setup, the remote expert positions the probe on a set of positions and asks the local user to follow the scan positions. The test looks at the visual positioning only – it did not involve the ultrasound images.

Key performance indicators measured

5G-Tours - Use Cases: direct specific Technical requirements			Units	UC7 – Teleguidance for diagnostics			Priority	Range	
				URLLC	mMTC	eMMB		Min	Max
General Vertical/Use Case Requirement									
	1	Latency (in milliseconds) - round trip - Min/Max	msec			100		10	25
	2	**RAN** Latency (in milliseconds) - one way	msec			10			
	3	Throughput (in Mbps) - Min/MAX - sustained demand	Mbps			1000		600	1500
	4	Reliability (%) - Min/Max	%			99.990%		99.00%	99.999%
	5	Availability (%) - Min/Max	%			99.990%		99.00%	99.999%
	6	Mobility (in m/sec or Km/h) - Min/Max	Km/h			130		0	130
	7	Broadband Connectivity (peak demand)	Y/N or Gbps			2		0.6	4
	8	Network Slicing (Y/N) - if Y service deployment time (m	Y/N			Y(1)		1	5
	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			6		1	10
	11	Device Density	Dev/Km^2			30		5	30
	12	Location Accuracy	m			1		1	25

The test case measures the latencies and bandwidth, next to the user experience (QoE).

The QoE is measured with the questionnaire as defined in Task 7.2.

Methodology and setup

The 3D demonstrator consists of two sides:

A. Local user side – 3D capture, ultrasound, HoloLens interface.

B. Remote expert side – VR visualization and interaction.

Each side can be either connected to the 5G RAN, or to the 5G core. This gives the following connectivity configurations:

1. A – 5G core –B
2. A – 5G core –5gRAN - B
3. A – 5gRAN - 5G core - B
4. A – 5gRAN - 5G core - 5gRAN – B

The datastreams are handled as follows:

- 3D data: The capture system can vary the number of cameras (between one and three) and switch resolution modes on the depth image capture (320x288, 640x576, 512x512, or 1024x1024). The application drops frames if transmission time exceeds the nominal framerate.
- The ultrasound is transmitted as WebRTC video. Degradation of the signal to handle low bandwidth is managed by the WebRTC libraries. We prioritize image quality.
- Probe position synchronization is sent as WebRTC text messages. This is never allowed to be lossy.

Results - lab

In the lab, the entire demo is deployed wired (configuration 1). With 3 cameras, we see bandwidth usage up to peaks of 600 Mbps. Frame rates drop as far as down to 2 fps. In Table 24 the average bandwidth values are presented for different depth mode selections. In Table 25 the average bandwidth values are presented for different number of 3D cameras.

Table 24. Network load for the 3D telepresence setup in the lab as function of depth camera resolution, with 3 cameras

KPI	Measured value in Application
Data rate 3D – depth mode 320x288	175 Mbps
Data rate 3D – depth mode 512x512	360 Mbps
Data rate 3D – depth mode 640x576	400 Mbps
Data rate 3D – depth mode 1024x1024	490 Mbps

Table 25. Network load for the 3D telepresence setup in the lab as function of number of cameras, at 640x576 depth camera resolution

KPI	Measured value in Application
Data rate 3D – 1 camera	420 Mbps
Data rate 3D – 2 cameras	420 Mbps
Data rate 3D – 3 cameras	400 Mbps

Results - Rennes RAN test

Due to deployment issues (e.g., no direct routing toward 5G RAN due to 5G encapsulation functionalities) the demonstrator could not be deployed on the 5G RAN. A QoE experiment was done with connections to the 5G Core. Results are reported in the next section.

4.3.2.4 QoE validation results

Figure 54 shows the results of the usability evaluation on the 5G core network in Rennes. The test was executed with a 3-camera system capturing at 640x576, with live ultrasound and full interaction. Although the technical maturity of the 3D telepresence is relatively low, the added value is recognized.

With the fixed cameras, this system could be installed inside ambulances. Not all ambulances need it though, so a flexible mounting system would be needed. The system should be set up such way that the staff do not need to be involved with calibration or configuration. Other possible applications that are mentioned are education and operating rooms. The systems allow for demonstration of physical gestures and movement that is hard to convey properly in 2D. Many ORs are nowadays already fitted with cameras for other purposes - an enhanced camera system may allow easy addition of the 3D telepresence capability.

The transfer of digital, minimally compressed ultrasound streams with associated descriptive metadata is perceived as highly useful for carrying out advanced diagnostics on specialized workstations, where the acquisition of images is done by less experienced medical staff in the field at the point of care and where remote medical specialists analyse these images on specialized workstations in the hospital.

In general, the use of tele-guided ultrasound is highly appreciated, especially when combined with the XpertEye smart glasses and the Philips Lumify app on Android with WebRTC based screen sharing of live ultrasound. The QoE score are depicted in Figure 53 and Figure 54.

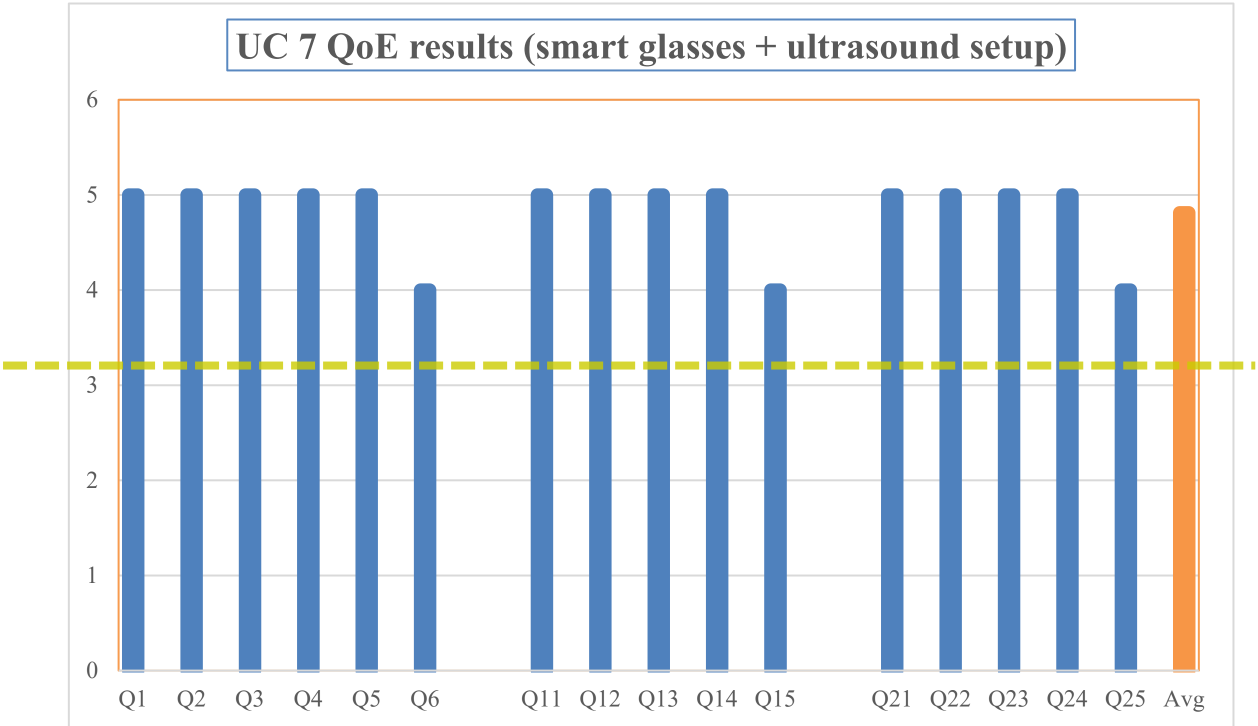


Figure 53. UC7 – smart glasses + ultrasound setup - QoE validation results.

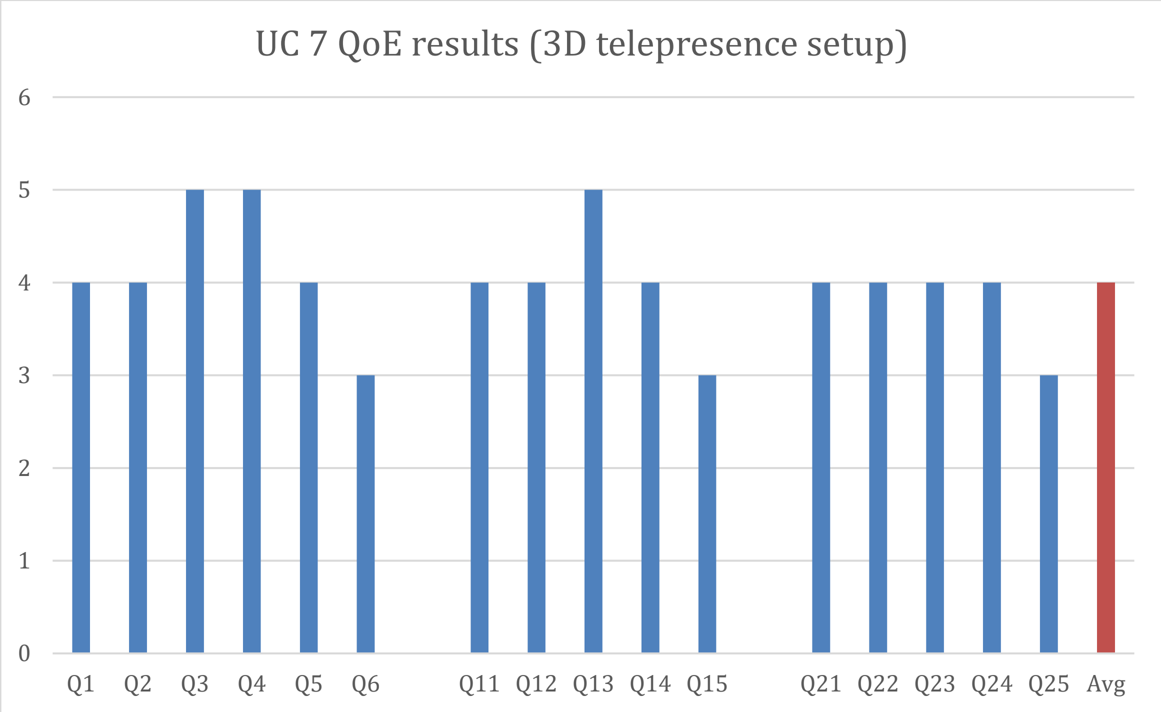


Figure 54. UC7 – 3D telepresence - QoE validation results.

4.3.3 UC8 Wireless Operating Room

4.3.3.1 UC summary

The goal of the use case is to demonstrate the impact of 5G inside the operating room. This use case faces 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 must go under a cardiac intervention procedure based on live, simultaneous X-Ray and ultrasound imaging.

The Table 26 below includes the KPIs and metrics relevant for the use case.

Table 26. 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/m^2 or Km^2)	Mbps/m^2	N/A					
11	Device Density	Dev/Km^2	N/A					
12	Location Accuracy	m	N/A					

From Table 26 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:
  - Measured via iperf3 tool in different segment of the infrastructure.
- Latency:
  - For E2E latency from the applications devices (UltraSound) to the Augmented Reality monitor, a dedicated tool was 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 were also carried out to measure the RTT (Round Trip Time).

In Figure 55, the deployment architecture used during the trials is illustrated. Measurements of throughput and latency are collected using the 5G EVE architecture, then analysed and validated.

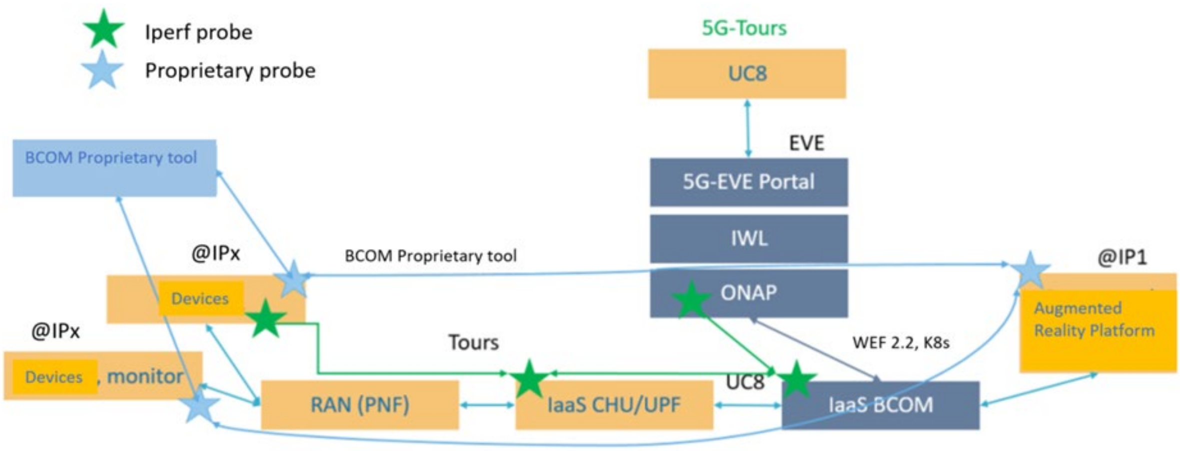


Figure 55. UC8 deployment architecture for technical validation.

4.3.3.2 Test / Trial scenarios and results

- Coverage/Power
  - An independent external company conducted 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 validating that those measurements are with respects of the regulations.
  - All details of this audit and certifications are available on the deliverable D5.4 [4].
- Network KPI
  - For the network latency, we used the ping method to measure the latency between different points of the network:
    - From the UE to Data Plane (DP) Server and vice versa.
    - From the UE to AR server and vice versa.

    Note that the latency due to the AR App was not included in those tests.

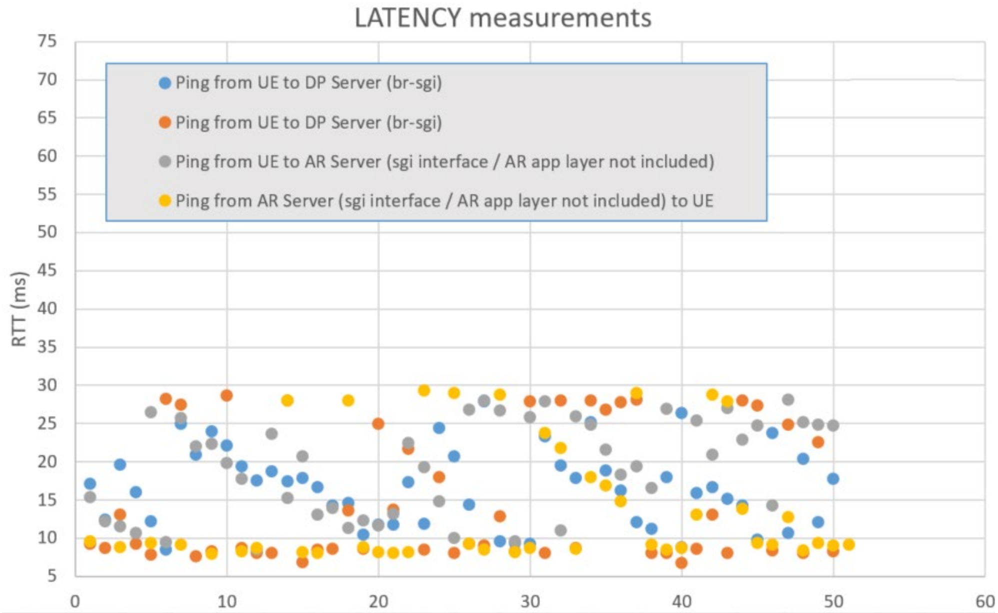


Figure 56. 5G network latency.

Latency	Average	Min	Max
UE to DP	16,74	8,45	27,90
DP to UE	14,88	6,73	28,60
UE to AR server	19,17	8,48	28,10
AR server to UE	14,43	7,88	29,30

Figure 57. Summary of 5G network latency.

- For the throughput, we used the iperf3 method to measure the downlink (DL) and uplink (UL) throughputs with UDP and TCP traffic

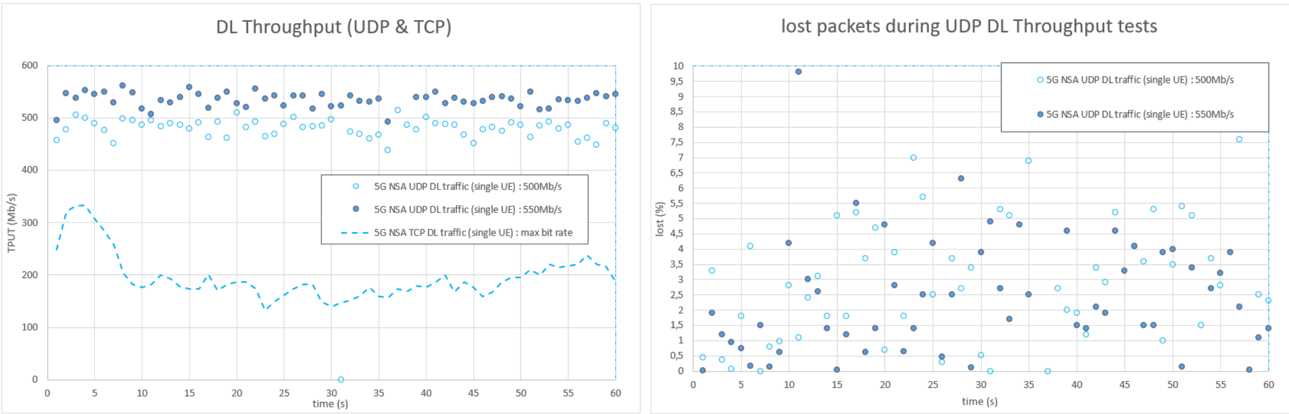


Figure 58. 5G DL throughput measured with this setup.

According to the lost packets ratio observed in those contexts, we could reach this maximum DL throughput supported by this setup. Higher throughput could be reached during the experimentations but with higher percentage of packets lost, involving degradation of the AR images, which was not acceptable.

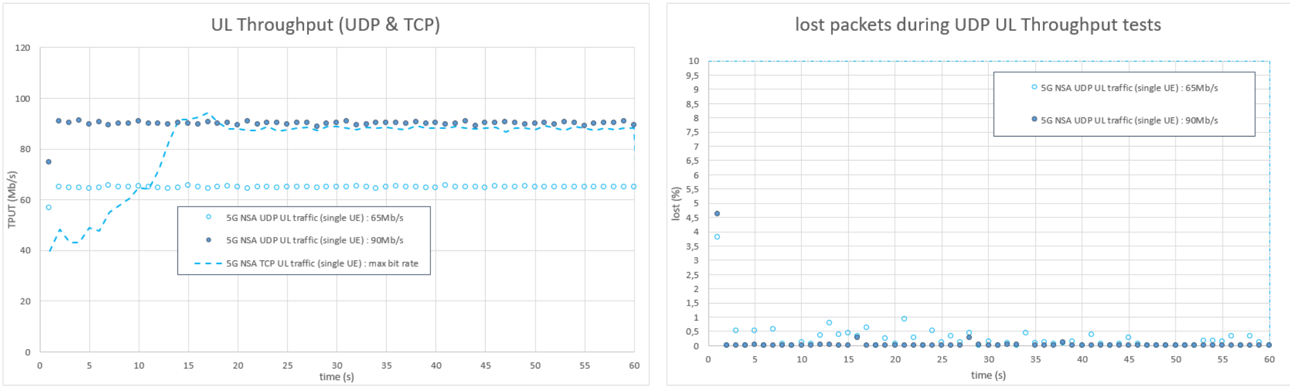


Figure 59. 5G UL throughput measured with this setup

In uplink direction, measurements could show that we could reach a throughput of 90Mbits with a packet lost rate below 1%. This value is sufficient to support the applications, i.e.: the throughput supported to transmit properly the streams from both ultrasound probe and smart glasses.

- Applications latency

For the functional tests, the setup described in Figure 55 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 transmission. Tests were carried out to identify the minimum value of latency to retrieve a video and images with the best quality to allow analysis and diagnosis.

E2E latency, included the complete setup, is around 300ms, including the latency due to the 5G network

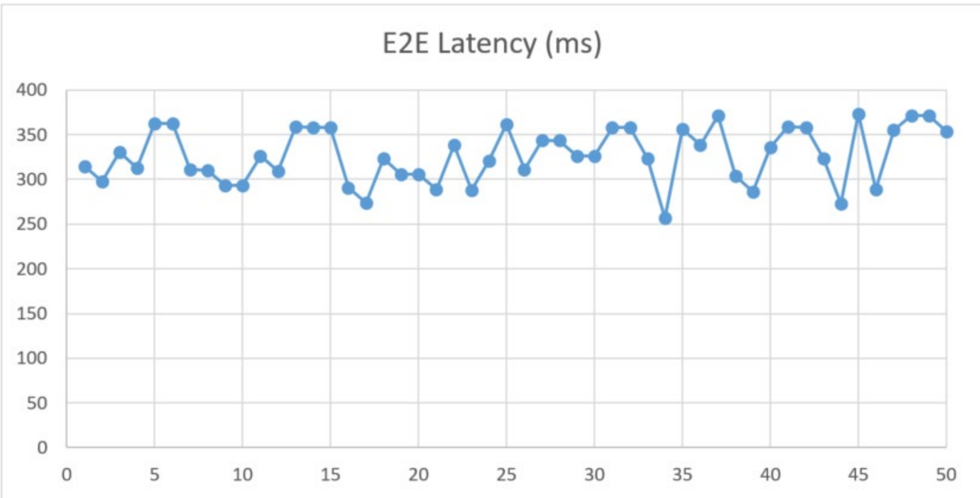


Figure 60. E2E latency.

Such latency is quite high compared to our requirements, but the quality of images and the manipulation of the ultrasound probe with this latency were acceptable for the usages of this use case and for the medical staff. However, this latency needs to be improved for further types of applications or higher resolutions of the images. Compression is a key parameter to improve this latency, especially in the uplink direction. This can be further examined and studied outside of the scope of the project.

4.3.3.3 QoE validation results

Feedback from the end users is crucial in this use case to see its benefits and to match with the real needs of the final users. A questionnaire was written with this purpose and shared with the medical staff after having demonstrated the use case in the operating room.

Figure 61 shows the answers of relevant stakeholders. Results a clearly show that the medical staff is willing to use such scenario with 5G and AR applications in their daily activities in the near future. See in Appendix the questions and answers provided by a cardiologist.

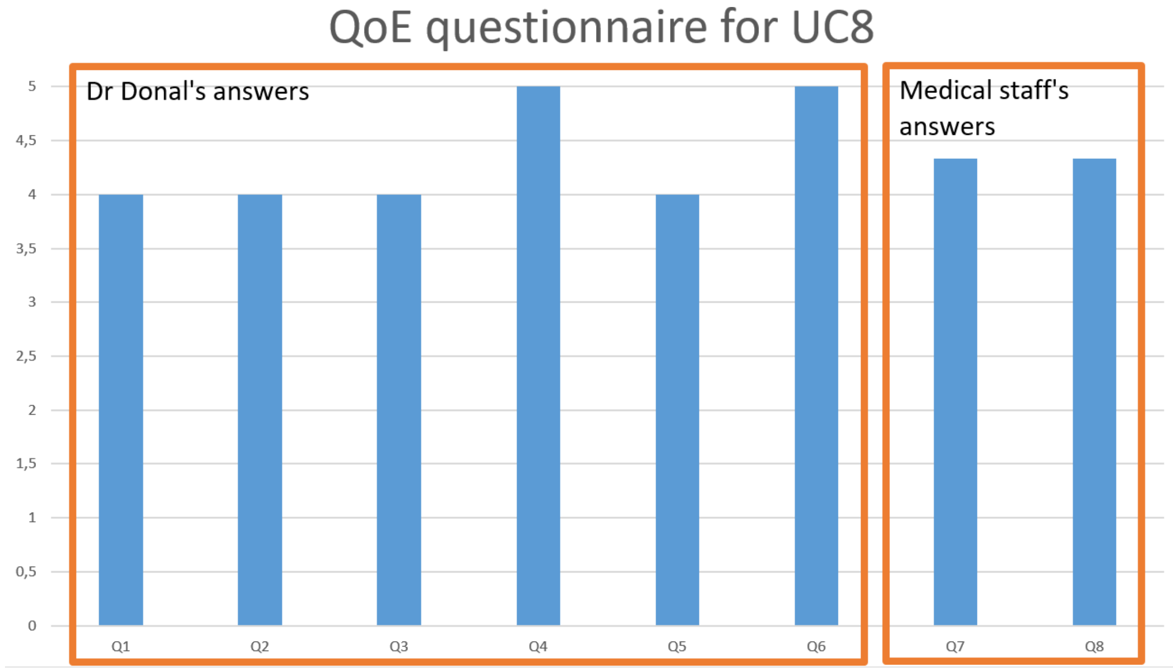


Figure 61. Results of the UC8 questionnaire.

4.3.4 UC9 Optimal ambulance routing

4.3.4.1 UC9 Description

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, once the patient has been stabilized on site, i.e. on emergency location. Figure 62 illustrates the high-level architecture of UC9, in which the different components of the deployment are presented. More information about UC9 can be found in 5G-TOURS D5.4 [4].

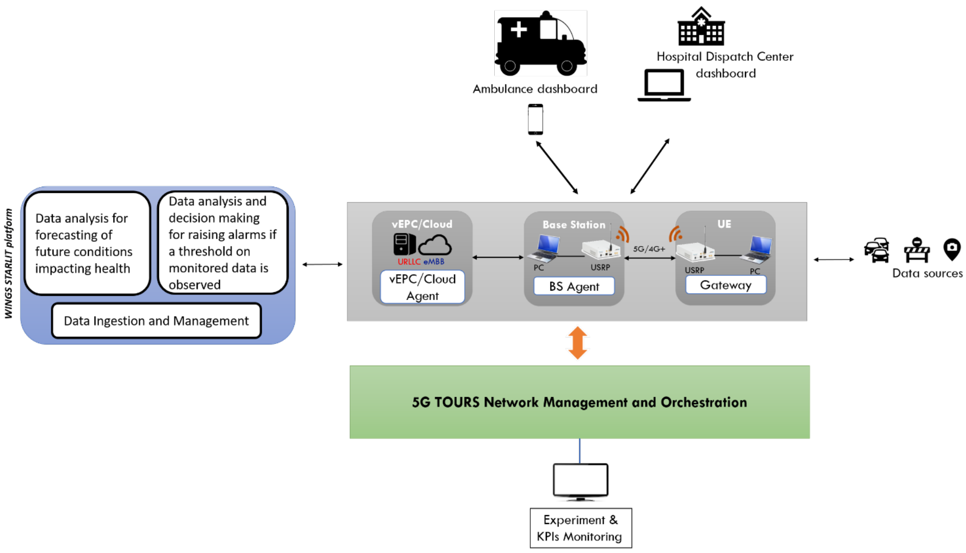


Figure 62. UC9 high level architecture.

4.3.4.2 Relevant KPIs

In Table 27, the full list of UC9 KPIs are presented together with their target values, as defined in D2.3 [1]. The relevant KPIs of UC9 are marked with green colour.

Table 27. UC 9 Optimal ambulance routing network requirements.

5G-Tours - Use Cases: direct specific Technical requirements			Units	(Reviewed) - 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		100	High	10	100
2		**RAN** Latency (in milliseconds) - one way	msec	5		25	High	5	25
3		Throughput (in Mbps) - Min/MAX - sustained demand	Mbps			50	High	10	50
4		Reliability (%) - Min/Max	%	99,99%		99,99%	High		
5		Availability (%) - Min/Max	%	99,99%		99,99%	High		
6		Mobility (in m/sec or Km/h) - Min/Max	Km/h	>=50Km/h		>=50Km/h	High	10	50
7		Broadband Connectivity (peak demand)	Y/N or Gbps	Y (1)		Y (1)	High	1	1
8		Network Slicing (Y/N) - if Y service deployment time (min)	Y/N	Y		Y	High	1	1
9		Security (Y/N) - if Y grade i.e. "Carrier Grade"	Y/N	Y		Y	Medium		
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	5		5	High	5	5

The KPIs that were collected and validated during the trials are in line with the above table and includes: RTT Latency, Throughput, Service Availability and Service Reliability.

4.3.4.3 Trial scenarios

The details of the trial scenarios (infrastructure, environment, deployment) are presented in Table 28 using the Testing Scenario Template. In addition, in Table 29, the metrics collected during the trials are presented; while in Table 30, the KPIs are presented together with details for their analysis methodology.

Table 28. UC9 Testing Scenario

Parameter group	Test scenarios parameter	Parameter value
3GPP standard	3GPP Release	Rel.15
	3GPP Architecture option	NSA
RAN	Band	3.5 GHz
	Bandwidth	50 MHz
	Carrier aggregation	16
	UL/DL pattern	TDD
	Modulation	DL:256QAM, UL:64QAM
	MIMO	DL:4x2 MIMO, UL:2x2 MIMO
Core	Deployment	Central
UE	Category	CAT 7
	MIMO	DL:4x2 MIMO UL:2x2 MIMO
Service	Deployment	Central
	Service type	eMBB/URLLC
Environment	Indoor/Outdoor	Indoor/Outdoor
	Number of UEs	3
	Number of cells	3
	Device density	-
	Mobility	0 – 30 Km/h
	Background traffic	No

Table 29. UC9 Metrics.

Metric parameters	Metrics			
Metric name	RTT latency	Packet loss	Throughput	APP RTT latency
Unit	ms	%	Mbps	ms
Probe position (network)	UE	UE	UE/Server	UE
Probe position (layer)	IP	IP	IP	APP
Sampling rate	1min	1min	30min	Every app request
Tool	Ping tool	Ping tool	VIAVI Speedtest tool	Inhouse tool

Table 30. UC9 KPIs.

KPI parameters	KPIs			
KPI name	RTT latency	Throughput	Service availability	Service reliability
Unit	ms	Mbps	%	%
Criteria	based on D2.3	based on D2.3	based on D2.3	based on D2.3
Analysis methodology	Average of RRT latency metrics	Average of throughput metrics	Calculated based on packet losses metric	Calculated based on packet losses metric and RTT latency metrics

4.3.4.4 QoS validation results

The next tables present the validation results for all three different service type requirements. Justification is provided in case that specific KPIs failed to reach the desired target value.

Table 31. UC9 (eMBB) validation results.

KPI	Measurements	WP2 requirements	Validation results	Justification
Latency (ms)	18.7	100	PASS	
Throughput DL (Mbps)	134.6	25	PASS	
Throughput UL (Mbps)	37.8		PASS	
Service Availability (%)	100	99.99	PASS	
Service Reliability (%)	99.994	99.99	PASS	
App layer Latency (ms)	225		PASS	

Table 32. UC9 (URLLC) validation results.

KPI	Measurements	WP2 requirements	Validation results	Justification
Latency (ms)	18.7	10	**FAIL**	Very strict requirement. Only 2.4% of the measured values are below 10ms.
Throughput DL (Mbps)	134.6	1	PASS	
Throughput UL (Mbps)	37.8		PASS	

Service Availability (%)	100	99.99	PASS	
Service Reliability (%)	99.994	99.99	PASS	
App layer Latency (ms)	225		PASS	

From the above tables, it becomes obvious that, similar to UC6, only for the very strict requirement of RTT latency in the URLLC case, the measured values failed to meet the criteria. In such a case, network prioritizing functionalities should be used in order to meet the target of 10ms. In practice, the measured latency values do not affect the quality of the service and the user satisfaction as illustrated in the next subsection, but it is rather an overestimation during the requirement analysis phase.

4.3.4.5 QoE validation results

In Figure 63, the QoE results as collected from the questionnaires are illustrated. The figure presents the average score per question, as well as the total average score for all the questions.

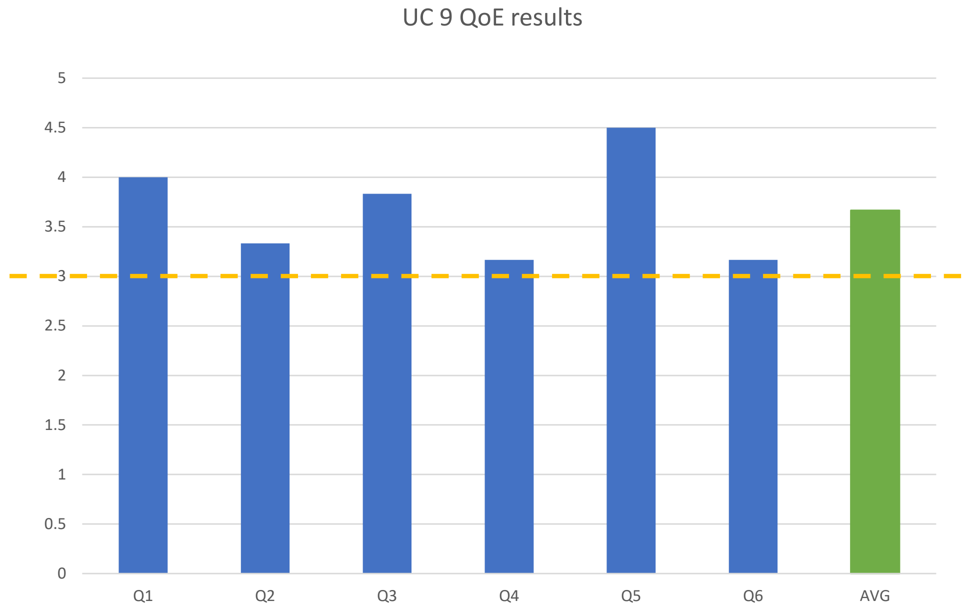


Figure 63. UC9 QoE validation results.

In UC9, we measured an average score of 3.67 which is above the targeted values of 3.0.

There are no questions that are below this threshold.

The question that has the higher score is:

- Q5: (Value: 4.5): How do you evaluate your experience in terms of the speed of service response?

Which means that the service performance in terms of speed (latency) experienced by the staff (users) was excellent.

5 Mobility-efficient city integrated ecosystem, trials, 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.

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

- **UC10. Smart airport parking management:** This is a solution that relies on the mMTC functionality provided by 5G. Around 50 parking sensors, installed at each parking position, 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.
- **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 developed 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.
- **UC12. Emergency airport evacuation:** This UC 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 is 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.
- **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.

These use cases revolve around the 5G EVE Athens site, including an extension to the Athens International Airport (AIA).

5.2 Integrated ecosystem

The 5G-TOURS architecture provides an improved responsiveness for real-time consumer applications and a faster service to users. At the airport, with real-time access to sensor data from 50 sensors and in the future with the capability of having more than 3000 sensors for all parking spots, intelligent infrastructure and 5G networks are in need. Indeed, one of the objectives of mMTC for 5G is to support very dense sensor deployments, such as the one that we have in UC10 – Smart airport parking management. The orchestration of the VNFs with the help of AI provides scalability, network slicing, independence from the service type (mMTC in the Smart Parking use case) or network technology of the sensors devices and users that access the application. This allows to deploy a network slice whose performance is not compromised by the other slices and whose features are tailored to the needs for the dense sensor deployments that we have in this UC. Thus, one of the key technologies that was used for UC10 is network slicing.

Automatic and optimized deployments intelligently fix any key issues per use case. Since Athens airport has more than 4 million people per month traveling and moving at and from the airport area, the orchestration optimizes the deployment of application networks and services to better support overcrowded areas. Algorithms running at OSM's embedded AI analyze the requirements received from verticals (i.e., UC 10 – Smart airport parking management and UC12- Airport evacuation) and with various performance indicator and measurements acquired from the VNFs, OSM intelligently decides the optimal resources and deployment for each service. Furthermore, orchestration allows verticals' services to be re-deployed, scaled in, scaled out or relocated from the cloud to the edge (e.g., closer to the users), improving the quality of user experience whenever is needed in an automatic, fast, and uninterrupted way. Thus, another key technology used in the use cases of the Greek node is orchestration.

Table 33 describes the innovations realised in the Athens node as part of the 5G-TOURS ecosystem.

Table 33. Mobility efficient city network innovations.

Network Innovations	WP6
Service Layer	Active real-time performance measurements while service is running (UC10 and UC12 were used for demonstration). AI-based enhanced MANO and the diagnostics component of the 5G-TOURS Service Layer (UC10 and UC12 were used for demonstration).
AI-based enhanced MANO	Resource (re)allocation, deployment, and migration of network application services in an automatic and optimized way using various metrics (infrastructure, VNFs, Applications, etc.) and verticals requirements (through 5G EVE OSM upgrade) - UC10 and UC12 were used for demonstration.
AI-based data analytics	Real-time feed of KPI values for better AI-based decision making (UC10 and UC12 were used for demonstration). Network monitoring for anomaly detection, performance degradation and root cause analysis of these problems were provided by the diagnostics component of the AI-based enhanced MANO (UC10 and UC12 were used for demonstration).
Other	Correlation of the user QoE (WP7) with active service KPIs to identify relations between network performance, Quantitative service KPIs and QoE (UC10 and UC12 were be used for demonstration).

All the details regarding the Athens node infrastructure, deployments and functionalities are described in details in deliverable D6.4 [5].

5.3 Technical validation results

5.3.1 UC10 Smart airport parking management

5.3.1.1 UC10 Description

Smart airport parking management use case targets the validation of 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 64 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. More information about UC10 can be found in 5G-TOURS D6.4 [5].

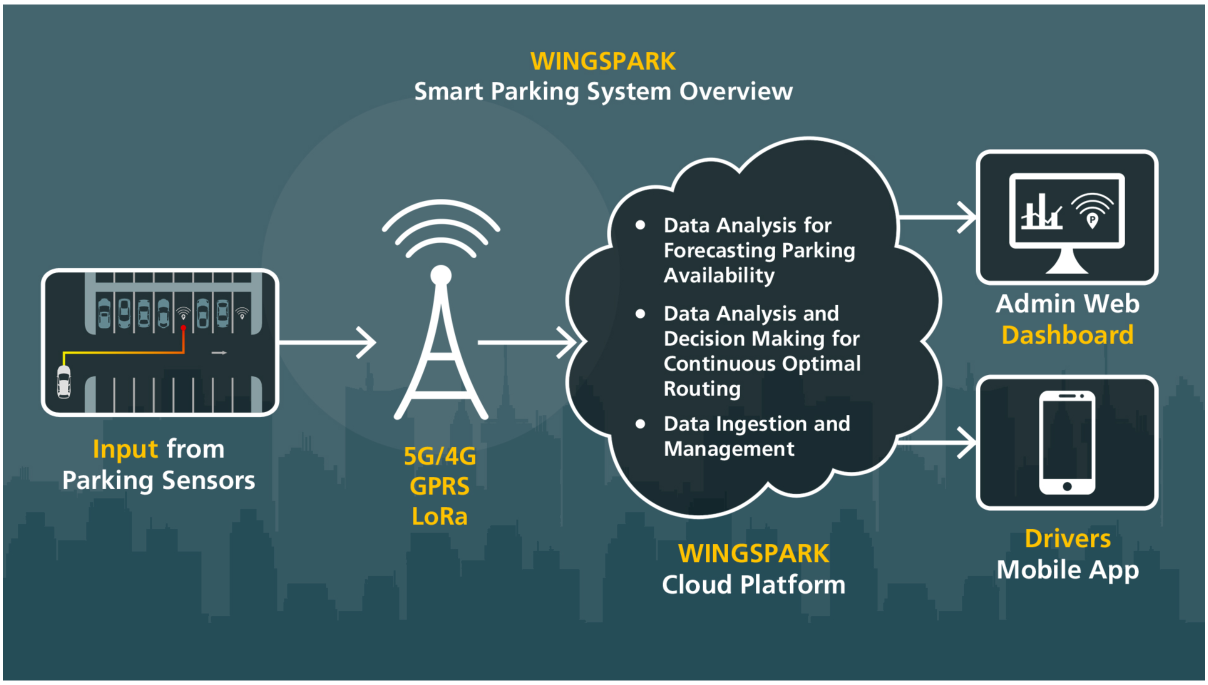


Figure 64. UC10 high level architecture.

5.3.1.2 Relevant KPIs

In Table 34, the full list of UC10 KPIs are presented together with their target values, as defined in D2.3 [1]. The relevant KPIs of UC10 are marked with green colour.

Table 34. UC 10 Smart parking management network requirements.

5G-Tours - Use Cases: direct specific Technical requirements		Units	(Reviewed) 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		100	100	High	10	100
2	**RAN** Latency (in milliseconds) - one way	msec		5	10	High	5	10
3	Throughput (in Mbps) - Min/MAX - sustained demand	Mbps		10	50	High	10	50
4	Reliability (%) - Min/Max	%		95,00%	99,99%	Medium	95	99
5	Availability (%) - Min/Max	%		95,00%	99,99%	Medium	95	99
6	Mobility (in m/sec or Km/h) - Min/Max	Km/h		50		High	5	50
7	Broadband Connectivity (peak demand)	Y/N or Gbps		0,1	0,1	High	0,1	0,1
8	Network Slicing (Y/N) - if Y service deployment time (min)	Y/N		Y	Y	Medium	1	1
9	Security (Y/N) - if Y grade i.e. "Carrier Grade"	Y/N		Y	Y	Medium		
10	Capacity (Mbps/m^2 or Km^2)	Mbps/m^2		0,1	12	Medium	0,1	12
11	Device Density	Dev/Km^2		100K		High	1K	100K*
12	Location Accuracy	m		(n/a)	(n/a)	High	5	5
(*) 1 parking space = 10m^2 => 1 Km^2 = 100.000 parking spaces								

The KPIs that were collected and validated during the trials are in line with the above table and includes: RTT Latency, Throughput, Network Availability, Network Reliability, App RTT latency, Service Reliability, Service Availability.

The other KPIs are considered non-relevant for this use case because they are of medium importance and/or they could not be tested (e.g., slicing was not deployed). For Location Accuracy, the location of a specific UE can, in principle, be provided by the 5G radio access network. However, since the trial network for UC10 is set up with only one cell, this was not possible. Therefore, Location Accuracy has not been measured.

5.3.1.3 Trial scenarios

Smart airport parking management use case targets the validation of 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 65 illustrates the actual deployment on the AIA and OTE premises and 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. 5G network paths between the sensors and driver UEs (located in AIA) and Server (located in OTE Labs) are established.

The validation approach was following the validation methodology generated in WP7 and reported in D7.2 [6], while it is in line with the final set of requirements defined in D2.3 [1]

In UC10, two types of KPIs were validated:

a) Network KPIs: which are measured and validated to demonstrate the network performance.

b) Application level KPIs: which are measured on the application layer, on the sensors/server/UEs and demonstrate the actual application performance.

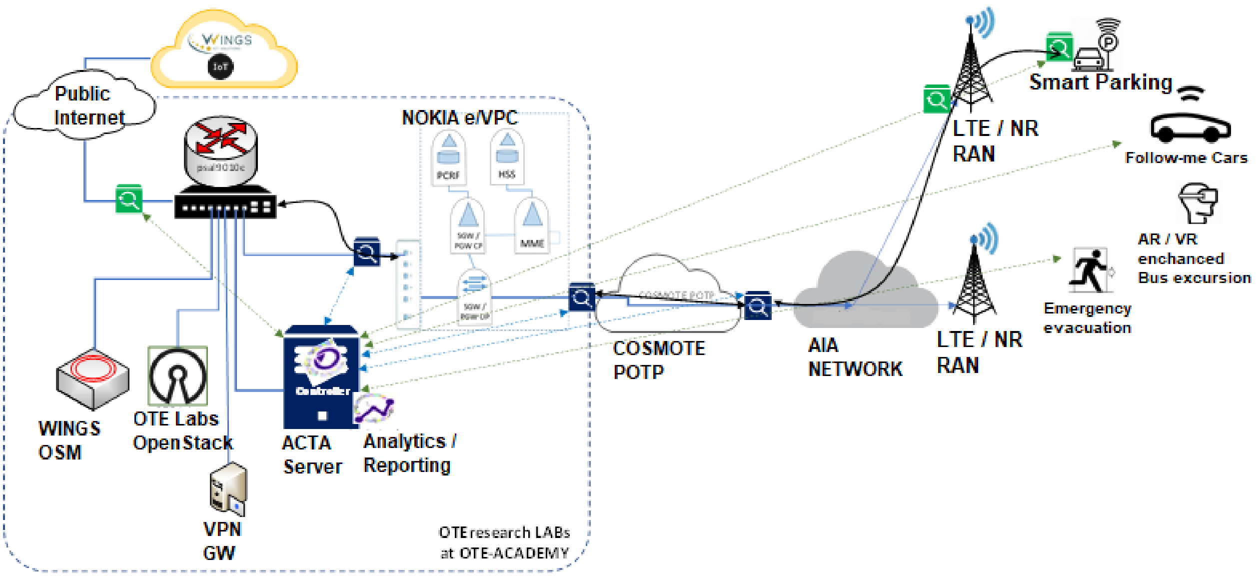


Figure 65. The participating probe components and their location for the KPI measurement of UC10.

Regarding network KPIs, Latency, Loss, Throughput (UL/DL) and Peak Throughput are 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 5G-TOURS D6.4, section 7.2.5.

Especially for this UC, a simulated UE, in the form of NOKIA Fastmile Router, has been used to collect e2e L2/L3 Loss and Latency measurements. This, while not physically located at exactly the same point as the end user (car driver seeking for parking spot), is served by the same BBU and is located in B17 building inside a window facing the UC 10 parking area (Figure 66). The Fastmile UE could not be itself permanently deployed outside in the AIA Parking area for security reasons.

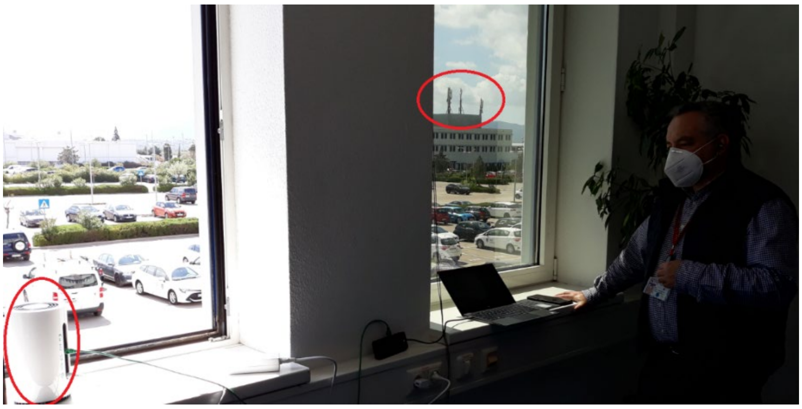


Figure 66. Nokia Fast Mile Router in AIA B17 building, serving the UC10 parking area.

Table 35. UC10 Testing Scenario.

Parameter group	Test scenarios parameter	Parameter value
3GPP standard	3GPP Release	Rel.15
	3GPP Architecture option	NSA
RAN	Band	3.5 GHz
	Bandwidth	50 MHz
	Carrier aggregation	16
	UL/DL pattern	TDD
	Modulation	DL:256QAM, UL:64QAM
	MIMO	DL:4x2 MIMO, UL:2x2 MIMO
Core	Deployment	Central
UE	Category	CAT 7
	MIMO	DL:4x2 MIMO UL:2x2 MIMO
Service	Deployment	Central
	Service type	eMBB/URLLC/mMTC
Environment	Indoor/Outdoor	Outdoor
	Number of UEs	5
	Number of cells	1
	Device density	-
	Mobility	0 – 20 Km/h
	Background traffic	No

Table 36. UC10 Metrics.

Metric parameters	**Metrics**			
Metric name	RTT latency	Packet loss	Throughput	APP RTT latency
Unit	ms	%	Mbps	ms
Probe position (network)	UE	UE	UE/Server	UE
Probe position (layer)	L2/L3	L2/L3	L4 TCP/IP	APP
Sampling rate	1min average	1min average	Measurement window average	Every app request

Tool	RFC5357 TWAMP/FUSION	RFC5357 TWAMP/FUSION	RFC 6349 VIAVI TrueSpeed	Inhouse tool

Table 37. UC10 KPIs.

KPI parameters			KPIs			
KPI name	RTT latency	Throughput	Network availability	Network reliability	Service availability	Service reliability
Unit	ms	Mbps	%	%	%	%
Criteria	based on D2.3	based on D2.3	based on D2.3	based on D2.3	based on D2.3	based on D2.3
Analysis methodology	Average of RRT latency metrics	Average of throughput metrics	Calculated as the percentage of Network layer packets successfully delivered out of all Network layer packets sent.	Calculated as the percentage of Network layer packets successfully delivered within the predefined Network layer KPI limits (e.g. latency <100ms) out of all Network layer packets sent.	Calculated based on packet losses metric	Calculated based on packet losses metric and RTT latency metrics

5.3.1.4 QoS validation results

The next tables present the validation results for all two different service type requirements, while justification is provided in case that specific KPIs failed to reach the desired target value. In cases that target values are not provided in WP2 requirements (e.g. Throughput UL and App layer latency), the results are validated (PASS or FAIL) based on the QoE results which are presented in the next subsection. In detail regarding throughput, requirements define one target value, which is the direction of the main service traffic (e.g., downlink in this use case). Therefore, this target values is compared against the measurements from the downlink throughput. The same applies for other use cases as well. Regarding App layer latency, this express the RTT latency for the whole service request-response cycle including network latency, latency in application (e.g., including data to be retrieved from a database, latency for calling a second service in multi-layer applications etc.). These are not captured in requirements, but we measure and present them here for completeness. Again, these values are characterised as PASS or FAIL based on the user experience results presented in next subchapter.

Table 38. UC10 (mMTC) validation results.

KPI	Measurements	WP2 requirements	Validation results	Justification
Latency (ms)	17	100	PASS	
Throughput DL (Mbps)	246,8	10	PASS	
Throughput UL (Mbps)	17		PASS	
NetworkAvailability (%)	99.9998	95.00	PASS	
Network Reliability (%)	99.9998	95.00	PASS	
Service Availability (%)	99.9998	95.00	PASS	
Service Reliability (%)	99.993	95	PASS	
App layer Latency (ms)	226 - 369		PASS	

Table 39. UC10 (eMBB) validation results.

KPI	Measurements	WP2 require-ments	Validation results	Justification
Latency (ms)	17	100	PASS	
Throughput DL (Mbps)	246.8	50	PASS	
Throughput UL (Mbps)	17		PASS	
Network Availability (%)	99.9998	99.99	PASS	
Network Reliability (%)	99.9998	99.99	PASS	
Service Availability (%)	99.9998	99.99	PASS	
Service Reliability (%)	99.993	99.99	PASS	
App layer Latency (ms)	226 - 369		PASS	

While the upload capability is peaking on average at approx. 17 Mbps, the download Throughput metric stays around 250 Mbps, which allows for sufficient application usage and exceeds the target values of Table 34, KPIs 3 and 7. Furthermore, one must factor in, the 50MHz bandwidth limitation, which was imposed by the interference conditions at the airport, and the subsequent throughput ceiling that as demonstrated by 5G PPP could not exceed 300Mbps. The average RTT latency value is around 17ms, while the latency distribution demonstrates that the latency values are kept below 20ms during the trials as illustrated in Annex A, Figure 79).

The overall conclusion is that the L2/L3 Network KPIs of Latency, Availability and Reliability comply with the targets set in Table 34 (respectively KPIs 1, 5 and 4). Overall latency remains well below the specified limits (below 17 ms for e2e), and this allows for calculation of the overall reliability as 99,9998%. Graphs detailing the above results for the period of the actual UC10 trial on 12/04/2022, are provided in Annex A.

In addition, service availability and reliability are higher than the target value of 95% and 99% for the mMTC and eMBB traffic respectively.

5.3.1.5 QoE validation results

In Figure 67, the QoE results as collected from the questionnaires are illustrated. Figure 67 presents the average score per question, as well as the total average score for all the questions.

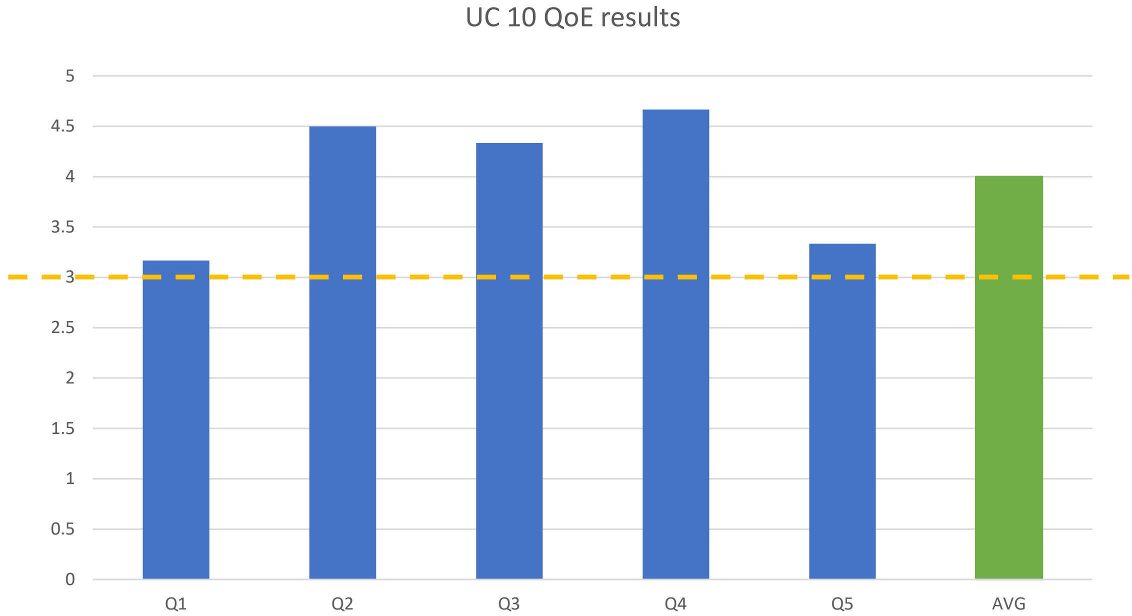


Figure 67. UC10 QoE validation results.

In UC10, we measured an average score of 4.05 which is above the targeted values of 3.0.

There are no questions that are below this threshold.

The question that has the highest score is:

- Q4: (Value: 4.67): 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?

Which means that the service performance in terms of speed (latency) experienced by the drivers (users) was sufficient.

5.3.1.6 Additional lab tests

The battery lifetime assessment reported in Section 4.3.1.6 for cellular-IoT compatible sensor devices involving mMTC requirements is also performed for relevant UC10 devices. The developed power consumption model is also validated with evaluations from lab tests with the Sequans prototype devices used in this use case for integration into the WINGSPARK smart parking sensor so as to attach to the COSMOTE NB-IoT network and provide real-time parking space data as reported in D6.4 [5].

The application scenario considered here includes the following assumed communication traffic and battery characteristics:

- Smart parking sensor
    - Traffic: One condition change (i.e., one transaction) per 1.5 hour in average. 10 Tx and 10 Rx bytes per transaction.
    - Energy supply: 4 Saft 17500 Li-ion batteries of 1200 mAh capacity each.

Similarly, to considerations reported in Section 4.3.1.6, different coverage conditions (Outdoor or Indoor), device behaviours (Power-off or Sleep), and device types (basic or optimized) are taken into account in the evaluations to help understand the energy consumption / saving potential from differently configured use cases and devices.

Table 40 summarizes the battery lifetime results from the power model evaluations.

Table 40. Smart parking sensor battery lifetime evaluation results.

<table>
<tr><th>Scenario</th><th>Device</th><th>Coverage</th><th>Device mode</th><th>Evaluation*</th><th>Target***</th><th>Validation result</th></tr>
<tr><td rowspan="8">Smart parking sensor</td><td rowspan="4">Basic</td><td>Indoor</td><td rowspan="2">Power-off</td><td>1.9 years **</td><td rowspan="8">> 7 years</td><td>FAIL</td></tr>
<tr><td>Outdoor</td><td>2.4 years **</td><td>FAIL</td></tr>
<tr><td>Indoor</td><td rowspan="2">Sleep (PSM)</td><td>3.7 years **</td><td>FAIL</td></tr>
<tr><td>Outdoor</td><td>5.2 years **</td><td>FAIL</td></tr>
<tr><td rowspan="4">Optimized</td><td>Indoor</td><td rowspan="2">Power-off</td><td>5.5 years **</td><td>FAIL</td></tr>
<tr><td>Outdoor</td><td>7.1 years **</td><td>PASS</td></tr>
<tr><td>Indoor</td><td rowspan="2">Sleep (PSM)</td><td>7.6 years **</td><td>PASS</td></tr>
<tr><td>Outdoor</td><td>8.3 years **</td><td>PASS</td></tr>
<tr><td colspan="7">* Assuming that communication device dominates the energy usage of the sensor device.
** Assuming 3% per year battery self-discharge rate.
*** Target selected based on current market expectations</td></tr>
</table>

The energy consumption reductions brought forward by the optimized device are same to what has been reported in Section 4.3.1.6. These reductions allow such optimized device to generally support the respective battery lifetime target of smart parking sensor scenario. When the device is using PSM feature to stay in deep sleep mode, only reachable for a time window after transmission yet registered to network with reduced signalling and wakeup time, the target can be achieved even under bad signal conditions (represented by the Indoor coverage scenario), where several retransmissions to achieve synchronization and exchange of data may keep most of the device's baseband and RF parts in fully ON state for a much longer duration. It is seen however that in case of complete Power-off mode, where a cold boot and robust synchronization is involved after a wake-up, the target cannot be achievable. Thus, we conclude that for the scenario of smart parking sensor, employing PSM feature is essential for the NB-IoT device. On the other hand, we observe that the basic device fails to achieve the set targets under all conditions, rendering the use of energy efficient features (as such used by the optimized device examined here) a must for NB-IoT devices targeting the smart parking use case.

5.3.2 UC11 Video-enhanced follow-me moving vehicles

5.3.2.1 UC11 Description

This use case provides high-definition cameras to the follow-me vehicles which lead aircrafts to parking positions, monitor and oversee the activity at the Airport Airside area, and attend incidents, emergencies and critical events, thus improving day-to-day airport operations as well as response activities to emergencies. This use case involves very large throughputs as well as highly critical communications.

This use case was implemented via the installation of high-definition cameras on the follow-me vehicles, which transmitted live video feeds to the ASOC as well as to other concerned third parties and stakeholders. Enhancing the ground-based moving vehicles with technologies that provide real time notification on the Apron situation at any given time is of great value to the airport in sustaining an efficient and safe operation, for the customers (Airlines) for whom, safety and avoiding flight delays is vital, as well as other stakeholders (emergency resource personnel – Police, Ambulance Services, Fire Brigade) in efficiently responding to emergencies.

The follow-me vehicles also access flight information on-demand service and provide the follow-me services for aircrafts, which leads aircrafts to their parking position. 5G technologies were used to provide on-demand and/or live video streaming data later in order to monitor and oversee the activity at the airport airside area, and attend incidents, emergencies and critical events. More information about UC11 can be found in 5G-TOURS D6.4 [5].

5.3.2.2 Relevant KPIs

In Table 41, the full list of UC9 KPIs are presented together with their target values, as defined in D2.3 [1]. The relevant KPIs of UC9 are marked with green colour.

Table 41. UC 11 Remote health monitoring network requirements

	5G-Tours - Use Cases: direct specific Technical requirements	Units	(Reviewed) 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

The KPIs that were collected and validated during the trials are in line with the above table and includes: RTT Latency, Throughput, Network Availability and Network Reliability

The other KPIs are considered non-relevant for this use case because they are of medium importance and/or could not be tested (e.g., slicing was not deployed). For Location Accuracy, the location of a specific UE can, in principle, be provided by the 5G radio access network. However, since the trial network for UC11 is set up with only one cell, this is not possible. Therefore, Location Accuracy has not been measured.

5.3.2.3 Trial scenarios

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 receives 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 the downstream one. Loss and Latency measurements are also being used to calculate Network Availability and Network Reliability as discussed in 5G-TOURS D6.4.

The network probes used in UC11 and the validation methodology are described in detail in 5G-TOURS D6.4 section 7.2.5. The above KPIs are measured and validated along the data path indicated in the diagram overlaid on the Athens site network architecture.

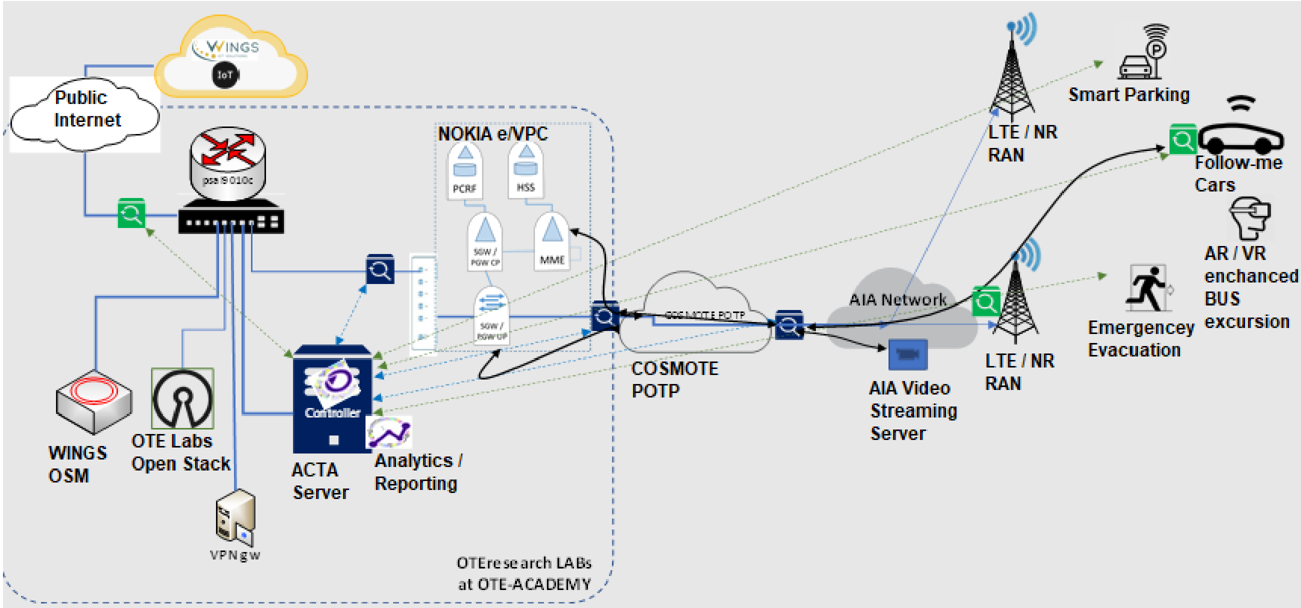


Figure 68. The participating probe components and their location for the KPI measurement of UC11.

In addition to that, the 5G routers selected for the trials are the Model: 5G Transit by Peplink (MAX-TST-5GD-T-PRM) which are car mountable (Figure 69).

Figure 69. Peplink Router.

Throughput measurements were taken with the PepLink as well as S20 UEs. However, for the Latency and Loss TWAMP L2/L3 KPIs measured in UC11, we used a NOKIA FastMile UE served by the BBU serving the Apron area, but not permanently deployed outside in the Apron area for security reasons. Also, due to port limitations of the Peplink router, one could not permanently occupy a port with a connected laptop configured as a TWAMP measuring device.

Table 42. UC11 Testing Scenario.

Parameter group	Test scenarios parameter	Parameter value
3GPP standard	3GPP Release	Rel.15
	3GPP Architecture option	NSA
RAN	Band	3.5 GHz
	Bandwidth	50 MHz
	Carrier aggregation	16
	UL/DL pattern	FDD
	Modulation	64QAM
	MIMO	2 layers
Core	Deployment	Central
UE	Category	CAT 7
	MIMO	2 layers
Service	Deployment	Central
	Service type	eMBB/URLLC/mMTC
Environment	Indoor/Outdoor	Outdoor
	Number of UEs	3
	Number of cells	3
	Device density	-
	Mobility	0 – 30 Km/h
	Background traffic	No

Table 43. UC11 Metrics.

Metric parameters	Metrics		
Metric name	RTT latency	Packet loss	Throughput
Unit	ms	%	Mbps
Probe position (net-work)	UE	UE	UE/Server
Probe position (layer)	L2/L3	L2/L3	L4 TCP/IP
Sampling rate	1min average	1min average	Measurement window average
Tool	RFC5357 TWAMP/FU-SION	RFC5357 TWAMP/FU-SION	RFC 6349 VIAVI TrueSpeed

Table 44. UC11 KPIs.

KPI parameters	KPIs			
KPI name	RTT latency	Throughput	Network availability	Network reliability
Unit	Ms	Mbps	%	%
Criteria	based on D2.3	based on D2.3	based on D2.3	based on D2.3
Analysis method-ology	Average of RRT latency metrics	Average of throughput metrics	Calculated as the per-centage of Network layer packets success-fully delivered out of all Network layer packets sent.	Calculated as the per-centage of Network layer packets success-fully delivered within the predefined Network layer KPI limits (e.g., latency <500ms) out of all Network layer pack-ets sent.

5.3.2.4 QoS validation results

The next tables present the validation results for the scenarios assuming eMMB type of traffic, while justification is provided in case that specific KPIs failed to reach the desired target value.

Table 45. UC11 (eMBB) validation results.

KPI	Measurements	WP2 requirements	Validation results	Justification
Latency (ms)	22	100	PASS	
Throughput DL (Mbps)	148,8	50	PASS	
Throughput UL (Mbps)	26,9		PASS	
Network Availability (%)	99,9999	99.999	PASS	
Network Reliability (%)	99,9999	99.99	PASS	

The average RTT latency value is around 22ms, while the latency distribution demonstrates that the latency values are kept below 25ms with small spikes during the trials as illustrated in Annex A, Figure 80.

While the upload capability remains independent of the device used as UE, peaking on average at approx. 26 Mbps, the download metric varies from 150 when the PepLink Router is used up to 220 Mbps for a S20 UE sending video from the AIA Apron area. Both figures allow for sufficient video streaming capacity. Furthermore, one must factor in, once more in this use case, the 50MHz bandwidth limitation, which was imposed by the interference conditions at the airport after the Targets of Table 41 were set. Given the above limitations, measured throughput figures are within the target's values, set in Table 3 for KPIs 3 and 7 respectively.

The overall conclusion is that the L2/L3 Network KPIs of Latency, Availability and Reliability comply with the targets set in Table 41 (respectively KPIs 1, 5 and 4). Overall latency remains well below the specified limits (below 100 ms for RAN latency and 500 ms for e2e), and this allows for calculation of the overall reliability as 99,9999%.

Graphs detailing the above results for the period of the actual UC11 trial on 08/04/2022 are provided in Annex A.

5.3.2.5 QoE validation results

In Figure 70, the QoE results as collected from the questionnaires are illustrated. The figure presents the average score per question, as well as the total average score for all the questions.

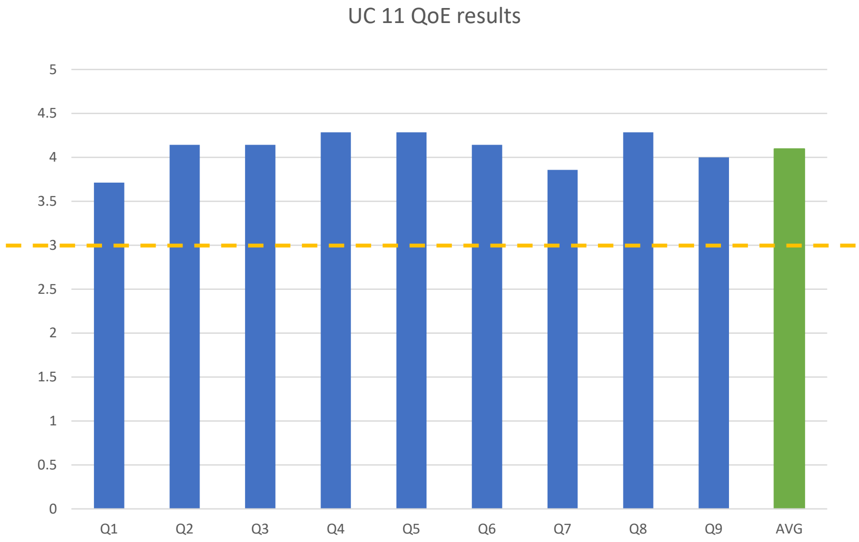


Figure 70. UC11 QoE validation results.

In UC11, we measured an average score of 4.095 which is above the targeted values of 3.0.

There are no questions that are below this threshold.

The questions that have the highest score are:

- Q5: (Value: 4.29): How much do you agree with the following: Connection remains stable and with no quality problems independent of the number of sources the videos are coming from
- Q8: (Value: 4.29): 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?

Which means that the users are highly satisfied by the network performance.

5.3.3 UC12 Emergency airport evacuation

5.3.3.1 **UC12 Description**

In this use case, AIA's objective is to process Airport terminal evacuees in an efficient and safe manner, while, at the same time, have in place the relevant plans, tools and processes required to mitigate any emergency with the use of 5G based tools. An efficient and effective evacuation is one of the mitigation measures that are of particular importance in security incidents or even in the case of fire, gas leakage, etc.

This scenario describes the way airports (in general) and other large-scale public infrastructures can exploit 5G capabilities to bring in place an effective evacuation plan where personalized, dynamic and smart instructions can be provided in a reliable, instantaneous and massive-scale manner.

Figure 71 illustrates the high-level architecture of UC12, in which the different components of the deployment are presented. More information about UC12 can be found in 5G-TOURS D6.4 [5]

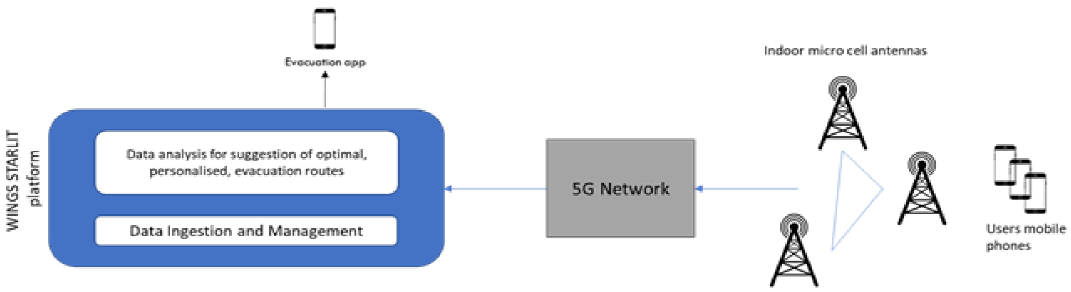


Figure 71. UC6 high level architecture.

5.3.3.2 **Relevant KPIs**

In Table 46, the full list of UC12 KPIs are presented together with their target values, as defined in D2.3 [1]. The relevant KPIs of UC12 are marked with green colour.

Table 46. UC 12 Emergency airport evacuation network requirements.

5G-Tours - Use Cases: direct specific Technical requirements		Units	(Reviewed) 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				15	100
2	**RAN** Latency (in milliseconds) - one way	msec	10				10	20
3	Throughput (in Mbps) - Min/MAX - sustained demand	Mbps	500				100	500 *
4	Reliability (%) - Min/Max	%	99,9999				99,999	99,9999
5	Availability (%) - Min/Max	%	99,99				99,99	99,99
6	Mobility (in m/sec or Km/h) - Min/Max	Km/h	10				0	10**
7	Broadband Connectivity (peak demand)	Y/N or Gbps	10				1	10
8	Network Slicing (Y/N) - if Y service deployment time (min)	Y/N	0			high	1	5
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	20				2	20***
11	Device Density	Dev/Km^2	1000K				1000K	1000K*****
12	Location Accuracy	m	<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

The KPIs that were collected and validated during the trials are in line with the above table and includes: RTT Latency, Throughput, Network Availability, Network Reliability, Service Availability, Service Reliability and Location Accuracy.

5.3.3.3 Trial scenarios

The key aspect 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.

For this use case, RTT Latency, Throughput, Reliability, Availability, and Location Accuracy have been measured, and the validation approach was following the validation methodology generated in WP7 and reported in D7.2, while it is in line with the final set of requirements defined in D2.3.

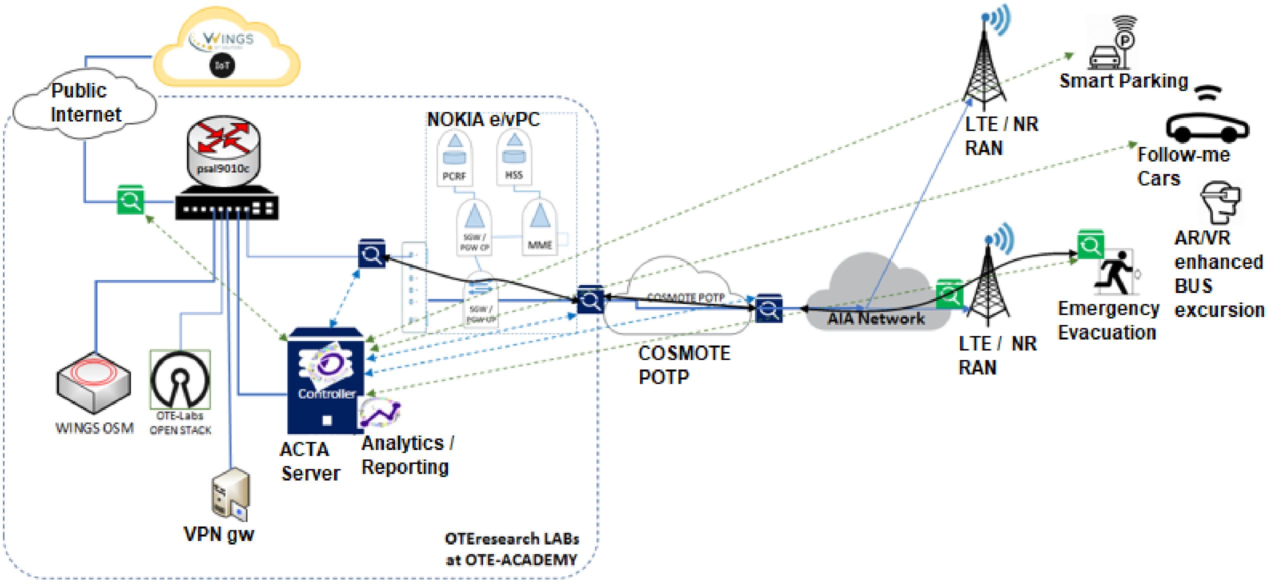


Figure 72. The participating probe components and their location for the KPI measurement of UC12.

ACTA has managed to capture these KPIs by deploying probes at various points of the network as shown in Figure 72 above. The validation methodology is elaborated in 5G-TOURS D6.4 [5] , but here it suffices to say that have set up also a simulated UE, in the form of NOKIA Fastmile Router, which was physically located at exactly the same point as the end users (satellite terminal, Figure 73).

Figure 73. Nokia Fast Mile Router in AIA Satellite Terminal, serving the UC12 trial area.

Table 47. UC12 Testing Scenario.

Parameter group	Test scenarios parameter	Parameter value
3GPP standard	3GPP Release	Rel.15
	3GPP Architecture option	NSA
RAN	Band	3.5 GHz
	Bandwidth	50 MHz
	Carrier aggregation	16
	UL/DL pattern	TDD
	Modulation	DL:256QAM, UL:64QAM
	MIMO	DL:4x2 MIMO, UL:2x2 MIMO
Core	Deployment	Central
UE	Category	CAT 7
	MIMO	DL:4x2 MIMO UL:2x2 MIMO
Service	Deployment	Central
	Service type	eMBB/URLLC/mMTC
Environment	Indoor/Outdoor	Indoor
	Number of UEs	25
	Number of cells	1
	Device density	-
	Mobility	Stationary
	Background traffic	No

Table 48. UC12 Metrics.

Metric parameters	Metrics			
Metric name	RTT latency	Packet loss	Throughput	APP RTT latency
Unit	ms	%	Mbps	ms
Probe position (network)	UE	UE	UE/Server	UE
Probe position (layer)	L2/L3	L2/L3	L4 TCP/IP	APP
Sampling rate	1min average	1min average	Measurement window average	Every app request
Tool	RFC5357 TWAMP/FUSION	RFC5357 TWAMP/FUSION	RFC 6349 VIAVI TrueSpeed	Inhouse tool

Table 49. UC12 KPIs.

KPI parameters	KPIs						
KPI name	RTT latency	Throughput	Network availability	Network reliability	Service availability	Service reliability	Location accuracy
Unit	ms	Mbps	%	%	%	%	m
Criteria	based on D2.3	based on D2.3	based on D2.3	based on D2.3	based on D2.3	based on D2.3	based on D2.3
Analysis methodology	Average of RRT latency metrics	Average of throughput metrics	Calculated as the percentage of Network layer packets	Calculated as the percentage of Network layer packets successfully	Calculated based on packet losses metric	Calculated based on packet losses	Calculated based on the posi-

			successfully delivered out of all Network layer packets sent.	delivered within the predefined Network layer KPI limits (e.g., latency <100ms) out of all Network layer packets sent.		metric and RTT latency metrics	tion estimated by the algorithm and the actual position.

5.3.3.4 QoS validation results

Table 50 presents the validation results for UC12 scenarios assuming URLLC service type. Justification is provided in case that specific KPIs failed to reach the desired target value.

Table 50. UC12 (URLLC) validation results

KPI	Measurements	WP2 requirements	Validation results	Justification
Latency (ms)	25	15	**FAIL**	Statistical fluctuations around 20 ms were observed. The 15 ms target was not met as rather strict for a trial network (even URLLC), but in a commercial network there can be re-design activities to ameliorate that.
Throughput DL (Mbps)	165-250	500	**FAIL**	5G Network bandwidth was restricted to 50MHz, due to interference issues with airport commercial mobile networks. Thus, the attainable figures approach the theoretical maximum for the available bandwidth, according to 5GPPP findings.
Throughput UL (Mbps)	11-27		PASS	
Network Availability (%)	100	99.99	PASS	
Network Reliability (%)	100	99.9999	PASS	.
Service Availability (%)	100	99.99	PASS	
Service Reliability (%)	99.966	99.9999	**FAIL**	Failed due to 15ms max. latency requirement. It can be increased if the max. value will be relaxed (in line with QoE results)
Location accuracy (m)	5.3	1	**FAIL**	Failed due to the limited number (3) and specifications (omnidirectional antennas) of indoor cells. It could be improved if more indoor cell are be deployed in the airport spaces.

The average RTT latency value is around 25ms, while the latency distribution demonstrates that the latency values are kept below 30ms with a few spikes up to 60ms (Annex A, Figure 84).

Depending on the UE used (S20 or FastMile Router), the upload capability varies from 11 to 27 Mbps on average, while the download metric varies from 165 to 250 Mbps. One must consider that the S20UEs were also running the evacuation application. Overall, measured throughput figures fail to meet the target values, set in Table 3 for KPI 3, but this is a specific situation considering the network bandwidth limitation of 50 MHz (frequencies between 3450MHz – 3500MHz), provided by OTE/COSMOTEs private band, which was imposed by the interference conditions at the AIA, since the lower frequencies from 3450MHz and the higher than 3500MHz belong to commercial 5G networks.

The overall conclusion is that the L2/L3 Network KPIs of Latency, Availability and Reliability comply or are close with the targets set in Table 4 (respectively KPIs 1, 5 and 4). In particular, for Latency, statistical fluctuations around 20 ms were observed. The 15 ms target was not met as rather strict for a trial network (even URLLC), but in a commercial network there can be re-design activities to ameliorate that.

Graphs detailing the above results for the period of the actual UC12 trial on 12/04/2022 are provided in Annex A

5.3.3.5 QoE validation results

In Figure 74, the QoE results as collected from the questionnaires are illustrated. The figure presents the average score per question, as well as the total average score for all the questions.

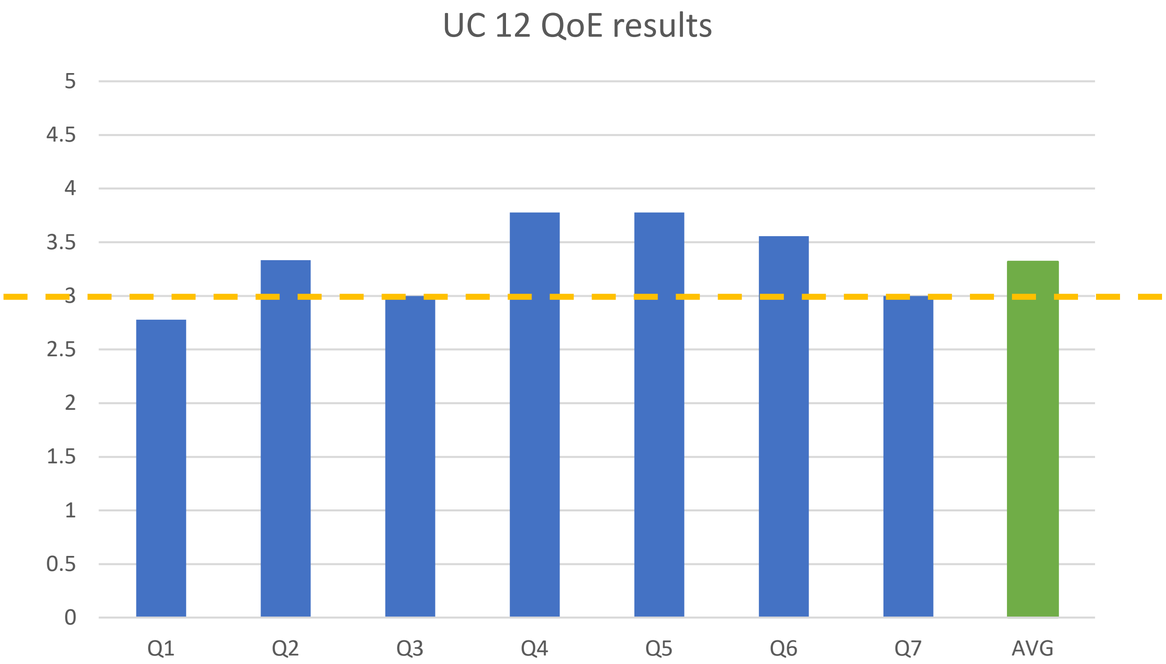


Figure 74. UC12 QoE validation results.

In UC12, we measured an average score of 3.32 which is above the targeted values of 3.0.

Questions that are **below the threshold**:

- Q1: (Value: 2.77): 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.

Which can be justified by the medium location accuracy provided by the solution.

Questions with **the higher score**:

- Q5: (Value 3.78): How much do you agree with the following: Connection remains stable and with no quality problems no matter how many people are evacuating the area with me.

Which ensures that users experience a high-quality network connection.

5.3.4 UC13 Excursion on AR/VR-enhanced bus

5.3.4.1 UC13 Description

This use case focuses on school students travelling to a destination of educational interest, generating good quality digital learning experiences both during the transportation to the destination and the visit of the exhibition, involving large throughputs and low latencies in highly mobile environments.

The main goal of this use case is to demonstrate the value offered using 5G technology in cases when groups of people travel (e.g., on a bus) in order to visit a site of interest. The use case focuses particularly on the example of school students travelling to a destination of educational interest during a field trip or excursion. In the trials, a group of 22 students from the school of Ellinogermaniki Agogi (EA) travelled on a school bus to AIA to visit an exhibit that is hosted in a public space of the airport. The fast, reliable wireless connectivity offered by 5G and the smooth streaming of online content that it can enable was utilized to generate good quality digital learning experiences both during the transportation to and from the destination, and during the visit of the exhibit.

More information about UC12 can be found in 5G-TOURS D6.4 [5].

5.3.4.2 Relevant KPIs

In Table 51, the full list of UC9 KPIs are presented together with their target values, as defined in D2.3 [1]. The relevant KPIs of UC9 are marked with green colour.

Table 51. UC 13 Excursion on an AR/VR-enhanced bus network requirements.

	5G-Tours - Use Cases: direct specific Technical requirements	Units	(Reviewed) - 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 (min)	Y/N			Y		30	5
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			10		1	10 **
11	Device Density	Dev/Km^2			1000		10K	1000K***
12	Location Accuracy	m			>=1		<4	>=1

(*) 10 Mbps per VR device downstream = 0,01 Gbps

(**) 1 device per m^2

(***) 1 or 2 students per m^2 = 1000K devices (AR/VR gogles) per Km^2

The KPIs that were collected and validated during the trials are in line with the above table and includes: RTT Latency, Throughput, Network Availability and Network Reliability. For Location Accuracy, the location of a specific UE can, in principle, be provided by the 5G radio access network. However, since the trial network for UC13 is set up with only one cell, this is not possible. Therefore, Location Accuracy has not been measured.

Trial scenarios

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 OTE-Labs) 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 to stream the correct content), the Upstream as well the Downstream one-way Latencies play a key-role.The participating components for UC13 are shown in Figure 75.

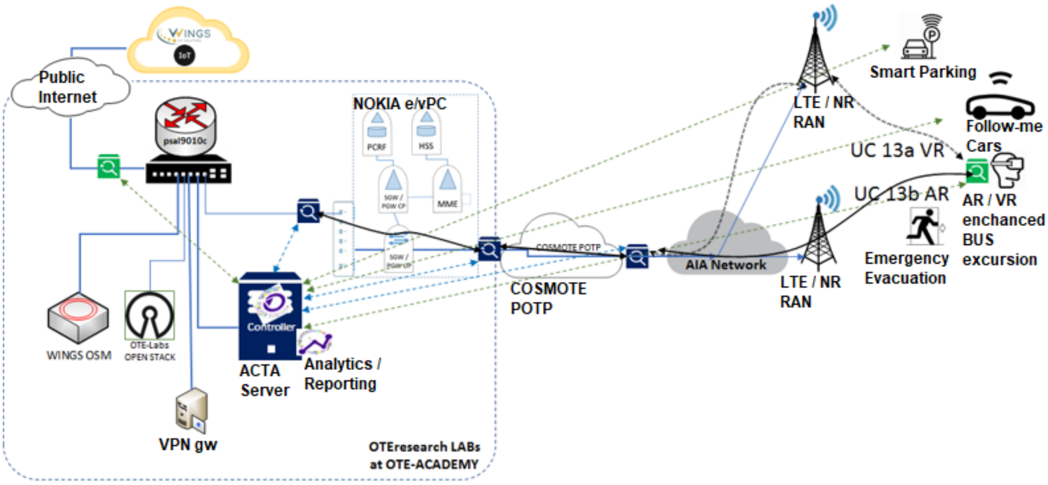


Figure 75. The participating probe components and their location for the KPI measurement of UC13.

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

Table 52. UC13 Testing Scenario.

Parameter group	Test scenarios parameter	Parameter value
3GPP standard	3GPP Release	Rel.15
	3GPP Architecture option	NSA
RAN	Band	3.5 GHz
	Bandwidth	50 MHz
	Carrier aggregation	16
	UL/DL pattern	TDD
	Modulation	DL:256QAM, UL:64QAM
	MIMO	DL:4x2 MIMO, UL:2x2 MIMO
Core	Deployment	Central
UE	Category	CAT 7
	MIMO	DL:4x2 MIMO UL:2x2 MIMO
Service	Deployment	Central
	Service type	eMBB/URLLC/mMTC
Environment	Indoor/Outdoor	Indoor/Outdoor
	Number of UEs	22
	Number of cells	3/3
	Device density	-
	Mobility	VR scenario (0 – 30 Km/h) AR scenario (Stationary)
	Background traffic	No

Table 53. UC13 Metrics.

Metric parameters	Metrics		
Metric name	RTT latency	Packet loss	Throughput
Unit	ms	%	Mbps
Probe position (network)	UE	UE	UE/Server

Probe position (layer)	L2/L3	L2/L3	L4 TCP/IP
Sampling rate	1min average	1min average	Measurement window average
Tool	RFC5357 TWAMP/FU-SION	RFC5357 TWAMP/FU-SION	RFC 6349 VIAVI TrueSpeed

Table 54. UC13 KPIs.

KPI parameters	**KPIs**			
KPI name	RTT latency	Throughput	Network availa-bility	Network reliabil-ity
Unit	ms	Mbps	%	%
Criteria	based on D2.3	based on D2.3	based on D2.3	based on D2.3
Analysis methodol-ogy	Average of RRT latency metrics	Average of throughput metrics	Calculated as the percentage of Network layer packets success-fully delivered out of all Network layer packets sent.	Calculated as the percentage of Network layer packets success-fully delivered within the prede-fined Network layer KPI limits (e.g., latency <500ms) out of all Network layer packets sent.

5.3.4.3 QoS validation results

The next tables present the validation results for both AR and VR scenarios, while justification is provided in case that specific KPIs failed to reach the desired target value.

Table 55. UC13 (eMBB) validation results.

KPI	**Measurements**	**WP2 require-ments**	**Validation results**	**Justification**
Latency (ms)	20-100	100	PASS	
Throughput DL (Mbps)	57 - 141,1	120	**FAIL** (VR) PASS (AR)	The low throughput values measured in the VR subcase are justified by the low signal strength in the outside area due to long distance from Base Sta-tion, as well as the 50Mhz bandwidth limitation.
Throughput UL (Mbps)	27,8		PASS	
Network Availability (%)	99,998	99.99	PASS	
Network Reliability (%)	97,267 -99,999	99.99	**FAIL** (VR) PASS (AR)	In the VR case, it is falling to 97,276% for a few minutes when the latency rises to 1-3s because of traffic congestion, caused by students accessing almost simultaneously the VR app in their S20s inside the bus.

The average RTT latency values are between 20 and 100 ms. Regarding delay distribution, the high percentage of values are below 30ms, with a small period of time (when network congestion appeared) with a few spikes over 50ms (Annex A, Figure 86).

While the upload capability remains impervious to indoor or outdoor environment radio conditions, peaking on average at approx. 30Mbps, the download metric varies from 150 to 60 Mbps when one moves to the outside parking area. This is to be expected, since the radio network used for the outside area is different from the one deployed in the exhibition area and, although they share common characteristics, the longer distance from the antenna installed on B11 Building to the VR parking trial area does have an impact on signal strength. Furthermore, one must factor in, once more in this use case, the 50MHz bandwidth limitation, which was imposed by the interference conditions at the airport after the Targets of Table 51 were set.

Due to the above limitations, measured throughput figures are within the target values set in Table 51 for KPIs 3 and 7 respectively.

With respect to Latency and Loss L2/L3 KPIs measured in UC 13, ACTA has managed to capture these KPIs by deploying a simulated UE, in the form of NOKIA Fastmile Router, that is not physically located at exactly the same point as the end user but is served by the same BBU under quite similar conditions. The Fastmile UE could not be permanently deployed either in the Myrtis exhibition area or the parking area for security reasons since both are public and heavily populated AIA areas. Again, the overall pattern of some KPIs deteriorating in the outdoor environment for the reasons discussed above, is also evident.

Overall latency remains within the specified limits (below 500 ms for e2e), apart from specific instances where network congestion appeared, that also impacted the overall reliability (from 99,999% falling to 97,267%, as the upper limit of 500 ms latency was momentarily exceeded).

More Specifically, the Reliability is 99,999% overall but in the VR case, it is falling to 97,267% for a few minutes when the latency rises to 1-3s because of traffic congestion, caused by students accessing almost simultaneously the VR app in their S20s inside the bus. In the trial network, this was very much a real-life situation and an indirect proof that device density which is anyhow difficult to be measured, can indeed prove critical. However, the additional signal strength, bandwidth and thus capacity of commercial 5G may make this easier to handle. Graphs detailing the above results for the period of the actual UC13 trial performed on 31/03/2022 are provided below in Annex A

5.3.4.4 QoE validation results

In Figure 76, the QoE results as collected from the questionnaires are illustrated. The figure presents the average score per question, as well as the total average score for all the questions.

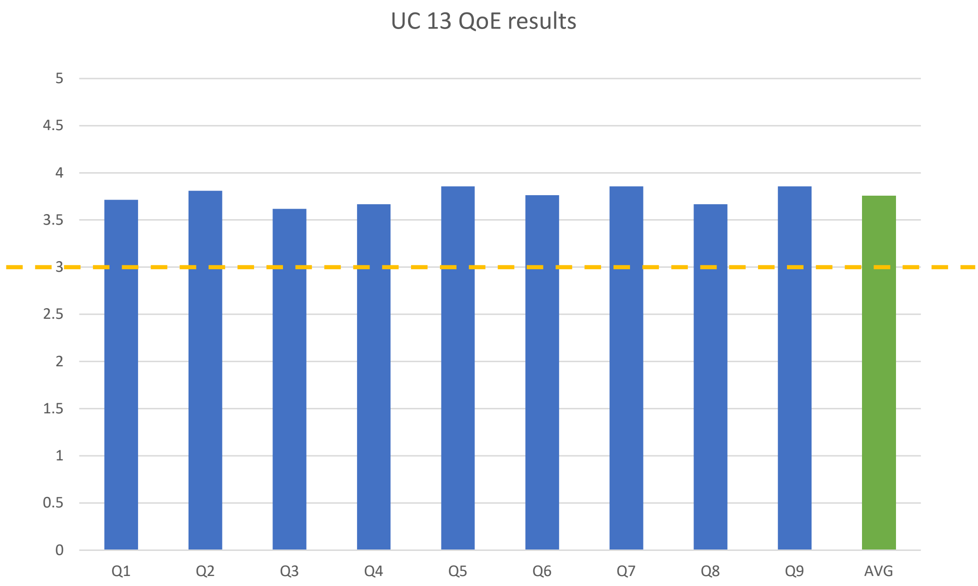


Figure 76. UC13 QoE validation results.

In UC13, we measured an average score of 3.76, which is above the targeted values of 3.0. There are no questions that are below this threshold. In addition, there are no questions that have a very high score (e.g., greater than 4.0).

5.4 Network slicing

5.4.1 UC6 and UC9 – Slicing scenario description

To validate the performance of the network slicing infrastructure, a scenario including two 5G-TOURS UCs was defined, deployed and executed. In detail, the scenario demonstrates the parallel execution and validation of two UCs: UC6 "Remote health monitoring and emergency situation notification" and UC9 "Optimal Ambulance routing".

The SA architecture and technical description of the network slices implementation can be found in D6.4 [5]. Here, we suffice to say that in this SA solution, different subscription profiles are created in UDM simulator, each associated with a Mobility-Efficient City Use Case, 6 and 9.

The topology of the network is illustrated in Figure 77, while the network deployment parameters are presented in Table 56.

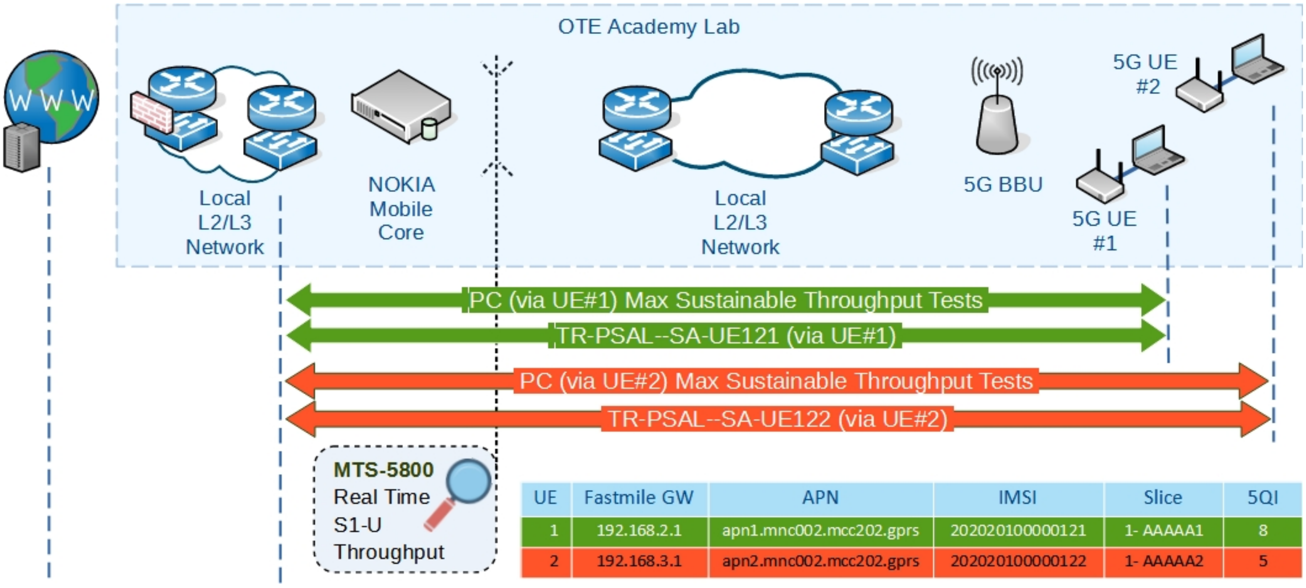


Figure 77. Network slice scenario topology.

Table 56. Network Slicing Testing Scenario.

Parameter group	Test scenarios parameter	Parameter value
3GPP standard	3GPP Release	Rel.16
	3GPP Architecture option	SA
RAN	Band	3.5 GHz
	Bandwidth	50 MHz
	Carrier aggregation	16
	UL/DL pattern	TDD
	Modulation	DL:256QAM, UL:64QAM
	MIMO	DL:4x2 MIMO, UL:2x2 MIMO
Core	Deployment	Central
UE	Category	CAT 7
	MIMO	DL:4x2 MIMO UL:2x2 MIMO

Service	Deployment	Central
	Service type	eMBB/URLLC/mMTC
Environment	Indoor/Outdoor	Outdoor
	Number of UEs	2
	Number of cells	3
	Device density	-
	Mobility	Stationary
	Background traffic	No

5.4.2 Trial scenarios and Validation results

Regarding the UC deployment, UC6 and UC9 services were deployed on the OpenStack instances in OTE premises, while a set of laptops acted as UC6 and UC9 clients respectively. The two laptops were connected to the 5G network through two Fastmile devices, ue1 and ue2, respectively supported by two different network slices (AAAA1 and AAAA2). In this way, all the traffic of UC6 was supported by network slice AAAA1, while the traffic of UC9 was supported by network slice AAAA2.

During the trial, both UCs were initiated, and traffic was injected in the 5G network in both network slices. In detail, UC6 (critical service) generated small packets in the uplink direction, while UC9 (not critical service) generated both service requests/response and video flows on both directions.

Several network and applications metrics were collected, analysed, and evaluated during the trial.

Table 57. Network Slicing Metrics.

Metric parameters	**Metrics**			
Metric name	RTT latency	Packet loss	Downlink Throughput	Uplink Throughput
Unit	ms	%	Mbps	Mbps
Probe position (network)	UE	UE	UE/Server	UE/Server
Probe position (layer)	L2/L3	L2/L3	L4 TCP/IP	L4 TCP/IP
Sampling rate	1min average	1min average	Measurement window average	Measurement window average
Tool	RFC5357 TWAMP/FUSION	RFC5357 TWAMP/FUSION	RFC 6349 VIAVI TrueSpeed	RFC 6349 VIAVI TrueSpeed

Table 58. Network Slicing validation results.

KPI	**Slice AAAA1**	**Slice AAAA2**	**Validation results**	**Justification**
Latency (ms)	12	11	PASS	
Throughput DL (Mbps)	254	50	PASS	Slice AAAA1" was limited to max 300mbps DL, by the network, while Slice AAAA2" was limited to max 50mbps DL
Throughput UL (Mbps)	19	22	PASS	
Packet Loss	0%	0%	PASS	
App layer RTT latency (ms)	25	200	PASS	
App layer (request/response) latency (ms)	32	6s	PASS	

Graphs detailing the above results for the period of the actual slicing trial performed on 26/05/2022 are provided below in Annex A

Regarding the application metrics, we can mention that the RTT app layer latency measured in the first (critical service) network slice was around 25 ms, while the RTT app layer latency measures in the video flow in the second (not critical service) network slice was around 200 ms. The time needed for the realisation of the whole service functionality (request/routing/video generation/video received/response) was about 6s.

6 Conclusion

In the current document, the final 5G-TOURS integrated ecosystem is presented together with the final validation results from all 13 Use Cases.

Regarding the integrated ecosystem, this deliverable act as a complement to deliverables D4.4 [3], D5.4 [4] and D6.4 [5], in which the final site infrastructure, the hardware and software components deployment and the preparation and execution of the trials were presented for each of the three sites respectively. Additional details are provided about the realised innovation in each site, the realisation of network slicing, as well as details about how this integrated ecosystem ensures the smooth deployment and execution of the trials.

Regarding the validation results, the realisation of the validation plan is described in each use case, as well as, the process of collecting the metrics, analysing the metrics, calculating the KPIs and finally validating the KPIs against the latest use case requirements presented in D2.3 [1]. In addition to the selected KPIs for each use case, the details behind the validation process are presented, including: a) the scenario details using a scenario template; b) the probe positions in the network; b) the probe positions in the protocol layers; c) the trial details (e.g.: duration, sampling period, collection method); d) the methodology used during the analysis and validation; and e) any assumptions made during collection/analysis/validation. All the collected metrics were analysed and the KPIs were calculated and validated against the predefined targets. In addition, insights were provided in the case of successful validation results, while, in case of not fulfilled KPIs, a justification. In addition, in selected use cases, models for QoS/QoE correlation were created by using correlation-regression analysis.

As a summary of the validation results (both QoS and QoE), we can mention that:

- Regarding the QoS validation results, these are successful for the vast majority of the Use Cases, meaning that the trials prove that the use of 5G was successful in fulfilling even the strict requirements of the verticals (D2.3 [1]). In only two scenarios, we identified misalignments, but these can be easily justified by the service deployment, the extremely strict requirement and some limitations of the trial deployment. All these are explained in the relative subsections.
- Regarding QoE (user satisfaction) validation results, in all scenarios the average score is above the defined threshold. This practically means that in all Use Cases, even in the two Use Cases where some of the QoS KPIs failed to fulfil the targets, the measured level of user satisfaction is high and the end-users are happy with the use of the application.
- It became obvious that for some use cases the use of 5G network is needed for the smooth operation of the services since 4G cannot support some of their strict requirements.

Regarding next steps, some trials from selected use cases can be executed in a commercial 5G SA network in order to evaluate the performance when all the limitations of a non-commercial network are removed (e.g., use of the full bandwidth of 100MHz, carrier aggregation of two or more technologies, optimisation of network slices).

Acknowledgment

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

ANNEX A – Use Cases 10-13 KPI diagrams

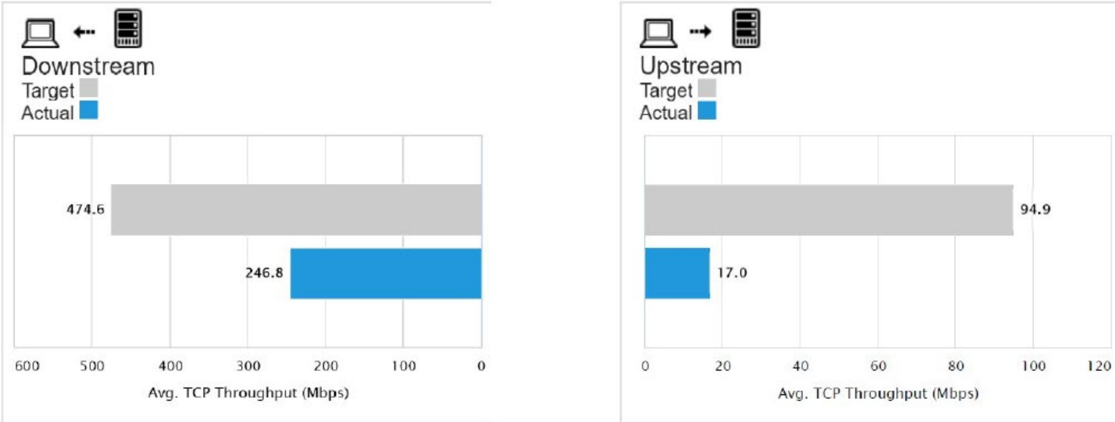


Figure 78. UC10 Max Throughput Measurement results with Samsung Galaxy S20.

In the above figure as in all maximum throughput measurements performed by ACTA, the setting of Target Values is configured high enough in order not to limit the measurement capacity but instead generate high demand and allow peak throughput of the network under monitoring to be reached.

Figure 79. UC10 Loss and Latency results for e2e path (L2/L3 switch before Core Network up to Fastmile UE at AIA B17.

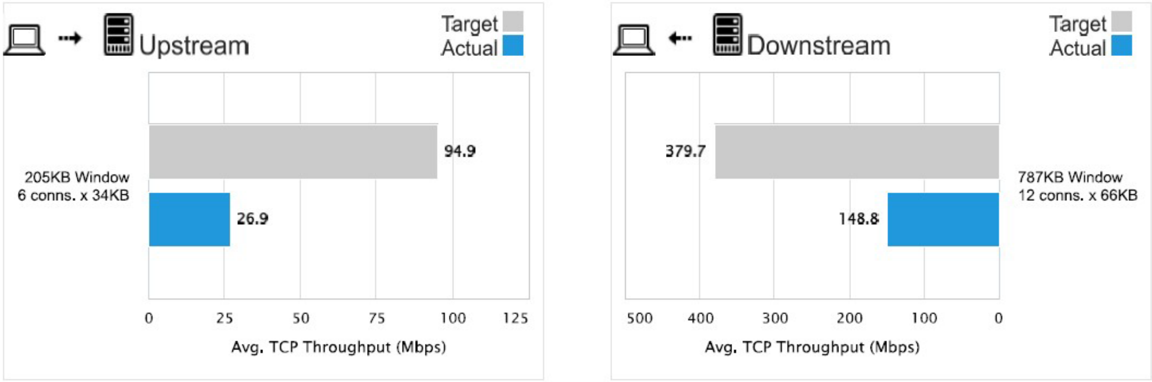


Figure 80. UC11 Max Throughput Measurement results with Peplink routers.

Figure 81. UC11 Loss, Latency, Availability, Reliability Measurement results for the e2e network.

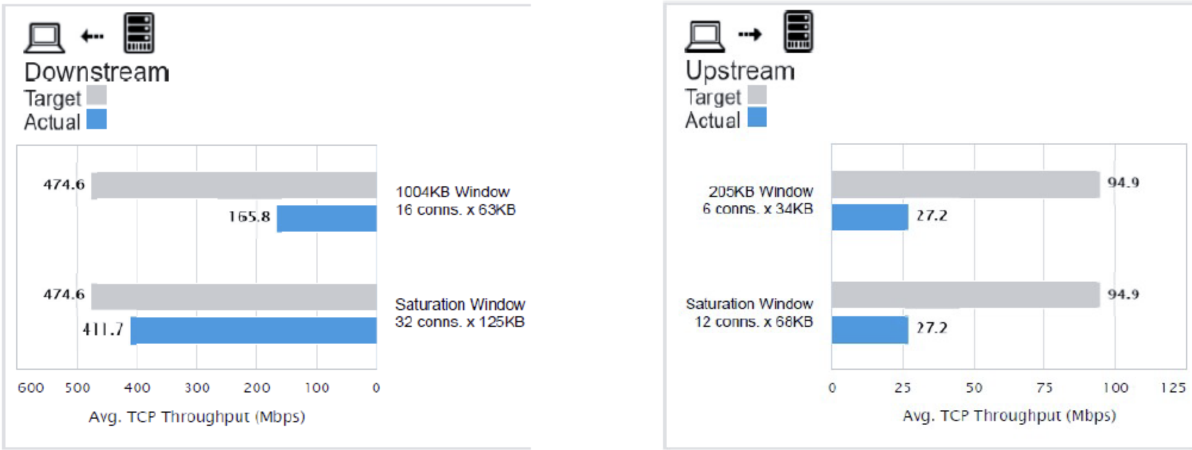


Figure 82. UC12 Max Throughput Measurement results with FastMile router UE.

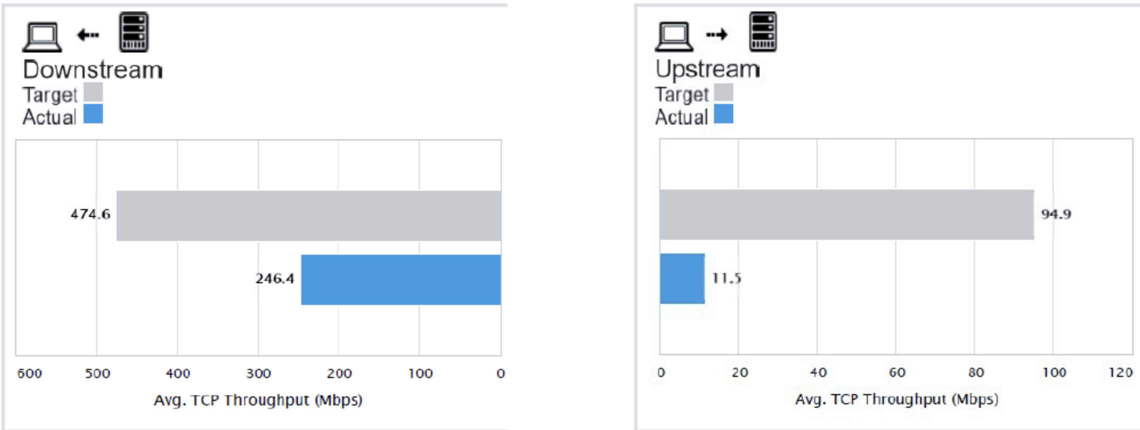
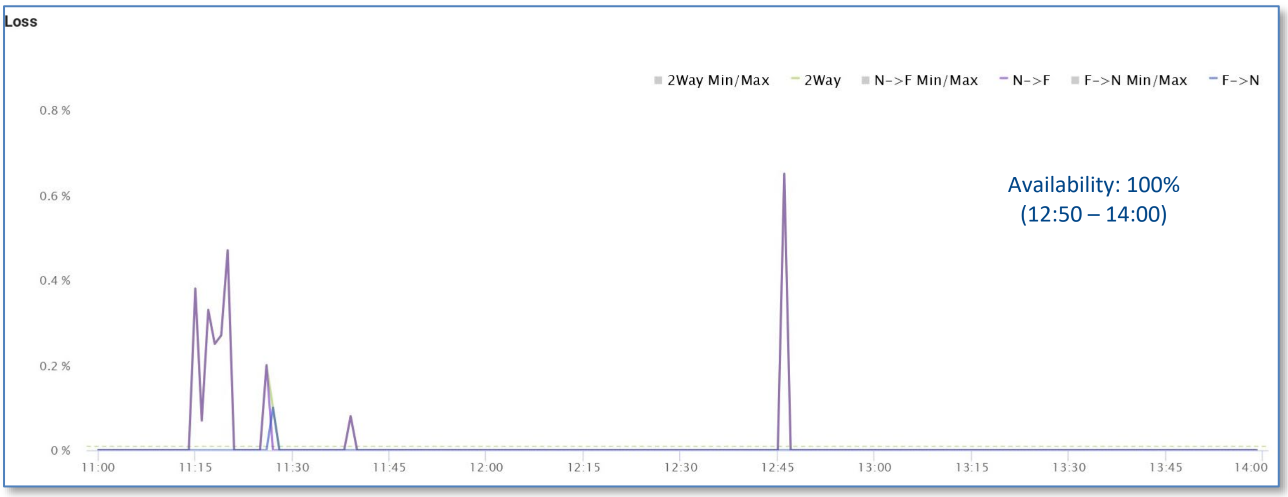


Figure 83. UC12 Max Throughput Measurement results with Samsung Galaxy S20.



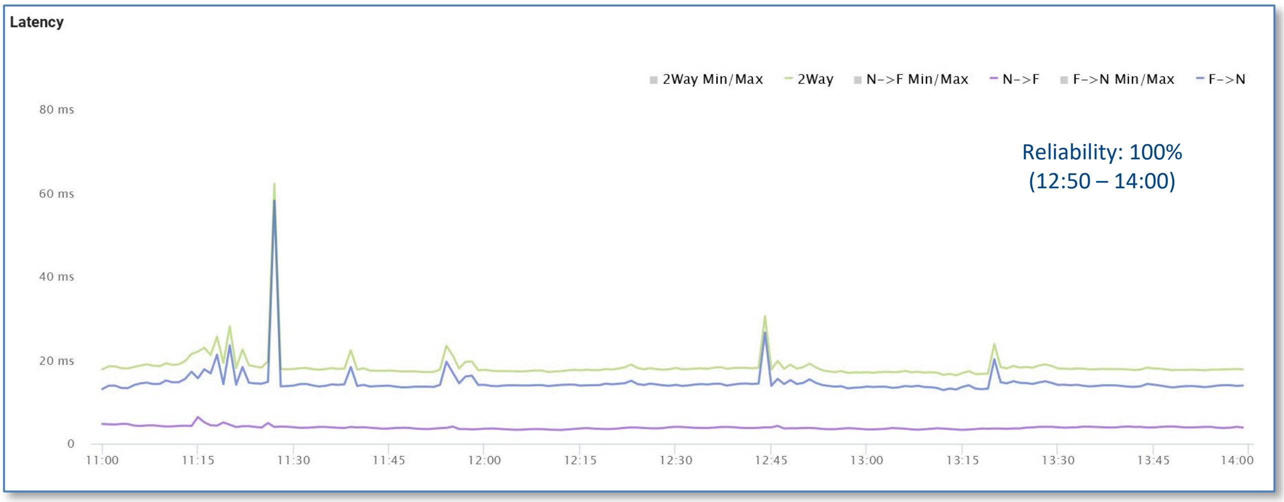


Figure 84. UC12 Loss, Latency, Availability, Reliability results for the e2e network.

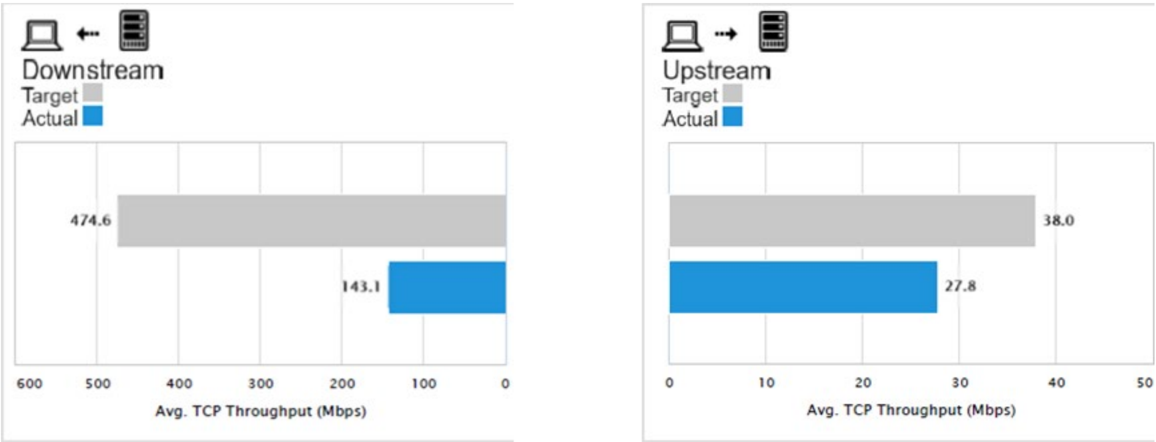


Figure 85. UC13b AR Myrtis exhibition Max Throughput Measurement results.

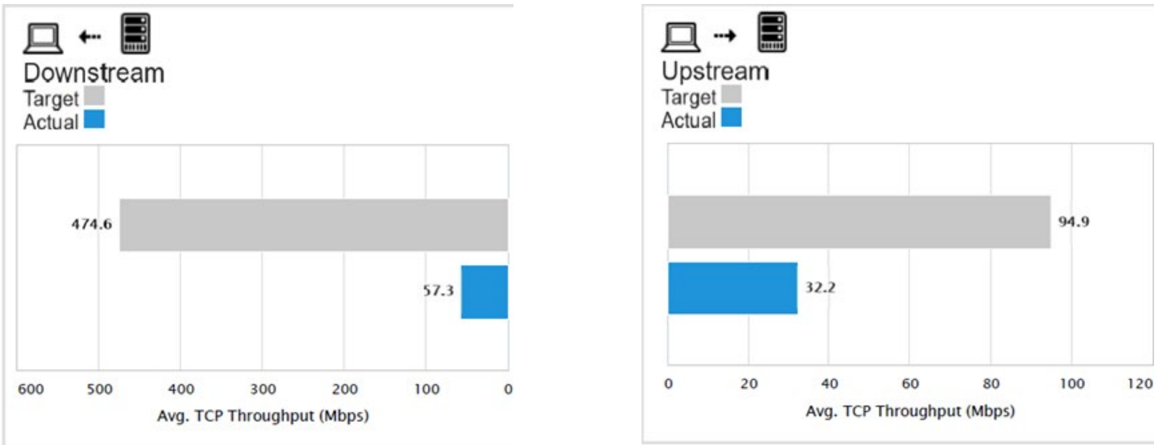


Figure 86. UC13a VR Bus excursion Max Throughput Measurement results.

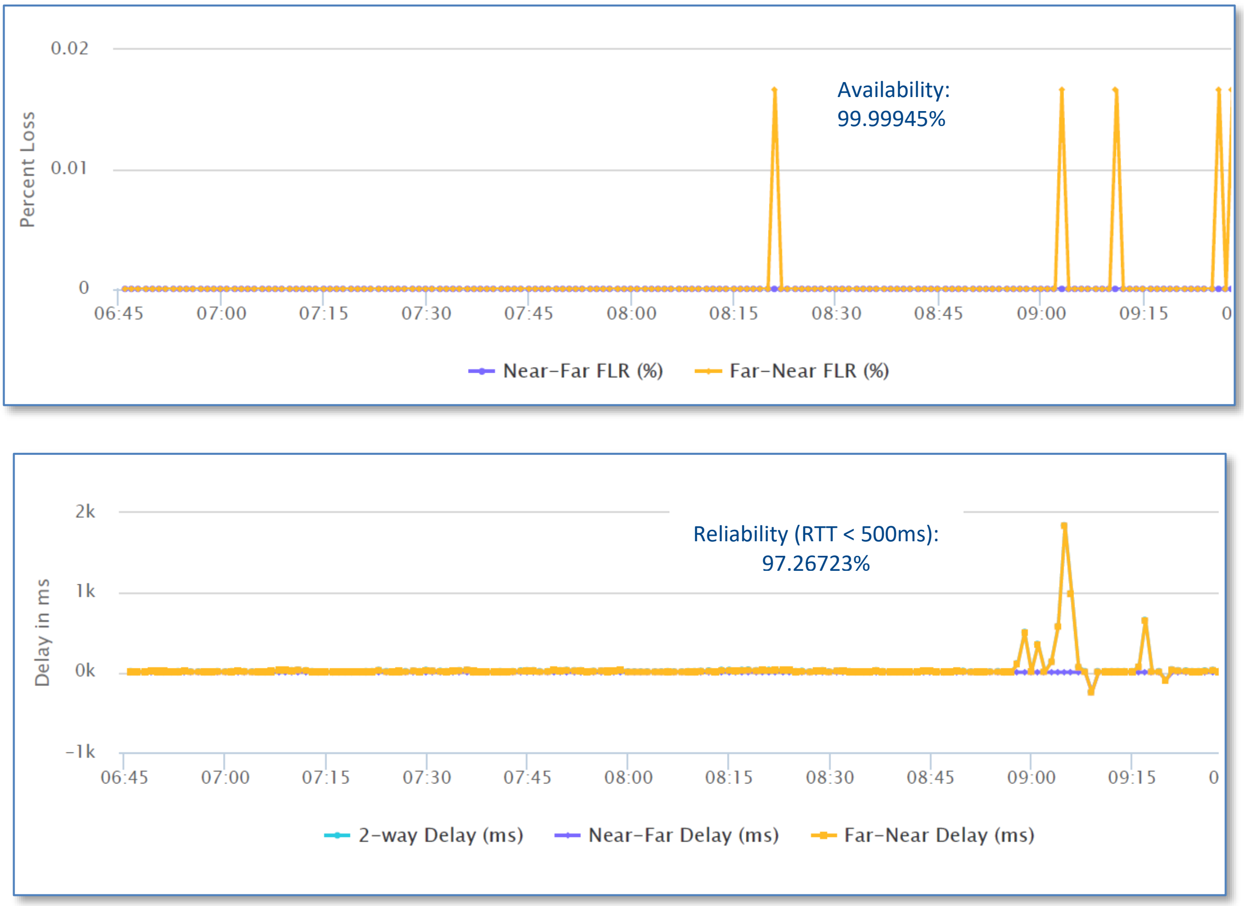
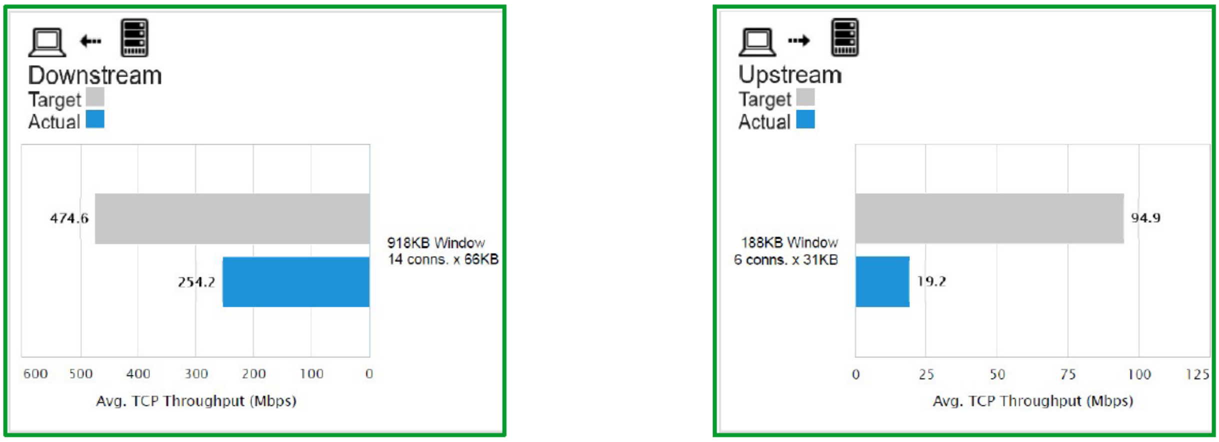
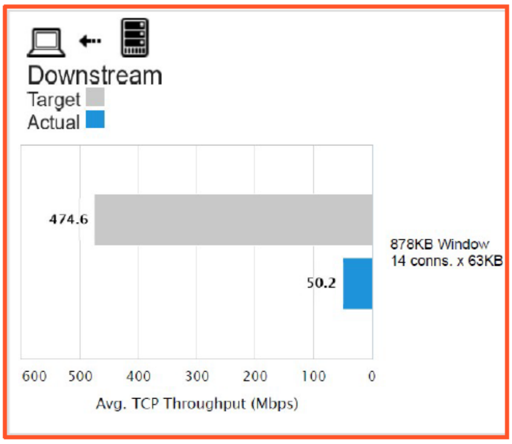
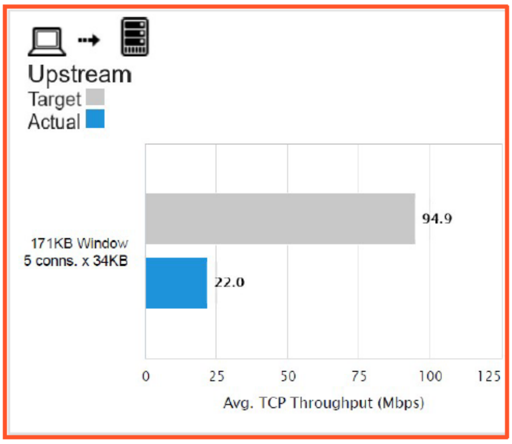


Figure 87. UC13a VR L2/L3 KPIs Transport path up to Fastmile UE.



UE	Fastmile GW	APN	IMSI	Slice	5QI
1	192.168.2.1	apn1.mnc002.mcc202.gprs	202020100000121	1- AAAAA1	8





UE	Fastmile GW	APN	IMSI	Slice	5QI
2	192.168.3.1	apn2.mnc002.mcc202.gprs	202020100000122	1- AAAAA2	5

Figure 88. Slice1 & 2 Max Throughput Measurement results.

Figure 89. UE performance supported by Critical slice (AAAA1).

Figure 90. UE performance supported by Non-Critical slice (AAAA2).

ANNEX B – Use case questionnaires (QoE)

UC1

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

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 artirstic 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 survaillance functionalities helped you to do better you job ?
Strongly agree, agree, neutral, disagree, Strongly Disagree

Please state how much you agree with the following statement: the fires and strutural 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

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 artirstic 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 survaillance functionalities helped you to do better you 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

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
'Open comment'

UC5

Please help us to know your impression! All feedback will be anonymous.

Familiarity with Live Video Production applications

1. 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

---

2. Please state your past/current profession, if relevant: ______________________________

General

Please rate the following statements on a scale of 1 to 5, with 5 being "strongly agree" and 1 being "strongly disagree".

3. The Demonstrated 5G Production is very important in order to succeed in my job

1	2	3	4	5

4. The Demonstrated 5G Production brings important benefits to standard production work-flows

1	2	3	4	5

5. The Demonstrated 5G Production brings important benefits to a News cast environment

1	2	3	4	5

6. The Demonstrated 5G Production brings important benefits to a live event production

1	2	3	4	5

7. 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

8. 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

9. I think the Demonstrated 5G Production can be also useful in:

   ____

10. The production in this Demonstrated 5G Production offers new possibilities over the traditional live production

1	2	3	4	5

11. The production in this Demonstrated 5G Production meets my needs very well

1	2	3	4	5

12. 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

13. 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

14. 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

15. 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:

- [ ] in 90%-100% of all cases
- [ ] in 70% - 90% of cases
- [ ] In 50% to 70% of the cases
- [ ] in 20% to 50% of the cases
- [ ] in less than 20% of the cases

16. 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:

- [ ] in 90%-100% of all cases
- [ ] in 70% - 90% of cases
- [ ] in 50% to 70% of the cases
- [ ] in 20% to 50% of the cases
- [ ] in 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.

17. How do you evaluate the video quality?

1	2	3	4	5

18. How do you evaluate the audio quality?

1	2	3	4	5

19. How is the video quality compared to current live street concert production?

1	2	3	4	5

20. How is the audio compared to a street concert production audio?

1	2	3	4	5

21. The given battery is sufficient for such broadcasts?

1	2	3	4	5

22. ` The 5G signal was stable (bars in the UI)

1	2	3	4	5

23. 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

24. 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

25. 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)

26. I think that I would like to use this live 5G video production service in my professional activity frequently

1	2	3	4	5

27. I thought the fact that this live 5G video production service was easy to deploy

1	2	3	4	5

28. 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

29. I found this live 5G video production service complex

1	2	3	4	5

30. 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

31. 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

5G-TOURS UC6 Questionnaire for Patients

1.

How do you asses your experience in terms of intuitiveness of the service?

Mark only one oval.

Very Poor

Poor

Fair

Good

Excellent

2.

How do you assess your experience in terms of usefulness of the service?

Mark only one oval.

Very Poor

Poor

Fair

Good

Excellent

3.

How do you asses your experience in terms of responsiveness of the service?

Mark only one oval.

Very Poor

Poor

Fair

Good

Excellent

4.

How do you assess the delays of displaying measurements results from the wearable devices by web dashboard?

Mark only one oval.

Very big

Significant

Perceptible

Acceptable

No delays

5.

How do you assess the reaction time (i.e ambulance arrive) in case of emergency notification by system?

Mark only one oval.

Very Poor

Poor

Fair

Good

Excellent

6.

Were situations when false alarm raised?

Mark only one oval.

All the time

Very often

Often

Rarely

Never

7.

Were situations when no alarm was raised even though measurement results should trigger it?

Mark only one oval.

All the time

Very often

Often

Rarely

Never

8.

Please rate the statement: I found the system unnecessarily complex

Mark only one oval.

Strongly agree

Agree

Neutral

Disagree

Strongly disagree

9.

Please rate the statement: I would imagine that most people would learn to use this system very quickly.

Mark only one oval.

Strongly disagree

Disagree

Neutral

Agree

Strongly agree

10.

How does this technology was important to increase your sense of health security?

Mark only one oval.

Not at all important

Slightly important

Moderately important

Important

Extremely important

11.

How do you rate the user experience in terms of the quality and promptness of the service?

Mark only one oval.

Very Poor

Poor

Fair

Good

Excellent

12.

How ready are you to use this technology as part of your daily routine?

Mark only one oval.

Not ready

Ready

Slightly ready

Medium ready

Extremely ready

13.

Please state how much you agree with the following statement: the technology is ready to be used in an operational environment

Mark only one oval.

Strongly disagree

Disagree

Neutral

Agree

Strongly agree

14.

Do you think that the cost to your health protection will be lower thanks to this technology?

Mark only one oval.

Strongly disagree

Disagree

Neutral

Agree

Strongly agree

15.

How likely do you feel that this technology might improve your overall health?

Mark only one oval.

Strongly disagree

Disagree

Neutral

Agree

Strongly agree

16.

If you like please provide your open feedback on your experienced during this use case:

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UC7

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

NAME:

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:
Add Comments

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:

Add comments

UC9

5G-TOURS UC9 Questionnaire for ambulance crews

1. Have you noticed any shortcomings in the ambulance management system, such as loss of service, misdirection, delays in issuing commands?

Mark only one oval.

All the time

Very often

Often

Rarely

Never

2. To what extent does the proposed technology improve patient transport?

Mark only one oval.

Very weakly

Weakly

Honestly

Well

Perfectly

3. How do you evaluate your experience in terms of intuitiveness of the service?

Mark only one oval.

Very weakly

Weakly

Honestly

Well

Perfectly

4. How do you evaluate your experience in terms of service utility?

Mark only one oval.

Very poor

Poor

Honestly

Well

Perfectly

5. How do you evaluate your experience in terms of the speed of service response?

Mark only one oval.

Very poor

Poor

Honestly

Well

Perfectly

6. How much you agree with the following statement: the technology is ready for use in an operational environment

Mark only one oval.

Strongly agree

Agree

Neutral

Disagree

Strongly disagree

7. If you like please provide your open feedback on your experienced during this use case:

UC10

5G-TOURS UC10 Questionnaire for user (driver)

1. 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?

Mark only one oval.

Strongly disagree

Disagree

Neutral

Agree

Strongly agree

2. 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?

Mark only one oval.

Strongly disagree

Disagree

Neutral

Agree

Strongly agree

3. 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?

Mark only one oval.

Strongly agree

Agree

Neutral

Disagree

Strongly disagree

4. 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?

Mark only one oval.

Strongly disagree

Disagree

Neutral

Agree

Strongly agree

5. 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?

Mark only one oval.

Strongly disagree

Disagree

Neutral

Agree

Strongly agree

6. If you like please provide your open feedback on your experienced during this use case:

UC11

5G-TOURS UC11 Questionnaire for airport staff

1. How much do you agree with the following: There are seldom (or no) perceptible delays in video.

Mark only one oval.

Strongly disagree

Disagree

Neutral

Agree

Strongly agree

2. How much do you agree with the following: There are seldom (or no) perceptible delays in audio.

Mark only one oval.

Strongly disagree

Disagree

Neutral

Agree

Strongly agree

3. How much do you agree with the following: There are seldom (or no) quality problems such as crackling audio and choppy audio/video.

Mark only one oval.

Strongly disagree

Disagree

Neutral

Agree

Strongly agree

4. How much do you agree with the following: There are seldom (or no) choppy or frozen audio/video.

Mark only one oval.

Strongly disagree

Disagree

Neutral

Agree

Strongly agree

5. 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

Mark only one oval.

Strongly disagree

Disagree

Neutral

Agree

Strongly agree

6. How do you rate the user experience in terms of precision?

Mark only one oval.

Very poor

Poor

Fair

Good

Excellent

7. Please state how much you agree with the following statement: the technology is ready to be used in an operational environment

Mark only one oval.

Strongly disagree

Disagree

Neutral

Agree

Strongly agree

8. 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?

Mark only one oval.

Strongly disagree

Disagree

Neutral

Agree

Strongly agree

9. 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?

Mark only one oval.

Strongly disagree

Disagree

Neutral

Agree

Strongly agree

10.

If you like please provide your open feedback on your experienced during this use case:

UC12

5G-TOURS UC12 Questionnaire for the User

1. 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.

Mark only one oval.

Strongly disagree

Disagree

Neutral

Agree

Strongly agree

2. 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.

Mark only one oval.

Strongly disagree

Disagree

Neutral

Agree

Strongly agree

3. 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.

Mark only one oval.

Strongly disagree

Disagree

Neutral

Agree

Strongly agree

4. 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.

Mark only one oval.

Strongly disagree

Disagree

Neutral

Agree

Strongly agree

5. How much do you agree with the following: Connection remains stable and with no quality problems no matter how many people are evacuating the area with me.

Mark only one oval.

Strongly disagree

Disagree

Neutral

Agree

Strongly agree

6. How do you rate the user experience in terms of precision?

Mark only one oval.

Very Poor

Poor

Fair

Good

Excellent

7. Please state how much you agree with the following statement: the technology is ready to be used in an operational environment

Mark only one oval.

Strongly disagree

Disagree

Neutral

Agree

Strongly agree

8.

If you like please provide your open feedback on your experienced during this use case:

UC13

5G-TOURS UC13 Questionnaire for visitors

1. How do you rate the time you had to wait to download content?

Mark only one oval.

Very poor (much too long)

Poor (too long)

Fair (bearable)

Good (not very long)

Excellent (not at all long)

2. How was the quality of video and audio?

Mark only one oval.

Very poor

Poor

Fair

Good

Excellent

3. How often did you experience problems such as delays, interruptions, bad video and audio?

Mark only one oval.

Very often

Often

Sometimes

Rarely

Never

4. Please state how much you agree with the following statement: I feel comfortable interacting with the AR and VR content.

Mark only one oval.

Strongly disagree

Disagree

Neutral

Agree

Strongly agree

5. How do you rate the overall VR experience on the bus?

Mark only one oval.

Very poor

Poor

Fair

Good

Excellent

6. 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.

Mark only one oval.

Strongly disagree

Disagree

Neutral

Agree

Strongly agree

7. How do you rate the overall interaction with the exhibit through the AR application?

Mark only one oval.

Very poor

Poor

Fair

Good

Excellent

8. 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.

Mark only one oval.

Strongly disagree

Disagree

Neutral

Agree

Strongly agree

9. 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.

Mark only one oval.

Strongly disagree

Disagree

Neutral

Agree

Strongly agree

10.

If you wish, please provide your feedback on your AR and VR experiences during the excursion in your own words:

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