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

D6.4

Final mobility efficient city use cases implementation results

Project Details	
Call	H2020-ICT-19-2019
Type of Action	RIA
Project start date	01/06/2019
Duration	38 months
GA No	856950

Deliverable Details	
Deliverable WP:	WP6
Deliverable Task:	T6.1, T6.2, T6.3, T6.4
Deliverable Identifier:	5G-TOURS_D6.4
Deliverable Title:	Final mobility efficient city use cases implementations results
Editor(s):	Velissarios Gezerlis (OTE)
Author(s):	Evangelia Giasla (AIA) Chrysoula Falangari (AIA) Nikos Papagiannopoulos (AIA) Vera Stavroulaki (WINGS) Stefania Stavropoulou (WINGS) Eleni Giannopoulou (WINGS) Vasilis Laskaridis (WINGS) Michalis Mitrou (WINGS) Niki Pantazi (WINGS) Charalampos Korovesis (WINGS) Kostas Tsagkaris (WINGS) Vangelis Kosmatos (WINGS) Panagiotis Demestichas (WINGS) Velissarios Gezerlis (OTE) Stelios Andoulidakis (OTE) Konstantinos Chelidonis (OTE) George Tsiouris (OTE) Vasilis Kassouras (KEMEA) Athanasios Giannopoulos (NOKIA-GR) Eleni Pappa (NOKIA-GR) Panayiotis Verrios (ACTA) Tilemachos Doukoglou (ACTA) Ioannis Patsouras (ACTA) Michalis Iliadis (ACTA) Konstantinos Tzalas (ACTA) Antonis Georgiou (ACTA) Efstathios Katranaras (SEQ)

	Pavlos Koulouris (EA) Sofoklis Sotiriou (EA) Gregory Milopoulos (EA)
Reviewer(s):	Evangelos Kosmatos (WINGS) Eleni Pappa (NOKIA-GR) Ran Rahav (LIV) Ghibaudo Elena (TOR) Silvia Provedi (ER-IT) Belkacem Mouhouche (SRUK) Eleni Giannopoulou (WINGS)
Submission Date:	31/05/2022
Dissemination Level:	PU
Status:	Final
Version:	1.0
File Name:	5G-TOURS_D6.4_Final mobility efficient city use cases implementation results

Deliverable History		
Version	**Date**	**Modification**
V1.0	31/05/2022	Initial version, submitted to EC through SyGMa.

Contents

List of Acronyms and Abbreviations

Acronym	Description
3D	3 Dimensional
3GPP	Third Generation Partnership Project
5G	5th Generation mobile Wireless Communication System
5G PPP	5G Public Private Partnership
5GC	5G Core
AI	Artificial Intelligence
AIA	Athens International Airport
AMF	Access and Mobility Management Function
AMIS	Airside Monitoring Inspection Specialist
ANN	Artificial Neural Networks
API	Application Programming Interface
AR	Augmented Reality
ASOC	Airport Service Operations Center
BBU	Baseband Unit
BLE	Bluetooth Low Energy
CMM	Cloud Mobility Manager
DDNS	Dynamic DNS
DNS	Domain Name System
eDRX	Extended Discontinuous Reception
EETT	Hellenic Telecommunications and Post Commission
eMBB	enhanced Mobile Broadband
eMBMS	evolved Multimedia Broadcast Multicast Service
EPC	Evolved Packet Core
EPG	Evolved Packet Gateway
EVK	Evaluation Kit
FDD	Frequency Division Duplex
FFmpeg	Fast Forward MPEG
FTP	File Transfer Protocol
glb	Graphics Language Binary
glTF	Graphics Language Transmission Format
gNB	5G Node B
HCAA	Hellenic Civil Aviation Administration
HLS	HTTP Live Streaming
HTTP	Hypertext Transfer Protocol
HTTPS	Hypertext Transfer Protocol Secure
ICMP	Internet Control Message Protocol
IGMP	Internet Group Management Protocol
IoT	Internet of Things
KPI	Key Performance Indicators
KVaP	KPI Validation Platform
KMVaP	KPI Management & Validation Platform
LTE	Long-Term Evolution
LTE-M	Long-Term Evolution for Machines
LWM2M	Lightweight M2M
MANO	Management and Orchestration
MEC	Multi-Access Edge Computing
mMTC	Massive Machine Type Communications
mmWave	Millimeter Wave
mRRH	micro Remote Radio Head
NB-IoT	Narrow Band IoT
NFV	Network Functions Virtualization
NR	New Radio
NRFs	Network Repository Function
NSA	Non-Standalone Access
NSSF	Network Slice Selection Function
NTP	Network Time Protocol
OSM	Open Source MANO
OSS	Operation Support Systems
P2P	Peer-to-Peer
PfSense	Open Source Firewall
PLMN	Public Land Mobile Network
POTP	Packet Optical Transport Protocol
PPPoE	Point-to-Point Protocol over Ethernet
PSM	Power Saving Mode
QoE	Quality of Experience

QoS	Quality of Service
RAN	Radio Access Network
RSSI	Received Signal Strength Indicator
RSRP	Reference Signals Received Power
RTCP	Real-Time Transport Control Protocol
RTMP	Real-Time Messaging Protocol
RTP	Real-Time Transport Protocol
RTT	Round Trip Time
RTSP	Real Time Streaming Protocol
SA	Standalone Access
SC	Small Cells
SMF	Session Management Function
SMTP	Simple Mail Transfer Protocol
SNMP	Simple Network Management Protocol
SSL	Secure Sockets Layer
STB	Satellite Terminal Building
TCO	Total Cost of Ownership
TCP/IP	Transmission Control Protocol/Internet Protocol

TOA	Time of Arrival
UART	Universal Asynchronous Receiver/Transmitter
UC	Use Case
UDM	Unified Data Management
UDP	User Datagram Protocol
UE	User Equipment
UI	User Interface
UPnP	Universal Plug and Play
URLLC	Ultra-Reliable Low Latency Communication
USB	Universal Serial Bus
vEPC	Virtual Evolved Packet Core
VNF	Virtual Network Function
VNFC	Virtual Network Function Components
VOD	Video on Demand
VPN	Virtual Private Network
VR	Virtual Reality
WP	Work Package
XpertEyE	Remote Assistance Solution software

List of Figures

List of Tables

Executive Summary

The 5G-TOURS project work within the mobility-efficient city aims at implementing a set of use cases that improve mobility-related experiences from various perspectives. These use cases revolve around the 5G EVE Athens site, including an extension to the Athens International Airport (AIA). This deliverable describes the mobility efficient city use cases final implementation evaluated on final network infrastructure that is deployed at AIA as an extension of the 5G EVE Athens site, as well as the final results that have been achieved.

The scope of this deliverable is to describe the final progress in the implementation of the use cases to date in terms of the network deployment and the equipment that is utilized, as well as from the application point of view and the terminal equipment components and interfaces. These interfaces enable the communication between the actors of each UC and the 5G-TOURS network infrastructure. Furthermore, a crucial part of this deliverable is to present the steps that have been taken in terms of integration and trials at the AIA facilities, while also presenting results that have been produced during the trials in the field.

Finally, this deliverable serves as a final successor to deliverable D6.1 [2], D6.2 [27] produced within WP6 - Mobility-efficient city use cases implementation, which focus on the implementation of the use cases of the mobility-efficient city. In D6.1 the focus was on the use cases description, in the definition of a detailed work plan as well as on the architecture definition of each use case. In addition, deliverable D6.2 described the progress in terms of the functionality implemented for the 4 UCs of the mobility-efficient city. Subsequently, D6.4 describes the final progress and achievements in terms of implementation of the infrastructure and the applications for the following 4 UCs of the mobility-efficient city, as well as the final validation results:

- **Use case 10** – Smart airport parking management: In this use case, parking users at the airport obtain real time information on available and occupied spaces through 5G-enabled parking sensors. They are able to locate available parking spaces directly through a mobile application and are guided there via the optimal route. This use case involves large throughputs, low latencies, and high capacity, which represents an essential functionality of the 5G family technology.
- **Use case 11** – Video-Enhanced ground-based moving vehicles: 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.
- **Use case 12** – Emergency airport evacuation: This use case focuses on the evacuation of the airport in a quick and organized fashion in case of an emergency, providing automated guidance of emergency routes from the affected area up to the muster areas. This use case focuses on the location accuracy part of 5G technology. The application relies on AR technology suitable for training exercises and simulations at the airport.
- **Use case 13** – Excursion on an Augmented Reality (AR)/Virtual Reality (VR)-enhanced bus: 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.

1 Introduction

The **mobility-efficient city** aims at presenting a set of use cases (UCs) that improve mobility and travel-related experiences from various perspectives. The UCs involved in the mobility-efficient city show how airport and mobility-related educational processes can be improved by leveraging the offering of 5G both from the side of the visitors and of the airport management. To this end, the project focuses on: (i) smart sensor and AI-based parking management, (ii) follow-me vehicles enhanced with high-quality video streaming capabilities, (iii) personalized evacuation procedure and (iv) efficient ways of entertaining/educating travelers/students going on an excursion on a smart bus.

This final deliverable describes the final progress of the mobility-efficient city UCs trials based on the implementation plan of WP6 and describes in detail the four UCs in terms of network infrastructure, applications and testing results.

The four use cases concerning the mobility-efficient city are:

a) **Smart airport parking management:** This is a solution that relies on large throughputs, low latencies and high capacity provided by 5G technology. 50 parking sensors, installed at AIA in 50 parking positions that help keep track of available and occupied spots in real time, facilitating the parking process within the airport.

b) **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 (Apron), and attend to incidents, emergencies, and critical events. 5G-TOURS is developing a solution to equip mobile units of the airport with full high-definition cameras, sending multiple live feeds to the Airport Security Operations Centers (ASOCs) and other stakeholders.

c) **Emergency airport evacuation:** This UC monitors the location of the different users and provides 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 simulating exercises to be held in the airport. Furthermore, this use case focuses on the location accuracy part of 5G technology.

d) **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, like 3D videos, 3D presentations, quiz, questionnaires, games, speaks, music e.tc, on the road during excursions, as well as at the places they visit; It was not possible to have such applications before 5G with the same quality and attractiveness as it is with 5G.

The content of this deliverable is structured as follows.

In Chapter 2 the definition and the final implementation of Smart parking management UC10 is described. This chapter also contains the UC10 final application component description and implementation details, which makes the UC10 section longer. More specifically, the definition of all implementation details of the smart parking UC as well as the progress on the application deployment in terms of terminal equipment components and communication interfaces are given. Also, integration and test results produced from tests and trials in the lab and the field are presented.

In Chapter 3 the definition and the final implementation of Video-enhanced ground-based vehicles UC11, is described. This chapter also contains the UC11 final application component description and implementation details of the media server. More specifically, the definition of all implementation details of Video-enhanced ground-based vehicles UC, as well as the progress on the application deployment in terms of terminal equipment components, media server and communication interfaces are given. Also, integration and test results produced from tests and trials in the lab and in the field are presented.

In Chapter 4 the definition and the final implementation of Airport evacuation UC12, is described. This chapter also contains the UC12 final application component description and implementation details of the Location Based Service (LBS) algorithm. More specifically, the definition of all implementation details of Airport evacuation UC, as well as the progress on the application deployment in terms of terminal equipment components, LBS and communication interfaces are given. Also, integration and test results produced from tests and trials in the lab and in the field are presented.

In Chapter 5 the definition and the final implementation of AR/VR student bus excursion UC13, is described. This chapter also contains the UC13 final AR/VR applications component descriptions and implementation details. More specifically, the definition of all implementation details of AR/VR student bus excursion UC, as well as the progress on the application deployment in terms of terminal equipment components, AR/VR apps, and communication interfaces are given. Also, integration and test results produced from tests and trials in the lab and in the field are presented.

In Chapter 6 two other UCs are shortly described in terms of application, UC6 and UC9 that have been hosted at the Greek Athens node infrastructure and belongs to WP5. In addition, another UC from WP5 which run as multisite UC (UC8 [33]) is described in terms of intra-site interconnection. Moreover, two other scenarios from UC6 and UC9 are described that run in parallel in a SA NOKIA core using two static slices.

In Chapter 7 the entire final network architecture and implementation of the Greek Athens node is described, the network deployment and the network equipment for each one of the four UCs. Also, all the needed equipment used for the measurements and validation of KPIs is described in detail. In addition, network enchantments and innovations of WP6 for the Athens mobility-efficient city are presented.

In summary, this document gives in detail the implementation progress of the four different use cases that was trialed in the Athens node of 5G-TOURS. Each of the use cases has been motivated by showing the usefulness for the corresponding vertical partners, highlighting the value for each partner. Furthermore, an analysis of the different components implemented to run the use cases has been performed, identifying the different applications and vertical equipment required in each case.

Beyond the vertical perspective, this document also analyzes the implementation of the network side of the UCs, describing the deployed final infrastructure, the refinement of the network level requirements involved in each use case, as well as the tests in the labs and in the field that have been conducted. Thus, this document serves as a reference of the final implementation and completion of the four use cases of WP6 mobility efficient city of 5G-TOURS project.

2 UC10 - Smart parking management

2.1 UC10 Definition

The AIA area accommodates three short and long-term parking lots for AIA visitors and travelers, altogether occupying an area of around 13 km^2. The parking process at AIA can be very time-consuming, and therefore stressful, especially when time until flight departure is limited. At the same time, purposeless and untargeted driving does not favor the environment from an emission perspective.

This use case allows the AIA parking users to obtain real time information on available and occupied spaces. This has been achieved by the installation of 5G-enabled (i.e., communicate using a 5G technology) parking sensors. This way the drivers are able to locate the available parking spaces directly through a mobile application and are guided there via the optimal route. The smart parking management contributes to the emission reduction by reducing unnecessary vehicle movements to locate a free parking space.

Situation example: On a peak day for AIA, approximately 20 vehicles can become congested in the parking facility of the B17 building. Upon arrival to park within the facility, the vehicles begin to search for an adequate parking spot, ideally near the entrance. Unfortunately, with so many vehicles simultaneously in search of the ideal spot and rushing to park, this inevitably causes congestion. A vehicle driving in the wrong direction, by accident or to get a spot before another vehicle gets to it first, can end up colliding with the second vehicle, which had been driving in the correct direction.

The developed service aims to minimize the time spent finding an available parking spot within the parking facility of AIA simultaneously optimizing the management and monitoring of the facility from the side of the respective authority. Specifically, an app-based service has been developed, which enables the user of the app to inspect the available parking places within the respective parking facility and get a recommendation for a parking slot, according to the specified criteria (e.g., the one closest to the entrance of the facility).

Partners involved: WINGS, SEQUANS, OTE, NOKIA-GR, AIA, ACTA

Location: AIA

2.2 UC10 implementation

The use case takes place in the B17 building parking facility of the AIA and involves the use of:

- A mobile application that presents the available parking spots in real time, optimally routing the driver to the selected parking spot, as well as historical data presentation regarding each driver's parking events. The app is powered by intelligent algorithms for choosing the optimal spot for each user by serving also concurrent requests and by spreading the drivers to the area of interest. The aim is to minimize the cases where one driver gets the spot that was proposed for another driver. If that happens the algorithm also provides rerouting capabilities. Furthermore, the app leverages 3D graphics on the area of interest to provide the driver with an optimal user experience. Finally, the driver can view the current occupancy in real-time even when he/she is away from the building B17 parking. In this way the driver can better schedule his/her trip to the airport by knowing whether there are free parking spots at the airport parking beforehand. This could further assist the driver in selecting the most suitable mode of transport for his/her trip. In a case when there are no free parking spots the driver can select another means of transport i.e., a taxi, the metro etc.
- A web dashboard to support the smart parking management staff that includes real time monitoring of the sensors installed in the facility as well as notifications regarding events of interest like a sensor that needs maintenance due to a low battery or due to a malfunction. Furthermore, the parking facility management staff can see useful statistics regarding the parking events and occupancy trends for different timeslots as well as access to historical data both at sensor level and for the parking facility as a whole, by providing various visualization services for the airport administrative user. Finally, the dashboard also provides access to statistical information based on predictive analytics about "busy" or "calm" days and times for the driver/parking user.

The real time monitoring is based on the deployment of a number of parking sensors at the AIA premises. WINGS sensor 2nd prototype has been developed and tested during the past few months. Currently, 52 sensors have been deployed: One (1) at OTE premises for collecting data and test, one (1) at WINGS Athens premises for testing and fifty (50) at AIA parking facility.

The final version of the dashboard containing enhancements regarding user and sensor management as well as additions regarding sensor and group statistics has been deployed since the summer of 2021 and has been thoroughly tested. This version also contains enhancements regarding notifications events, parking events management, statistics in facility level and access to historical data through various visualization services. In this version, two new statistics widgets have been added to the home page for the parking facility. These widgets depict the average occupancy per month and per weekday. The user can also select to view the respective information for a specific year or for a specific group/ zone in the facility. The corresponding information can be also exported as pdf for offline processing.

The final version of the mobile application has been developed and has been thoroughly tested with 3 concurrent drivers and the 50 sensors that have been deployed at AIA. This version contains 3D graphics to provide an optimal UI experience as well as User Account management. Integration with the routing component reported in D6.1 [2] and D6.2 [27], has been completed.

With respect to the network implementation, a two phase's implementation approach has been followed. This decision has been reached based on the requirements that have been defined in D2.1[1], the large area that needs to be covered in AIA, the time plan of each of the use cases, and, last but not least, the need of integration with the 5G EVE infrastructure. From the above, it was clear that it would not be possible to deploy a network which would meet all these aspects already at its first implementation while being compliant with the main objectives of 5G-TOURS that are to validate the need of 5G and to demonstrate the benefits of the 5G-TOURS innovations.

More specifically, the two phases deployment approach that was followed for UC10 is analyzed below. Phase 1 started in June 2020 while the 2nd phase started on February 2021 as soon as NOKIA-GR's experimental network was in place.

- **Phase 1**: During phase 1, five (5) parking sensors had been installed on the AIA staff parking. These sensors used SIM cards provided by OTE and communicated via NB-IoT connectivity with the WINGSPARK platform [1][27], through the NB-IoT OTE network. The same network was also used for WINGS testing deployments during the development period. The app used the commercial 4G+ network of OTE for testing purposes.
- **Phase 2**: During phase 2, a larger number of parking sensors (50 sensors in total) has been installed in the AIA premises. The sensors deployed during Phase 2 also communicate via NB-IoT connectivity with the WINGSPARK platform, through the NB-IoT OTE network. The app run on the Samsung Galaxy S10 and S20 smartphones provided by SRUK using the SIM cards provided by NOK-GR and communicates with the platform through the 5G-TOURS network at AIA (integrated with 5G EVE infrastructure at OTE Psalidi premises).

The sensors communication system constitutes an mMTC use case and as described above, for both the 1st and the 2nd phase, NB-IoT connectivity has been utilized. It should be noted that the mMTC requirements (which continue to evolve with newly arising applications and use cases) have already been addressed as part of 3GPP Release 13/14 low power wide area (LPWA) technologies development, which includes LTE-M and NB-IoT. These cellular IoT technologies (which have also been evolving in specification at each subsequent 3GPP Release, i.e., 15, 16 and 17, for improved performance such as better throughput, power consumption, etc.) have been confirmed to meet the 5G mMTC requirements that were set for IMT-2020 evaluation. With the rise of more diversified (in terms of requirements, e.g., more bandwidth and ultra-reliable low latency) mMTC-related scenarios, 5G Core deployment may be required. In that regard, it is also worth noting that coexistence of the cellular IoT technologies with NR carrier is already there since 3GPP Release 13/14 (one of the deployment scenarios that is supported from the start of 5G NR work in 3GPP is to allow LTE-M/NB-IoT transmissions to be placed directly into a 5G NR frequency band [5]). Release 16 has made this coexistence more efficient and supports the capability for connection to a 5G core instead of only 4G cores (EPC).

2.2.1 Application Components

The service provided is an extension in the functionality of the existing WINGS' STARLIT platform [1], [27] tailored to parking facilities, entitled WINGSPARK, and consist of:

- A mobile application that provides the user searching for parking with the aforementioned capabilities (i.e., visualizing the available parking slots and guidance/instructions to the optimal slot);
- A web-based application for controlling the parking area offered to the respective airport authority;
- 5G-enabled occupancy sensors.

Sensors that monitor the state of the respective parking slots (available or occupied) have been installed at each individual slot. This enables the real-time monitoring of the available and occupied spaces. In parallel, a relational database, which contains the state and other relevant information for each sensor, is maintained on the server side, hosted in WINGS cloud infrastructure. For the trialing phase of 5G-TOURS, the KPIs measurement and the innovations showcasing, a new deployment at WINGS OSM which is part of the 5G EVE infrastructure at Psalidi, has been performed. Every time the state of the slot changes, the sensor sends via NB-IoT connection the respective information of the state change to a server which in turn updates the state in the database. Each time a request from the user-side (client) to get the optimal available parking slot is sent, the server queries the database to get the state of each sensor and calculate the slot that meets the specified needs, as well as the shortest route towards this slot. The route and the parking slots are visualized at client's device. Below, a schematic representation of the implemented architecture is shown (Figure 1):

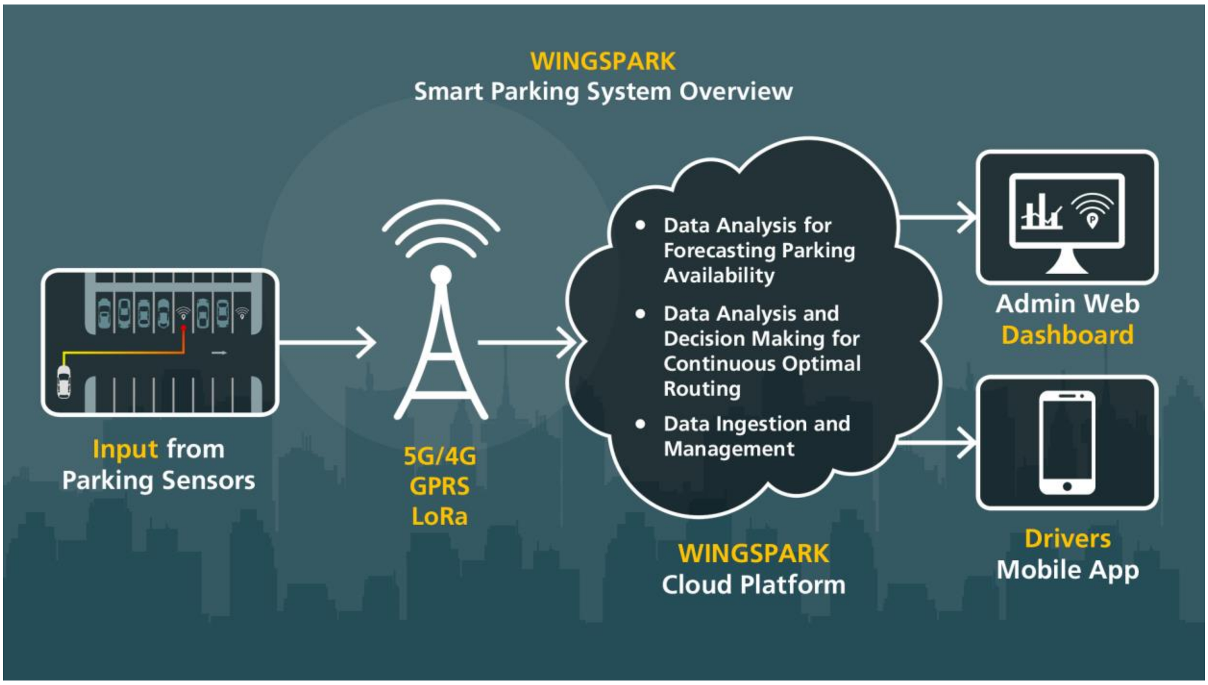


Figure 1. High-level view of smart parking system architecture.

2.2.1.1 High level view of smart parking application

The end user interfaces are divided into two user level applications: i) a mobile app, addressed to the parking user and ii) a web app, addressed to the parking administrator. A complete consolidated backend system is developed to support and serve these two applications in a way that the intercommunication between them is assured. A high-level view of the smart parking frontend and backend applications is shown in Figure 2.

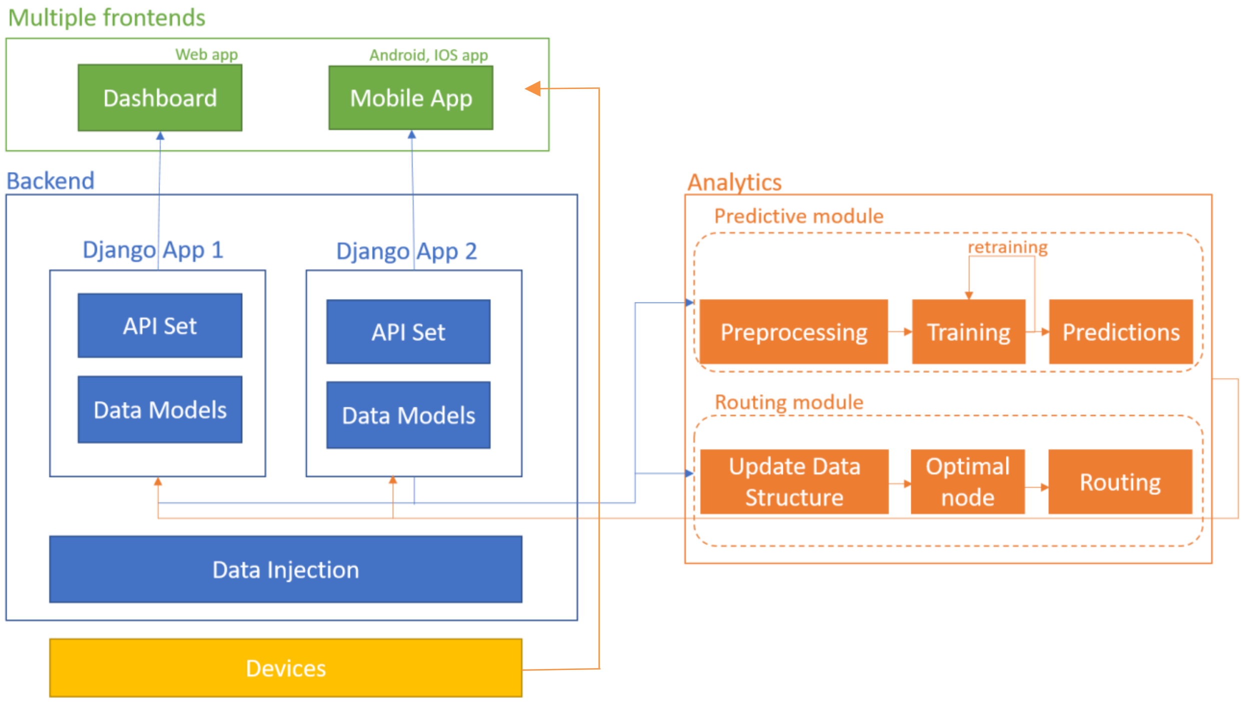


Figure 2. High-level view of smart parking application.

2.2.1.2 The WINGSPARK driver's application

The mobile application developed in the context of 5G-TOURS enables the user to have a real time view of the available parking slots in the parking facility of the airport. Moreover, it provides the user with the possibility to get the optimal parking slot according to the criteria specified, that is, the one closest to his/her point of interest.

More specifically, when the driver is logged into the application, a top view of the parking facility is provided on the screen. There, the user has the choice to:

- Select and see the available parking slots on the map of the parking facility, or
- Retrieve the available parking slot closest to the specified point of interest,
- Be routed to the selected spot via the optimal route.

The figures below present the final version of the driver's android application. Figure 3 depicts the login screen of the WINGSPARK driver's application. If the user has an account, he/she can input his/her username and password and in case these are correct the user is redirected in the main application page (Figure 5 and Figure 6). If the user does not have an account, he/she can create one by pressing the link "*No account yet? Create one*". Then, the user is redirected to the Register screen shown in Figure 4. When the user creates his/her account successfully then he/she is redirected to the information screen of the application as shown in Figure 5, where he/she can find some basic information about the application. The main screen of the app loads when the button "*Continue*" is pressed. The application can be viewed either in vertical (Figure 7) or in horizontal orientation (Figure 9).

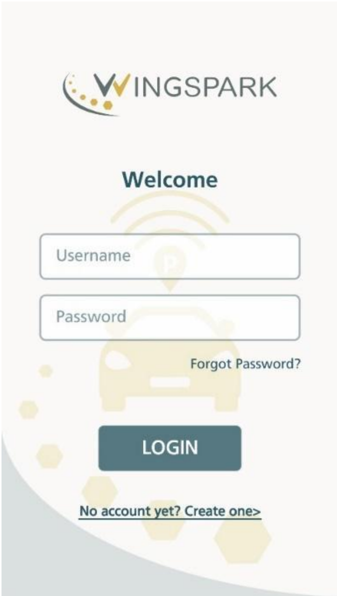


Figure 3. The login screen of the WINGSPARK driver's application.

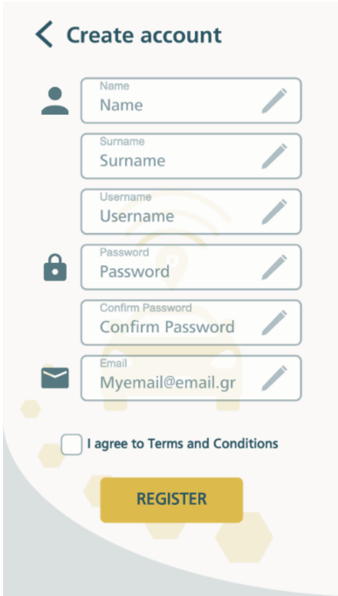


Figure 4. The create account screen of the WINGSPARK driver's application.

In the main screen, the user has various options. In the header of the application, he/she can change the application's language. Currently, the application is offered in two languages: Greek and English. The user can also see the current date and time. Below, the B17 building parking facility 3D version is loaded based on the user's location (Figure 9). There, he/she can see their relative location with respect to the parking slots. In the parking slots that are occupied, car graphics are loaded to give the user the information visually. The free parking slots are marked with yellow. Also, at the bottom of the screen, the user can have a look at B17 building parking facility top view, always according to his location.

When the user opens the application and his location is at the entrance of the parking facility, where the phone can be attached to the 5G antenna, the system retrieves the available parking slot closest to the specified point of interest, as well as the shortest navigation guidelines towards it. The user can also access the menu of the application from the bottom of the screen, where he can view and edit his profile (Figure 10) and vehicle information, view the current slot that he is parked in, as well as access historical information (Figure 11) regarding his parking events in the period of interest (Figure 12). For each parking event, he can see the data, the duration as well as the parking spot that he parked to. If he/she wants, they can select a specific period of interest in order to see his parking events as shown in Figure 12. Finally, they can also choose to log out of the application.

Figure 5. The information screen of the WINGSPARK driver's application.

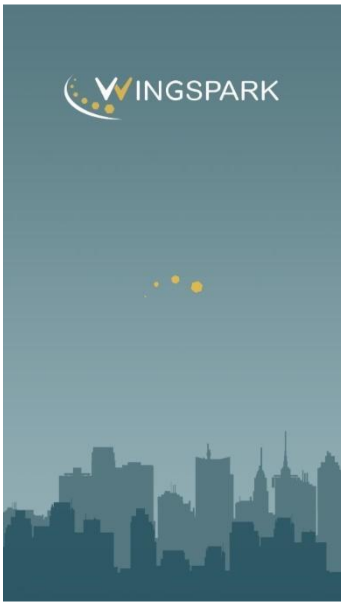


Figure 6. The loading screen of the WINGSPARK driver's application.

Figure 7. The main screen of the WINGSPARK driver's application in vertical orientation.

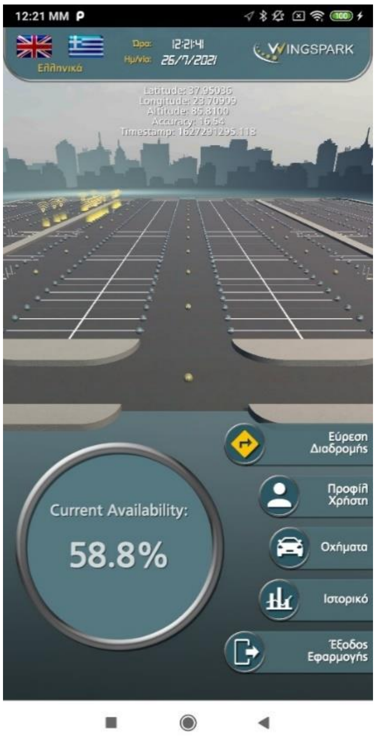


Figure 8. The user can view the current occupancy in real-time even if he/she is not inside the B17 parking.

Figure 9. The main screen of the WINGSPARK driver's application in horizontal orientation.

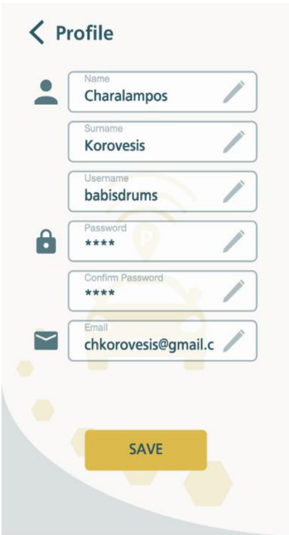


Figure 10. The edit profile screen of the WINGSPARK driver's application.

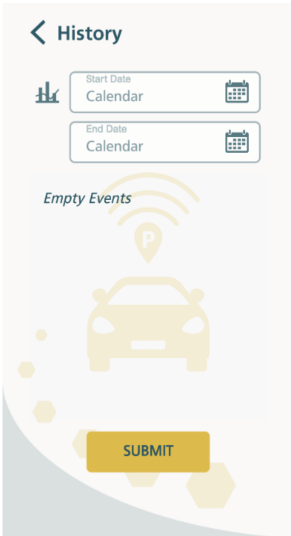


Figure 11. The view historical data screen.

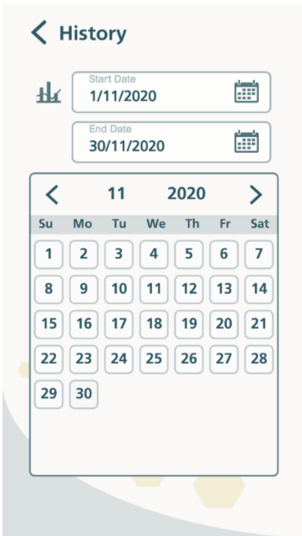


Figure 12. The user can select the dates of interest to see his/her parking events, as well as the duration and the parking spots that he/she parked to.

2.2.1.3 The WINGSPARK web dashboard

Also, a web dashboard is developed for the airport facility management staff to keep track of the whole smart parking system (Figure 13). The dashboard provides information about all the parking events, and the occupancy time. It also includes all the necessary information for each sensor such as status, battery level, exact position etc. Finally, a parking map is also available presenting all the parking positions and their live status (Figure 14). Initially, the user is presented with the main page of the dashboard. This page consists of the following elements.

- A toolbar which on the rightmost side, a login icon is presented, where the user can login and manage his/her account, can also change the language (currently Greek and English are supported) and an icon for the Notifications bar.
- In the main panel, the user can see the status of the parking area as well as the occupied sensors, the disabled ones, as well as the parking spot occupancy. Below, an interactive map can be seen, on which,

each sensor is denoted with the corresponding marker (Figure 13, Figure 14). Upon clicking on a marker, the information of this sensor is presented on top of the map. The information depicted are the name of the slot, the sensor id as well as its location, its current status (occupied or free) and information whether the sensor is active or disabled.

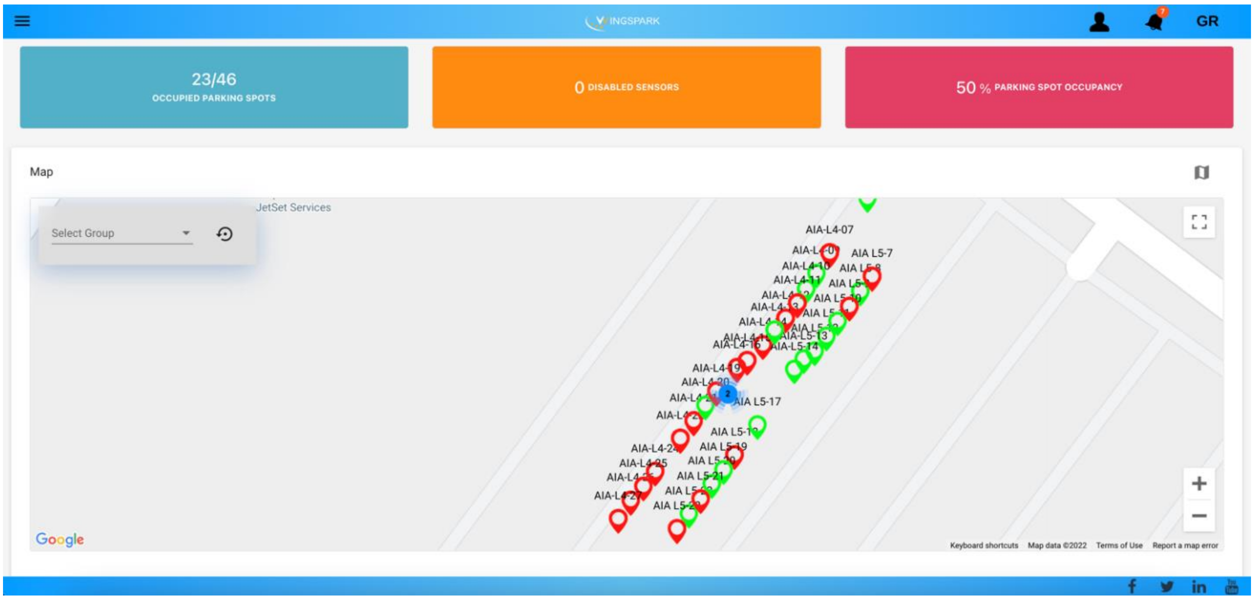


Figure 13. View of the Smart Parking management dashboard.

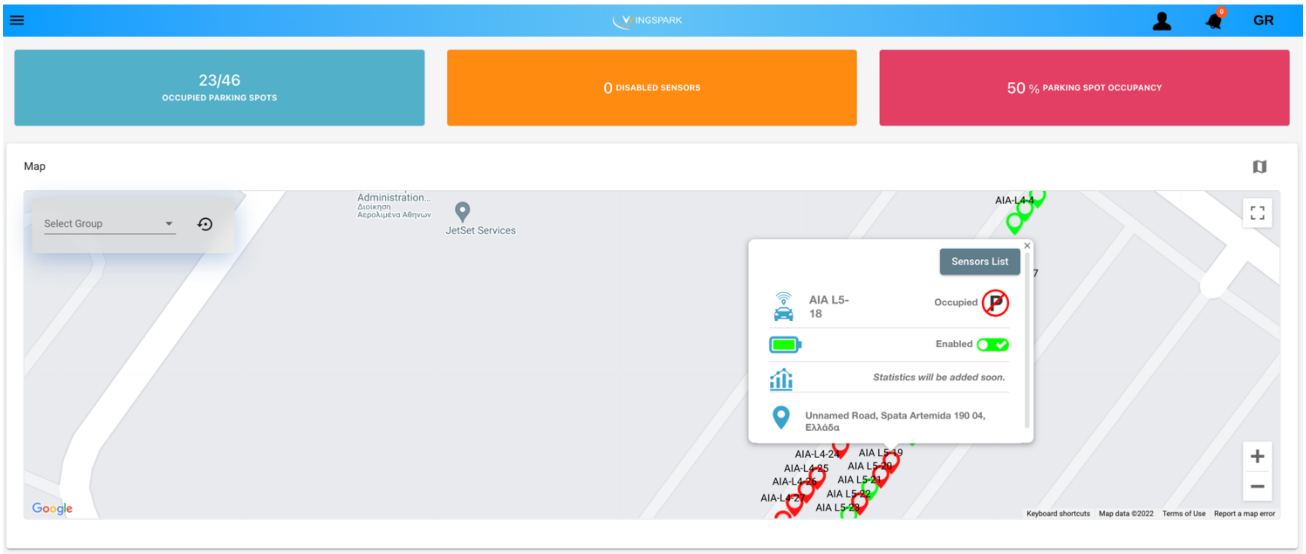


Figure 14. View of the Smart Parking management dashboard – Map view – Select Sensor.

- Just below the map, two new statistics widgets have been added that depict the average occupancy per month and per weekday. The user can also select to view the respective information for a specific year or for a specific group/ zone in the facility. The corresponding information can be also exported as pdf for offline processing.

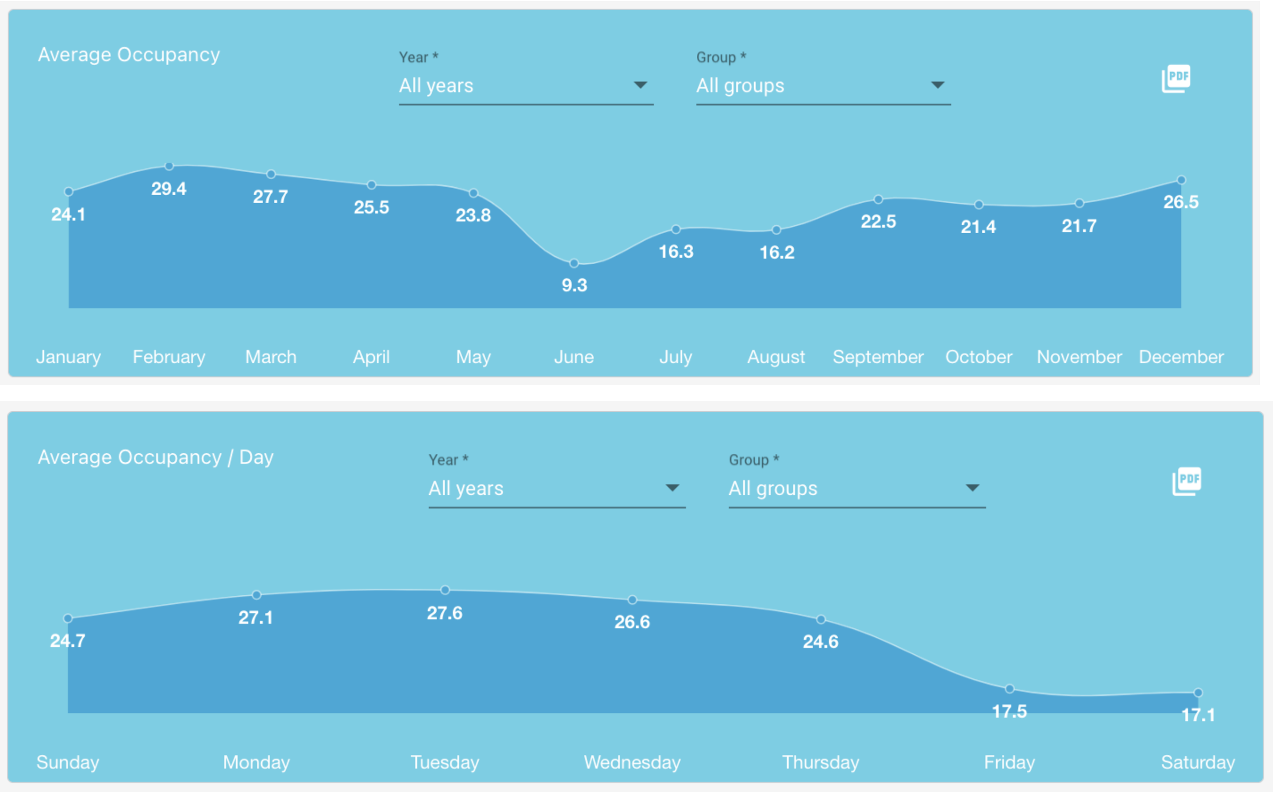


Figure 15. Statistics widgets for average occupancy per month and per day.

- A sidebar on the left side, where the user can access the list of sensors and to view their location as well as their status (occupied or not in real-time). The admin user can also have access to all the sensors' information in real time, like the sensors' status, their battery level, the particular slot where it is located and the coordinates of the slot (Figure 16).

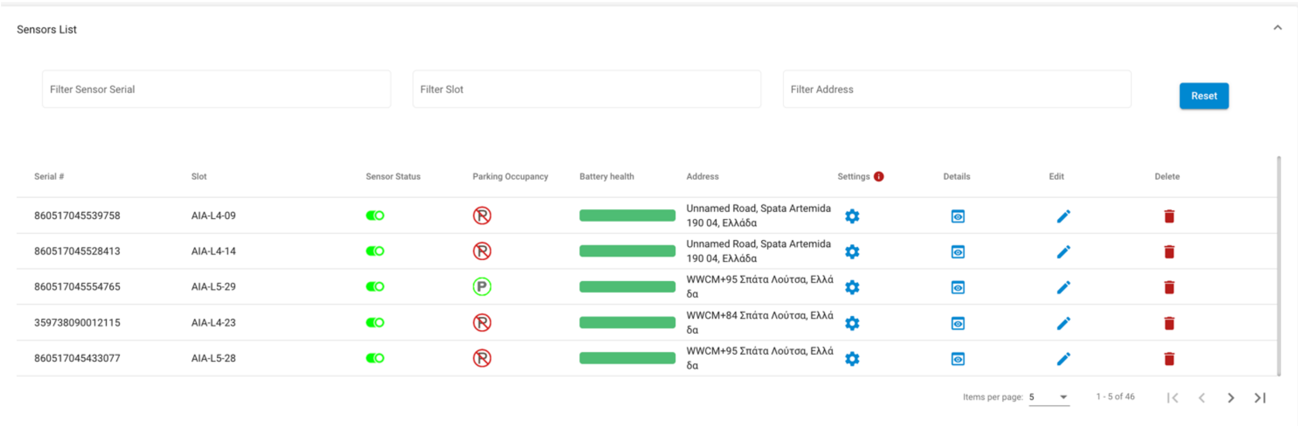


Figure 16. View of the Sensors panel.

- When the admin user selects an individual sensor, he has access in two different charts, one that demonstrates the daily occupancy for that spot and another one that demonstrates all the different parking events on a daily (Figure 17), weekly and monthly basis (Figure 18). This kind of information is also available in the form of raw data (Figure 19). The admin user has also the right to add, edit or delete an individual sensor (Figure 20, Figure 21).

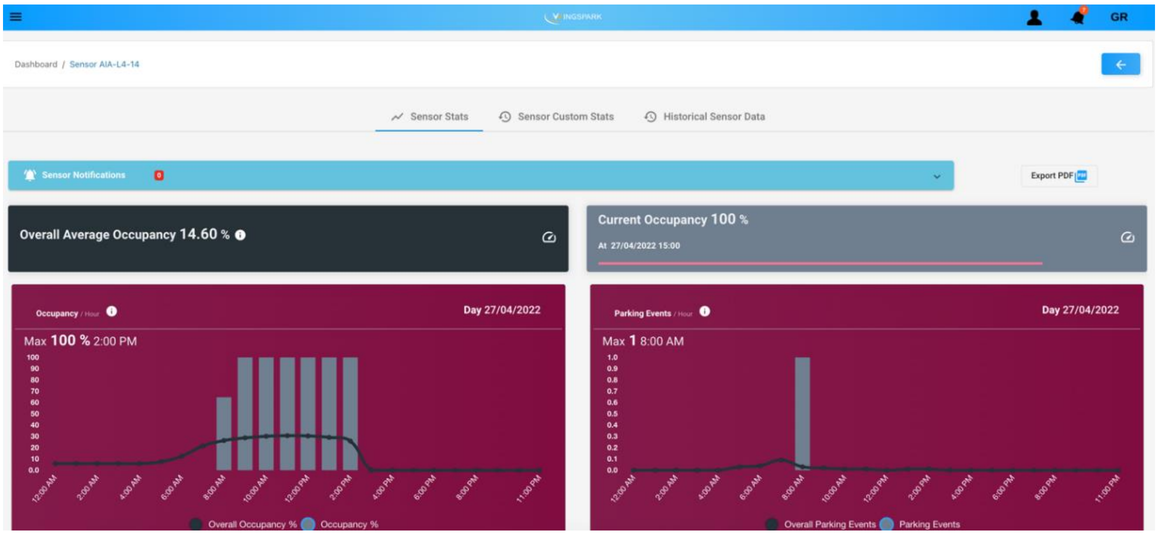


Figure 17. Sensor stats in a daily basis.

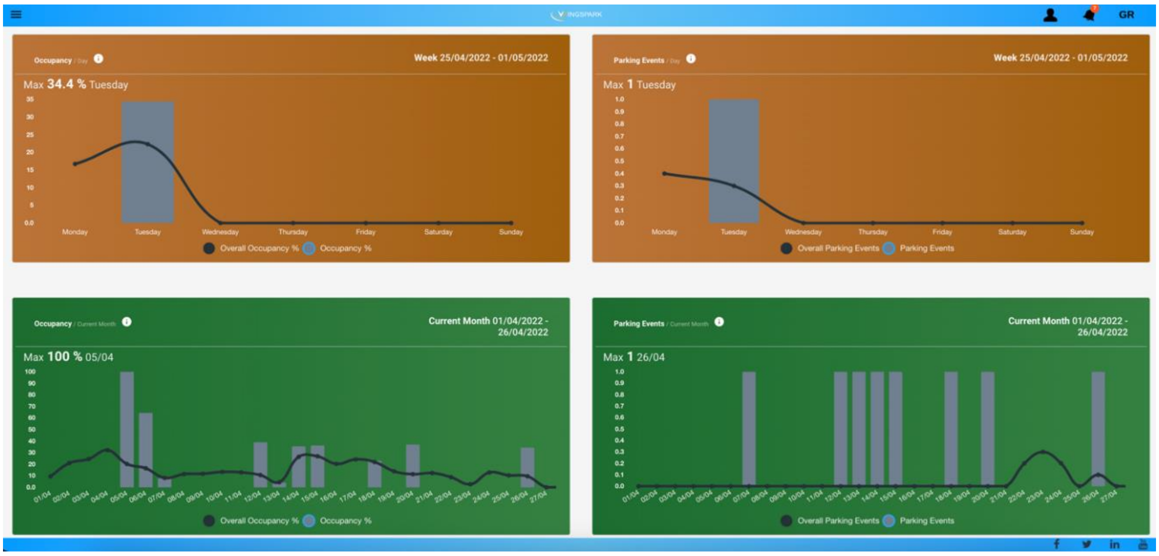


Figure 18. Sensor stats in a weekly and monthly basis.

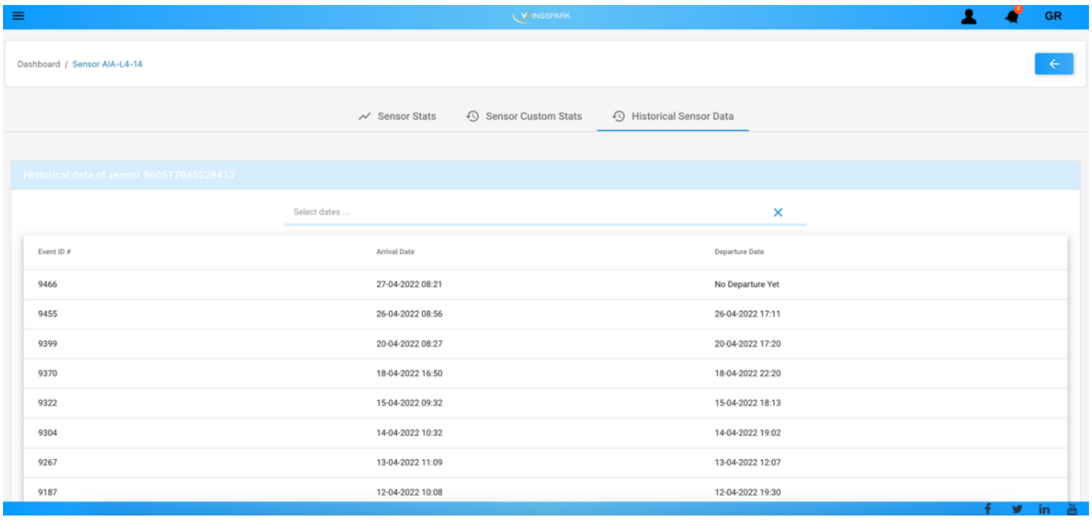


Figure 19. Raw data view for an individual sensor.

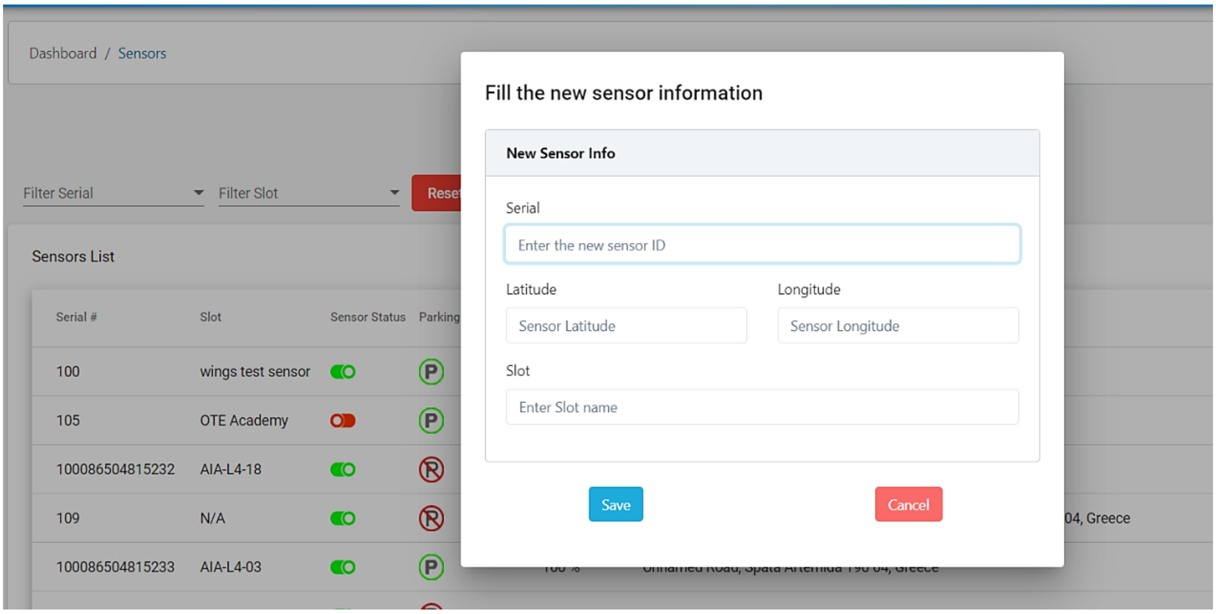


Figure 20. Add new sensor panel.

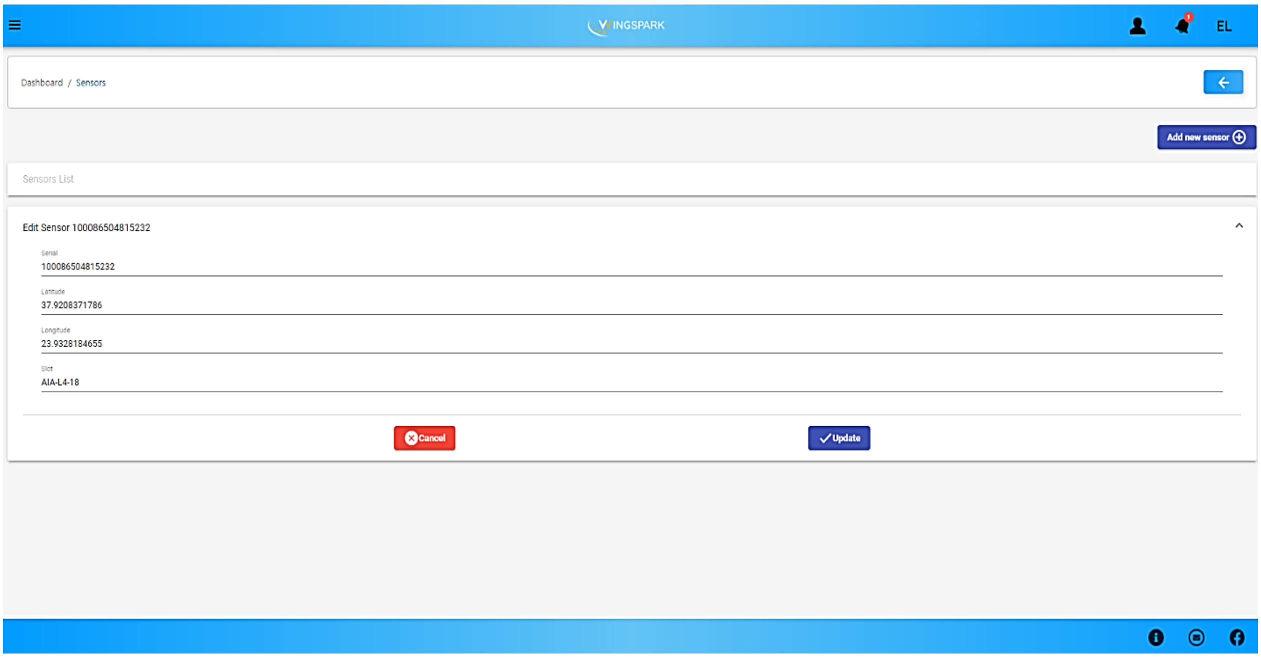


Figure 21. Edit sensor panel.

From the main panel the user can access the Notification Center, where he can see the notifications for each sensor as shown in Figure 22.

- Furthermore, from the Sensor Groups menu item, the administrator can view the existing groups and create a new one (Figure 23) and edit the group and assign or unassigned sensors to the selected group (Figure 24).

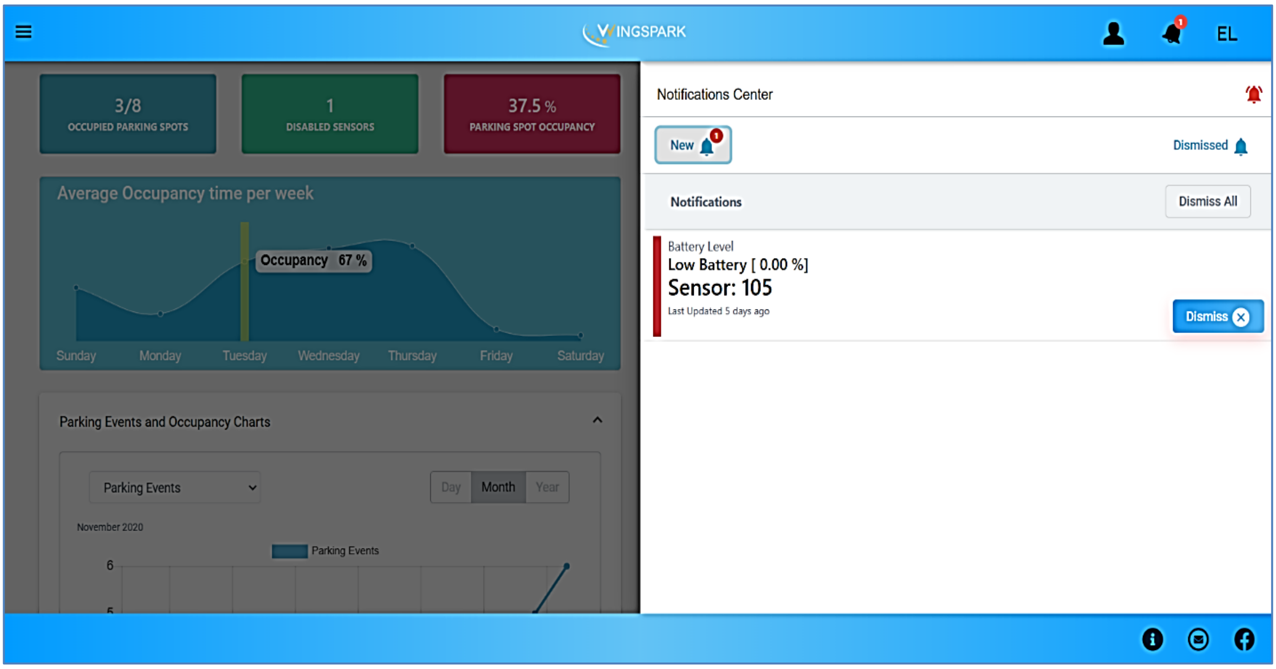


Figure 22. Notifications Center.

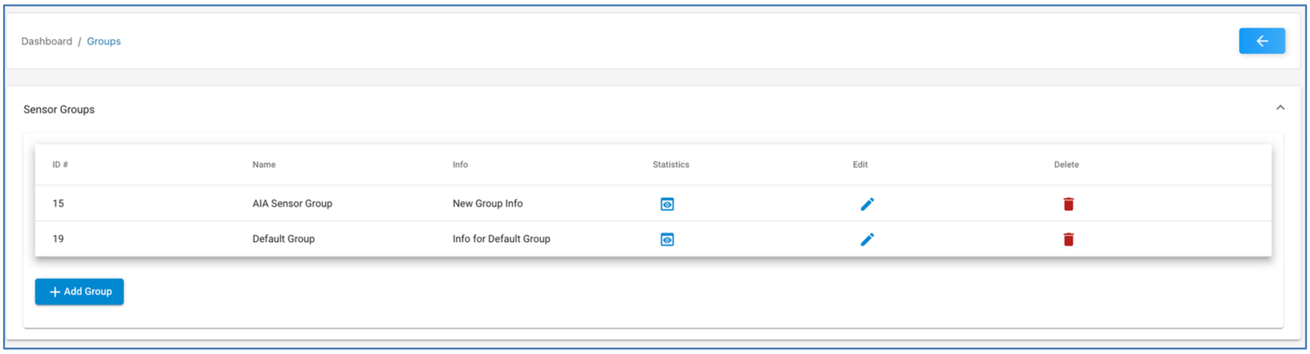


Figure 23. Sensor Groups.

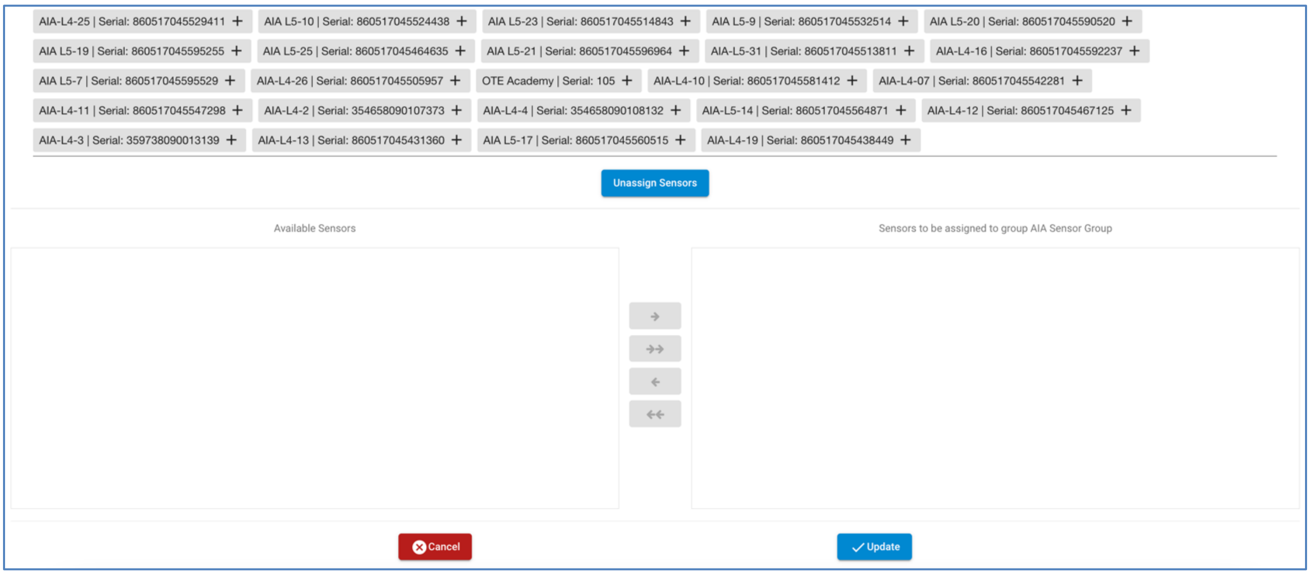


Figure 24. Sensor Allocation to group.

2.2.2 Terminal equipment components

The technical components required for this use case are:

- 46 WINGS prototype 5G-enabled parking sensors each of which includes a Queqtel NB-IoT connectivity module.
- 4 WINGS prototype 5G-enabled parking sensors each of which includes an NB-IoT connectivity module, provided by SEQUANS (these prototypes complement the ones above, using the corresponding communication module used also to take power consumption measurements from the device to compare also with the other prototype sensors).
- 3 smartphone/mobile devices for testing the mobile application during the trials, provided by SRUK.

The parking sensors both with Quectel and the SEQUANS communication module transmit data using the COSMOTE NB-IoT network by using NB-IoT SIM cards provided by OTE (Phase 1 and Phase 2 of the UC).

The details for each technical equipment component that is used in this use case are described below.

2.2.2.1 Mobile/smartphone

To make use of the 5G network available, a 5G compatible phone is essential. Specifically, for this UC Samsung Galaxy S10 and S20 5G had been used. Samsung provided 3 x (S10 or S20) mobile devices for the needs of the trials of this specific use case that run on the Athens node. These devices have been configured with the specific PLMN ID, which is provided from OTE to NOKIA-GR's trial network at AIA.

Samsung Galaxy S10/S20 5G [7]: is powered by a Snapdragon 855 5G processor (octa-core CPU at 2.84 GHz) and is equipped with 8GB RAM, enabling multitasking and fast switching between apps. S10 5G is built to take advantage of sub-6 GHz frequency bands of 5G networks, while being to automatically fall back to LTE when 5G service is not available. Although the smartphone can attain speed over 1Gbps, it cannot exploit the low band 600 MHz FDD (frequency division duplex) 5G service. Finally, it is equipped with a non-removable Li-Ion 4500 mAh battery and supports super-fast charging with its 25-watt adapter. Samsung Galaxy S20 specification are depicted in Table 1.

Table 1. Technical Specifications of the Samsung Galaxy S20 5G Smartphone.

NETWORK	Technology	GSM / CDMA / HSPA / EVDO / LTE / 5G
	2G bands	GSM 850 / 900 / 1800 / 1900 - SIM 1 & SIM 2 (Dual SIM model only)
		CDMA 800 / 1900 & TD-SCDMA
	3G bands	HSDPA 850 / 900 / 1700(AWS) / 1900 / 2100
		CDMA2000 1xEV-DO
	4G bands	1, 2, 3, 4, 5, 7, 8, 12, 13, 17, 18, 19, 20, 25, 26, 28, 32, 38, 39, 40, 41, 66 - SM-G981B
		1, 2, 3, 4, 5, 7, 8, 12, 13, 14, 18, 19, 20, 25, 26, 28, 29, 30, 38, 39, 40, 41, 46, 48, 66, 71 - SM-G981U
	5G bands	1, 3, 5, 7, 8, 28, 40, 77, 78 SA/NSA/Sub6 - SM-G981B

		2, 5, 41, 66, 71 SA/NSA/Sub6 - SM-G981U
	Speed	HSPA 42.2/5.76 Mbps, LTE-A (7CA) Cat20 2000/200 Mbps; 5G (5+ Gbps DL)
LAUNCH	Announced	2020, February 11
	Status	Available. Released 2020, March 06
BODY	Dimensions	151.7 x 69.1 x 7.9 mm (5.97 x 2.72 x 0.31 in)
	Weight	163 g (5.75 oz)
	Build	Glass front (Gorilla Glass 6), glass back (Gorilla Glass 6), aluminum frame
	SIM	Single SIM (Nano-SIM and/or eSIM) or Hybrid Dual SIM (Nano-SIM, dual stand-by)
		IP68 dust/water resistant (up to 1.5m for 30 mins)
DISPLAY	Type	Dynamic AMOLED 2X, 120Hz, HDR10+, 1200 nits (peak)
	Size	6.2 inches, 93.8 cm^2 (~89.5% screen-to-body ratio)
	Resolution	1440 x 3200 pixels, 20:9 ratio (~563 ppi density)
	Protection	Corning Gorilla Glass 6
		Always-on display
		120Hz@FHD/60Hz@QHD refresh rate
PLATFORM	OS	Android 10, upgradable to Android 11, One UI 3.0
	Chipset	Exynos 990 (7 nm+) - Global
		Qualcomm SM8250 Snapdragon 865 5G (7 nm+) - USA
	CPU	Octa-core (2x2.73 GHz Mongoose M5 & 2x2.50 GHz Cortex-A76 & 4x2.0 GHz Cortex-A55) - Global
		Octa-core (1x2.84 GHz Kryo 585 & 3x2.42 GHz Kryo 585 & 4x1.8 GHz Kryo 585) - USA
	GPU	Mali-G77 MP11 - Global
		Adreno 650 - USA
MEMORY	Card slot	microSDXC (uses shared SIM slot)
	Internal	128GB 8GB RAM, 128GB 12GB RAM
		UFS 3.0
MAIN CAMERA	Triple	12 MP, f/1.8, 26mm (wide), 1/1.76", 1.8µm, Dual Pixel PDAF, OIS

		64 MP, f/2.0, 29mm (telephoto), 1/1.72", 0.8µm, PDAF, OIS, 1.1x optical zoom, 3x hybrid zoom
		12 MP, f/2.2, 13mm, 120˚ (ultrawide), 1/2.55" 1.4µm, Super Steady video
	Features	LED flash, auto-HDR, panorama
	Video	8K@24fps, 4K@30/60fps, 1080p@30/60/240fps, 720p@960fps, HDR10+, stereo sound rec., gyro-EIS & OIS
SELFIE CAMERA	Single	10 MP, f/2.2, 26mm (wide), 1/3.24", 1.22µm, Dual Pixel PDAF
	Features	Dual video call, Auto-HDR
	Video	4K@30/60fps, 1080p@30fps
SOUND	Loudspeaker	Yes, with stereo speakers
	3.5mm jack	No
		32-bit/384kHz audio
		Tuned by AKG
COMMS	WLAN	Wi-Fi 802.11 a/b/g/n/ac/6, dual-band, Wi-Fi Direct, hotspot
	Bluetooth	5.0, A2DP, LE
	GPS	Yes, with A-GPS, GLONASS, BDS, GALILEO
	NFC	Yes
	Radio	FM radio (Snapdragon model only; market/operator dependent)
	USB	USB Type-C 3.2, USB On-The-Go
FEATURES	Sensors	Fingerprint (under display, ultrasonic), accelerometer, gyro, proximity, compass, barometer
		Samsung DeX, Samsung Wireless DeX (desktop experience support)
		ANT+
		Bixby natural language commands and dictation
		Samsung Pay (Visa, MasterCard certified)
BATTERY	Type	Li-Ion 4000 mAh, non-removable
	Charging	Fast charging 25W
		USB Power Delivery 3.0
		Fast Qi/PMA wireless charging 15W

		Reverse wireless charging 4.5W
SAR	SAR	1.07 W/kg (head) 1.03 W/kg (body)
	SAR EU	0.38 W/kg (head) 1.52 W/kg A(body)

2.2.2.2 WINGSPARK Smart Parking Sensor

The device detects the state of each parking spot, i.e., whether it is free or occupied. The device consists of a custom board designed by WINGS, an NB-IoT connectivity module, a magnetometer used for vehicle detection, which measures magnetic field in 3 axes and 4 to 6 Li-ion batteries. Data are transmitted through the COSMOTE NB-IoT network. In Figure 25, the final version of the device is depicted.

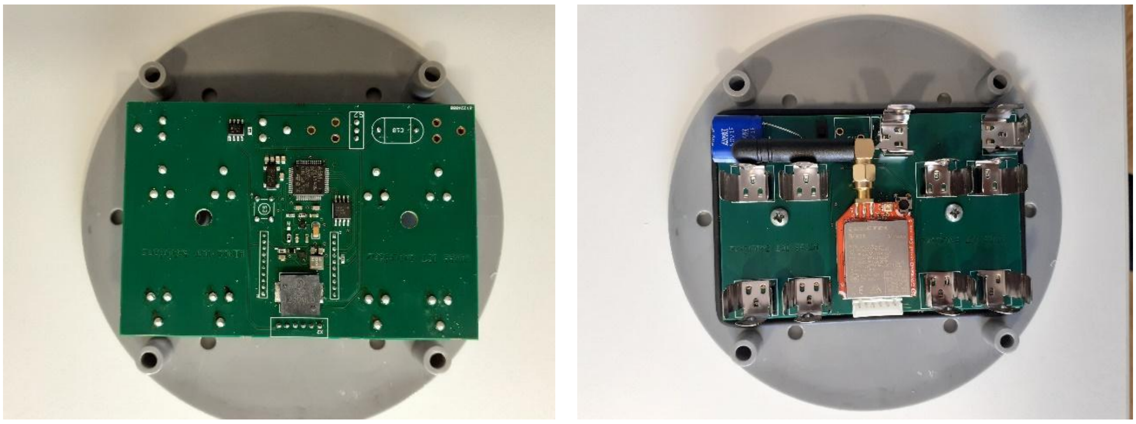


Figure 25. Parking occupancy sensor device.

The 5G-enabled smart parking sensor case supports the specifications listed in Table 2.

Table 2. WINGSPARK Smart Parking sensor characteristics.

Characteristics	NB-IoT sensor values
Material	Polycarbonate
Protection class	IP67 / IP68
Load resistance	Up to 15 tons
Operating temperature	-30 ... +65°C
Storage temperature	-30 ... +65°C
Humidity range	0 to 95%
Height	40 mm
Diameter	220 mm

The current case prototype is depicted in Figure 26.

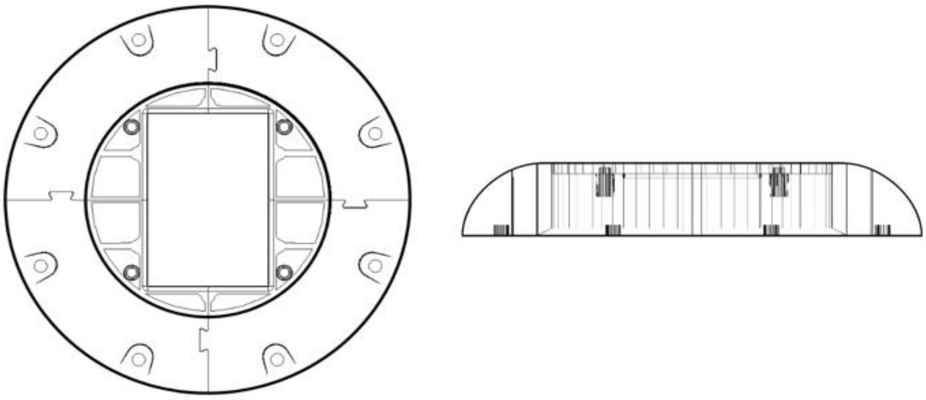


Figure 26. WINGSPARK Smart Parking NB-IoT sensor prototype.

WINGS Smart Parking sensor is running with a 32-bit CPU STM32L476RET6 which processes all the data from the peripherals like the magnetometer. For the parking detection, we use a 3-axis magnetometer which is the lis2mdl [8] and a Quectel bg96 NB–IoT module [9] to connect to the network. In addition, integration of SEQUANS NB-IoT module into the sensor device was explored collaboratively by the two partners and was achieved.

The device wakes up every 10 seconds and checks with the magnetometer if the parking slot is occupied. The time that the device wakes up to check the magnetometer is configurable and can be altered at the initial configuration. This set up has been selected as other commercially available sensors use similar wake up times for their parking sensors. The notion behind this choice is the following: If the wake-up frequency time is too short, the energy consumption of the device is higher. On the other hand, if this time is too long, there may be a change in the sensor state that the device may miss due to the longer wake up frequency time. Based on data from field trials both in the context of 5G-TOURS and other pilots the probability of losing a state change is negligible. An example to better illustrate this is the following: In order to lose a state change, a car should unpark and another one should park within those 10 seconds. In order for this to happen the spots should be placed horizontally and the second car (the one that parks) to park in 5 seconds which is not likely to happen. If a sensor state change is detected, i.e., an empty parking spot is occupied and vice versa, the device sends information to the UDP server. From the network side, there is an ACK packet sent to the device that ensures that all transmitted data is received in the server side. If the ACK packet is not received, then the sensor state update is considered to have been unsuccessful and all the required information is re-transmitted from the device. When the ACK packet is received, the device enters sleep mode, to minimize energy consumption. The device currently uses four (4) Saft 17500 Li-ion batteries. If the batteries power falls below a certain threshold, the sensor is disabled, and a notification is sent from the device to the dashboard.

2.2.2.3 SEQUANS NB-IoT connectivity module

SEQUANS connectivity modules have been used for integration into the WINGSPARK smart parking sensor to attach to the COSMOTE NB-IoT network and provide real-time parking space data, which are then sent to the WINGSPAK cloud platform.

The chosen SEQUANS communication device is a small size (34 x 29 mm mechanical form factor, 8 grams) embedded modem including a module from the Monarch family of solutions (https://www.sequans.com/products-solutions/modules/). Monarch is a low-power single-chip LTE Cat-M1/Cat-NB1 solution whereby baseband, RF transceiver, power management, and RAM memory are integrated into a tiny 6.5 x 8.5 mm package, running SEQUANS carrier-proven LTE protocol stack, a lightweight M2M (LWM2M) client for over-the-air device management, and a rich set of AT commands. The modem features 1 U.FL port, connectivity via Serial

UART or USB, and is pin-compatible – with a 20 pin interface – which enabled integration with the parking occupancy sensor solution. Figure 27 depicts the device.

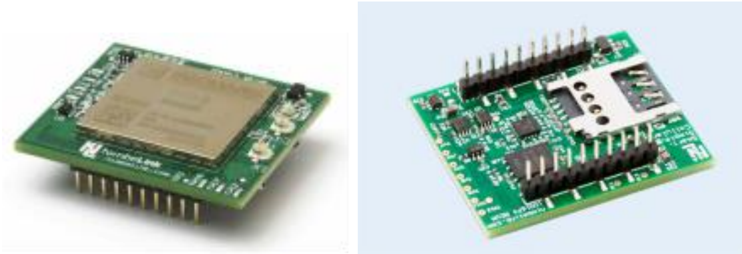


Figure 27. Embedded modem for NB-IoT connectivity.

The modem also features throughputs of 375 Kbps download and upload as Cat-M1, or 26 Kbps download and 66 Kbps upload as Cat-NB1, supports frequencies from 700 MHz to 2.2 GHz and includes a removable Micro-SIM card slot.

For prototyping the Cat-NB solution for the OTE NB-IoT network and developing the integration of the modem with WINGS Parking Occupancy sensor, SEQUANS also provided development/evaluation kits (Figure 27) which are compatible with the embedded modem and specifically designed to help minimize the power requirement of the prototype solution. The development/evaluation kit (EVK) includes an adapter board which breaks out the serial UARTs for easier computer/laptop access to the mounted embedded modem via AT commands through PC terminal application. It also includes 1 SMA port and antenna, as well as power supply.

Figure 28. Development kit with mounted embedded modem.

2.2.3 Interfaces

The WINGSPARK smart parking platform consists of a combination of different components and interfaces aiming to cover the needs and requirements that have been identified in the first phase of the project. A high-level view of the platform components is presented in Figure 29.

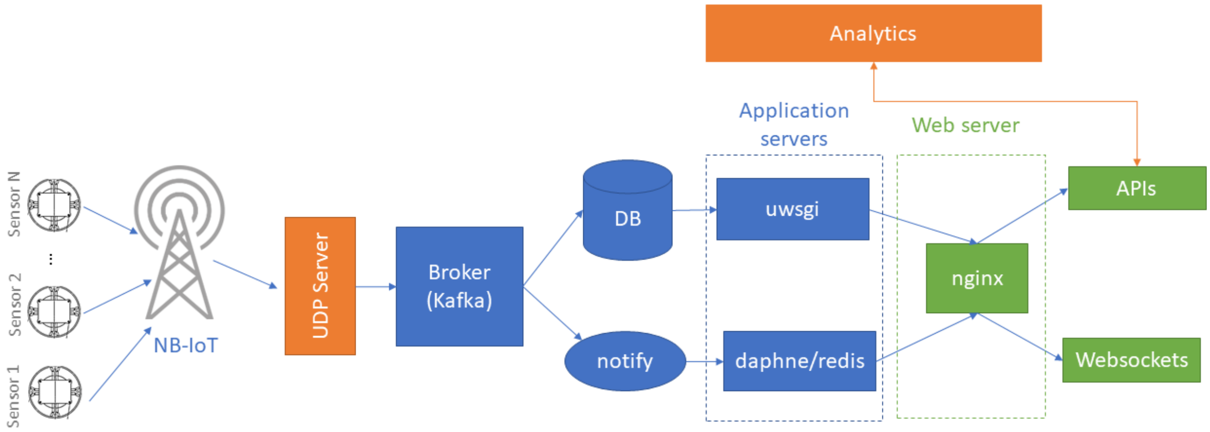


Figure 29. High level view of the platform components.

UDP Server [10]: The UDP packets, containing the sensor state measurements as well as the timestamp, cannot be written directly to the Kafka Broker, but requires transformation into a compatible format. Therefore, a light-weight Java (netty[1]) server is deployed in a Docker container and communicates with the Kafka container. After a UDP packet is received, the UDP server reads the packet body and feeds a Kafka producer that drops the information into a Kafka topic.

Kafka Broker [11]: Kafka uses a producer that collects the packet sent from the UDP server and stores it in a Kafka topic. Then a Kafka consumer retrieves that data from the topic and stores them in the Postgres database.

Django [12]: Django is the backed application of the platform. Django is deployed through two different application servers: **uwsgi** and **daphne/redis**. The uwsgi is responsible for the deployment of the REST API that the system uses to display the historical data (data stored in the database). The daphne/redis server is responsible for the deployment of the real time feed of the data through the web sockets. Django is also responsible for the creation of the data model. It also includes several different views and serializes in order to provide a set of APIs in a json format, filtered in the desired way, accessed through a REST framework. Django includes a number of notifiers in order to provide real time information to the web sockets.

Nginx [13]: is the Web server used for serving both uwsgi and daphne/redis application servers to the Web through ssl protocols.

Frontend applications: An Angular [14] based web app supports the communication between the parking administrator user and the platform. An Android mobile app supports the communication between the driver/parking user and the platform.

Analytics: A python-based module consisting of a predictive component, which utilizes ANN (Artificial Neural Networks) and specifically **keras**[2], to predict the occupancy and a routing component based on graph implementation of the parking area's topology. For the purposes of the latter, the **networks** python library was utilized, representing the parking slots as the graph nodes and the corridors connecting the parking junctions, the slots and the entrances/exits of the area as the graph edges. On this base, several configurable options have been integrated, so that the implementation considers the exit/entrance that the car is approaching from or the user wishes to be nearest to, considers the current ongoing requests to best split the users uniformly around the desired area, etc. The output of the component is the optimal parking slot and the suggested route towards it, according to the specified criteria, encoded in **json** format.

[1] https://netty.io/
[2] https://keras.io/

2.3 Integration and tests in labs

A summary of the progress that has been made during the past months, based on the project's Gantt chart and the specific time plan created for each individual use case is described below. The following tasks concerning the smart parking platform have been completed.

- Installation of 45 WINGSPARK 5G-enabled sensors at AIA
- SEQUANS sensor integration to WINGSPARK sensor board.
- Testing of Queqtel and SEQUANS connectivity modules and feeding data to WINGSPARK cloud platform.
- Final version of the WINGSPARK admin dashboard deployed at WINGS cloud and WINGS OSM part of the 5G EVE infrastructure at Psalidi.
- Final version of the WINGSPARK Mobile application deployed and tested at AIA.
- Testing, evaluation and KPIs measurements from AIA utilizing the 5G-TOURS trial infrastructure.
- Testing and demonstration of the Greek node Innovations utilizing the 5G-TOURS trial infrastructure.

2.3.1 Modem-Sensor integration

During the 1st and 2nd phase of the UC, the following tasks have been performed: establish connectivity to COSMOTE NB-IoT network, integrate with the WINGSPARK smart parking sensor, and feed data to the WINGSPARK UDP server. Initially, one EVK (evaluation kit) with embedded modem was shared to WINGS and two test-sites in Greece were established for troubleshooting, a WINGS-based and a SEQUANS-based test-site. The following summarize the key activities and outcome for each task:

- Connect Sequans modem to COSMOTE NB-IoT network
  - Received appropriate COSMOTE SIM card for prototyping and to perform connection tests. The SIM card is used to connect in the COSMOTE NB-IoT public network operating at band 20 that corresponds to uplink 832 – 862 MHz and downlink 791 – 821 MHz.
  - At SEQUANS test-site, modem could register to COSMOTE NB-IoT network and attach/camp to cell but there was initially no response after going to idle mode. This was resolved after upgrading modem firmware and managed a basic ping to Ipv6 address.
  - At WINGS test-site, an additional problem was faced to scan networks which was resolved after joint troubleshooting (issue was related to modem configuration and AT commands order) and managed to connect to COSMOTE network as well.
- Integration with WINGSPARK smart parking sensor
  - SEQUANS device documentation (datasheets, etc.) and a debug/monitoring software tool for development purposes was shared to WINGS together with the modem and EVK devices.
  - Using the above, WINGS completed SEQUANS modem integration into their print circuit board (PCB) and produced a SEQUANS-based integrated device.
- Feeding data to WINGSPARK server
  - Initially tested basic connectivity from EVK to push dummy data to WINGS server. After replacing domain name with IPV6 address, data was successfully sent to WINGSPARK UDP server from both test-sites.
  - Then, an issue of unstable connection was faced with the integrated device: The device often could not open a socket to WINGSPARK server (NO CARRIER responses) or was failing to transmit/receive data when opening socket, leading to big runtime (1-2mins instead of expected ~20sec). After extensive troubleshooting sessions, blockers were identified and connection problems were resolved via appropriate configuration of the device, resulting into feeding eventually working well and to the deployment of 1 WINGSPARK sensor with the SEQUANS connectivity module at the airport.

After accomplishing the tasks above, SEQUANS prepared three additional modem devices with updated firmware, which WINGS integrated to the WINGSPARK smart parking sensors and deployed at the airport. A last modem device has been kept at SEQUANS site to set up properly (initially showing highly delayed response to AT commands) and to perform tests for power consumption evaluations.

In parallel to the connection and integration activities, a realistic NB-IoT module power model was developed (validated with evaluations from tests with the prototype devices). The motivation behind such model was to help assess the contribution of the communication device to the energy usage of the total solution and understand the consumption from differently configured use cases (e.g. energy required to send modem originated UDP data while modem is powered off or while sleeping using eDRX or PSM features) and the different states of the device within each use case, e.g. wake-up, resynchronization, service request, data session, Radio Resource Control (RRC) inactivity and connection release, etc. Figure 30 depicts a typical power consumption profile (top) and an exemplary summary of the energy spent into different modem states during a data session (bottom).

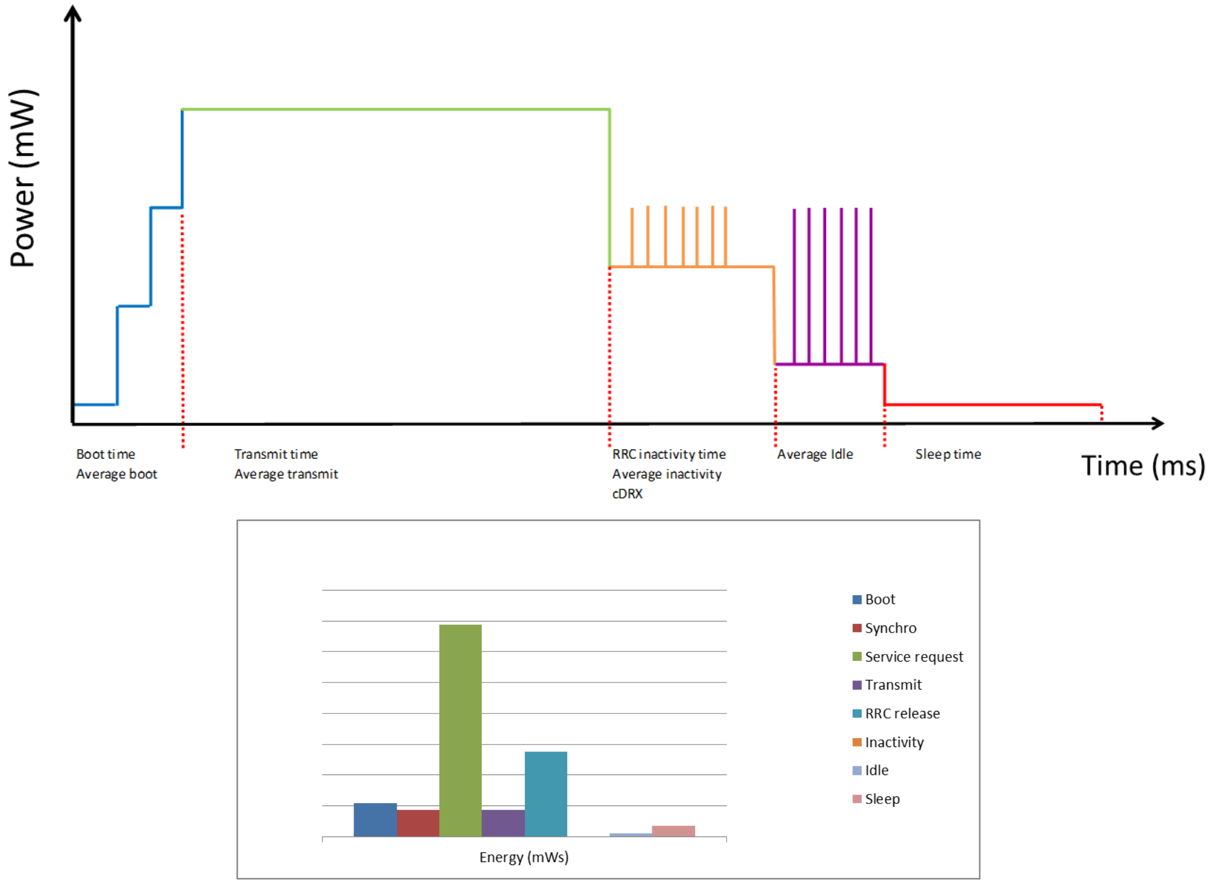


Figure 30. Example of NB-IoT modem energy consumption during a data session.

The results on evaluation of the device battery lifetime according to modem power characteristics, the different modem and network configurations as well as the traffic characteristics of the use case will be reported into the final deliverable of WP7.

2.3.2 Smart parking platform

A detailed description of the current state of the platform is described below. A visual representation of the logic is depicted in the figure below.

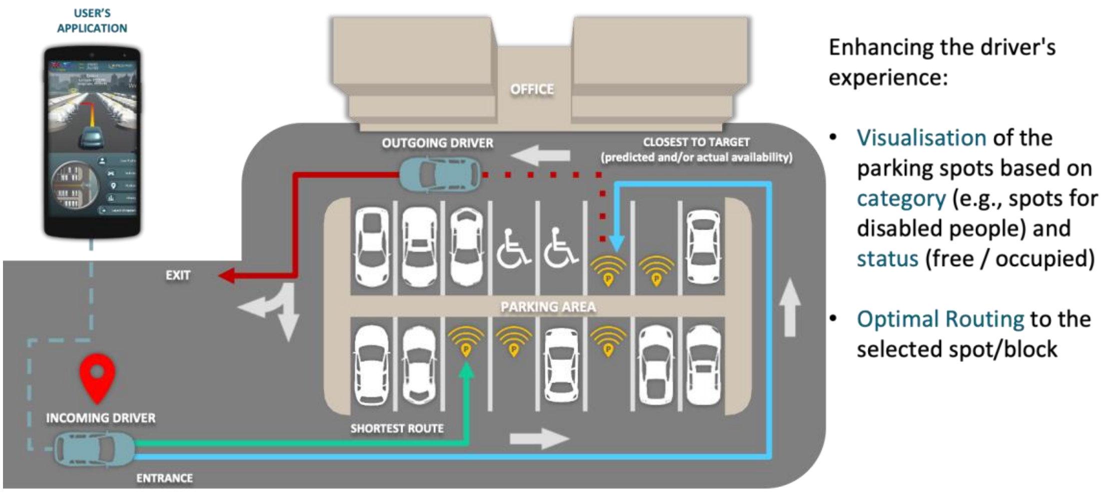


Figure 31. Visual representation of the routing logic.

52 WINGS prototype sensors have been installed, deployed and monitored in three test locations, namely WINGS (1 sensor), OTE (1 sensor) and AIA premises (50 sensors). All the parking events are recorded in the database and all information about these events (sensor ID, timeframe of the event, sensor battery level etc.) are available through the WINGSPARK platform's REST API.

For testing the functionality of the analytics component, several scenarios were studied, for each of which, different arrangements of occupied parking slots were considered. In Figure 32, two of these scenarios are depicted. For simulation purposes, a testing parking area consists of two parking sections, with each having 8 parking slots, i.e., 16 parking slots in total. The cars on the slots represent the occupied slots, as monitored by the respective sensors.

As Figure 32 shows, a User 1 approach from the entrance located at the upper left part of the figure and has specified a desire to park as close as possible to the entrance located at the upper right part of the figure. The system finds the slot that is closest to the specified point of interest (POI) and provides the shortest route towards it (blue route) considering if the respective corridor has one-way or both-ways directionality. User 2 on the other hand, approaches from the entrance located at the middle right part of the figure, and desires to find an available slot closest to his entering point. The system again, finds the slot compatible with these criteria and provides the corresponding route (yellow route).

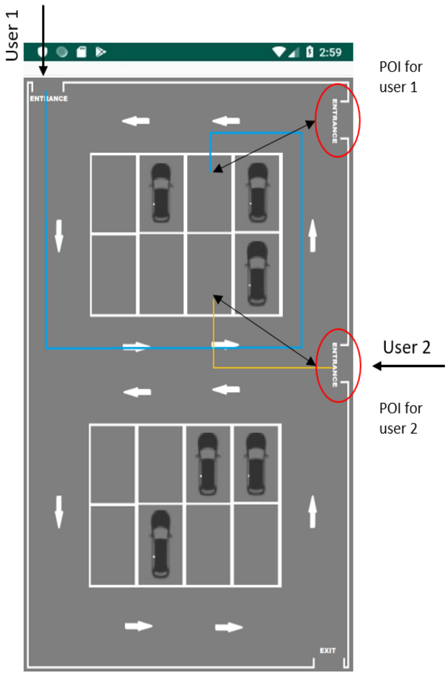


Figure 32. Simulation scenario for testing the analytics functionality.

Finally, to demonstrate how the algorithm models the traffic within a big parking facility, a simulation scenario was conducted based on the actual parking area of AIA. As depicted in Figure 33, several users (1,2,3,4) are approaching from the left – hand side entrance and want to park as close as possible to the administration building. The numbers indicate the chronological order of the requests. As User 4 arrives, just after the previous three users have been navigated by the service to the appropriate slots, the algorithm specifies the slot, from the available ones, closest to the entrance of the administration building (green slot). Although the shortest route towards this slot is from the left-hand side of the parking (dashed blue line), as were the routes of the previous requests, an alternative route (blue line) is suggested to avoid congesting the corridors of the parking. The algorithm achieves this by keeping record of the most recent requests and updating weights of the respective edges to simulate the traffic within the parking area. It should be noted here that the service also avoids sending users to slots that are adjacent to an occupied place. If the driver decides not to follow the slot proposed by the system, then the system is able to take this into consideration in the next requests for parking from other users. In this case, the real-time information from sensors is used to propose a slot that is not taken (see Figure 33-Figure 34).

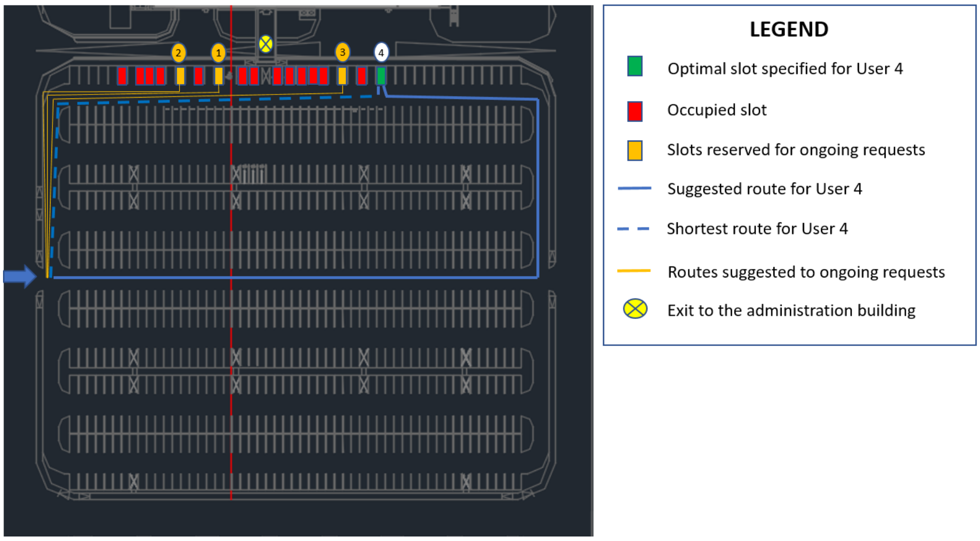


Figure 33. Simulation scenario implemented for the AIA's parking area.

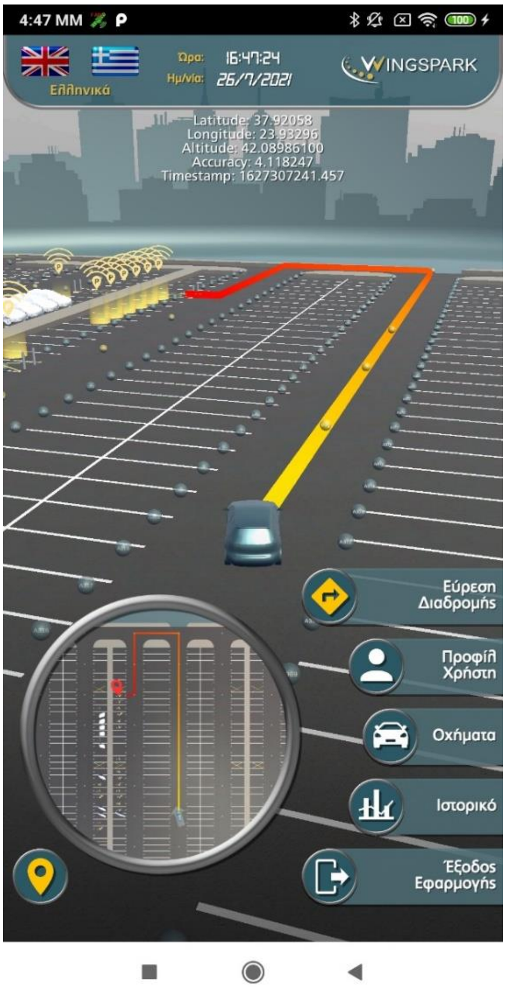


Figure 34. WINGSPARK app minimap and route on map.

2.4 Tests in the Network

During the deployment phase of the Network, various tests and measurements are conducted (based on the use of ICMP/ping and iPerf) [15] to evaluate the maximum performance of the network (when user traffic is absent) and the involved platforms.

During the phase of the verticals' integration and during operation and demonstrations, additional types of measurements are performed. This is needed in order not to affect the network operation and influence the service delivery. These measurements are based on enterprise-level network probes (software, hardware or both) that are placed in key locations of the infrastructure and passively measure the required KPIs. The architecture and methodology of these measurements is described in the section that follows.

ACTA, together with NOKIA-GR and OTE, identified the network-elements and their interfaces for optimal measuring probe placement. A variety of probes (both hardware and software, open source and proprietary) were considered. ACTA based on prior expertise has selected and purchased different types of probes together with the central management software. ACTA also identified the probes' configuration, to match the interfaces & placement location with that of the network links and interfaces. The target is to achieve end to end measurement of Network KPI values, as well as in segments of the network. A Proof of Concept has been performed at ACTA Labs, as well as at OTE Labs premises, to gather real time measurements (using 4G connectivity). Currently, field tests and optimization activities have been performed in the Athens International Airport (AIA) 5G networks. In addition, WINGS developed and used during the trials: a) software (Android) agents running on the UEs for the collection of RTT latency metrics (both in IP and APP layers) and b) software probes in the Server for measuring latency in different position of the service chain.

2.4.1 KPIs Validation

Smart airport parking management use case, targets in validating the 5G capabilities to support smart parking application including both mMTC services, for the support of the sensors-server communication as well as eMBB services for the support of UE APP-server communication. Figure 35 illustrates the actual deployment on the AIA and OTE premises and the UC10 high level architecture, in which the parking sensors (WING-SPARK 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 [31], while it is in line with the final set of requirements defined in D2.3 [34] (Table 3).

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.

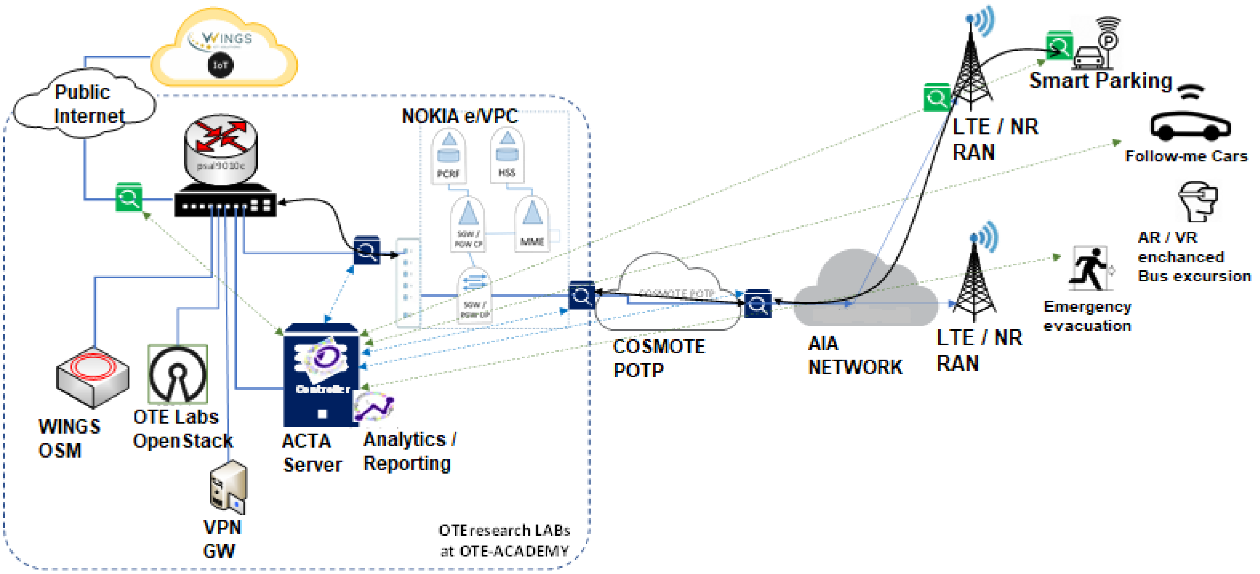


Figure 35. The participating probe components and their location for the KPI measurement of UC10.

The KPIs are measured and validated along the data path indicated in the diagram of Figure 35, overlaid on the Athens site network architecture.

Regarding network KPIs, latency, throughput (UL/DL) and peak throughput is validated. The technical validation methodologies of the aforementioned KPIs apply to all the UCs of the Athens node and therefore are described in detail in section 7.2.6.

Table 3. UC 10 Smart airport 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								

● **Non relevant KPIs**

● **Difficult to be demonstrated KPIs**

● **Relevant KPIs**

The Non relevant KPIs are considered non-relevant for this use case, because they are of medium importance and/or the relevant requirements could not be tested, e.g., slicing was not deployed.

In Figure 37, the total throughput created by the user traffic for UC 10 during the full-scale trial performed on 12/04/2022 afternoon, was measured. As a total, the data traffic does not exceed a peak of 50 Mbps, mostly staying around 10 Mbps, which shows that the parking application is not posing high bandwidth demands on the network. Of course, this may change depending on the car traffic load at the parking area, but still, we feel there is enough headroom to accommodate that.

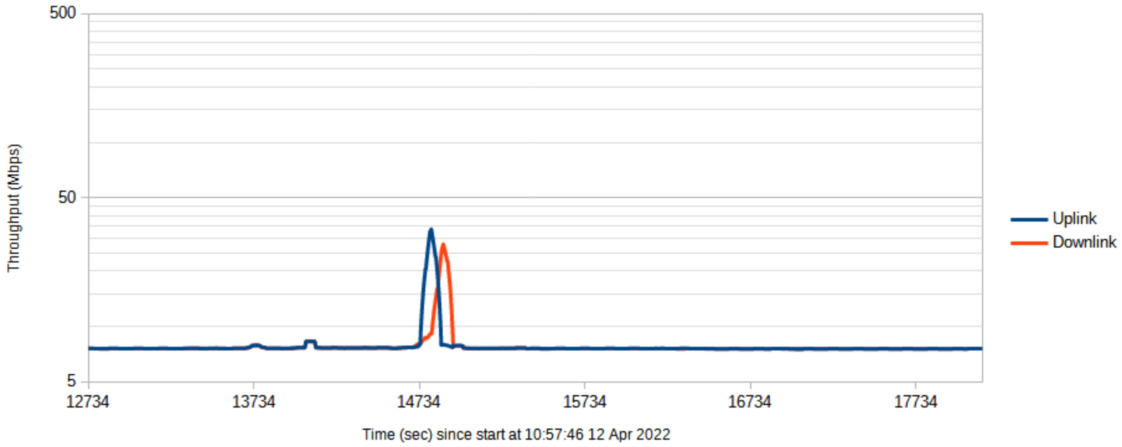


Figure 36. Real Time Throughput Measurements of UC10.

Apart from that, we can see the TCP Throughput (maximum sustainable) for UC 10, as experienced by the Samsung Galaxy S20 mobile UEs on the vehicles, in the Figure 37 below.

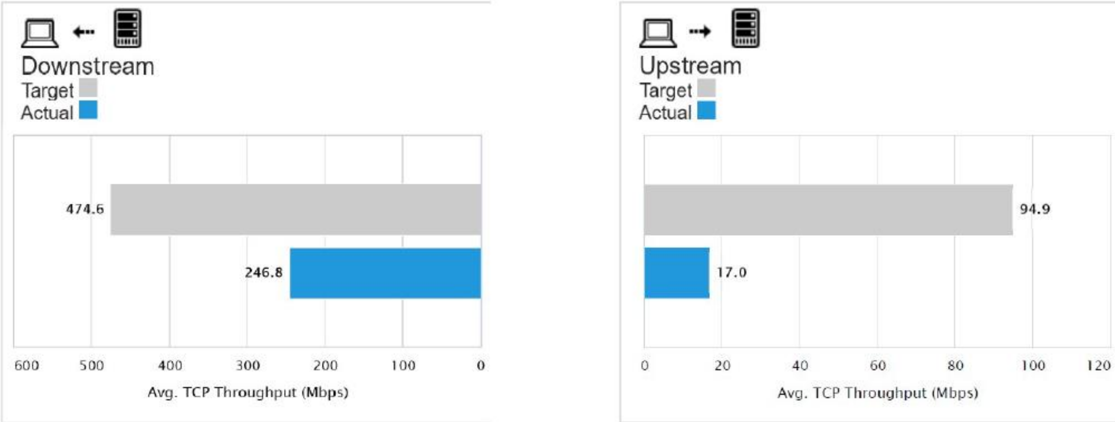


Figure 37. UC10 Max Throughput Measurement results with Samsung Galaxy S20.

While, the upload capability is peaking on average at approx. 17 Mbps, the download metric stays around 250 Mbps, which allows for sufficient application usage and exceeds the target values of Table 2, KPIs 3 and 7. 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. 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.

Regarding the Latency, Loss and Jitter L2/L3 KPIs measured in UC 10, the first two are also being used to calculate Network Availability and Network Reliability as discussed in Section 7.2.5.

ACTA has managed to capture these KPIs by deploying probes at various points of the network as shown in Fig 32 above. The segmentation methodology is elaborated in Section 7.2.5, but here it suffices to say that we provide measurement results for the backhauling part up to the L2/L3 switches at OTE Labs and AIA, the AIA BBU as well as up to a simulated UE, in the form of NOKIA Fastmile Router, which 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 38). The Fastmile UE could not be itself permanently deployed outside in the AIA Parking area for security reasons.

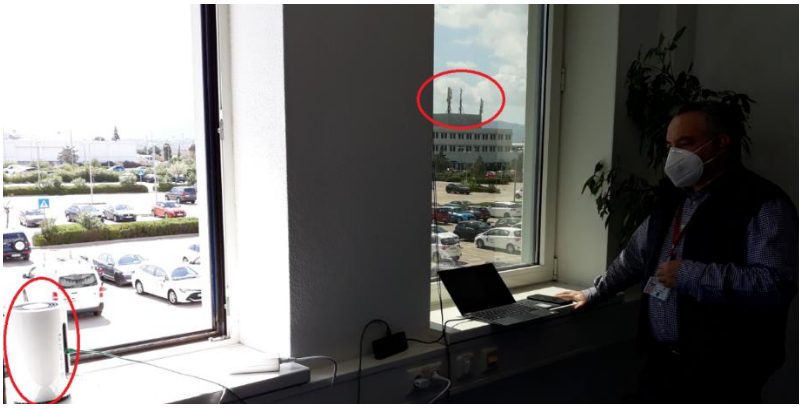


Figure 38. Nokia Fast Mile Router in AIA B17 building, serving the UC10 parking area.

Overall, the network KPIs were measured as follows:

- Loss remaining well below 0,02% for all parts of the network (transport and over-the-air)
- Latency below 0,9ms for the transport segment (local switches in OTE labs and AIA), and 17 ms for the e2e path

- Jitter (delay variation) below 250μs for the transport segment and 6 ms for the e2e path.
- Availability 99,9998% (100% for the transport part)
- Reliability 99,9998%   (100% for the transport part)

The overall conclusion is that the L2/L3 Network KPIs of Latency, Availability and Reliability comply with the targets set in Table 2 (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 Figure 39 for the transport part and Figure 40 for the E2E path below.

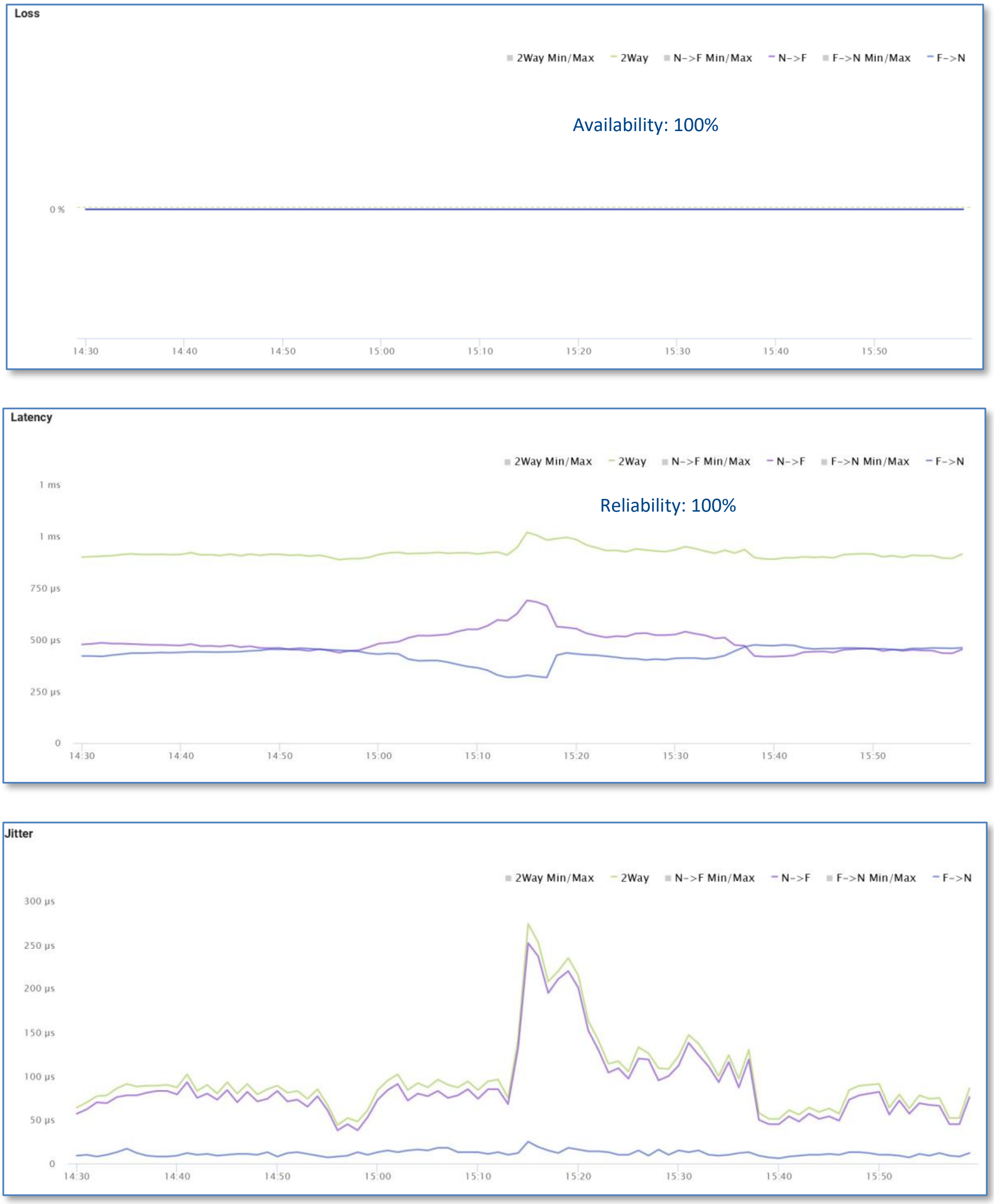


Figure 39. UC10 Loss, Latency and Jitter results for the transport part of the network between local switches at OTE Labs and AIA.

Figure 40. UC10 Loss, Latency and Jitter results for e2e path (L2/L3 switch before Core Network up to Fastmile UE at AIA B17.

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

RTT latency (IP and APP layers)

The calculation of RTT latency is realised as illustrated in Figure 41.

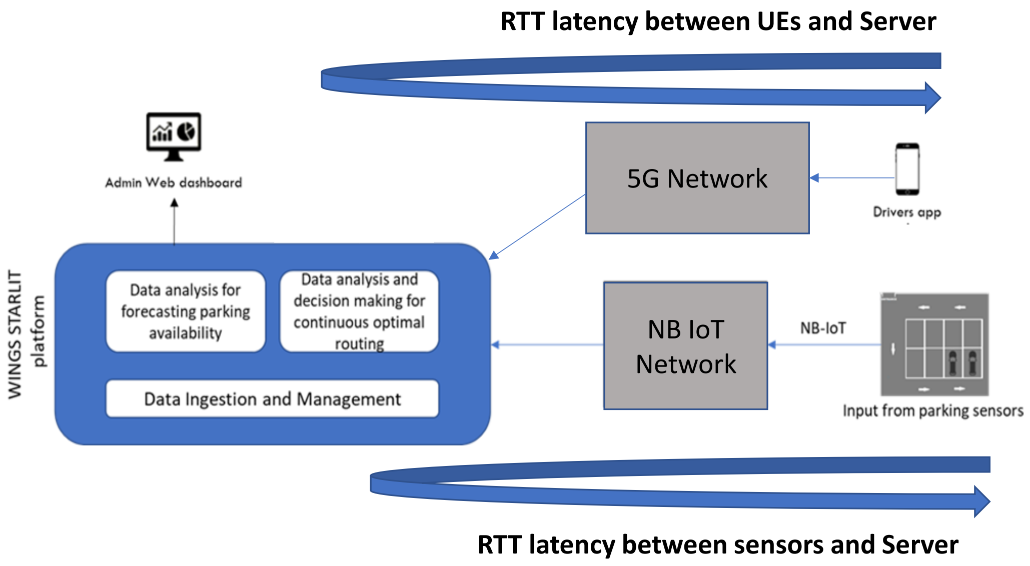


Figure 41. RTT latency.

The RTTL latency metrics (both in IP and APP layers) are collected using an Androids Agent developed by WINGS and deployed in UEs.

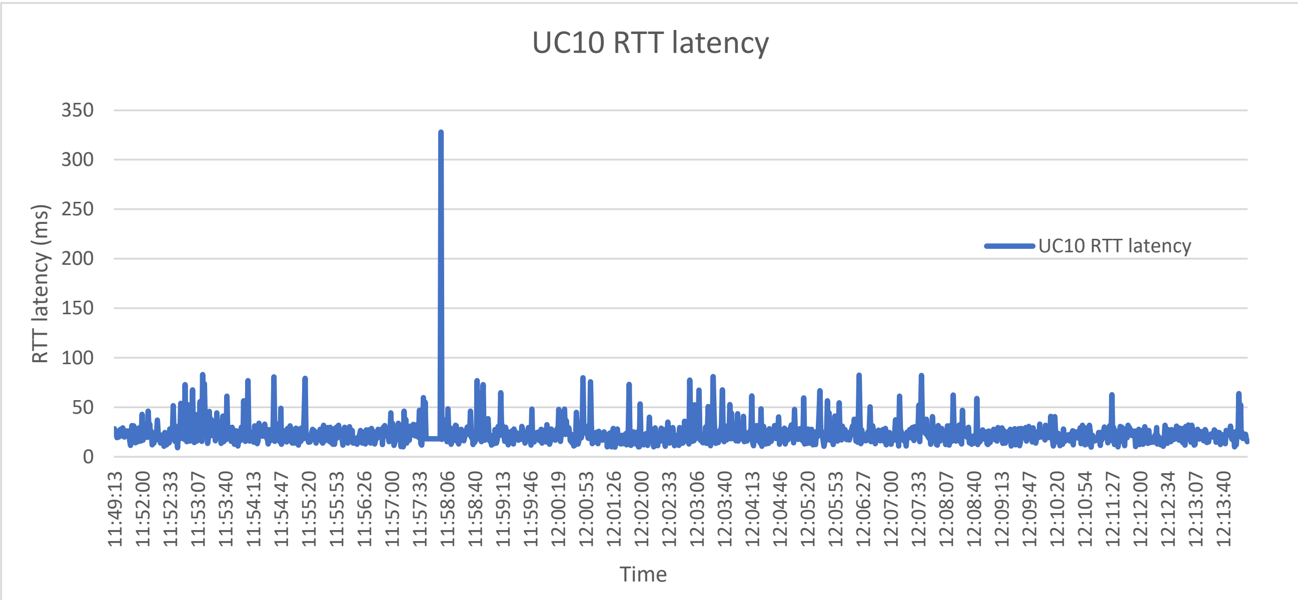


Figure 42. RTT latency results.

The subset of the results (selected trial on 18/4/22) is illustrated in Figure 42. The analysis of the collected metrics illustrates an average RTT latency of about 23.56ms. The minimum value observed is 9.22 ms, while the maximum value is 328 ms. In the figure a spike in the values indicates a high latency mainly due to channel conditions at the specific time (weak coverage). These spikes occurred rarely during the whole trials duration, and they mainly affect service reliability (99.93% <100%), while at the same time service availability remains at 100%.

Service reliability (APP layer)

To measure and validate service reliability, the definition in ITU-R M.2410 is considered. The packet error rate at the APP layer (packets that arrive delayed or erroneous are considered as lost packets) is measured by analysing the results of RTT latency metrics and packet loss metrics. An initial analysis of the results demonstrates service reliability of around 99.93%. More details will be provided in D7.4.

Service availability (APP layer)

Service availability is defined as one minus the measured packet error rate during the operation of a service. Therefore, the packet error rate at the APP layer (packets that arrive delayed are considered as arrived packets) are measured by analysing the results of RTT latency metrics and packet loss metrics.

An initial analysis of the results demonstrates service reliability of around 100%. More details will be provided in D7.4.

3 UC11 - Video-enhanced ground-based vehicles

3.1 UC11 Definition

In respect to the issues and concerns of the follow-me vehicles (efficiency of provisions for aircraft during their arrival and departure from parking positions, staff's misdemeanors, such as exceeding the speed limit or smoking, safety hazards such as fuel spillages, etc.), 5G technologies via the installation of high definition cameras on the follow-me vehicles were utilized to transmit live video feeds from the area where the incident took place, not only to ASOC, but potentially to other concerned third parties and stakeholders such as Police HQ, Civil Protection, HCAA (Hellenic Civil Aviation Administration), Fire Brigade operation centers, etc.. This use case resulted in coordinating and expediting the assessment, decision making and response to emergencies as they occurred and maintained the safety of the Apron area.

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.

Partners involved: WINGS, OTE, NOKIA-GR, ACTA, AIA

Location: AIA

3.2 UC11 Implementation

Apron Monitoring and Inspection is a core operational function of the airport which safeguards the safe guidance, maneuvering and parking of aircrafts to and from the parking positions. Dedicated operators are utilizing follow-me cars, for monitoring and overseeing the activity at the airside areas. They attend incidents, emergencies, and or critical events. The use case aims in developing a solution to equip follow me cars with high-definition cameras, which in its turn allowed for feeding the Airport Services Operations Center (ASOC, see Figure 43) and potentially other selected stakeholders with real time virtual data and information to achieve common operational and situational awareness.

In respect to providing the necessary to effectively perform their mission = to ensure safety and proper operational condition on the airside and monitor for irregularities or incidents (e.g. efficiency of provisions for aircraft servicing during their arrival and departure from parking positions, staff's misdemeanors, such as exceeding the speed limit or smoking, safety hazards such as fuel spillages, etc.), 5G technologies via the installation of high definition cameras on the follow-me vehicles utilized to transmit live video feeds from the area where the incident is taking place not only to ASOC, but also to other concerned third parties and stakeholders such as Police HQ, Civil Protection, HCAA (Hellenic Civil Aviation Administration), Fire Brigade operation centers, etc., (see Figure 43). This solution helps to coordinate and expedite the response to needs and emergencies as they occur and assists to maintain the safety of the Apron area.

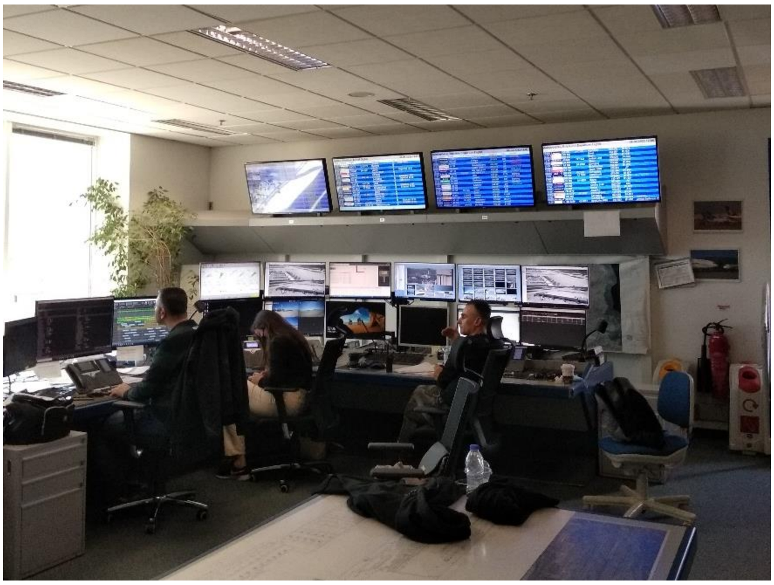


Figure 43. Airport Services Operations Centre, Apron Monitoring & Inspection position.

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 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.

Figure 44. Follow-me Vehicle with Camera mounted.

Figure 45. Apron Area with the three Follow-Me camera enabled vehicles.

<u>Situation example:</u> On April 8^{th}, 2022, during the morning shift at 11:20 hours, an Airside Monitoring Inspection Specialist (AMIS), was driving northbound on the Apron and encounters an aircraft that was leaking fuel. The AMIS notified the ASOC and summoned additional vehicles which secured the area to reduce the risk of fire and sent live footage of the incident in order for the ASOC to assess and proceed to the required mitigation measures, (Figure 46).

During the peak morning hours at approximately 04:30 – 07:30, there are several arrivals and departures that the AMIS must facilitate, thus the AMIS are unable to accommodate all arriving and departing aircrafts by inspecting their positions which results in aircraft departure delays. The late departure of aircrafts from Aircraft parking stands delays also, the arriving aircrafts as their parking position has not been vacated.

The follow-me vehicles also access on-demand service and provide the follow-me services for aircrafts, which lead aircrafts to their parking position. 5G technologies were used to provide, on-demand and/or live video streaming, to monitor and oversee the activity at the airport airside area, and attend incidents, emergencies and critical events.

Figure 46. ASOC AMI Operator position monitoring the live broadcasting of the three video feeds.

This resulted in a significant increase of the situational awareness of the stakeholders responsible for the running of the airport operations. Moreover, the ASOC were able to have an immediate overview and decide of the situation the required mitigation actions in a timely manner, regardless of the area of the airport that the incident took place, and irrespectively of whether the ASOC had direct viewing capability of the area or not.

3.2.1 Application Components

The live streaming process fed a dashboard presenting the live view from the different cameras that are installed on the follow-me vehicles (see Figure 44, Figure 45). This user interface was accessed by the airport apron monitoring and inspection operators at the ASOC and in case of an emergency it could potentially be accessed by other emergency resource personnel/stakeholders (e.g., Police, Security, ASOC, Fire Brigade, Medical Response teams etc.) as well. The deployment was done on the media server provided by WINGS at AIA. A mock-up screen of the described functionality is shown in Figure 47.

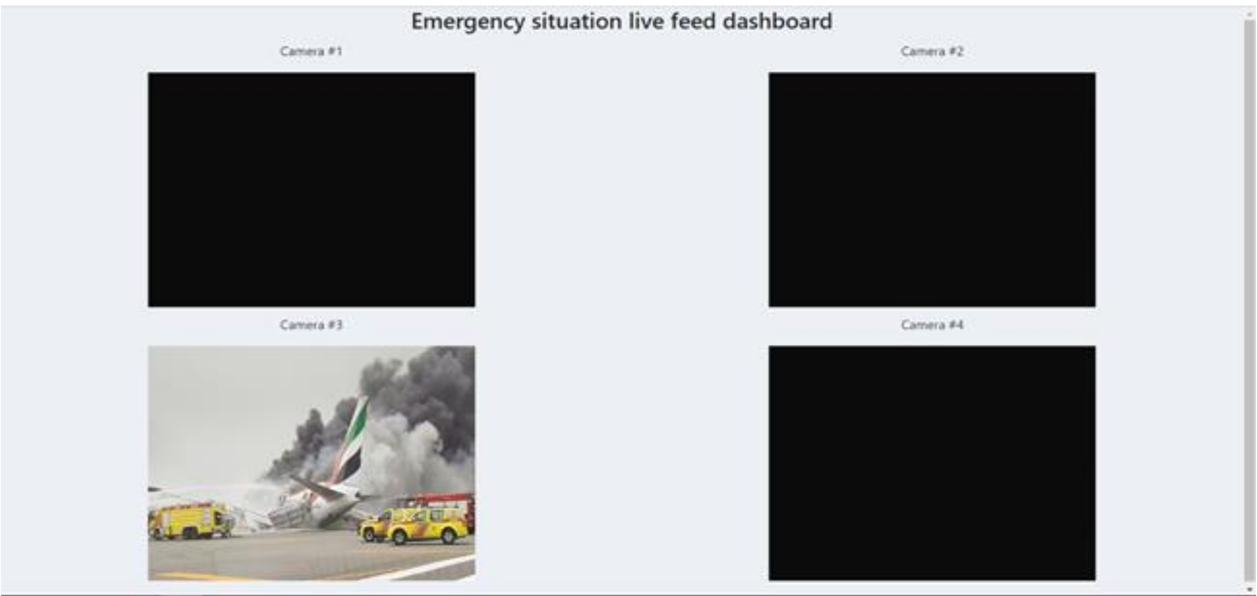


Figure 47. Situational awareness application mock-up screen.

The application provided for this use case comprises:

- The Nginx web server [13], which is a free, open-source, high- performance HTTP server.
- FFmpeg[3], which is a software project consisting of a variety of libraries for handling video, audio and other multimedia files and streams.
- RTMP (Real-Time Messaging Protocol)[4], a TCP-based protocol which maintains persistent connections and allows low-latency communication.
- HLS (HTTP Live Streaming)[5], which is a streaming protocol, widely supported across multiple devices and platforms.
- Video JS player[6], a JavaScript-based video player that uses the HTML5 video functionality built into advanced browsers.

The live streaming application developed in the context of this use case receives video feeds from multiple cameras and provides live video streaming on a one-page website. The feed from each camera is sent to different ports on the Nginx web server in RTMP format. This is achieved through the FFmpeg framework which encodes the feed and allows the setting of bitrate, resolution, quality and other video parameters. Then, each RTMP feed is converted to HLS, which delivers video files as small MPEG2-TS file downloads that are interpreted as a seamless stream. The conversion is done using the appropriate settings in the configuration file of the Nginx server. The live streaming process feeds a simple HTML page integrated with the Video.js player (Figure 48).

The final test was performed using 3 high-definition cameras installed in the follow me vehicles.

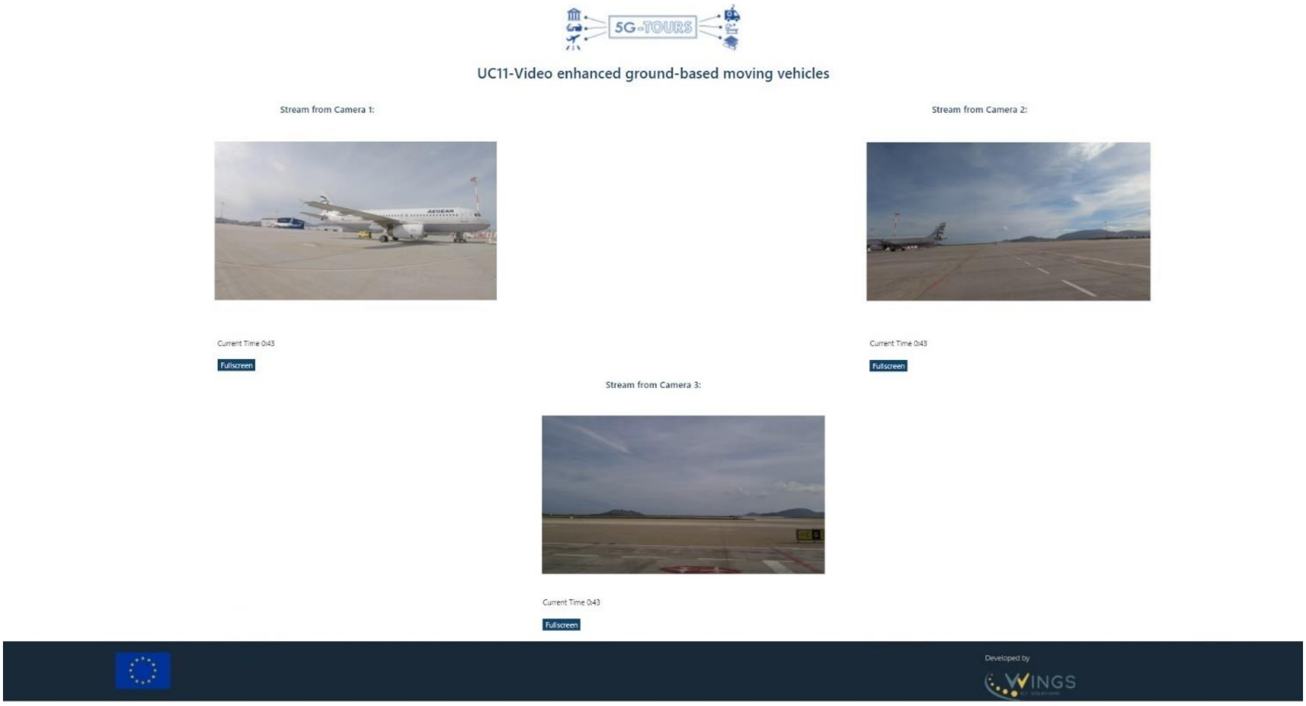


Figure 48. Current version of the live streaming application.

[3] https://ffmpeg.org/
[4] http://www.adobe.com/devnet/rtmp.html
[5] https://developer.apple.com/streaming/
[6] https://videojs.com/

3.2.2 Terminal Equipment components

The technical components required for this use case are:

- Three smartphone/mobile devices for testing the mobile application during the trials provided by SRUK.
- Three 5G routers for testing 5G capabilities provided by NOKIA-GR
- Three 5G car Peplink routers (provided by AIA)
- Probes to measure the backhaul traffic between AIA and OTE provided by ACTA.
- Three IP Cameras for vehicles for testing live steaming through 5G network provided by AIA.
- Media Server for storing the video streaming provided by AIA
- Three SIM cars for 5G routers provided by NOKIA-GR

Mobile/smartphone:

To make use of the 5G network available, a 5G compatible phone is essential. Specifically, Samsung Galaxy S10 5G was used. More details can be found in section 2.2.4.

5G routers with Wi-Fi and Ethernet interfaces:

To make use of the 5G network available, a 5G compatible router is essential.

Hikvision Cameras:

To make use of the 5G network available, a **reliable** Mobile Network Camera is essential.

HIKVISION DS-2XM6522G0-I(D)(M)(/ND): has high quality imaging with 2 MP resolution, clear imaging against strong back light due to 120 dB true WDR technology, efficient H.265+ compression technology, is water and dust resistant (IP68) and vandal proof (IK10), has advanced streaming technology that enables smooth live view and data self-correcting in poor network and 3D DNR technology delivers clean and sharp images. Its video max resolution is 1920x1080 and the power supply and consumption are 24VDC (Figure 49).

Figure 49. Hikvision Cameras.

Media Server:

The video streaming was transferred and stored to a Media Server on AIA premises. The server requirements are 4 core vCPUs and RAM 4GB. The operating system is Linux.

3.2.3 Interfaces

The Video-enhanced ground-based vehicles platform consists of a combination of different interfaces:

- The end devices - IP cameras transferred the live streaming to AIA's Media Server
- The web dashboard took the appropriate data from the server and were visualized in parallel the live streaming from three different cameras (see Figure 46, Figure 48).

The communication between the interfaces is depicted in Figure 50:

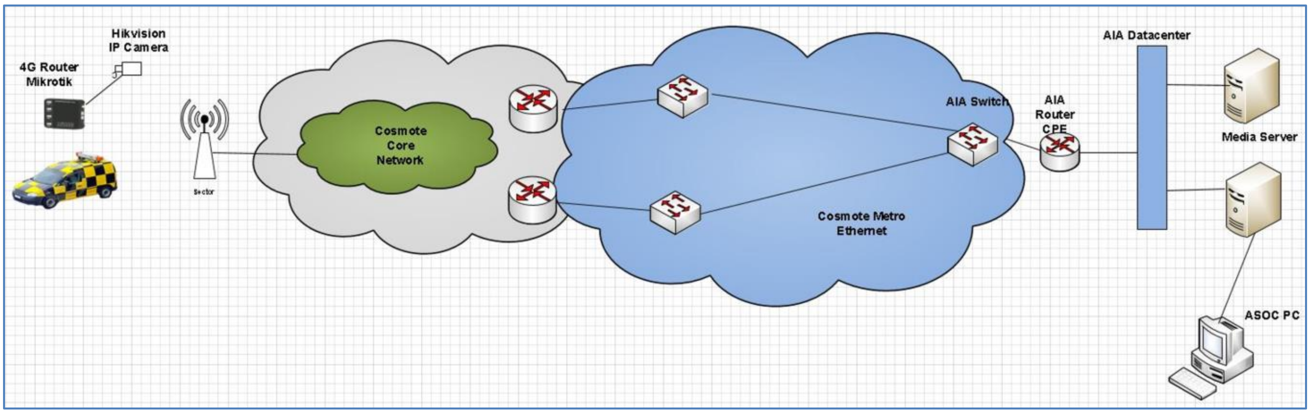


Figure 50. Network diagram for UC11.

The video streams were received by a NGINX open source webserver that provides load balancing, socket streaming and reverse proxy servers. The NGINX webserver has a variety of application modules that facilitate a multitude of options for video streaming, such as pushing the streams on a web media player, re-streaming the streams elsewhere, saving the video stream locally in various video formats, or playing video files later on demand (VOD). Using the NGINX Real-time Messaging Protocol (RTMP) module we receive the video streams on the NGINX server in RTMP format on the standard RTMP port (1935). The streams can be encoded to the HLS format using the FFMPEG library, with different bitrates and video quality for adaptive streaming. The FFMPEG library also allows for recording the streams in numerous video formats and compressions. The HLS streams are served to our platform, where users with access can see all 4 different streams played simultaneously.

3.3 Integration and tests in labs

A summary of the progress that has been made during the past months, based on the project's Gantt chart and the specific time plan created for each individual use case is described below.

Full-scale installation to one of the three vehicles:

- We have installed the 5G router to one Follow me vehicle and the router connected to Nokia 5G network installed at AIA premises.
- The final version of the web-based streaming application has been deployed to the AIA streaming server and has been tested with the 5G-TOURS infrastructure.
- The Samsung 5G mobile phone and a laptop connected through Wi-Fi to 5G routers.
- We have measured the network traffic through speed test by Ookla by both devices.
- We have checked the network connectivity between the end device (smartphone) and the media server and we have tried to send live streaming traffic to the media server.

3.4 Tests in the Network

This task addresses the facilitation of the logistics processes at the Athens International Airport (AIA). In particular, in the context of this Use Case 11 (UC11), three (3) emergency ground-based vehicles (also referred to as "follow-me" vehicles), that lead/guide aircrafts to parking positions, monitor and oversee the activity at the Airport Airside area, and attend incidents, emergencies and critical events. All three vehicles are equipped with 5G-enabled video capturing and transmitting devices, providing support both for day-to-day airport operations to the airport and response to emergencies. The video is delivered to the Airport Control Center in order to enhance the Situation Awareness of the Staff that are responsible for coordinating Airport operation. Presently the communication between the ground-based vehicles and the Control and Command Center is two-way voice only communication (TETRA or Mobile GSM/4G).

The network probes described in UC10 are also used in UC11 (see section 7.2.6).

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 51).

Figure 51. Peplink Router.

They connect to the Nokia 5G network installed at AIA premises. For additional tests, an ACTA measuring probe is connected via an Ethernet port to the routers. This allows the performance monitoring of the peripherals connected to the router in the vehicles. The peripheral includes the Dashboard Cameras, the driver's and possibly co-driver's mobile phones and future sensor that AIA includes in the vehicles (environmental, etc.).

For the needs of this UC11 and for the Athens site, OTE as site manager, provides all the telecommunication infrastructure at OTE Labs in Psalidi (OTE Labs facilities) and AIA (data rooms, poles for antenna mounting, racks, switches, routers, etc.) for the implementation of UC11, in co-operation with NOKIA-GR. For the implementation of KPI validation ACTA and OTE have selected the points of interest for installation of the measuring probes. In addition, OTE, for the needs of the interconnection of AIA with Psalidi (5G EVE infrastructure) has established a 10 Gbit dedicated Connection.

3.4.1 KPIs Validation

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. For this use case, Latency, Throughput, Availability, Broadband connectivity, and Location Accuracy is measured, as depicted in Table 4 below. More importantly, as mentioned above, the Latency from the UE (vehicle terminal) to the Server and the Throughput in the same direction are the most important KPIs to validate. Also, since Broadband connectivity is to be measured, high volume traffic should be generated from the UE towards the Video Streaming Server.

These are the KPIs that are relevant and important here and are possible to be measured, with the existing measurement setup. Latency refers to the Latency between the end user equipment (in the follow-me-vehicle) and the AIA video Streaming Server. Throughput is measured at the interconnection of two points e.g., between the e/VPC and COSMOTE's Packet Optical Transport Protocol (POTP) node. Network availability is measured as a percentage and is monitored to ensure that the service being offered continues to operate for end-users. Broadband connectivity (peak demand) is measured via Speed test at the video Streaming Server. 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 UC 11 is set up with only one cell, this is not possible. Therefore, Location Accuracy has not been measured.

The KPIs to be measured and validated along the data path are indicated in the diagram overlaid on the Athens site network architecture. For Latency, probes are installed in the follow-me car in AIA, at the Nokia ePC, and next to the video server, to allow us to measure latency from the source video traffic up to the video server. This distribution of the probes provides latency data at segments of the network, as well as the end-to-end Latency (Figure 52)

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

The probes gather locally network metrics data. This data is collected centrally for analysis and reporting. If metrics values are worse than the expected 5G network values, feedback has been given to the network providers, to study, identify and resolve issues.

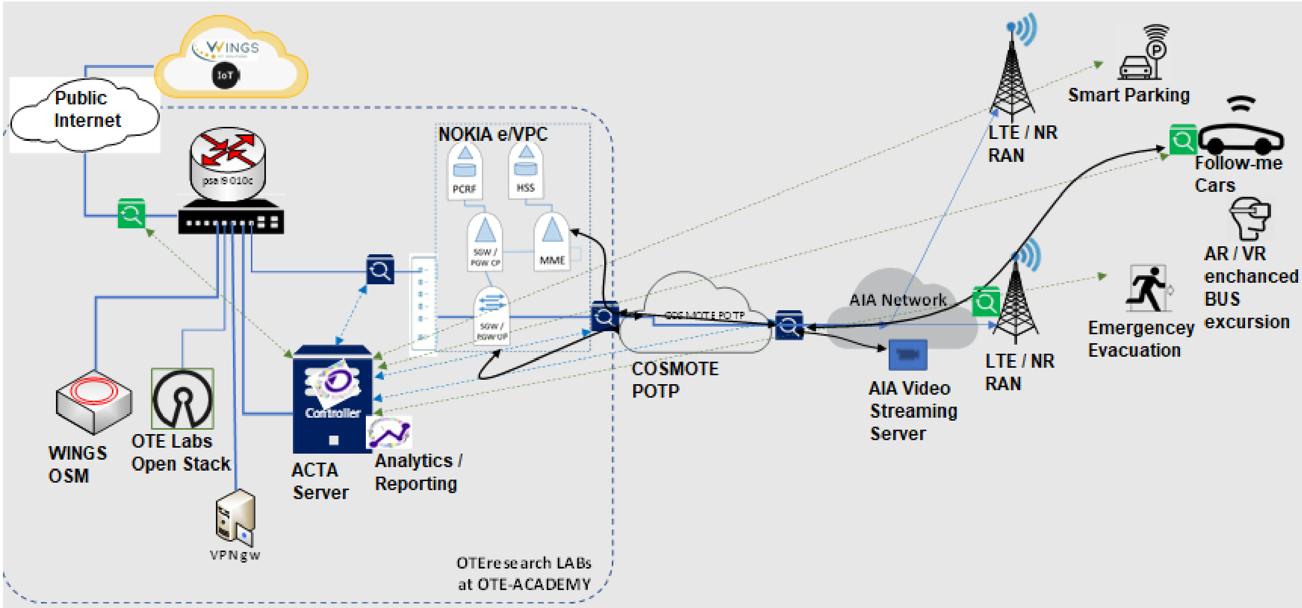


Figure 52. The participating probe components and their location for the KPI measurement of UC11.

The KPIs are measured and validated along the data path indicated in the diagram overlaid on the Athens site network architecture. 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 (Table 4) .

Table 4. UC 11 Video-enhanced ground-based moving vehicles network requirements.

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

(*) per vehicle 50 Mbps video stream is transmitted

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

(***) 50 vehicles

● **Non relevant KPIs**

● **Difficult to be demonstrated KPIs**

● **Relevant KPIs**

The Non relevant KPIs are considered non-relevant for this use case, because they are of medium to low importance and/or the relevant requirements could not be tested, e.g. slicing was not deployed.

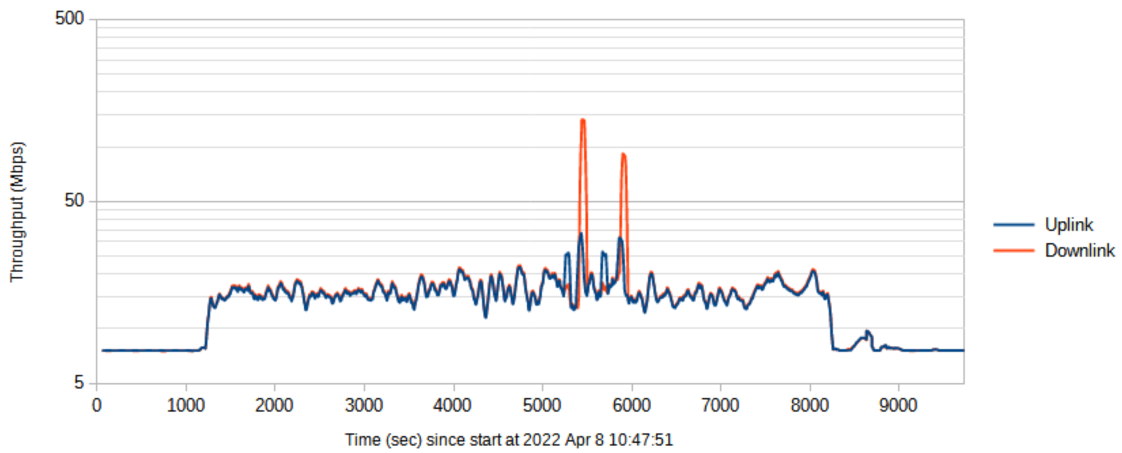


Figure 53. Real Time Throughput Measurements of UC11.

In Figure 53, the total throughput was measured, created by the user traffic for UC 11 during the full-scale trial performed on 08/04/2022. As a total, the data traffic does not exceed a peak of 150 Mbps, mostly staying around 30 Mbps, which shows that the video streaming is not posing unreasonably high bandwidth demands on the network.

In more detail, we can see the TCP Throughput (maximum sustainable) for UC 11, as experienced by the Peplink routers on the vehicles as well as using Samsung Galaxy S20 mobile UEs, in the Figure 54 and Figure 55 below.

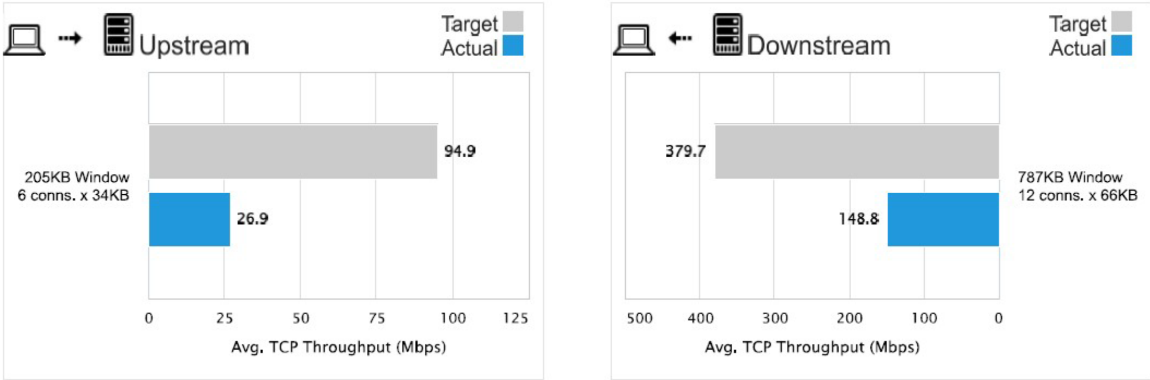


Figure 54. UC11 Max Throughput Measurement results with Peplink routers.

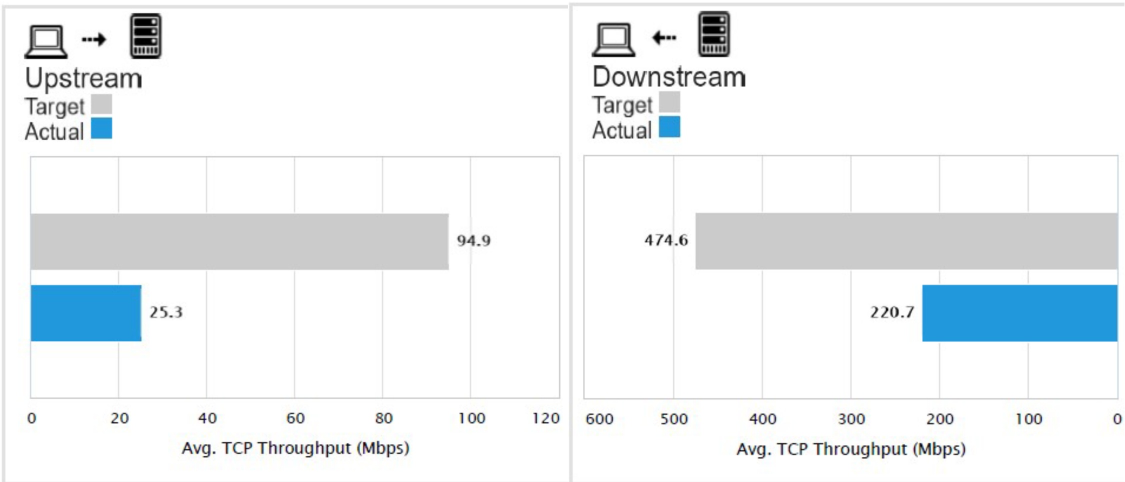


Figure 55. UC11 Max Throughput Measurement results with Samsung Galaxy S20.

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 to 220 Mbps. Both figures, allow for sufficient video streaming capacity. In the above figures, 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. 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 7 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.

Let us now turn our attention the Latency, Loss and Jitter L2/L3 KPIs measured in UC 11. The first two are also being used to calculate Network Availability and Network Reliability as discussed in Section 7.2.5.

ACTA has managed to capture these KPIs by deploying probes at various points of the network as shown in Figure 52. The participating probe components and their location for the KPI measurement of UC11.above. The segmentation methodology is elaborated in Section 7.2.5, but here it suffices to say that we provide measurement results for the backhauling part up to the L2/L3 switches at OTE Labs and AIA, the AIA BBU as well as up to a simulated UE, in the form of NOKIA Fastmile Router, which while not physically located at exactly the same point as the end user, is served by the same BBU. The Fastmile UE could not be permanently deployed 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.

Overall, the network KPIs were measured as follows:

- Loss remaining well below 0,02% for all parts of the network (transport and over-the-air)
- Latency below 0,8ms for the transport segment and 22 ms for the e2e path
- Jitter (delay variation) below 150µs for the transport segment and 7 ms for the e2e path.
- Availability 99,9999%
- Reliability 99,9999%

Graphs detailing the above results for the period of the actual UC11 trial on 08/04/2022, are provided in Figure 56 below:

Figure 56. UC11 Loss, Latency and Jitter Measurement results for the transport part of the network.

Figure 57. UC11 Loss, Latency, Availability, Reliability and Jitter Measurement results for the e2e network.

The overall conclusion is that the L2/L3 Network KPIs of Latency, Availability and Reliability comply with the targets set in Table 3 (respectively KPIs 1, 5 and 4). An added benefit is that the RAN Latency (KPI 2 in Table 3) which is characterised as “difficult to be demonstrated”, can be indirectly measured by subtracting the respective latency values of the transport part from the end-to-end part (Figure 57).

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 99,999%.

4 UC12 – Airport evacuation

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.

4.1 UC12 Definition

The main goal of this use case is to exploit the 5G capabilities for assisting current evacuation plans in large crowded indoor public spaces and thus, reduce the possibility or magnitude of casualties. The idea of this scenario is to support occupants to be safely guided, (for screenshot from mobile device application, see Figure 58), to the nearest exit, after an unattended item is left, for example, at Gate A38 of the STB and based on the current protocols an evacuation is deemed necessary.

The overall objective is to validate whether the 5G capabilities can complement existing processes and capabilities by providing automated guidance for the evacuation route to residents and regular users of the facility to visitors, travelers, and possible vulnerable people who are not aware of the facility. Real time data such as numbers of evacuees within an area, persons trapped, assistance to impaired people, visualization of real-time flows of people are evaluated to assess the impact of 5G technology.

Figure 58. Screenshot from mobile device during trials.

The evacuation of an Airport Terminal in case of an emergency is fundamental for ensuring the protection of human lives and reducing as much as possible, the number of casualties or injuries. The elements of panic that may ensue during an evacuation process may result in unnecessary and severe repercussions. In previous incidents where evacuation procedures were initiated and handled with the use of simple technologies such as tetra and telephone, uncontrolled evacuees have been found scattered beyond the designated muster areas.

In respect to efficient and rapid evacuation in cases of security emergencies (security threats, threatening phone calls etc.) or other related emergencies (fire, earthquakes, natural disaster etc.), 5G technologies may enhance the evacuation process and thus, reduce the possibility or magnitude of casualties. Evacuating in a quick and organized fashion such as that which the 5G provided by automated dynamic emergency routes from the affected area up to the muster areas, is of the utmost importance. 5G provides the capability to obtain real-time data from the emergency environment which is to be evacuated, such as numbers of occupants within the area, persons trapped in isolated areas of the building and about the real-time flow management of the evacuees.

Furthermore, this use case can accommodate for incidents that have complex and dynamic evacuation requirements such as a fire spreading or a terrorist attack, that require dynamic information to be conveyed to evacuees.

Airport terminals are very large and complex public venues with many travelers, visitors and employees. Airport evacuations in general, are currently based on pre-established plans and procedures to be executed during the emergency.

AIA is the main gateway to Athens and Greece in general. On a daily basis AIA serves approximately fifty to sixty thousand passengers travelling through the airport, while during the peak traffic days this number can reach approximately one hundred and twenty thousand persons or even more, including visitors and employees.

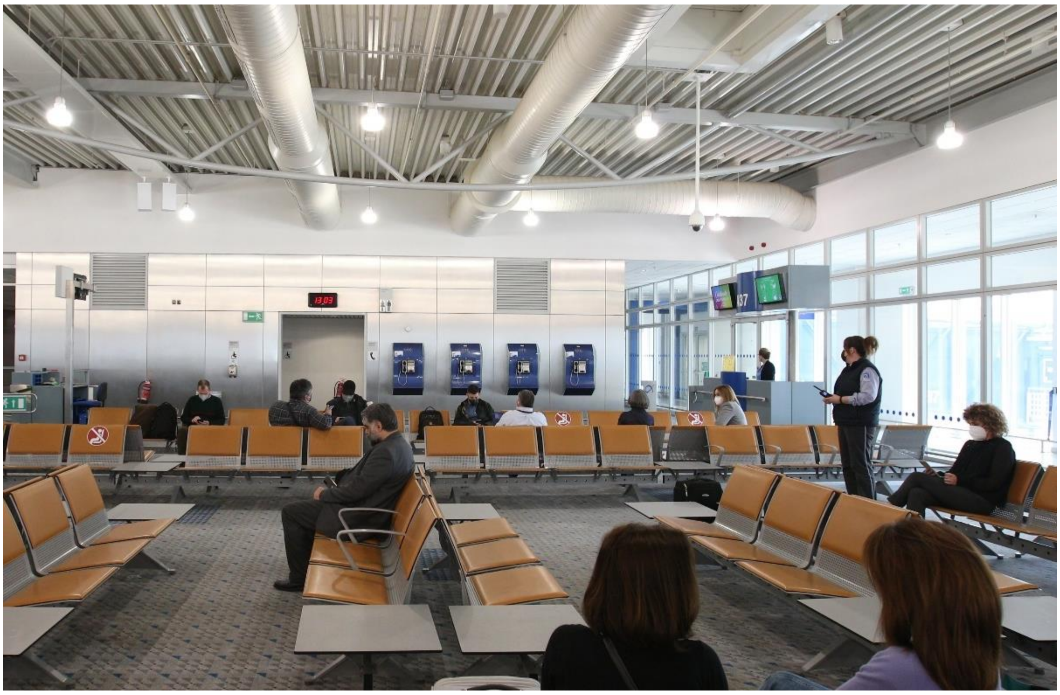


Figure 59. AIA Terminal Area - UC12 testing.

Initially, the Evacuation use case participants are notified with a message to their mobile device about the emergency situation, while from that point on, they receive further notifications on regular time intervals. Guidance is provided in a personalized manner, taking into consideration the physical design of the terminal area, any obstacles that might exist, the current occupancy, the capacity of the evacuation routes and the travelers' individual needs and limitations, such as their age, health status and mobility capabilities, etc. The location of the travelers is also tracked to provide more targeted guidance especially for evolving events such as a fire spreading or an evacuation route becoming unavailable. The system can also be explored for early detection of passenger movement anomalies that can signify evolving emergency and timely alarm airport response units. Enhanced location services are made available through the 5G network.

Partners involved: AIA, KEMEA, WINGS, OTE, NOK-GR, ACTA

Location: AIA APRON

4.2 UC12 implementation

In the context of this use case, a section of AIA's Satellite terminal was provided, and since COVID19 restrictions were applied, 17 volunteers (actors) participated in the evacuation exercise. An example of a typical airport terminal gate/lounge, which was a part of the airport terminal dedicated to the 5G-Tours UC12 testing, can be seen in Figure 59.

Naturally, such an emergency situation calls for low latency communications with high reliability of being realized, which means that a URLLC slice had to be allocated so as to ensure that all travelers and AIA personnel are notified and guided to the most appropriate exit immediately. A detailed 3D digital model of the section that was evacuated along with all objects contained therein, such as seats, desks and monitors, had been developed and fed into the evacuation support system. Emergency exits were all recorded and fed into the system - supporting the evacuation procedure - along with information on their exact location as well as their capacity, if they are accessible, etc.

By utilizing the location-based services from WINGS using AR and VR at the passenger's smart devices (see Figure 60, Figure 58), we managed to guide passengers to safety by utilizing the most efficient route depending on their location within the terminal. The platform provided dynamic way finding instructions according to the progression of the passengers to the nearest emergency exit, see Figure 61.

Figure 60. AR based way finding guidance over 5G during the AIA trials.

Figure 61. Assisted airport terminal evacuation utilising the AR application and 5G network.

4.2.1 Application Components

The provided service consists of a mobile application that provides the user with personalized suggestions aiming to evacuate the area that the use case took place as fast as possible, while ensuring that the people are safely guided out of the area. To achieve this, three indoor 5G micro cells provided by NOKIA-GR have been deployed to calculate each user's location accurately, see Figure 60, as it is analyzed in section 4.3. AIA has provided the exact layout of the area for WINGS to create its digital twin in the mobile application. In such a way the user can have an instant view of his location within the area while the system provides him/her with personalized suggestions on how to evacuate the building considering the others users' locations, to avoid congestion of users in a specific route (it is explained in the coming section 4.3). A schematic representation of the proposed architecture is shown in Figure 62:

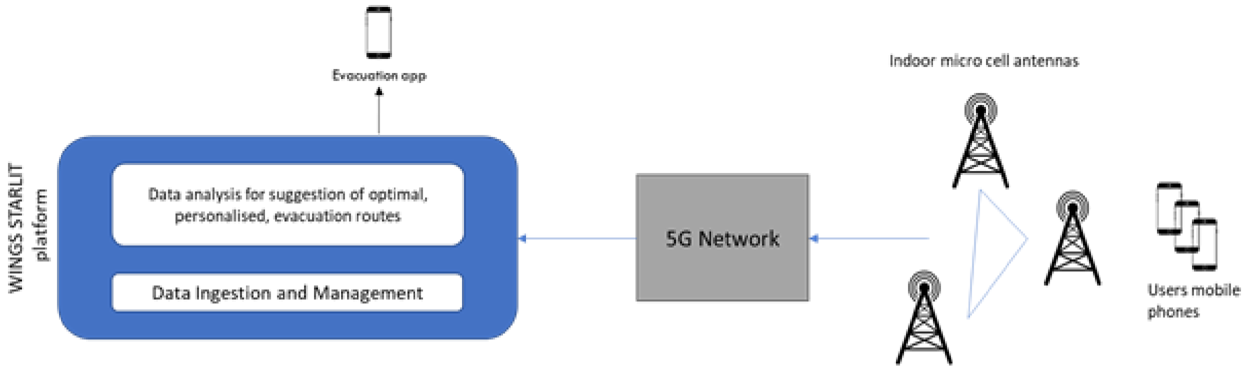


Figure 62. High level architecture of the evacuation system.

As far as the application is concerned, its key components are:

- The server/cloud component, responsible for processing the data received from the respective end-user device. This component is responsible to implement the graph-based approach followed for selecting the preferred exit, as well as providing the optimal route towards it.
- The end-user device and namely the respective mobile application, responsible for sending the appropriate data to the cloud for further processing, as well as for the visualization scheme/augmented reality environment. The appropriate data consists of the relative location of the user, defined in the appropriate indoor environment reference system, e.g., in which part/room/area of the building is the user currently, as well as the personalized options/preferences of the user, if any.

4.2.2 Terminal Equipment components

The technical components required for this use case are:

- Samsung Galaxy S10 and Galaxy S20 smartphones for testing the mobile application during the trials provided by SRUK.
- SIM cards for 5G mobile devices provided by NOKIA-GR.

4.2.3 Interfaces

Backend server: A python REST framework as the central backend system responsible for orchestrating the user requests and the analytics component and for delivering the information to the end user.

Unity/Vuforia modelling: The framework responsible for modelling the space and environment of the test site as well as managing the AR components. This has been integrated into the end-user device application.

End-user device application: The end-user device/devices responsible for delivering the appropriate information (current location and status, preferred destination, etc.) to the backend server in json format for further processing and visualizing the relevant information (routing, estimated arrival time, etc.) in an AR environment.

Analytics: A python-based module responsible for calculating the optimal exit and the optimal path towards it, using a graph-based approach.

LBS component: The component gets the RSRP (Reference Signals Received Power) signal from the 3 indoor cells and is responsible for sending the information to the back-end server in order to estimate the user's location.

4.3 Integration and tests in labs

For the current simulation scenario, a top view of a section of AIA was used and for testing purposes a part of this area was considered. This top view, as well as the area under consideration for the testing purposes, can be seen in Figure 63 below:

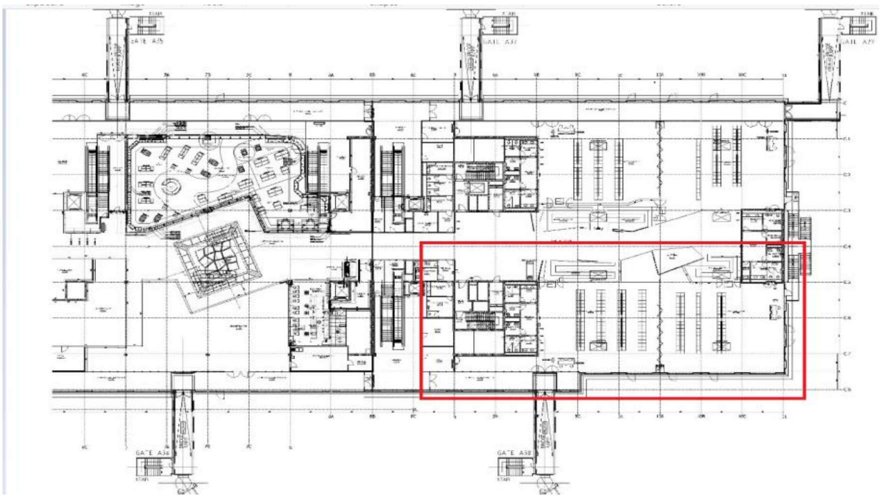


Figure 63. Top view of an AIA's section and the area considered for the purposes of the simulation scenario, denoted with red.

For modelling the indoor geometry into a corresponding graph, an abstraction of the indoor topology was conducted, meaning that the room-level topology details were omitted, and the rooms were considered empty. The reason for this is that the purpose of the service is to provide an indicative room level guidance providing instructions to which room/section to move towards, rather than how exactly to move within the room/section. The graph to model the possible navigation of the user within the area is shown in Figure 64, on top of the AIA's top view. More specifically, the top view of the AIA's area considered for the simulation with the corresponding graph which models the possible movements of the users. The division of the area into the sections A, B and C was arbitrary to organize the nodes of the graph into groups.

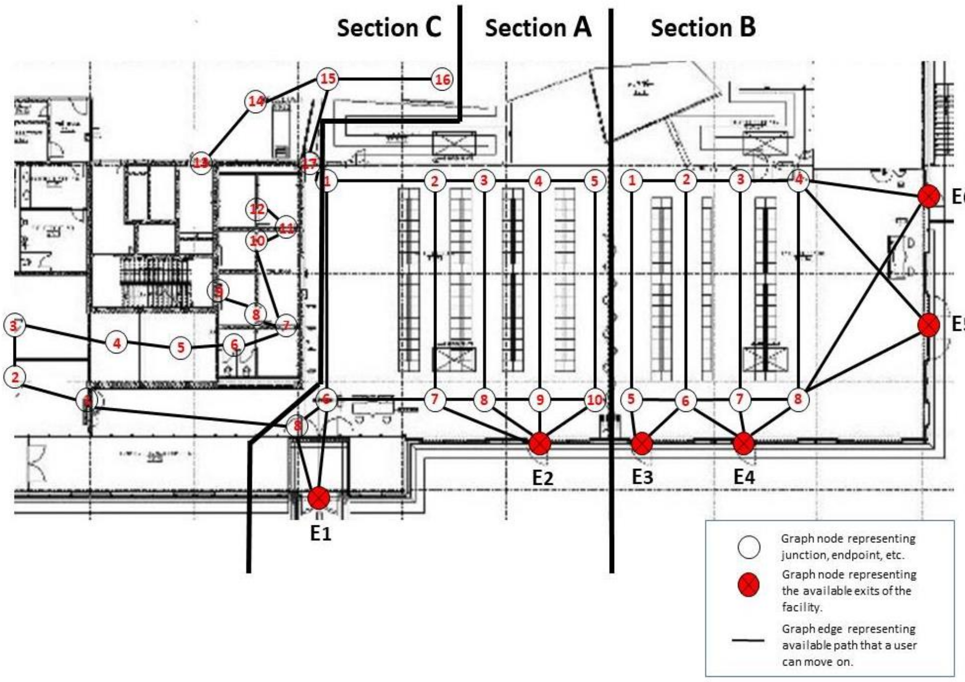


Figure 64. Navigation graph based on AIA's area.

A simulation scenario, consisting of two users asking for routing towards the closest exit is shown in Figure 65. The users located at the respective pins, request navigation to the closest exit and the algorithm specifies the closest one for each user and provides the shortest path towards it. It should be noted here that the algorithm considers the latest requests, in order to split the users towards the available exits, as uniformly as possible, to avoid crowding in a specific section. The study area, with the available exits indicated with the red arrows, the end users located at the respective pins and the provided routes towards the optimal -according to the specified criteria- exit (in this case the criterion is closeness to the exit). Dynamic management of the exits is considered to cover potential terrorist scenarios where the terrorists are on the move and as such specific exits may be out of reach.

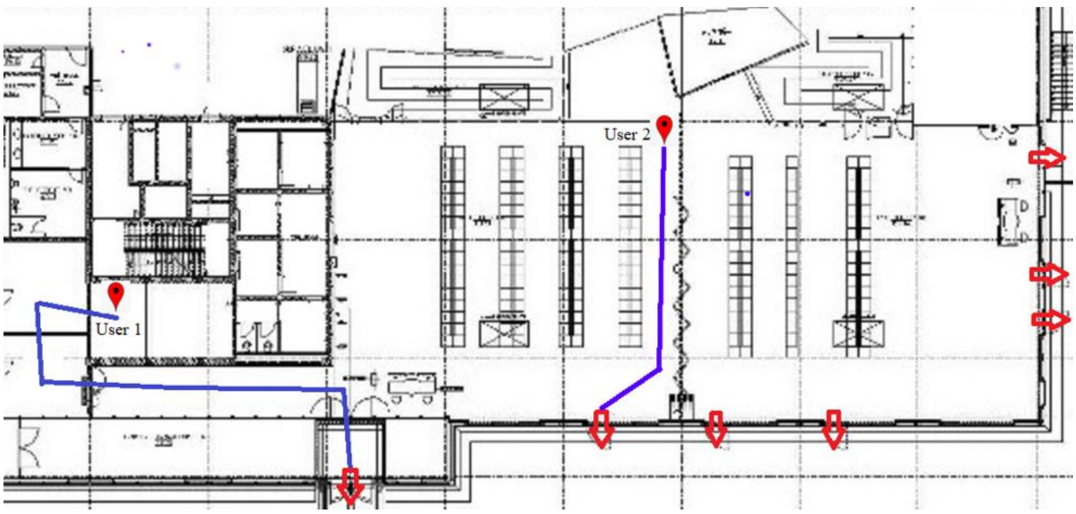


Figure 65. Simulation scenario for routing towards the closest exit.

The next step in the process of integrating the provided solution to a complete and easily perceptible to the user system was to incorporate the provided route in a unified AR environment application, which accurately guides the user based on the route calculated. In the section below, a brief overview of this AR environment is provided.

The first step was to create a digital 3D model of the area being studied. To create the digital three-dimensional structure of the evacuation space, the airport's architectural plans have been used for the basic structure of the building (floors, walls, doors, partitions, exits, corridors, stairs, columns, windows). Then, all the objects that constitute fixed constructions in the space (offices, screens, shops and more generally objects that cannot be moved have been placed in it. The large objects that were inside the space and may be moved to other places (sliding doors, chairs, space bans) have been also constructed. This way a digital capture of the airport in its basic features had been created. Then, this digital model had been utilized by **Unity** game engine, which allows a virtual navigation within the model. This, in combination with **Vuforia**, enabled augmenting the real space with digital information, which in this case is directions towards the selected exits through the optimal path, identified by the algorithm described above.

Indicatively, in the Figure 66 one can see, an actual scene from the airport, the corresponding digital model created to enable the virtual navigation in Unity and the scene augmented with easily perceived directions.

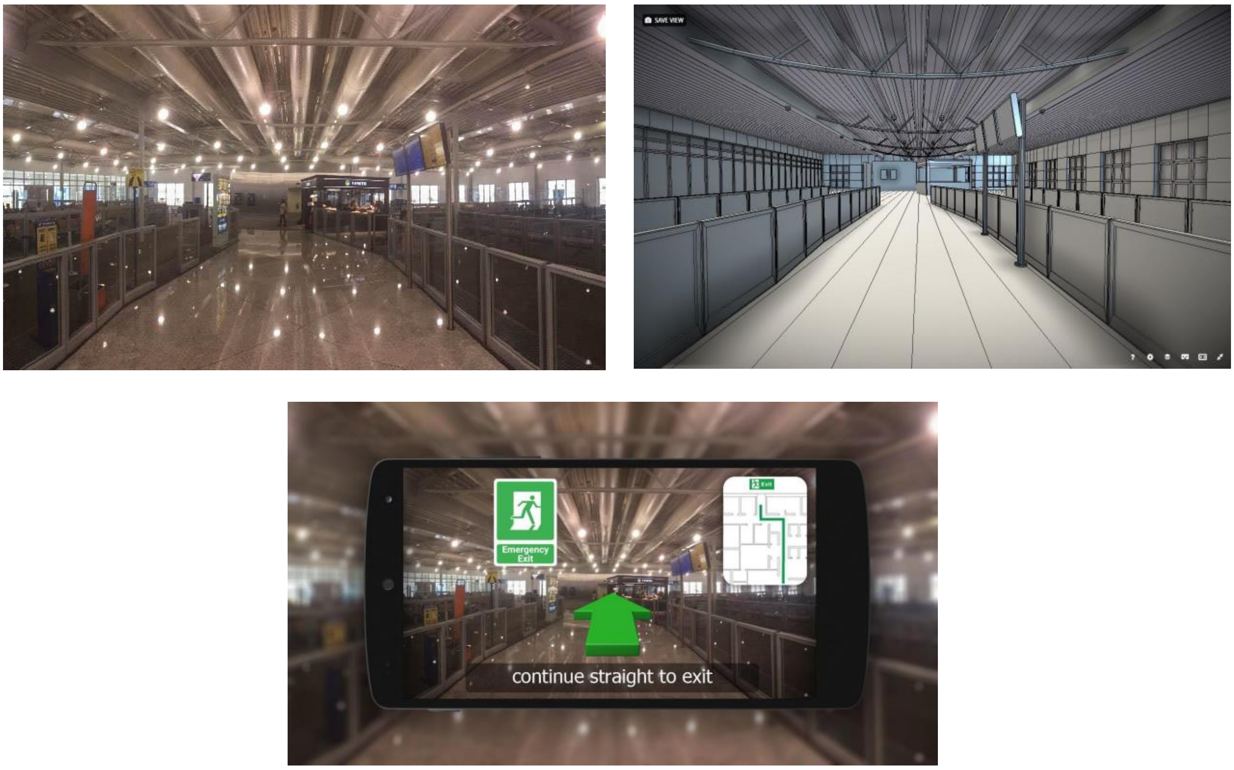


Figure 66. a) The actual scene from a section of AIA, b) the corresponding digital model c) augmented directions, as well as a top view of the suggested route towards the optimal exit.

The AIA top view cad files had been utilized for the virtual 3D model creation as shown in the figures below (Figure 67 - Figure 70).

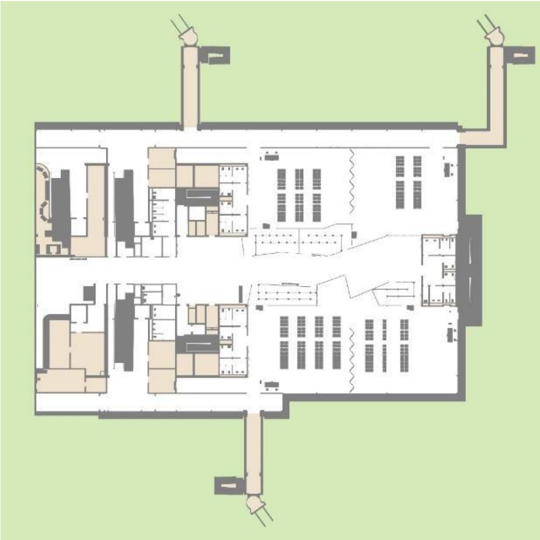


Figure 67. The AIA top level view.

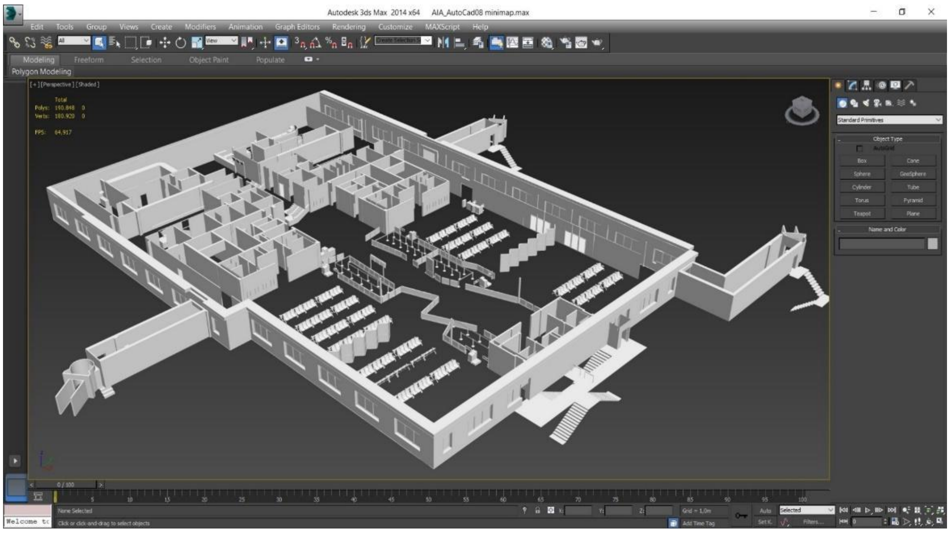


Figure 68. The constructed 3D model in Unity based on the top view.

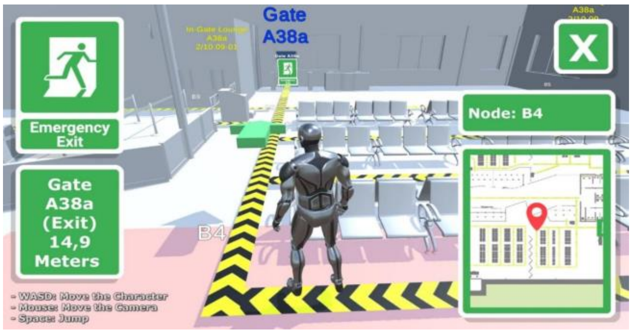


Figure 69. Integration of 3D model in the Unity environment.

Figure 70. Virtual navigation of the user within the modelled area.

4.3.1 Location Based Service (LBS) Algorithm – Getting user's location

Regarding the indoor localization component, there are several approaches that have been studied recently. The most prominent categories to which the various algorithms can be divided to, that have been also utilized at commercial level are listed below:

- Time of arrival (TOA)
- Angle of arrival
- Arrival time delay
- Received signal strength Indicator (RSSI)
- Hybrid systems (mix of different physical principles related metrics)

According to the State-of-the-Art studies, calculating the TOA using Ultra Wideband Positioning can provide some of the most promising results in terms of accuracy [15]. As the lower bound of the variance of TOA measurements is dependent on the signal bandwidth [16], the exploitation of the higher bandwidths that 5G networks offer could be of great benefit, to reach sub-meter accuracies that would enable accurate room-level localization, which is crucial for the evacuation case study. Nevertheless, there have been studies showing that the RSSI algorithms can achieve comparably high accuracies, while offering scalability of the size of the network and enabling hundreds of devices to connect, without any interference. It should be noted that regardless of the method the final accuracy perceived by the end user, is dependent on the indoor test site environment and the complexity of the configuration, obstacles and extends of the area [17]. Given that the LBS server from NOKIA-GR side could not be provided, we decided to use the RSRP information from the 3 indoor cells in order to implement the localization algorithm. It should be noted that this task was undertaken by WINGS due to the unavailability of the LBS component from the NOKIA-GR side.

To determine the indoor user's location, an application has been created with a functionality to record the RSRP (Reference Signal Received Power) values or otherwise the signal strength received, from the nearby cell towers to which the mobile phone is connected.

Through a rectangular grid, which is illustrated in the application, we divide the actual space into smaller square areas. Then holding the mobile phone in hand, we move around the space based on the grid, by matching each square to an area in the actual space. When we are in the area we want to record, we click on the square that matches this area in the grid, which is then changes colour to red.

A view from the application is shown in Figure 71 below. For example, the upper left corner of the actual space corresponds to square 0 of the grid displayed on the mobile phone.

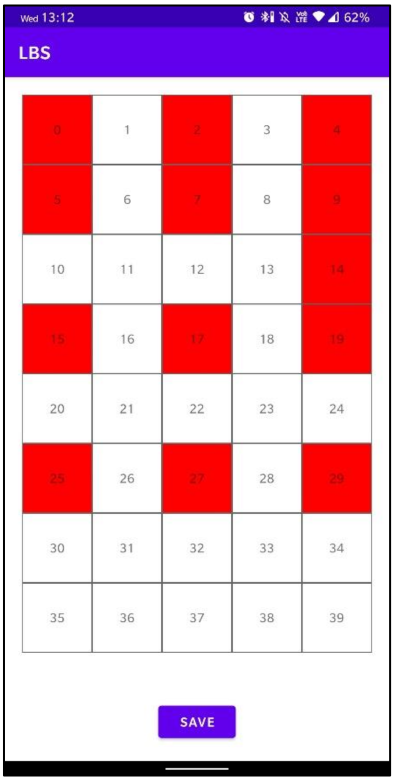


Figure 71. A view from the WINGS RSRP logging application for nearby cell towers.

The results from the application are depicted in the table below, where the RSRP information from an indoor space, based on 3 different cells is shown. In order to define the actual user's location, the RSRP measurements are mapped to specific sections within the area of interest. The first (offline) phase required to create a grid of points for which the actual signal strengths (RSRPs) had been recorded. The second (online) phase, based on the received RSRP and on the aforementioned grid created offline, mapped via interpolation the signal strengths to approximate user coordinates. It should be noted that the accuracy of the positioning is dependent on the accuracy of the RSRP as well as on the spatial resolution of the grid. Then based on the location the evacuation algorithm implemented by WINGS calculates the route for this specific location towards the nearest exit. During the lab tests, in which the commercial outdoor macro cells were used as the reference signal sources, an accuracy of about 3 meters was achieved. During the actual trials in AIA, in which the 3 indoor (omni) NOKIA cells were used, the accuracy was measured to about 5.3 meters. This increase in the accuracy value can be explained by the positions of the indoor cells and their technical characteristics (omnidirectional antennas in indoor cells instead of direction antennas in macro cells). The results will be explained in detail in D7.4.

Grid	Cell_IDA : RSRP	RSRQ	Cell_IDB : RSRP	RSRQ	Cell_IDC : RSRP	RSRQ		RSRQ		RSRQ		RSRQ		RSRQ		RSRQ
0	255: -108	-12	400: -111	-14	12: -114	-17	295: -65	-7	294: -73	-9	463: -79	-18	26: -81	-20		
2	255: -108	-12	400: -111	-14	12: -114	-17	295: -65	-7	294: -73	-9	463: -79	-18	26: -81	-20		
4	255: -108	-12	400: -111	-14	12: -114	-17	295: -65	-7	294: -73	-9	463: -79	-18	26: -81	-20		
5	255: -101	-9	400: -108	-11	292: -109	-14	12: -116	-19	295: -65	-7	294: -73	-9	463: -79	-18	26: -81	-20
7	255: -101	-9	400: -108	-11	292: -109	-14	12: -116	-19	295: -65	-7	294: -73	-9	463: -79	-18	26: -81	-20
9	255: -108	-12	400: -111	-14	12: -114	-17	295: -65	-7	294: -73	-9	463: -79	-18	26: -81	-20		
14	255: -101	-9	400: -108	-11	292: -109	-14	12: -116	-19	295: -65	-7	294: -73	-9	463: -79	-18	26: -81	-20
15	255: -97	-9	400: -99	-10	12: -112	-14	295: -65	-7	294: -73	-9	463: -79	-18	26: -81	-20		
17	255: -97	-9	400: -99	-10	12: -112	-14	295: -65	-7	294: -73	-9	463: -79	-18	26: -81	-20		
19	255: -101	-9	400: -108	-11	292: -109	-14	12: -116	-19	295: -65	-7	294: -73	-9	463: -79	-18	26: -81	-20
25	255: -97	-9	400: -98	-14	292: -106	-20	295: -65	-7	294: -73	-9	463: -79	-18	26: -81	-20		
27	255: -97	-9	400: -98	-14	292: -106	-20	295: -65	-7	294: -73	-9	463: -79	-18	26: -81	-20		
29	255: -97	-9	400: -98	-14	292: -106	-20	295: -65	-7	294: -73	-9	463: -79	-18	26: -81	-20		

Figure 72. Results from the RSRP from 3 different cells for different places in the indoor space are captured.

4.4 Tests in the Network

A mobility-efficient framework is also targeted by means of the airport evacuation use case leveraging advanced 5G capabilities, especially in relevance to low latency and enhanced reliability to ensure the timely notification of travelers being part of a hazardous situation. The Trial was intended to be accomplished by using 75 volunteers acting the parts of evacuees, security personnel, Police, etc. Whilst in a normal evacuation process, social distancing is neither feasible nor recommended, given that the objective is to evacuate the building the soonest possible. However, due to covid19 pandemic restrictions we had to:

- Reduce the total number of participants from 75 to 20
- Increase the evacuation exits to 3 instead of 2
- The evacuation process was closely monitored so that there was social distancing amongst the evacuees all the way up to the Muster points.

The network probes described in UC10 are also used in UC12 (see section 2.4).

For the needs of the Airport Evacuation UC and the corresponding test and trials OTE as site manager provides all the telecommunication infrastructure at Psalidi (OTE Labs facilities) and AIA (data rooms, poles for antenna mounting, racks, switches, routers, etc.) for the implementation of the UC in cooperation with NOKIA-GR, as well as for implementation of KPI validation in cooperation with WINGS and ACTA. In addition, OTE, for the needs of the interconnection of AIA with Psalidi (5G EVE infrastructure) has established a 10 Gbit line.

4.4.1 KPIs Validation

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.

The airport evacuation system comprises of:

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

For this use case, RTT Latency, Throughput, Reliability, Availability, and Location Accuracy 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 (Table 5).

These are the KPIs that are relevant and important in this case and are possible to be measured, with the existing measurement setup. RTT Latency refers to the Latency between the end user equipment (at an emergency situation) and the WINGS STARLIT Platform and back to the end user.

Throughput is measured at the interconnection of two points e.g., between the Starlit Platform and the 5G Network and between end users and the network. Network availability is measured as a percentage and is monitored to ensure that the service being offered continues to operate for end-users. For Location Accuracy, the location of a specific UE is provided by a software module developed by WINGS.

ACTA has managed to capture these KPIs by deploying probes at various points of the network as shown in Fig 70 above. The segmentation methodology is elaborated in Section 7.2.5, but here it suffices to say that we provide measurement results for the backhauling part up to the L2/L3 switches at OTE Labs and AIA, the AIA BBU as well as up to 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.

Loss and Latency are also measured from a probe at the L2/L3 switch at NOKIA ePC up to the L2/L3 switches at AIA, This distribution of the probes in the BBUs as well as the AIA OTE control room, provides loss and latency data at segments of the network, as well as the end to end Latency and Loss. For real time Throughput, a pass-through probe is installed at the e/VPC.

The probes gather locally network metrics data. This data is collected centrally for analysis and reporting. During installation, when metrics values were worse than the expected 5G network values, feedback was given to the network providers, to study and identify if issues can be resolved.

The components that implement UC12 in the Athens site and their relative placement are shown in the Figure 74. The KPIs to be measured and validated along with the data path are indicated in the diagram, overlaid on the Athens site network diagram. The data path, over which the KPIs are to be measured and validated, is indicated in Figure 75.

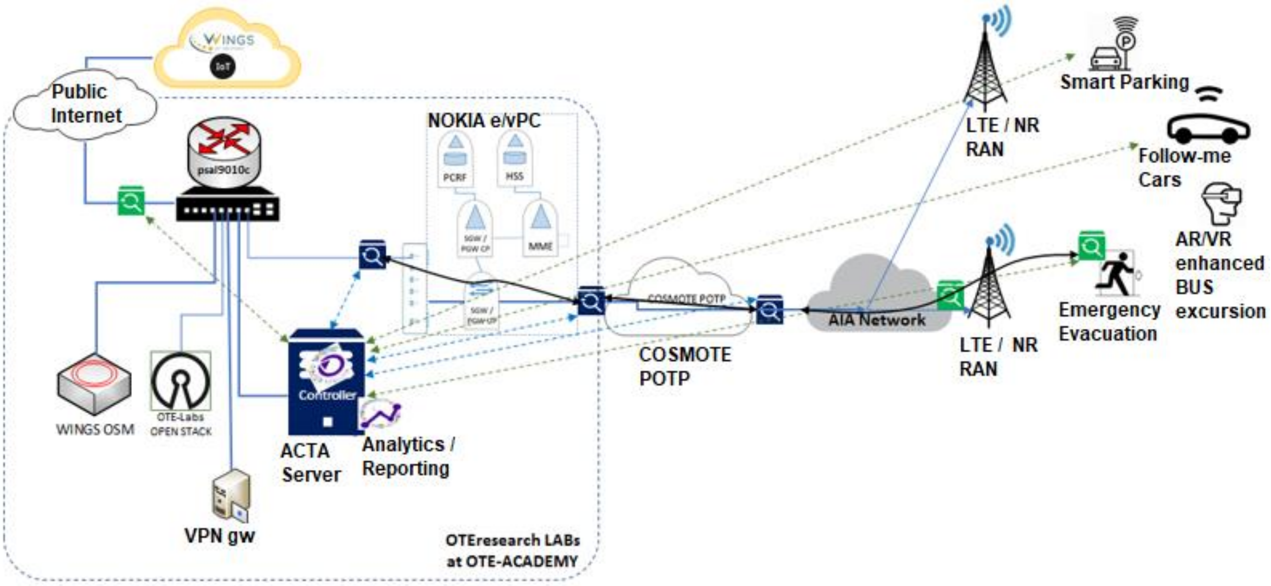


Figure 74. The participating probe components and their location for the KPI measurement of UC12.

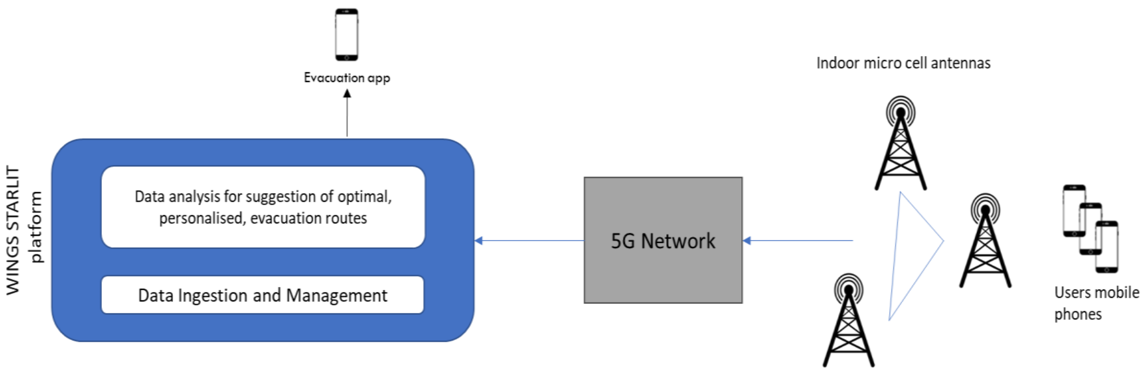


Figure 75. Data path of UC12.

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 (Table 4).

Table 5. 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									
● (green)	1	Latency (in milliseconds) - round trip - Min/Max	msec	15				15	100
● (red)	2	**RAN** Latency (in milliseconds) - one way	msec	10				10	20
● (green)	3	Throughput (in Mbps) - Min/MAX - sustained demand	Mbps	500				100	500 *
● (red)	4	Reliability (%) - Min/Max	%	99,9999				99,999	99,9999
● (green)	5	Availability (%) - Min/Max	%	99,99				99,99	99,99
● (black)	6	Mobility (in m/sec or Km/h) - Min/Max	Km/h	10				0	10**
● (green)	7	Broadband Connectivity (peak demand)	Y/N or Gbps	10				1	10
● (red)	8	Network Slicing (Y/N) - if Y service deployment time (min)	Y/N	0			high	1	5
● (black)	9	Security (Y/N) - if Y grade i.e. "Carrier Grade"	Y/N	Y				Y	
● (black)	10	Capacity (Mbps/m^2 or Km^2)	Mbps/m^2	20				2	20***
● (black)	11	Device Density	Dev/Km^2	1000K				1000K	1000K*****
● (green)	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

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

The Non relevant KPIs are considered non-relevant for this use case, because they are of medium to low importance and/or the relevant requirements could not be tested, e.g., slicing was not deployed.

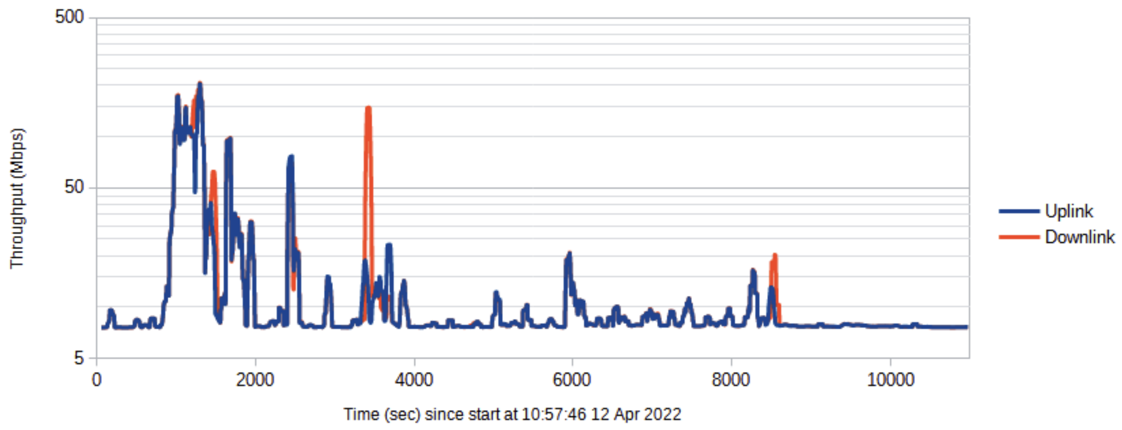


Figure 76. Real Time Throughput Measurements of UC12.

In Figure 76, we measured the total throughput created by the user traffic for UC 12 during the actual full scale trial performed on 12/04/2022. As a total, the data traffic does not exceed a peak of 250 Mbps, mostly staying around 30 Mbps, the fluctuations corresponding to the instance of heavy network usage by the evacuees. This shows that the application, even when used concurrently by many users, is not posing a bandwidth demand too high for the network to handle (i.e. minimum peak demand of 1Gbps, KPI 7 in Table 4, was not reached).

In more detail, we can see the TCP Throughput (maximum sustainable) for UC 12, as experienced by the FastMile router UE at the satellite terminal, as well as using Samsung Galaxy S20 mobile UEs, in the Figure 77 and Figure 78 below.

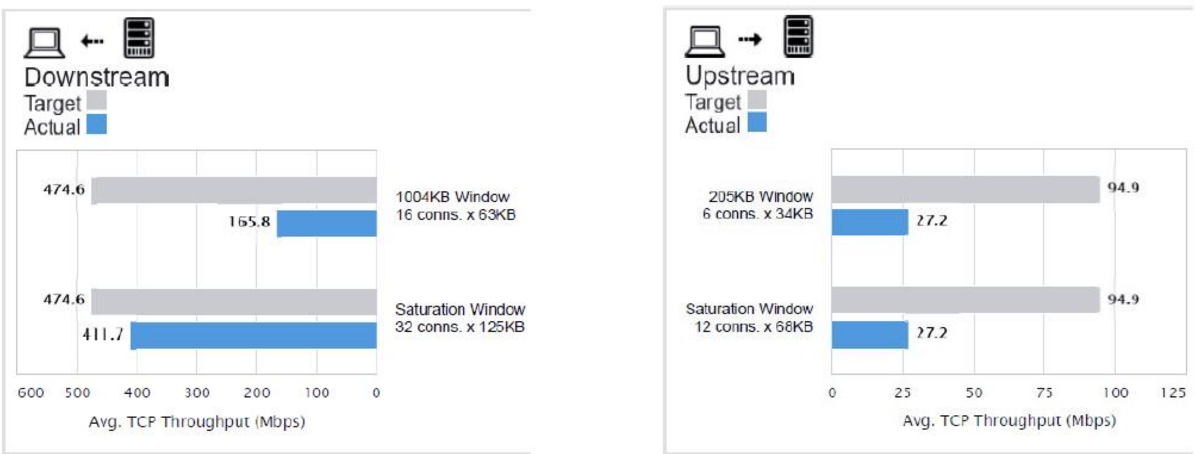
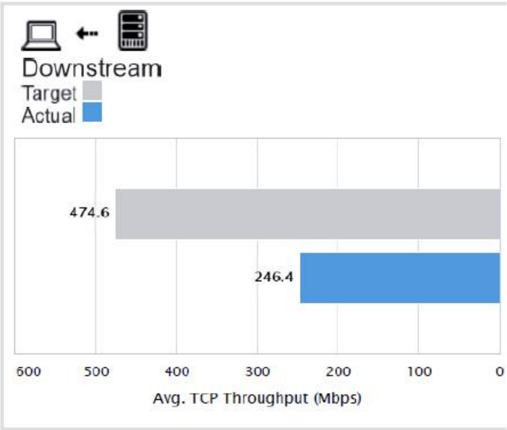


Figure 77. UC12 Max Throughput Measurement results with FastMile router UE.



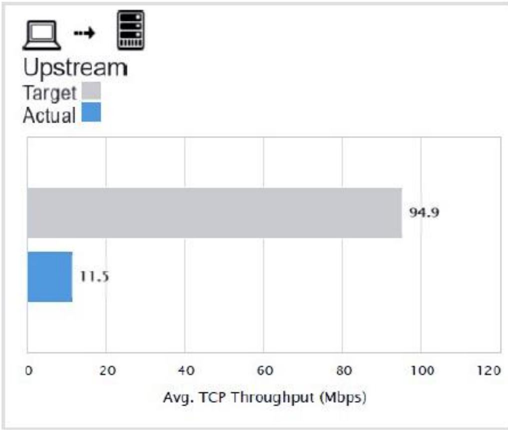


Figure 78. UC12 Max Throughput Measurement results with Samsung Galaxy S20.

Depending on the UE used, 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. In the above figures, 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. Overall, measured throughput figures are within the target values, set in Table 3 for KPI 3, particularly relevant 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.

Let us now turn our attention to the Latency, Loss and Jitter L2/L3 KPIs measured in UC 12, with the use of the TWAMP protocol running in the ACTA server probes located in AIA OTE control room. These probes were interconnected to the FastMile UE in the Satellite Terminal as well as to the TWAMP SW probes running in the UC12 BBUs. Loss and Latency KPIs are also being used to calculate Network Availability and Network Reliability as discussed in Section 7.2.5.

Overall, the L2/L3 network KPIs were measured as follows:

- Loss remaining around 0,02% (momentary peaks of up to 0,5% are non-critical as they correspond to some equipment set-up activities)
- Latency below 2ms for the transport segment and 25 ms for the e2e path
- Jitter (delay variation) below 150μs for the transport segment and 8 ms for the e2e path
- Availability 99,9997% for the transport part of the network and 100% overall
- Reliability 99,9997% for the transport part of the network and 100% overall

Graphs detailing the above results for the period of the actual UC12 trial on 12/04/2022, are provided in Figure 79 and Figure 80 below for the transport and e2e paths.

Figure 79. UC12 Loss, Latency, Availability, Reliability and Jitter Measurement results for the transport network up to the BBU.

Figure 80. UC12 Loss, Latency, Availability, Reliability and Jitter Measurement results for the e2e network.

The overall conclusion is that the L2/L3 Network KPIs of Latency, Availability and Reliability comply with the targets set in Table 4 (respectively KPIs 1, 5 and 4). The short peak shown in the packet loss figure above, represents a fluctuation of the radio conditions that required the FastMile UE to re-camp to the 5G network. An added benefit is that the RAN Latency (KPI 2 in Table 3) which is characterised as “difficult to be demonstrated”, can be indirectly measured by subtracting the respective latency values of the transport part from the end-to-end part. Here it stays around 23ms which is well within the KPI 2 values in Table 5.

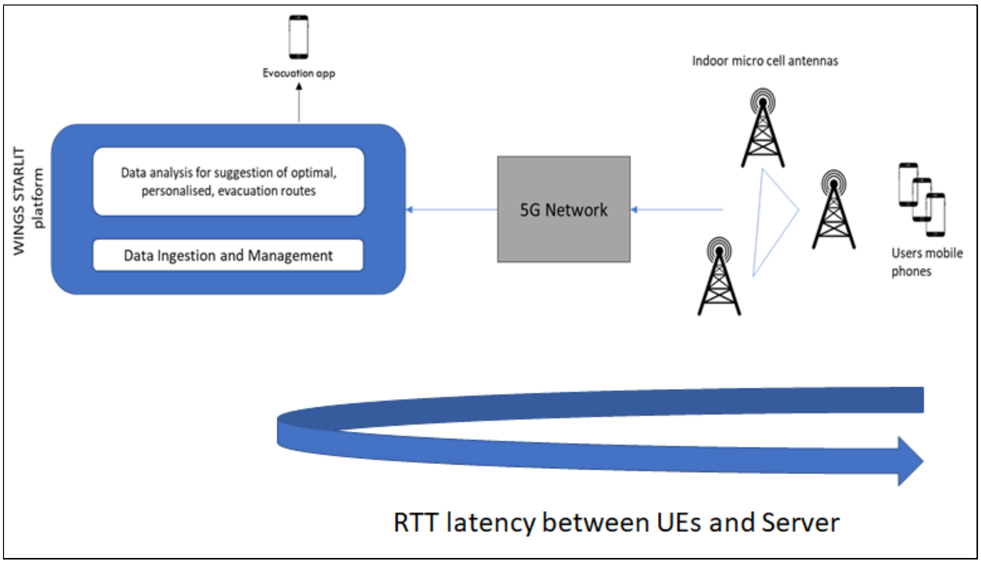


Figure 81. Data path for RTT latency.

<u>RTT latency</u>

The RTTL latency metrics (both in IP and APP layers) are collected using an Androids Agent developed by WINGS and deployed in UEs.

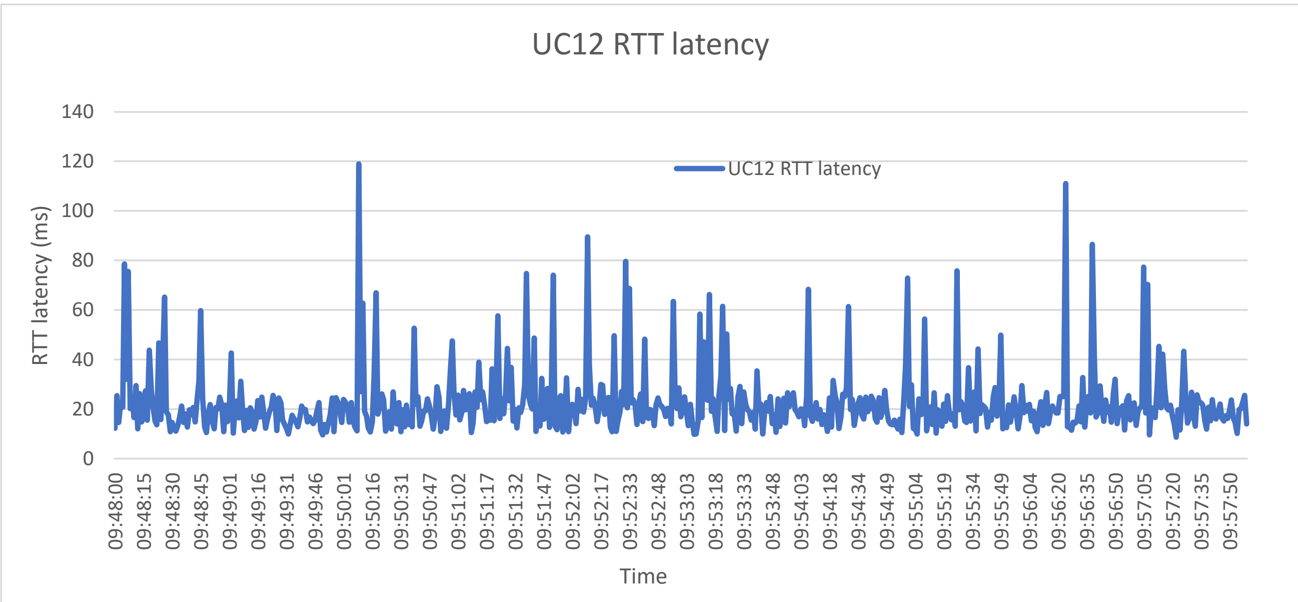


Figure 82. RTT latency results.

The subset of the results (selected trial on 12/4/22) is illustrated in Figure 82. The analysis of the collected metrics illustrates an average RTT latency of about 22.56ms. The minimum value observed is 9.6 ms, while the maximum value is 118 ms.

Service reliability (APP layer)

In order to measure and validate service reliability, the definition in ITU-R M.2410 is considered. The packet error rate at the APP layer (packets that arrive delayed or erroneous are considered as lost packets) is measured by analyzing the results of RTT latency metrics and packet loss metrics.

An initial analysis of the results demonstrates service reliability of around 99.66%. More details will be provided in D7.4.

Location accuracy

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

In UC12, the location of a UE is provided to the application by using the WINGS Location Based Service (LBS) developed and testing in the project. In order to validate location accuracy, the location of a specific UE provided by the LBS service developed in the project. In UC12, three 5G indoor cells are used in the LBS algorithm in order to estimate the UC location.

In order to validate location accuracy this collected location (from LBS service) is compared against the “real location”. “Real location” is defined as follow:

- “Real location” in outdoor: Measurements coming from GNSS (GPS, Galileo) and/or relative position (e.g., laser telemeter) from known spots.
- “Real location” in indoor: Relative position from known spots. This is the case in UC12, since all trials are conducted in the indoor areas of AIA (satellite building).

Initial analysis demonstrates a location accuracy of about 4-5 meters. The full list of metrics is under analysis and the final results will be presented in D7.4.

5 UC13 - AR/VR bus excursion

5.1 UC13 Definition

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.

Situation example: The school bus transferring the students and their teacher starts from the premises of EA in the suburb of Pallini in the northeast of Athens, heading towards the airport (Figure 83). During their bus transfer to the destination, students are presented with rich informational and educational content preparing them for the visit of the exhibit in the airport, using VR technologies and 5G-enabled smartphones and headsets. The high-quality rich content is delivered simultaneously to the 22 students riding the bus. At the destination, students interact with the exhibit using AR technologies on their 5G-enabled smartphones. Finally, during their return to school on the bus after the visit, they participate in educational wrap-up and follow up activities embedded in VR experiences supported by each student's 5G-enabled smartphone and headset. Overall, the distribution of content to the students is personalized, in accordance with their preferences and requirements, as well as the educational decisions and design made by their teacher. The content includes different objects (video, audio, 3D objects, etc.) and the student decides which object to interact with.

The different phases of the trials of UC13 are presented in further detail in Figure 83.

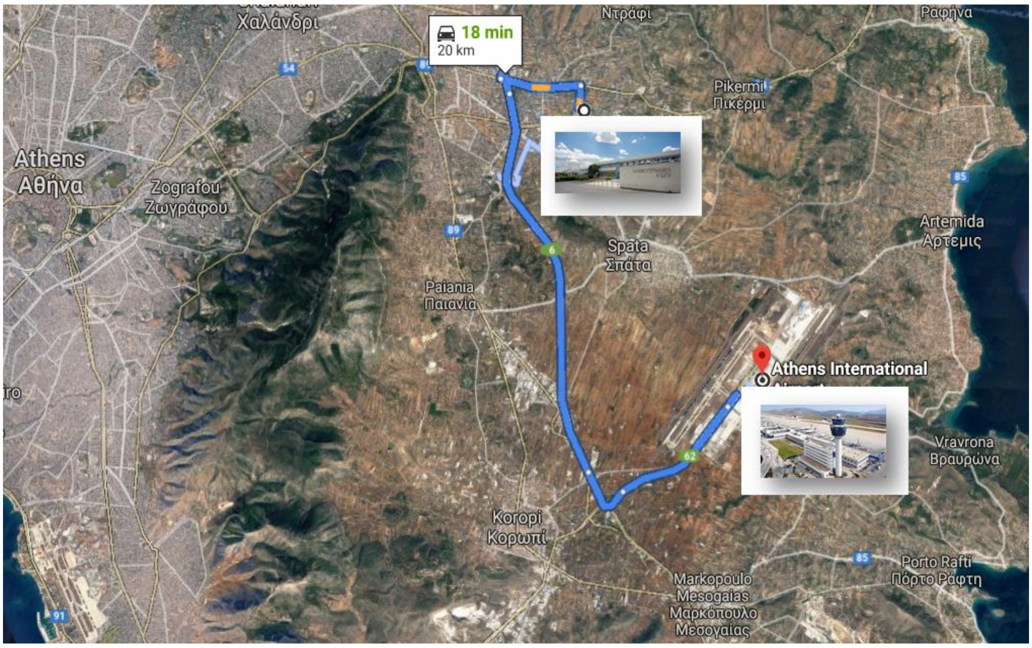


Figure 83. The 20-km bus route from the school (EA) to the airport (AIA).

Partners involved: EA, ATOS, SRUK, ACTA, WINGS

Location: school bus, AIA

5.1.1 UC13.a Students travelling to the Athens Airport: the VR-enhanced pre-visit experience

On a school bus, EA's school students have travelled to the AIA (see Figure 84, where they visited an exhibit in the arrivals area introducing Myrtis to the travelers arriving in Athens. Myrtis is the result of renowned interdisciplinary research led by Professor Manolis Papagrigorakis of the University of Athens and his team, based on archaeological skeletal material excavated in modern-day Athens. 'Myrtis' is the fictional name given to the reconstructed face of an 11-year-old Athenian girl who was, along with Pericles, one of the tens of thousands of victims of typhoid fever in the year 430 BC.

Figure 84. Teacher is giving to students the VR Headset, which includes the S20 smartphone.

This part of the trials has been implemented on the school bus while it is moving in a small area of the airport with 5G coverage (a parking area and surrounding roads behind Building 17).

- *Interface:* Students used the Samsung S20 5G Smartphone to enter a 3D VR space, where they were able to explore the environment and select to interact with various digital assets.
- *Duration of the pre-visit VR experience:* 5-10 minutes
- *Scenario and content:* EA has provided the structure and script of the VR experience, as well as the digital assets, which were implemented in a 3D VR space by SRUK.

The parts VR-enhanced pre-visit experience is comprised of the following parts:

UC13.a.i Profiling mini-game

The purpose of the profiling mini-game is to enable offering personalized experiences to each student.

Each student was asked 3-4 questions, which were disguised in a mini game. The answers the user gave has affected the way the app worked for that user. (See Figure 85)

The questions asked, refer to language, age/educational level, etc.

Figure 85. Screenshot from the VR Profiling minigame.

UC13.a.ii Video introducing the experience

The students watched a 3-5-minute video which introduced them to what they would see and learn about during their visit to the Myrtis exhibit.

EA created a relevant high definition 2D video of a size appropriate to test the system, using and editing existing video material on Myrtis.

UC13.a.iii Video introducing the gamified aspects

In a short, 1-2-minute video, students were informed that after the visit, during their bus journey back to school, they would participate in game-based testing of what they have noted and learned during their trip to the exhibit.

Figure 86. Dr Papagrigorakis is introducing EA's students to the experience, through the VR app.

The video explained the purpose and rules of the game. It encouraged students to be careful to collect information and evidence during the visit, so that they could later prove their achievements and win relevant prizes/emblems. (See Figure 86).

EA designed the gamification and created a high definition 2D video of a size appropriate to test the system.

5.1.2 UC13.b Students in the Athens Airport: the AR-enhanced visit experience

The students entered the public area of the "International Arrivals Hall" in the Athens Airport. (See Figure 87). They stood, in groups, in front of the exhibit, i.e., a large banner introducing Myrtis to the travelers arriving in Athens. The accompanying teachers talked to them briefly about the purpose and procedure of the visit, including information on how to use the AR application to enhance the learning experience and its game-like feeling.

- *Interface:* Students use the Samsung S20 5G Smartphone to point to different parts of the banner and so trigger AR content on their screens. They explored the different items represented on the banner and the information they were hiding, and they were free to select to interact with any of the available digital assets.
- *Personalization:* The AR content offered to each user was personalized on the basis of the input the user provided in the profiling mini-game (UC13.a.i).
- *Duration of the AR experience:* 10-15 minutes
- *Scenario and content:* EA provided the structure and script of the AR experience, as well as various digital assets, which were implemented in the AR environment by ATOS. EA also designed, produced, and set up the banner exhibit, collaborating with AIA for its appropriate integration in the environment of the airport. In addition, WINGS developed further AR experiences on related themes to provide even richer opportunities for students' and the public's interaction with Myrtis' messages through 5G.

Figure 87. EA's students and teachers at the International Arrivals Hall at AIA.

The AR-enhanced visit experience is comprised of the following parts:

UC13.b.i Rich information on Myrtis and Athens through AR

A number of different areas with short texts and other visual elements appear on the exhibit banner. Some of these items act as triggers of AR experience, popping up a panel with additional information when looked through the end-user device.

The central item was an image of Myrtis (e.g., a close-up of the back of her head, with atmospheric background light around it).

Around the central image, diagrammatically, areas of short text and images triggered AR content on three corresponding thematic areas: a) Everyday life in Ancient Athens through a child's eyes; b) The perils of war and a pandemic crisis that devastated Ancient Athens; and c) the reconstruction of Myrtis' face and its science.

Each one of approximately ten active visual items on the banner trigger a different line of XR experience (approximately three items per thematic area, plus the central item), as presented in Figure 88.

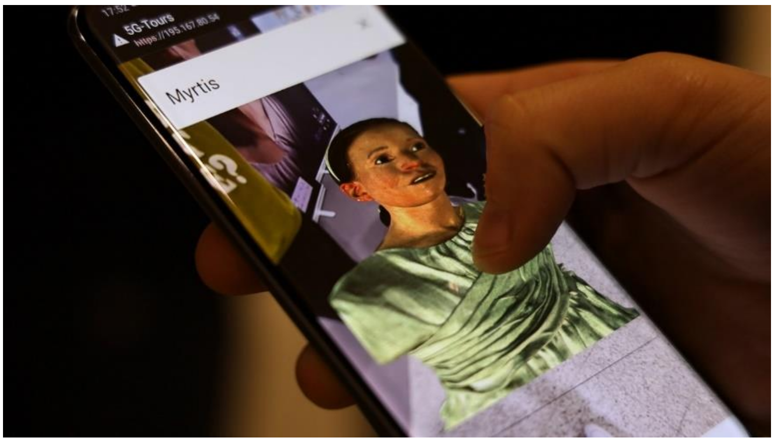


Figure 88. The 3D model of a Myrtis statue is displayed through the mobile phone, when the right AR tag is targeted.

All 14 AR Tags have been designed by ATOS (Figure 89):

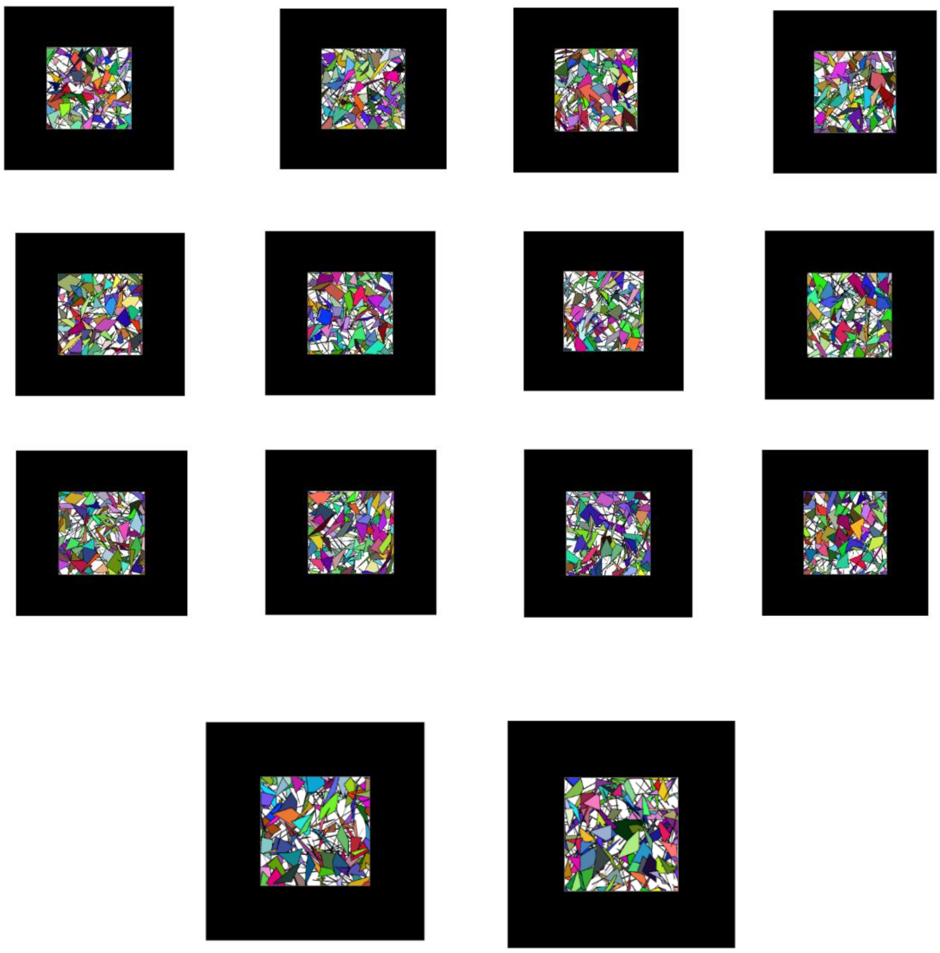


Figure 89. 14 AR tags by ATOS.

Content:

(i) *Myrtis AR first introduction screen*

Welcome to Myrtis' exciting story! Turn your mobile device towards the exhibit to find out details about her ancient life and how she has traveled to the future to meet us. Every now and then I will be giving you hints about what you should pay attention to. And there will be a treasure hunt game for you to excel as a detective! Let's start!

(ii) *Hello!*

Hello, my name is Myrtis. I was an eleven-year-old girl who lived in Ancient Athens, in Pericles' glorious golden age. How can I have "come back to life" after two and a half thousand years?

Come with me to find out about my story: the unusual story of a little Athenian girl from the 5th century BC, who is being introduced to you today, in the 21st century AD.

Take my hand and prepare for a journey to my own distant past; thanks to science, it has been linked to your present time, and, hopefully, to a brighter future for all of us.

(iii) *Result of collaborative scientific work*

You will surely wonder how I can "live a new life" in your time. The answer will take us on a journey into the fascinating world of science.

My biological parents lived in Ancient Athens 2,450 years ago. For centuries, my city has been a global symbol of democracy and of the human love for knowledge and justice. In the photo you can see how Leo von Klenze, a German architect, painter and writer imagined my city about 200 years before your time, in 1846.

My new "parents", however, live in your time. They are scientists from different scientific fields, such as dentistry, biology, archeology, and technology, as well as artists who have collaborated with them. Thanks to their joint effort I got the face with which I am meeting you today.

See the spot in the map:

https://www.google.com/maps/@37.9787729,23.7156888,77m/data=!3m1!1e3

(iv) The mass burial

My modern-day story began with the discovery of a mass burial of 150 people in Kerameikos, as part of an excavation that took place in 1994-1995.

Based on the few ceramic vessels that accompanied the journey of those people to the other world, the team of archaeologists dated the burial to 430/429 BC, i.e., during the second year of the Peloponnesian War.

In today's Athens you can visit the archeological site of Kerameikos. After two and a half thousand years everything has changed, but this place still retains some of the atmosphere of sanctity and tranquility that it had in my time. Then, the public cemetery of my city, Athens, was there.

Archaeologists found me nearby when modern Athenians began digging the ground to build a metro station. Above the place of my burial, there is now a small park next to a noisy big road which is called Pireos Street. See the exact point here, on the digital map!

(v) The Plague, the pandemic that killed us

There, in Kerameikos, I was buried along with many others, hurriedly and not in the way Athenians used to honour their dead. We had died from the infamous Plague of Athens, the terrible disease that took the lives of myself and thousands of my compatriots in that horrible second year of the great war between Athens and Sparta.

The epidemic broke out in Athens during the second year of the Peloponnesian War, in 430 BC, while the Spartans were besieging my city. The Plague returned in 429 BC and then again in the winter of 427/426 BC, causing great destruction to the population of Athens.

The Plague even killed our famous leader, Pericles, as well as his entire family. It was the first major blow to the city, which affected the course of the war. Subsequent generations learned much about this calamity, thanks to the historian Thucydides, who was himself an eyewitness. He was infected but survived.

In the photo you can see how a Flemish painter, Michael Sweerts, was inspired by the story of the Plague that struck my city, in his work entitled 'Plague in an Ancient City'. He painted it in around 1652, almost four centuries before your time.

(vi) A child's skull

In the skeletal material of the hasty mass burial in Kerameikos, archaeologists also found me, two and a half millennia after my death.

They found a child's skull in excellent condition, and the scientists estimated that it belonged to a girl that was about eleven years old when she died.

That skull caught the attention of the Orthodontics Professor Manolis Papagrigorakis, as it maintained part of the girl's baby teeth together with her permanent teeth.

On this occasion, a pioneering scientific effort began for the regeneration of my face, i.e. the face of a child from the 5th century BC!

(vii) Face reconstruction

So, I, that unfortunate eleven-year-old girl who died in the Plague of Athens, saw the light again, I smiled again!

I was 'reborn' through the reconstruction of my face which was based on the scientific work of Professor Manolis Papagrigorakis and his team.

The excellent preservation of my skull gave the scientists the opportunity to reconstruct the features of my face following the 'Manchester method'.

Their work was careful and complex. It lasted two whole years and was completed in 2009.

(viii) Why the name 'Myrtis'?

After 2,450 years, I, a little unlucky girl from a time of pandemic and war, had the good fortune to get not only my face again, but also a beautiful name, full of symbolism.

The scientists who introduced me to the people of your time, named me Myrtis.

They chose this beautiful ancient name because it reminds of the myrtle, one of the plants that grew on the banks of the Eridanus River, where I played when I lived in Ancient Athens.

I like the name you gave me in your time.

As for the name I had then, do not ask me, I will not reveal it to you! But if you go to Kerameikos and listen, the wind of History of my beloved city may whisper it to you...

(ix) The solution to the mystery of the Plague of Athens

Using knowledge and techniques of biomedical sciences during the study of the skeletal material from the archeological excavations in Kerameikos, scientists were able to determine which pathogen caused the Plague of Athens.

So, this collaboration among various scientists managed for the first time to explain the cause of my death and that of famous Pericles as well as of about 50,000 other Athenians.

As Thucydides described in his History book, the Plague, the terrible disease that killed us, struck Athens from 430 to 426 BC. That pandemic marked Ancient Greek History, influencing the development of the Peloponnesian War and ultimately contributing to the defeat of mighty Athens.

Giving the answer to a mystery that had remained unsolved for centuries, the research concluded that cause of the Plague of Athens was typhoid fever, for which the bacterium Salmonella enterica serovar Typhi is responsible."

(x) Face to Face with the Past

I came in contact with the public of my future and of your present, on 9th April 2010, when I was presented at the new Acropolis Museum as the eleven-year-old Athenean of the 5th century BC who regained her face.

Since then I have known friends and admirers through the exhibition 'Myrtis: Face to Face with the Past', which travels to museums in Greece and abroad, as well as through many other initiatives of the inspirer for my revival, Professor Manolis Papagrigorakis.

(xi) Myrtis' 3D model

Ever since I was 'reborn', the science and technology of your time have not ceased to amaze and fascinate me, with the so many new possibilities they offer to human beings.

The fact that you can see my 3D digital representation here is due to the love and care given to me by very capable technologists, who digitally recorded the geometry and texture of my shape in great detail. Explore my 3D digital model to discover every little detail of my shape!

(xii) In the times of COVID-19

Since my first presentation at the Acropolis Museum in 2010, I have been constantly sending my messages to the world about the devastating consequences that war, poverty, and disease have on all people, and especially on us children.

I have been declared a friend of the Millennium Development Goals by the United Nations Regional Information Center. As part of the Agency's campaign against poverty, I sent a message to the world on the prevention of dangerous diseases.

Nowadays, I am joining forces with you in the global fight against the coronavirus pandemic. With the wisdom and experience of my two and a half thousand years, I also feel the danger that the whole planet is experiencing in the face of the threatening COVID-19 disease.

So, I, a little Ancient Greek woman who regained her face in the 21st century AD and can speak to you, I invite you to think about my personal history, the power of science, but also the common universal values that have accompanied and connected us from antiquity to the present day.

(xiii) Messages reaching far

You may see my face on a stamp, but also on a very beautiful silver collector coin, so that I can travel even further and send my message to every person of your time.

Science and knowledge of the past can give us, humans, the power to create a better tomorrow, day by day - as long as this is what want and make our goal in life!"

Symbolically, the back of my coin displays the DNA sequence of the bacterium Salmonella enterica serovar Typhi, which causes typhoid fever. As the scientists who revived me discovered, this bacterium was responsible for my death and that of thousands of other Athenians during the Plague.

(xiv) The 5G ERA

The creators of my reconstructed face are now bringing me to you through the world of modern technology.

So, utilizing fifth generation (5G) telecommunications and virtual and augmented reality technologies that are provided to me by the European research project 5G-TOURS, I would like to welcome and guide you through my world, sending my timeless and universal messages to all people on Earth.

Students uncover the abovementioned items by scanning the corresponding AR tags (see Figure 90) on the poster (see Figure 91)

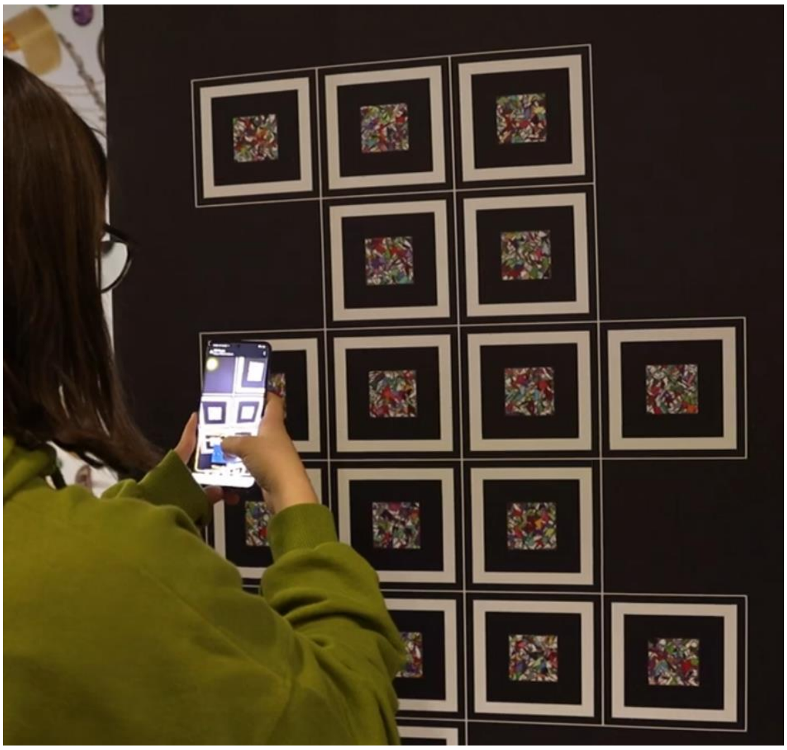


Figure 90. Student exploring the AR tags.

UC13.b.ii Gamified AR experience

"Note this": While exploring the exhibit, at times students were receiving alerts in the AR environment encouraging them to pay attention to some details or trivia that they will later find useful in a knowledge quiz (in the post-visit experience, cf. UC13.c).

The treasure hunt: The AR application also included a hunting game, in which the students were asked to find certain items by following tips that were given.

Once the students found the object, they had to point their device to it. The app recognize it, and registered it on the student's list. This unlocked the next tip leading to the next object.

Once an object was captured, the students could further explore it in detail later.

The game gave more tips if the students could not find an item.

The targets were provided to the students randomly, so that they could not just follow what the others were doing.

Content:

- *(i) Introduction to the treasure hunt game*
- *(ii) The items to be captured:*
- *(iii) The tips:*
- *(iv) Ending of the treasure hunt game*

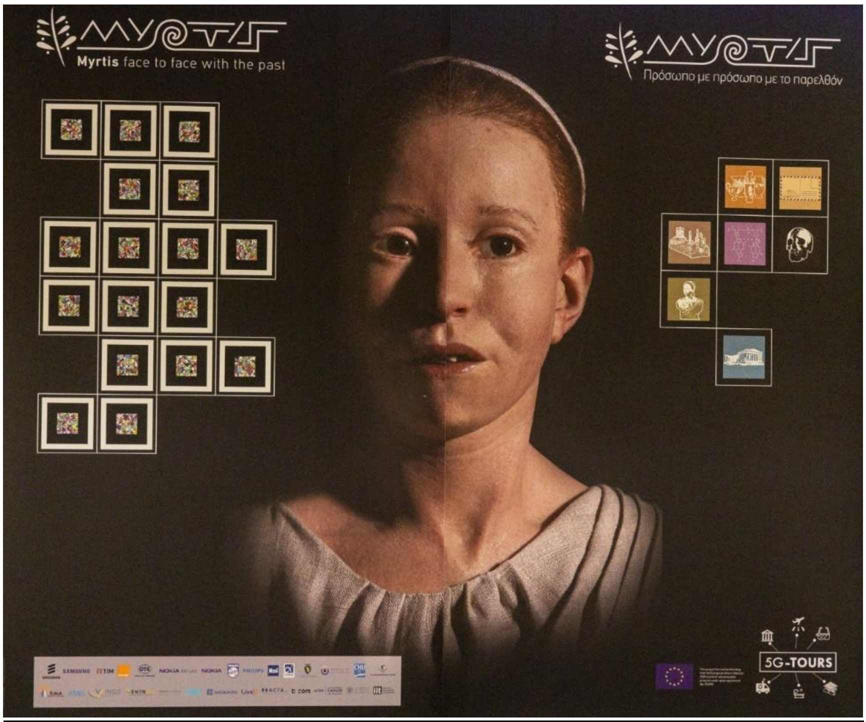


Figure 91. The Myrtis "exhibit" with the imprinted AR tags.

UC13.b.iii Additional AR experiences

While exploring the exhibit in the Airport, as well as independently of that in any other location with 5G coverage, students and other members of the public can interact with Myrtis' messages through additional AR experiences developed by WINGS. This involves virtual exhibits with which users interact through AR. The content is diverse covering: a) ways in which ancient Greek art becomes a source of information for modern historical descriptions; b) Myrtis' story and the journey of knowledge that this research has generated; c) information on the site where Myrtis' skull was found in excavations; d) the DNA analysis involved in the Myrtis research, which revealed the cause of her death; e) the 3D model of Myrtis; f) representations of Myrtis, such as on a recent collection coin; g) more information on the classical period of Ancient Athens, in which Myrtis lived.

5.1.3 UC13.c Students travelling back from the Athens Airport: the VR-enhanced post-visit experience

On the school bus once again, school students were traveling back to their school after their visit to the exhibit in the airport. (See Figure 92).

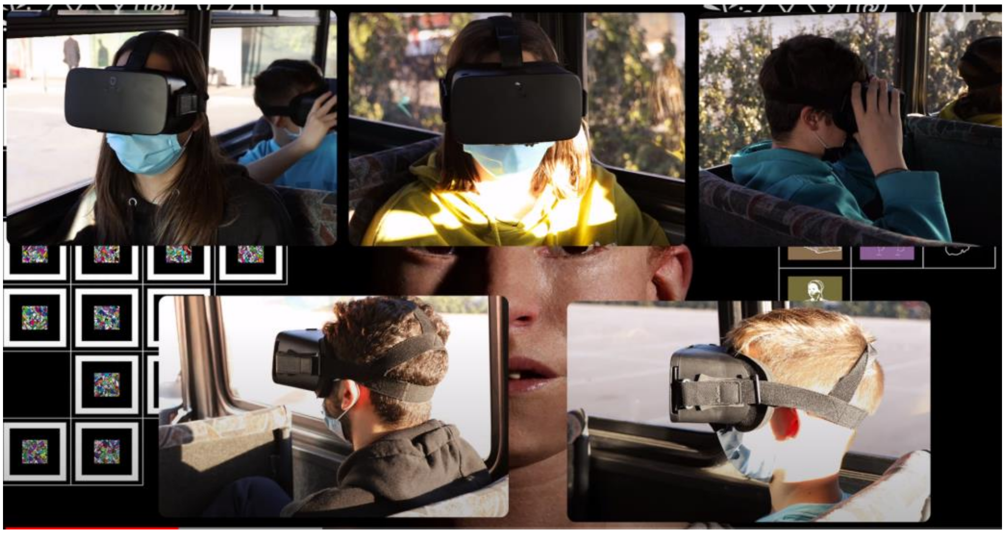


Figure 92. Students re-enter the bus and mount their headsets again to play the Knowledge Quiz while returning.

This part of the trials was implemented on the school bus while it is moving in a small area of the airport with 5G coverage (a parking area and surrounding roads behind Building 17).

- *Interface:* Students used the end-user devices to enter a 3D VR space, where they were able to explore the environment and select to interact with various digital assets.
- *Duration of the post-visit VR experience:* 5-10 minutes.
- *Scenario and content:* EA provided the structure and script of the VR experience, as well as the digital assets, which were be implemented in a 3D VR space by SRUK (see Figure 93).

Figure 93. Screenshot from within the VR App, browsing around the VR Myrtis Museum created for the UC13 a.ii. based on the Myrtis 3D Museum created by Dr. Papagrigorakis and EA in Second Life.

The parts VR-enhanced post-visit experience is comprised of the following parts:

UC13.c.i The knowledge quiz

In the VR environment, students participated in game-based testing of what they have noted and learned during their trip to the exhibit. This was a knowledge quiz in the form of a "Who wants to be a millionaire?" game. Using the information and evidence they collected during the visit (including the trivia and hunted items from the AR experience, cf. UC13.b.ii), they provided their answers to multiple-choice questions. To answer some of the questions, students had to interact with digital assets, e.g., by exploring details of a 3D model or watching a short video (see Figure 94).

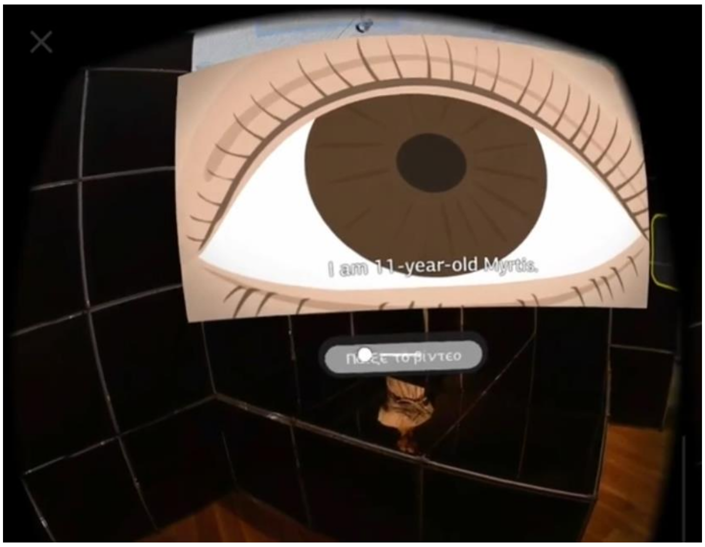


Figure 94. Myrtis is introducing herself through a TV screen inside the Myrtis VR Museum that Samsung has recreated.

Content of the knowledge quiz (see Figure 95).

Content of the VR game-based testing (including the right answers only):

- Q1: Myrtis is an eleven-year-old girl who… *lived in ancient Athens.*
- Q2: The Golden Age of Ancient Athens was… *when Myrtis lived, in the 5th century BC.*
- Q3: Myrtis face was reconstructed…through the collaboration of different scientists and artists
- Q4: In Kerameikos, about 2,450 years ago…*a hasty mass burial of 150 people took place.*
- Q5: The Plague of Athens was a pandemic that killed… *thousands of people in Athens, including Pericles*
- Q6: Myrtis died… *in the second or third year of the Peloponnesian war*
- Q7: A child's skull was found in the excavations which…included part of the child's baby teeth.
- Q8: The reconstruction of Myrtis' face was of high quality because… *it was based on a well-preserved skull.*
- Q9: Myrtis was given this name because… *it reminds of the name of a plant.*
- Q10: The mystery of the Plague of Athens was solved… *because scientists identified the bacterium that caused it.*
- Q11: Myrtis was first presented to the modern public… in 2010 at the new Acropolis Museum
- Q12: As an unlucky girl from an ancient time of pandemic and war, Myrtis… *is sending messages to all people in the world.*
- Q13: On a silver collector coin, you can see Myrtis' face and the DNA sequence of a bacterium.

Figure 95. Screenshots from within the VR App, showing the Knowledge Quiz and Query 4 above.

UC13.c.ii Recognition of achievements

After the completion of the knowledge quiz, the VR application presented each student with their achievements during the whole experience, in the form of prizes, badges, other emblems, etc. (see Figure 96). Some of those were easy to achieve, so that every student could receive at least a few. Examples of achievement include awards for having answered all questions, for having hunted most of the items, for taking less than a certain amount of time in the treasure hunt, etc.

Figure 96. Screenshot from within the VR App, showing the achievements won.

Consent Forms

All the participating students and their parents have signed the 5G-TOURS consent forms, provided by EA.

5.2 UC13 implementation

In order to develop the whole experience that Use Case 13 offered to the participating students, a team of people from EA, Wings, Samsung and ATOS worked together. EA provided the documented content and the scenarios for the ATOS AR app and the Samsung VR app. EA also reviewed and translated the content for the WINGS AR app. Countless zoom meetings took place among the members of this team, resulting to an experience that was unique, seamless and unified for the users (see Figure 97).

Where?	Around B17	Around B17	Around B17	Terminal	Terminal	Around B17	Around B17
When?	Pre-Visit Experience "Going to AIA"	Pre-Visit Experience "Going to AIA"	Pre-Visit Experience "Going to AIA"	Main Visit Experience	Main Visit Experience	Post-Visit Experience "Returning from AIA"	Post-Visit Experience "Returning from AIA"
What?	3-4 profiling questions (Language, Age, Educational level)	Video introducing students to the experience.	Video explaining the process and the rules of the AR game.	Each one of approximately ten active visual items on the banner will trigger a different line of XR experience	The Myrtis poster will include AR Tags.	Game-based testing of what students learnt in steps 4&5	Student will see their achievements form of badges & other emblems
Requirements	Explorable 3D VR Space & interaction with assets	HD Video playing inside the VR Space	HD Video playing inside the VR Space	1. The "Myrtis Exhibit/Poster" 2. The AR Tags 3. The content	1. The "Myrtis Exhibit/Poster" 2. The AR Tags 3. The content	The quiz/test	1. The emblems 2. Integration between A & S
Content Type	Text & 3D Assets from EA	HD Video	HD Video	Text/Videos and 3D objects from EA	Text/Videos and 3D objects from EA	VR Environment & Text from EA	2D Images
Status	Finalized	Finalized	Finalized	The "Exhibit" is ready The AR Tags are ready The content is ready	Everything is ready	Everything is ready.	The emblems are ready.
Duration	5 mins	5 mins	5 mins	30 mins	10 mins	10 mins	10 mins

Figure 97. Step by step building and integrating the Use Case 13 experience for the students.

Furthermore, a large number of test trials were performed at AIA in order to ensure a smooth run of the pilot. (See Figure 98).

Figure 98. Gregory Milopoulos from EA, testing the VR app in one of the trials at AIA.

In one of the pilots, 5 students from EA, visited AIA and tested the applications, giving valuable feedback to the software and hardware technical teams. (See Figure 99).

Figure 99. Testing the AR app with 5 EA students in one of the trials.

5.2.1 Application Components

Technical features of the AR application

For the AR application ATOS has defined the following technical features:

- The API served using a Node backend and exposed using Swagger. That allows SRUK to access ATOS's API easily. SRUK access the API for saving the results of the preliminary test, for getting the questions of the quiz or getting which emblems has each student won, for example.
- Database: mongo DB
- If possible, one would use different docker containers for every module and deploy them easily to production.
- The client is an AR Android app developed using Unity and Vuforia.
- The static assets are served using Nginx.

"Developed in Node, the backend has been deployed in the VM provided by OTE. It provides several endpoints, exposed and fully documented using swagger, that are fundamental to the UC. It makes possible data sharing between the AR and VR sides, and adds functionality to support the hunting and quiz games, emblems calculation, user management, etc. As the project goes on, more features were added to it, to support any of the client app needs".

The suggested architecture is presented in the following diagram (Figure 100).

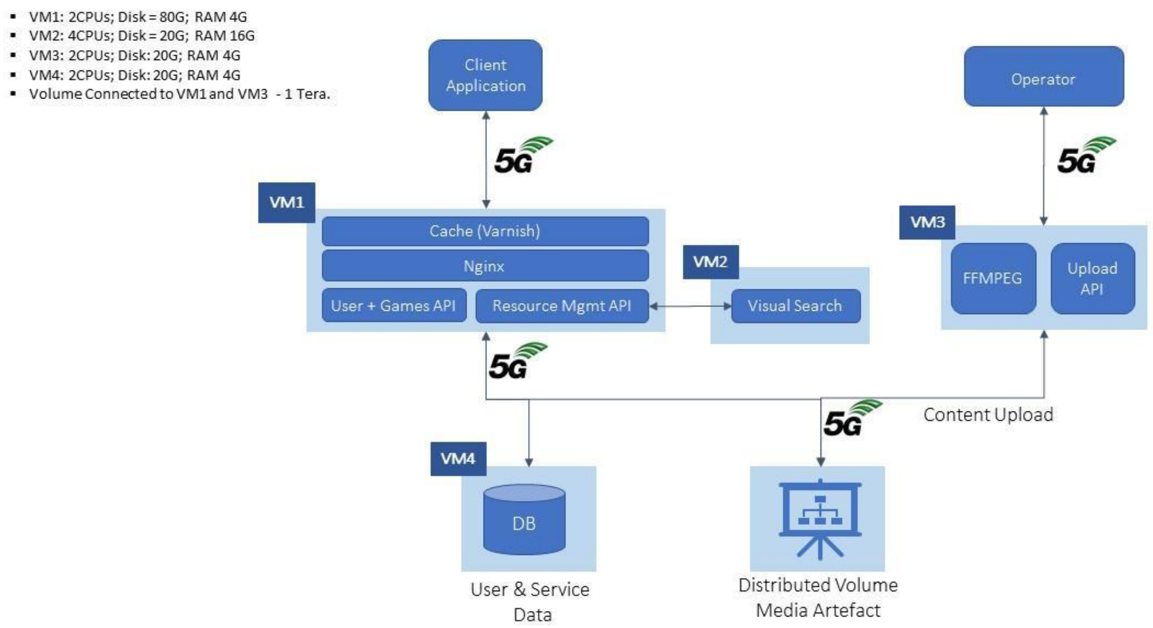


Figure 100. Architecture diagram of the AR application.

Technical features of the VR application

SRUK used the WebXR API (see Figure 101), allowing it to use the application on Android, iOS, Windows, MacOS, and headsets of the Oculus, HTC Vive, Windows Mixed Reality and Cardboard variations.

Figure 101. The WebXR logo

The WebXR Device API provides access to input (pose information from headset and controllers) and output (hardware display) capabilities commonly associated with Virtual Reality (VR) and Augmented Reality (AR) devices. It allows the development and hosting of VR and AR experiences on the web.

Benefits of doing XR on the Web

Instant deployment to every XR platform with a WebXR enabled Web Browser. Future proof experiences, new AR and VR hardware comes about regularly, so apps that are designed now continue to work on new hardware without needing to push new code. An experience can choose to target both VR and AR, Handheld and head mounted devices with a single release. Minimal code changes needed to support VR and AR together. No app stores or large downloads required; users get immediate access to the experience. Since the rendering is handled by WebGL, which has been around since 2011, there is WebGL's rich development tool ecosystem and a large, active developer community.

Support Table for the WebXR Device API (see Figure 102).

Feature Name	Standardisation	Polyfill	Chrome	WebXR Viewer	Magic Leap Helio	Samsung Internet	Oculus Browser	Microsoft Edge
WebXR Core	Explainer Spec MDN	Supported, will make use of WebVR if available and WebXR is not.	Chrome 79	iOS	Magic Leap Helio 0.98	Samsung Internet 12.0	7.0, December 2019	Edge 87 on Windows Desktop Edge 91 on Hololens 2
WebXR AR Module	Explainer Spec MDN		Chrome for Android, 81	iOS	Magic Leap Helio 0.98	Samsung Internet 12.1		Edge 91. Hololens 2 only
WebXR Gamepads Module	Explainer Spec MDN	Supported	Chrome 79		Partially supported on Magic Leap Helio 0.98	Samsung Internet 12.0	7.1, December 2019	Edge 87 on Windows Desktop Edge 91 on Hololens 2
Hit Test	Explainer Spec MDN		Chrome for Android, 81	iOS		Samsung Internet 12.1		Edge 93. Hololens 2 only
DOM Overlays	Explainer Spec MDN		Chrome for Android, 83	iOS		Samsung Internet 14.2		
Layers	Explainer Spec MDN	Supported. See here.					16.1	
Hand input	Explainer Spec MDN						15.1, April 2021	Edge 93. Hololens 2 only
Anchors	Explainer Spec MDN		Chrome for Android, 85			15.2		Edge 93. Hololens 2 only
Depth Sensing	Explainer Spec MDN		Chrome for Android, 90					
Light Estimation	Explainer Spec MDN		Chrome for Android, 90			15.2		
Additional Details			Hardware Support Details	2.0 announcement				The new Microsoft Edge for Windows Mixed Reality

Figure 102. WebXR is support is already extensive and continues to evolve.

The 3D assets are of **glTF extension,** the standard file format for three-dimensional scenes and models, guaranteeing that they are optimized for transmission. glTF (derivative short form of Graphics Language Transmission Format or GL Transmission Format) is a standard file format for three-dimensional scenes and models. A glTF file uses one of two possible file extensions: .gltf (JSON/ASCII) or .glb (binary). Both .gltf and .glb files may reference external binary and texture resources. Alternatively, both formats may be self-contained by directly embedding binary data buffers (as base64-encoded strings in .gltf files or as raw byte arrays in .glb files). An open standard developed and maintained by the Khronos Group, it supports 3D model geometry, appearance, scene graph hierarchy, and animation. It is intended to be a streamlined, interoperable format for the delivery of 3D assets, while minimizing file size and runtime processing by apps. As such, its creators have described it as the "JPEG of 3D."

SRUK saves and consumes information through web-friendly endpoints exposed by ATOS.

For the needs of installing the back-end content of the AR/VR applications OTE provided a VM server at their facilities at OTE Labs Psalidi (where the infrastructure of 5G EVE exists) and a VPN connection to this server.

ATOS has already installed the back-end content and a lot of interconnection tests were tried.

5.2.2 UC13.b.iii Additional AR experiences implementation details

As mentioned also in the UC13 overview the purpose of this application is to represent the story of the Athenian girl from the 5th century B.C. named Myrtis and the scientific reconstruction of the scull and her facial characteristics. It is a modern digital museum presenting virtual exhibits, based on the technology of AR and the interaction with the user through predefined buttons and touch-screen hand gestures. The story telling consists of target images, which are recognized from the user’s mobile camera and augmented by 3D virtual objects with visual and sound information about them. All the sources about the story of Myrtis were found in the official site: www.myrtis.gr.

If we can put a series in the events of the application we would say that we start with a general description of the way in which ancient Greek art is a source of information for modern historical descriptions. An important ancient Greek burial vessel “Lykithos” and its painting is the first 3D target. As we continue the tour, we describe in a few words the story of Myrtis and the journey of knowledge that has come through this research. The new upcoming 5-euro coin consists of the second 3D model target. After that we quote information about the excavation that took part in Keramikos, in 1994-5. A slideshow of photographs from this excavation is the third AR target of our story.

One of the most important aspects of this research about Myrtis is the DNA analysis to find the cause of her death. Thus, we represent a 4th target of a 3D DNA helix model. Modern technologies, such as 3D printing, have helped the scientists to create an identical copy of Myrtis skull, to avoid damaging the fragile original one. Therefore, we present a 3D model of a human skull as the 5th AR target. The most important one is the actual reconstruction and representation of Myrtis face (3D model of Myrtis as 6th target), using data from the analysis of her face characteristics and the knowledge that we have got know about this Greek era. Finally, we quote information about the ancient Greek classical period, as we present the 7th and last 3D model of Parthenon, the great architectural monument that has similar age to our character Myrtis.

Technical Information and 3D Modelling implementation details

The application itself has a horizontal “locked” orientation easy to understand. When the user opens the application there are intuitive messages that guide the user on how to use the app as shown in Figure 103.

Figure 103. User guidance in using the app.

In the beginning, there is a language option (there could be more options than "English" and "Greek", including audio clips and subtitles). There are two options such as "credits" and "exit" that can be used anytime. The 3D models have been created with 3Ds Max (https://www.autodesk.eu/products/3ds-max/overview) and Pixologic ZBrush (https://pixologic.com/) as modeling tools, Photoshop Quixel (https://quixel.com/) as texturing tool, 3D Coat (https://3dcoat.com/)as an unwrapping tool and Photoshop as fine detail tool. All these models are described below:

1) Ancient Greek art is a great general source of information. At this point, a classical-period burial vessel (such as those made in the era Myrtis lived) was constructed to show a painting of a vessel presenting a girl's face. Since realistic representations often show images of war, while the application is being seen by young children, the following vessel Lykithos was selected, which is located in the National Archaeological Museum of Athens and presents a mythical Harpy, with a girl's face and a hawk's body (The image shows the vase in the Acropolis Museum –Figure 104 and its three-dimensional representation-Figure 105). Figure 106 shows the model integration within the mobile app.

Figure 104. The Lykithos vessel selected.

Figure 105. The 3D model constructed using the Lykithos vessel.

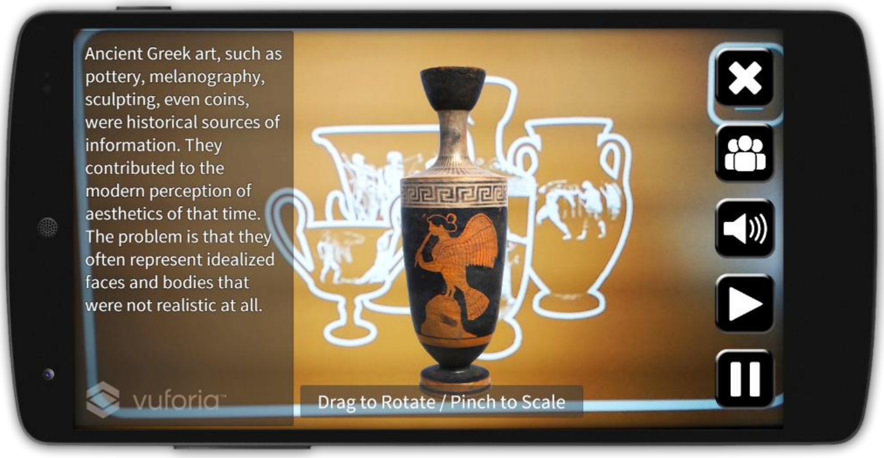


Figure 106. Model integration in the AR application.

2) Introduction with Myrtis. Since her publication, she traveled the world and told us her story. At this point, her stamp is presented in a travel envelope as well as the collector's-colored coin of 5 euros as shown in Figure 99 (the coin was released in 2020). From the information we have known, it has been constructed the 3D object of the following image (Figure 108 and Figure 109).

Figure 107. The Myrtis collector's colored coin of 5 euros.

Figure 108. The 3D model constructed using the collector's colored coin.

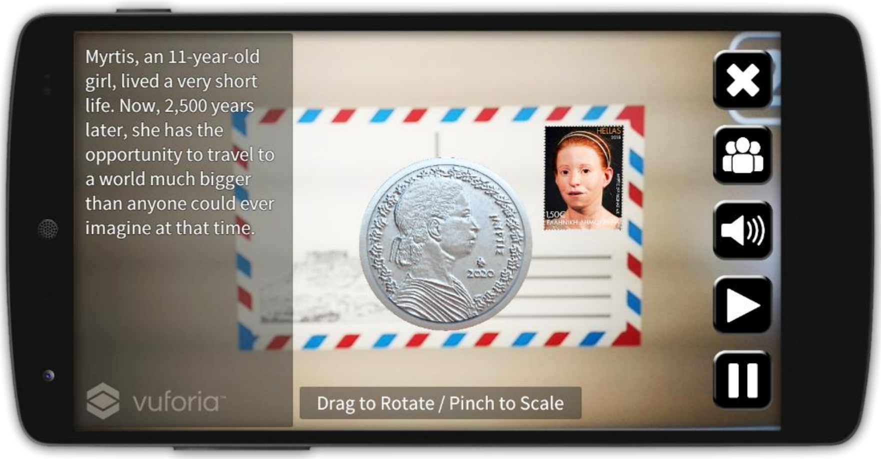


Figure 109. 3D Model integration in the AR application.

3) The excavation of Myrtis took place in Keramikos, Athens, in 1994-5. In this discovery a mass grave of 150 people who lived in the 5th century B.C. were found. Among them young children. A collection of photographic images of the excavation site (Figure 110) is presented in the form of a slideshow and useful information about them (Figure 111).

Figure 110. The slideshow used from the Myrtis excavation.

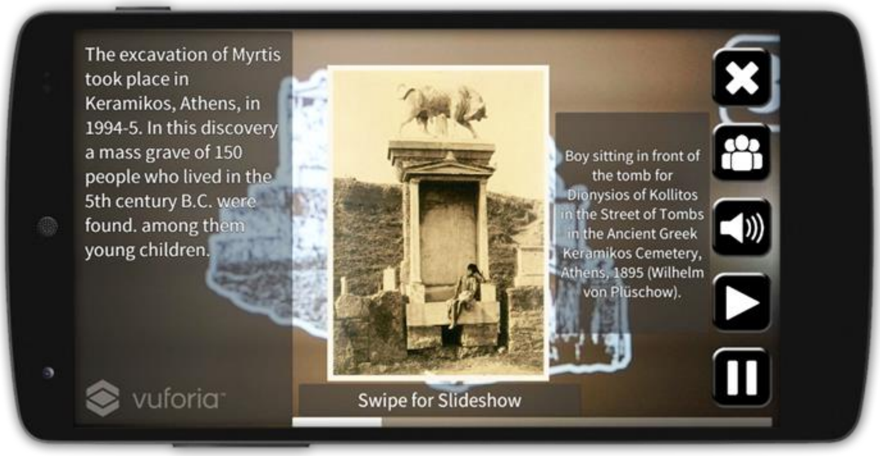


Figure 111. Slideshow integration in the AR app.

4) One of the most important aspects of the research about Myrtis was to find the cause of her death. A DNA analysis was performed for that reason. The geneticists concluded that the cause of her death was "Salmonella Typhi". This was a very important finding as it has been the cause of the sickness known as the Plague of Athens. It was an epidemic that devastated the city-state of Athens in ancient Greece during the second year of the Peloponnesian War (430 BC). The plague killed an estimated 75,000 to 100,000 people including Pericles. At this point a DNA helix (Figure 112) is represented as a simplified 3D object (Figure 113 and Figure 114).

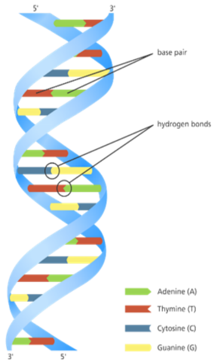


Figure 112. The DNA helix used for the 3D model. creation.

Figure 113. The 3D model constructed using the helix.

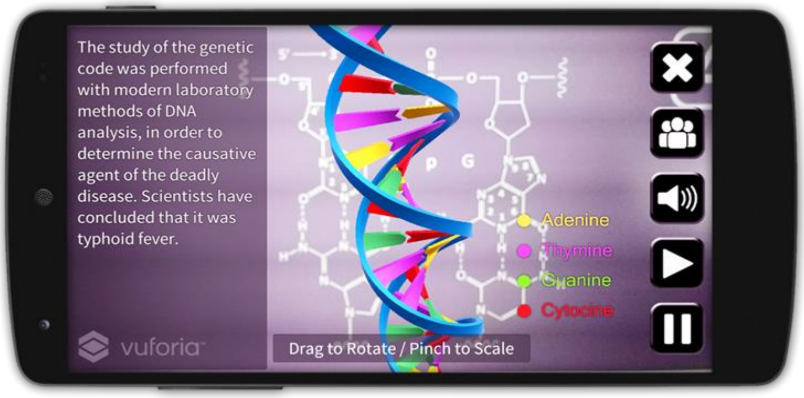


Figure 114. 3D Model integration in the AR application.

5) Modern technologies, such as three-dimensional reconstruction and printing, have helped the scientists to create an identical copy of the Myrtis skull, in order to avoid damaging the fragile original one. Therefore, we present a 3D model (Figure 115, Figure 116) based on a medical atlas (Figure 117), which represents a 12-year-old girl's skull.

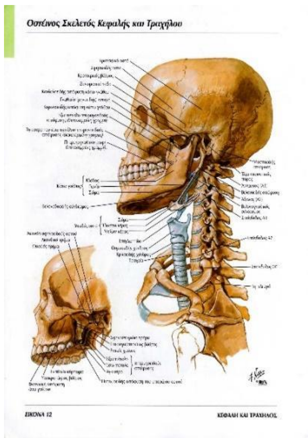


Figure 115. The medical atlas.

Figure 116. The constructed 3D model based on the medical atlas.

Figure 117. 3D Model integration in the AR application.

6) Representation of Myrtis. At this point we present a 3D model of Myrtis originally constructed by Mr. Maravelakis (Figure 118) with a few changes for the needs of a mobile application (Figure 119) (less polygons, better unwrapped model, and textures). Figure 120 show the integrated model in the mobile application.

Figure 118. The scanned model of Myrtis.

Figure 119. The 3D model constructed.

Figure 120. Myrtis 3D Model integration in the AR application.

7) At this point we present an architectural 3D model of the Parthenon and the way it looked when first constructed (Figure 121 and Figure 122).
8) The Parthenon is the temple the Athenian Acropolis, dedicated to the goddess Athena (Figure 122). Construction began in 447 BC when the Athenian Empire was at the peak of its power. It was completed in 438 BC, although decoration of the building continued until 432 BC. It is the most important surviving building of Classical Greece. The ancient Greek historian Thucydides describes the situation of that era. Athens around 430 B.C. was in the period of the Peloponnesian War. At the same time, the Plague of Athens broke out, killing 50,000 people, including Myrtis and Pericles. Figure 123 shows the 3D model of Parthenon in the AR application.

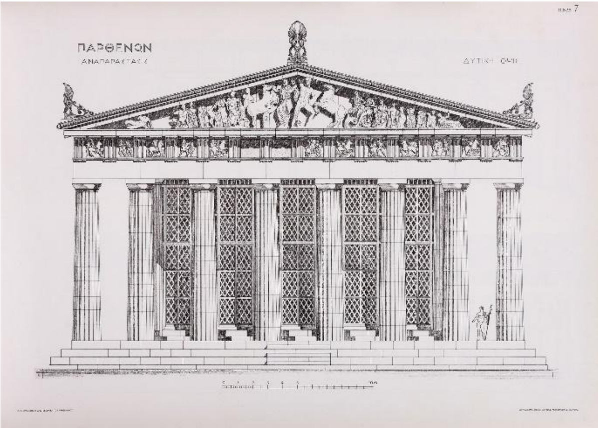


Figure 121. The Parthenon architectural design.

Figure 122. The 3D model constructed.

Figure 123. Parthenon 3D Model integration in the AR application.

Some initial results from the June trials at AIA are shown in the figures below (Figure 124-Figure 133).

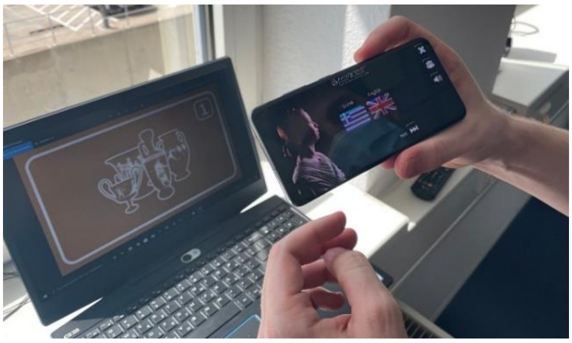


Figure 124. WINGS AR app language selection.

Figure 125. WINGS AR app assets loading from server.

Figure 126. WINGS AR app interaction with the Lekythos 3D model.

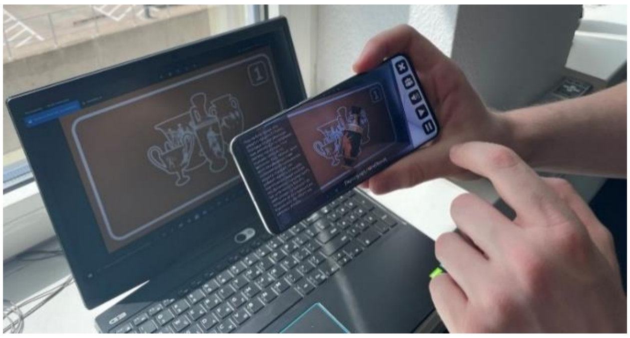


Figure 127. WINGS AR app Lekythos 3D model animation.

Figure 128. WINGS AR app interaction with the Coin 3D model.

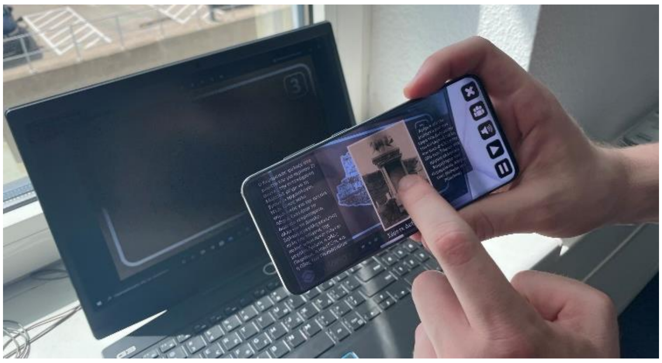


Figure 129. WINGS AR app interaction with the excavation pictures.

Figure 130. WINGS AR app interaction with the DNA 3D model.

Figure 131. WINGS AR app interaction with the skull 3D model.

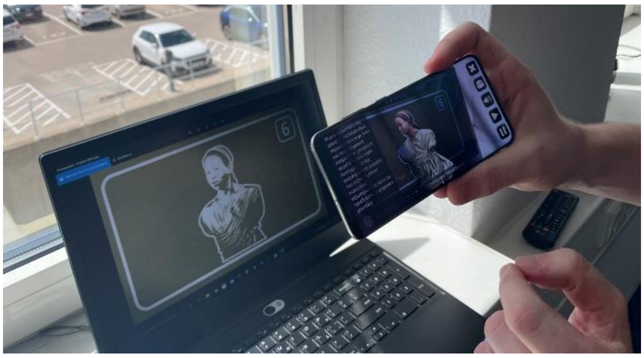


Figure 132.WINGS AR app interaction with the Myrtis 3D model.

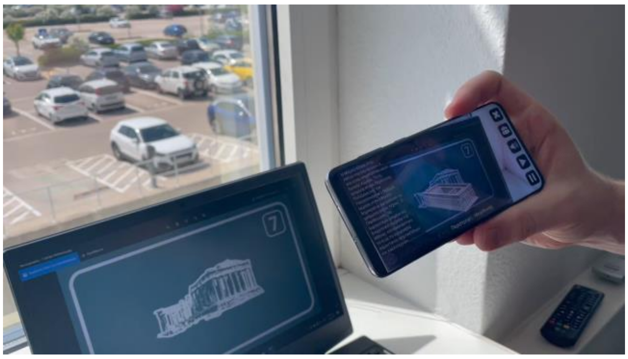


Figure 133. WINGS AR app interaction Parthenon reconstruction.

5.2.3 Terminal Equipment components

The application run and tested on Samsung Galaxy S20 5G devices for the AR part, mounted on DESTEK V5 VR headsets for the VR part. This provides the connectivity needed on the mobile clients.

The Samsung Galaxy S20 5G Smartphone is a very powerful mobile device, able to support the VR & AR requirements of Use Case 13. Its technical specifications are depicted in the Table 1.

The VR app of Samsung and the AR app from ATOS were server based and only shortcuts were made on the initial screen of the Samsung Galaxy S20, in order to be easier for the participating students to run the applications. All S20s used in UC13 trials were configured by EA, as displayed in Figure 134.

Figure 134. The S20 configured for Use Case 13. "Samsung 1st" was the profiling app, "Samsung" was the VR App, "5G-Tours was the ATOS AR app" and "AR Myrtis was the WINGS AR app. "Viavi" was the link for the technical measurements".

DESTEK V5 mobile VR headset (see Figure 135) was also used with great success.

Figure 135. The DESTEK V5 mobile VR headset.

The Samsung Galaxy S20s were inserted into the DESTEK V5 mobile VR headset (see Figure 136), so that students could use the Samsung VR profiling app and browser inside and outside of the VR Myrtis Museum.

Figure 136. DESTEK V5 mobile VR headset with the inserted Samsung Galaxy S20 smartphone.

Technical specifications of the DESTEK V5 mobile VR headset:

- Supports wearing glasses: Unlike most VR headsets, DESTEK V5 provides universally accepting spaces for most glasses to suit more customer needs.
- The Pupil Distance button with a larger range to optimizes visual experience for students.
- Comfortable & lightweight: compared to 13.4oz V4 headset, DESTEK 5th generation VR headset decreased in weight due to plastic component swaps and improvements in manufacturing. The headset only weights 11.3oz, It significantly reduces the pressure with the help of head strap design, making it tight but fairly comfortable fit. The removable face pad of VR headset is made of ultra-soft washable breathing Fabric, helping you stay comfortable during use.
- 8 Years Electronics Product Brand, Work Hard on Quality and User Experience
- Wide Compatibility: DESTEK V5 mobile VR headset supports smartphones with 4.7-6.8 inches screen (gyro sensor required) such as iPhone 12 Mini/ 12/12 Pro/Max/ 11/ 11 Pro/11 Pro Max/Xs Max/XR/XS/ 6/ 6s/ 7/ 8, for Samsung Galaxy S20 FE/S20/S20 Plus/S10/S10 Plus/S9/S8/Note 10/Note 10 Plus/ Note 9/Note 8/Samsung Galaxy A50/A51/A71, for OnePlus 8T/7 Pro/Huawei P30 Pro/Google Pixel 3XL/4XL.

Figure 137. EA's students inside the school bus, using the DESTEK V5 mobile VR headset and Samsung Galaxy S20 to live the VR experience of Use Case 13.

5.2.4 Interfaces

The UC13 platform consists of a VR client, an AR client, and a backend that provides them with information and processes the feedback given by the students. (See Figure 137).

The backend is a very lightweight node server deployed using Kubernetes that provides load balancing across the 2 machines.

Both clients are connected to it to retrieve information about the exhibit, the quiz questions, etc. Also, it serves the multimedia content using a NGINX server.

The AR client, developed in Unity, play the different activities inside the exhibit room.

The AR client, developed as a web app, play the different activities while the students are in the bus.

5.3 Integration and tests in labs

All the endpoints provided by the backend are available through an API rest. The endpoints are documented using swagger, so it is possible to check the calls and test them in live.

5.4 Tests in the Network

This task presents an *AR/VR enhanced experience inside a school bus*, transferring students to and from the destination of their excursion, in this case the AIA. This use case (namely UC13) gave the opportunity to present how 5G connectivity behaves while demanding content in terms of network resources is being served inside a moving vehicle. The network probes described in UC10 are also used in UC13 (See section 2.4).

For the needs of the AR/VR bus excursion UC, and the corresponding trials OTE, as site manager, provides all the telecommunication infrastructure at OTE R&D Labs (OTE Academy’s facilities) and AIA (data rooms, poles for antenna mounting, racks, switches, routers, etc.). Implementation of the UC is also done in co-operation with NOKIA-GR and ACTA (for implementation of KPI validation). In addition, OTE, has constructed a 10 Gbit line, for the needs of the interconnection of AIA with OTE-Labs (where the 5G EVE infrastructure is located) and provided a VM backend content server.

5.4.1 KPIs Validation

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 in order to stream the correct content) the Upstream as well the Downstream one-way Latencies play a key-role. Finally, since the content that is streamed to the UE is dependent on the user viewing angle and placement in space, location information should also be provided and transmitted with low latency (in the upstream direction) to the AR/VR Server.

For this use case, Latency, Throughput, Availability, Mobility, Broadband connectivity, and Location Accuracy are measured, as depicted in Table 6 below. These are the KPIs that are relevant and important in this case, and it is possible to be measured, with the existing measurement setup. Latency refers to the Latency between the end user (AR/VR user headset) and the AR/VR Server. Throughput is measured at the interconnection of two points e.g., between AR/VR server and end-devices. Network availability is measured as a percentage and is monitored to ensure that the service is not being interrupted (or unavailable) for end-users. Mobility is still under consideration. Broadband connectivity (peak demand) is measured via Speed test at the AR/VR Server end. 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 UC 13 is set up with only one cell, this is not possible.

The participating components for UC13 are shown in Figure 137. The KPIs measured and validated along the data path, are indicated in the diagram overlaid on the Athens site network architecture.

The probes gather local network metrics data. These data were collected centrally for analysis and reporting.

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 (Table 6).

Table 6. UC 13 Excursion on an AR/VR-enhanced bus network requirements.

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

● **Non relevant KPIs**

● **Difficult to be demonstrated KPIs**

● **Relevant KPIs**

The Non relevant KPIs are considered non-relevant for this use case because they are of medium to low importance and/or the relevant requirements could not be tested, e.g., slicing was not deployed.

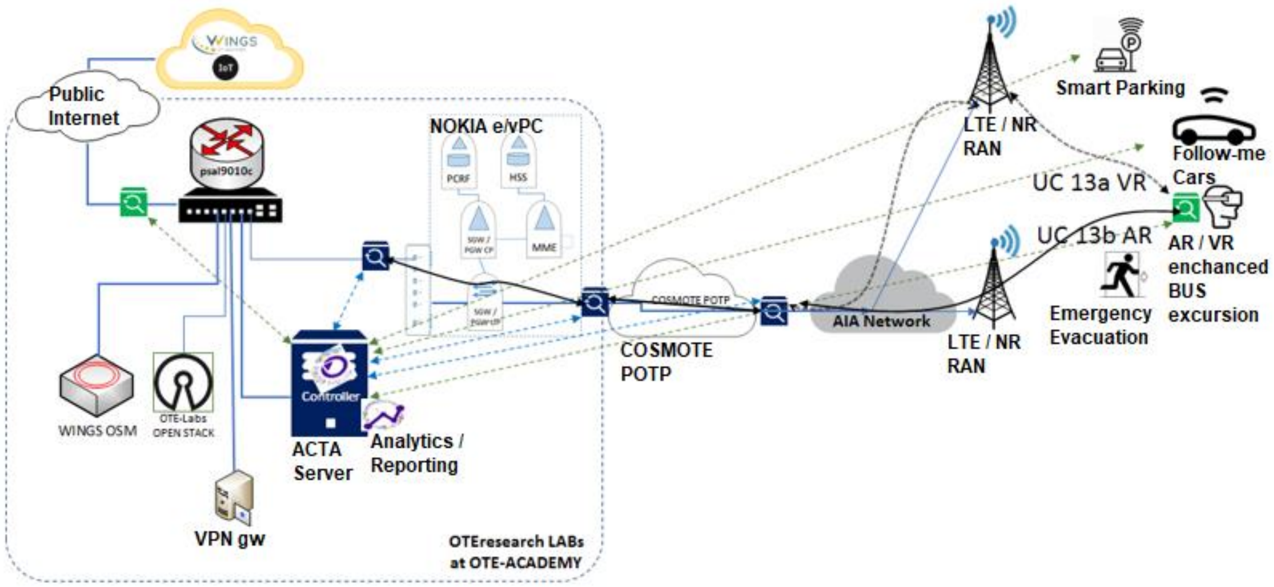


Figure 138. The participating probe components and their location for the KPI measurement of UC13.

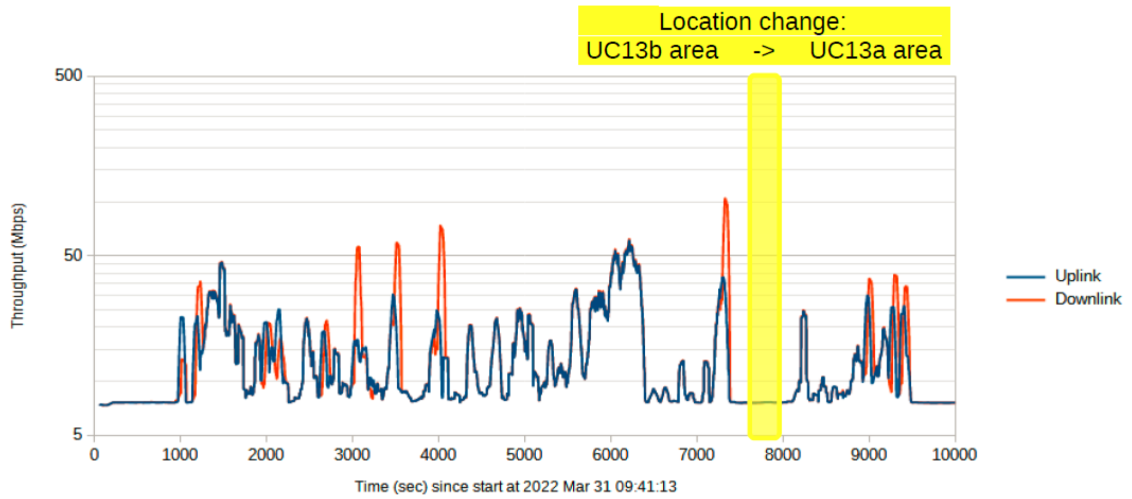


Figure 139. Real Time Throughput Measurements of UC13.

In Figure 139. Real Time Throughput Measurements of UC13, the total throughput was measured, created by the user traffic for UC 13 during the full-scale trial performed on 31/03/2022. One can observe the fluctuation in traffic as the students move from the indoor UC13b AR Myrtis area to the UC13a VR parking area outside Building B17. As a total, the data traffic does not exceed 100 Mbps, which shows that the applications used are not posing high bandwidth demands on the network.

In more detail, we can see the Throughput (maximum sustainable) for the UC 13b and UC 13a, as experienced by the students using Samsung Galaxy S20 mobile UEs, in the Figure 140 and Figure 141 below.

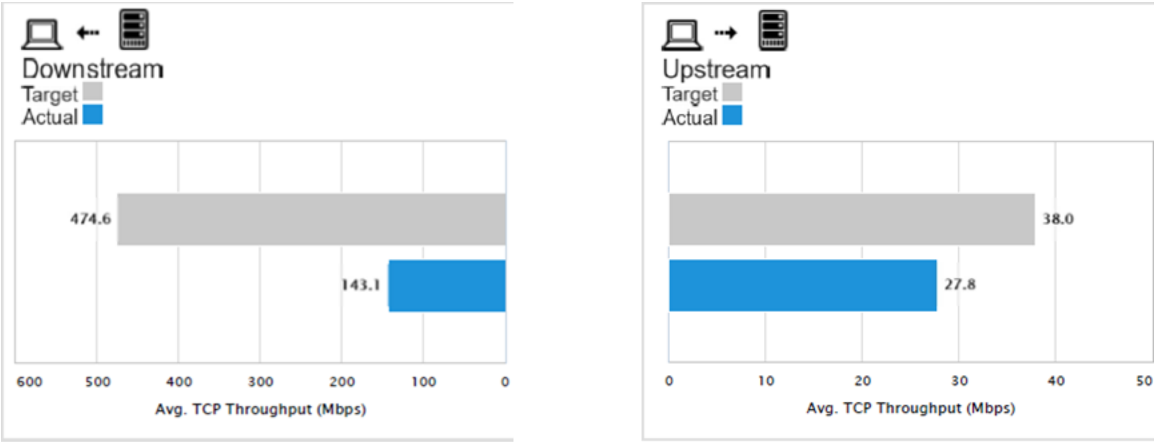


Figure 140. UC13b AR Myrtis exhibition Max Throughput Measurement results

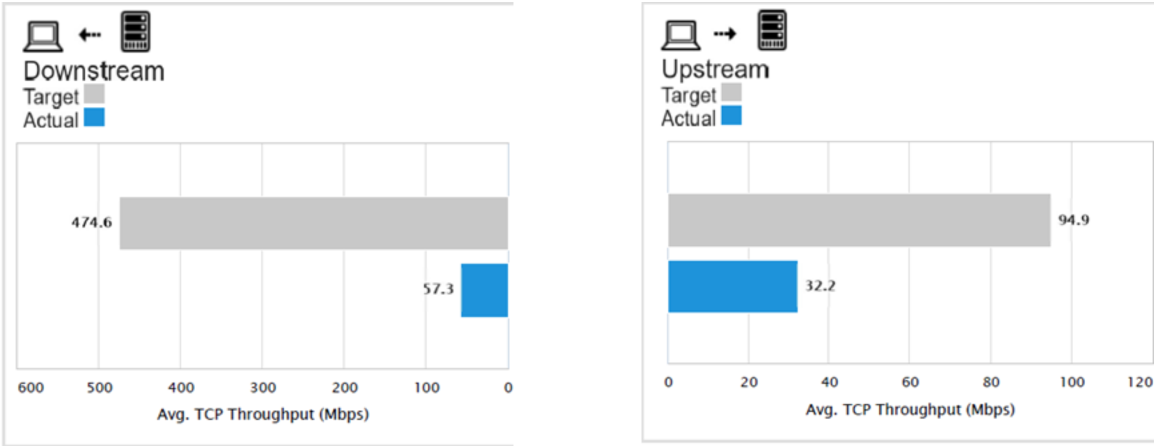


Figure 141. UC13a VR Bus excursion Max Throughput Measurement results

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 6 were set.

Due to the above limitations, measured throughput figures are within the target values, set in Table 6 for KPIs 3 and 7 respectively.

In the above figures, 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.

Let us now turn our attention the Latency, Loss and Jitter L2/L3 KPIs measured in UC 13a & b. The first two are also being used to calculate Network Availability and Network Reliability as discussed in Section 7.2.5.

ACTA has managed to capture these KPIs by deploying probes at various points of the network as shown in Fig 126 above. The segmentation methodology is elaborated in Section 7.2.5, but here it suffices to say that we provide measurement results for the backhauling part up to the L2/L3 switches at OTE Labs and AIA, the AIA BBU as well as up to 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.

More Specifically:

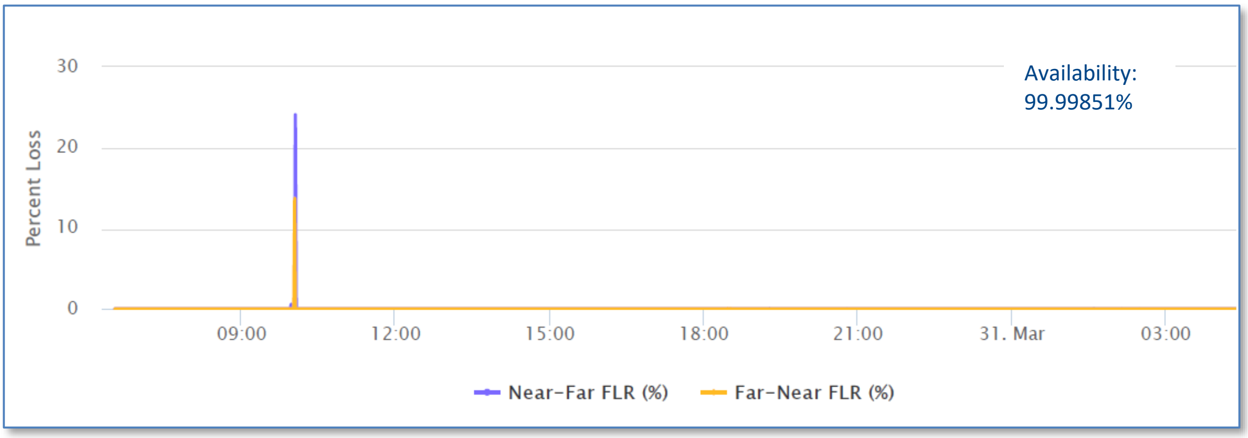
UC 13a VR inside the bus

- Loss remaining below 0,05% for all parts of the network (transport and over-the-air)
- Latency below 1ms for the transport segment and 100 ms for the e2e path (momentary peaks of up to 3s and it is discussed later)
- Jitter (delay variation) below 0,1 ms for the transport segment and 4-6ms for the e2e path.
- Availability 99,99945% (99, 99851% for the transport segment)
- Reliability 99,99945% overall but 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. 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.

UC 13b AR Myrtis exhibition

- Loss remaining below 0,2% for all parts of the network (transport and over-the-air)
- Latency below 1ms for the transport segment and 20 ms for the e2e path
- Jitter (delay variation) below 0,1 ms for the transport segment and 6 ms for the e2e path.
- Availability 99,99952% (99,99862% transport)
- Reliability 99,99952% (99,99862% transport)

Graphs detailing the above results for the period of the actual UC13 trial are provided below in Figure 142 - Figure 145.



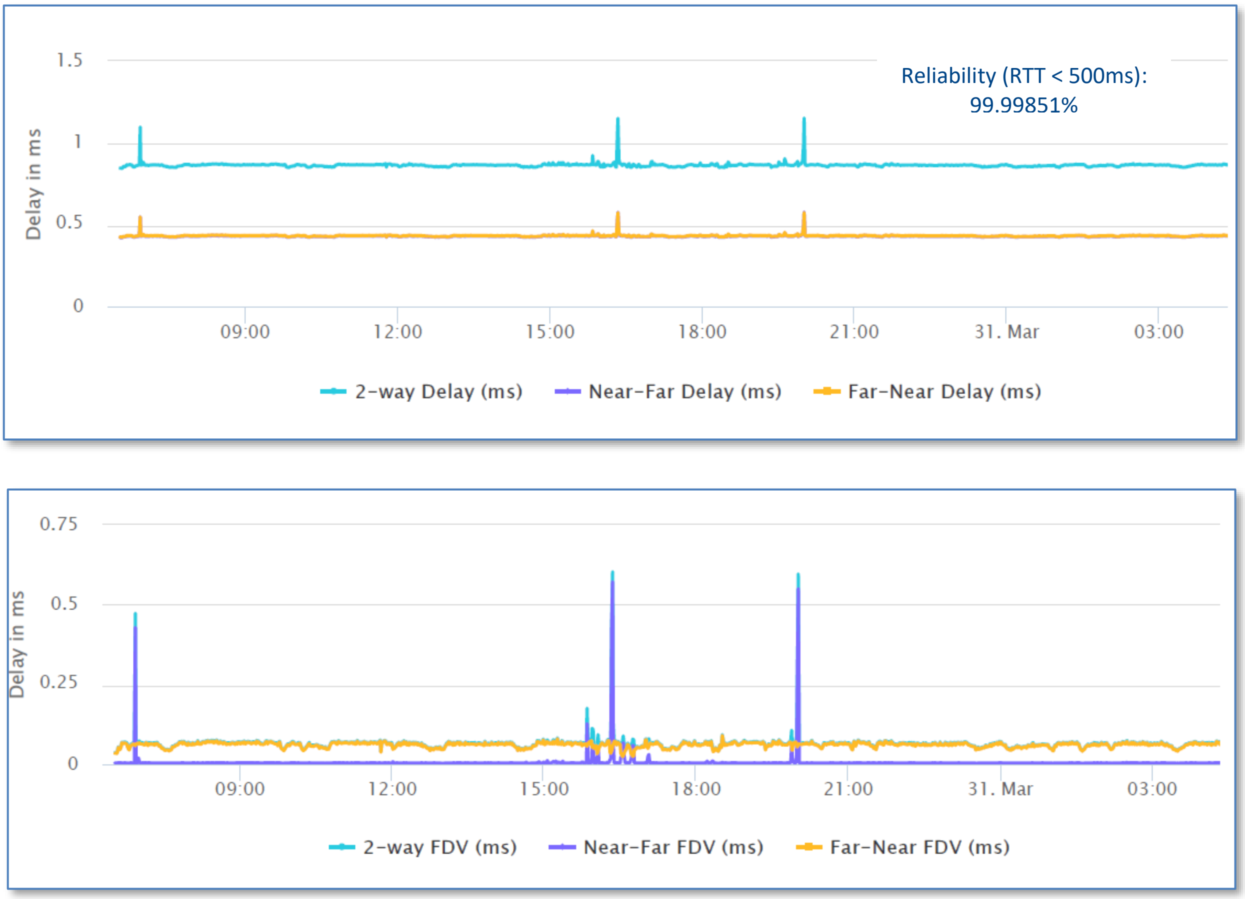
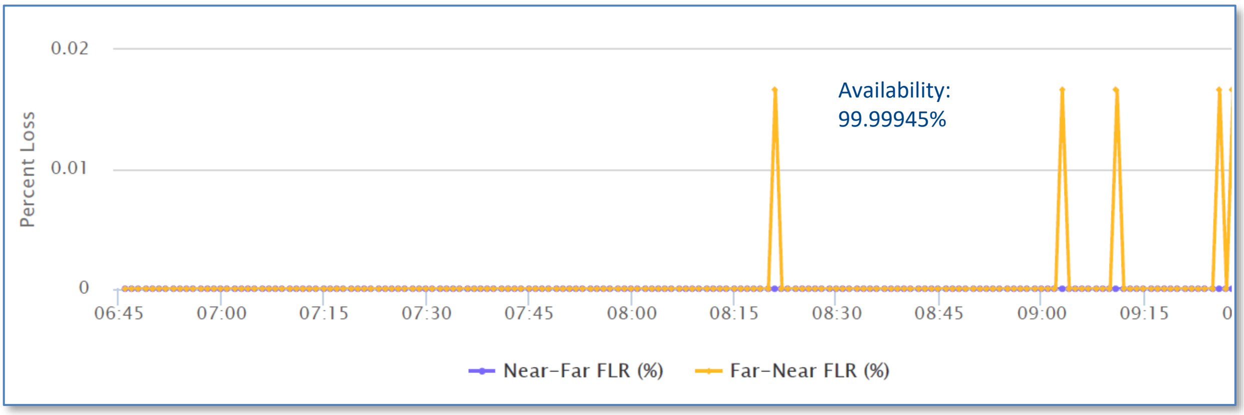


Figure 142. UC13a VR L2/L3 KPIs Transport path up to BBU.



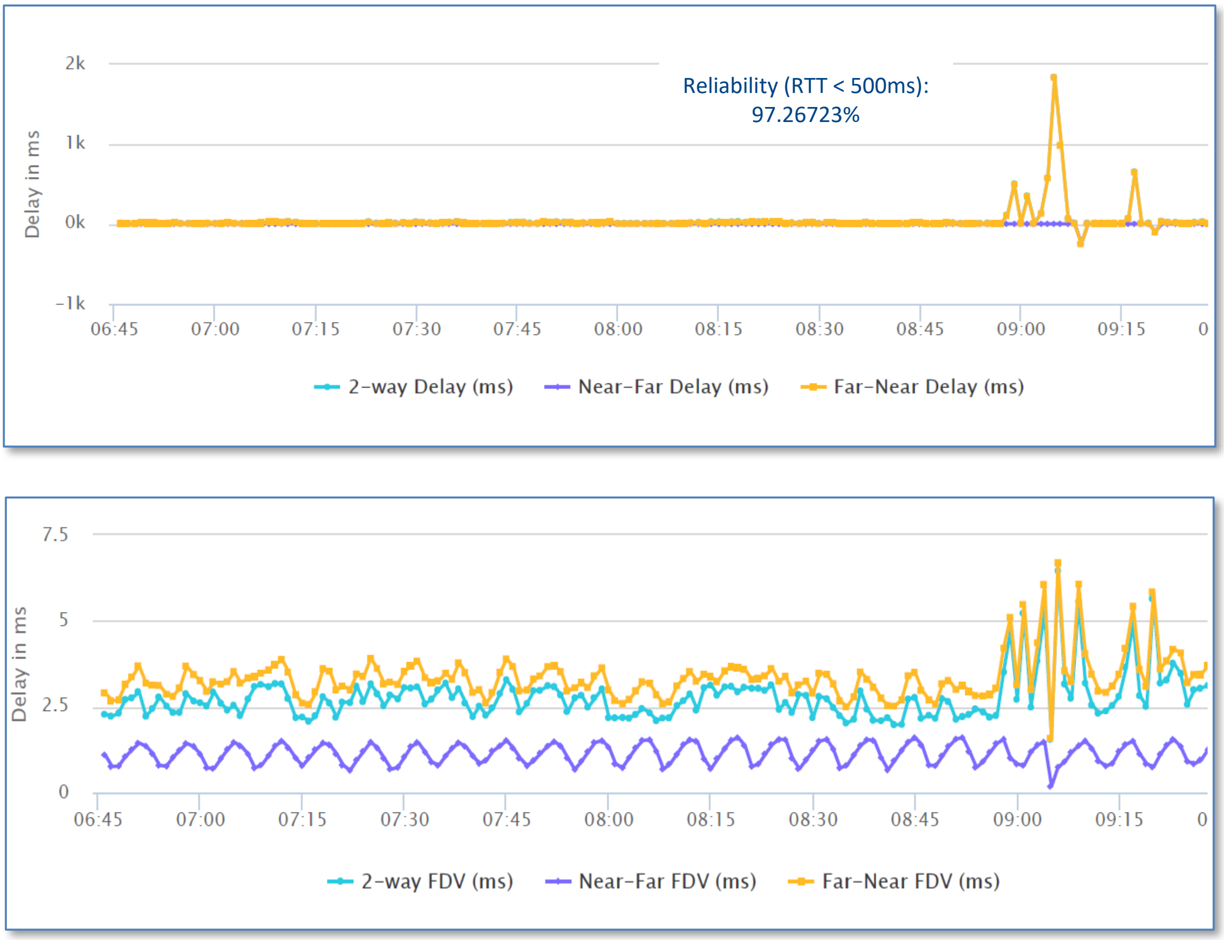
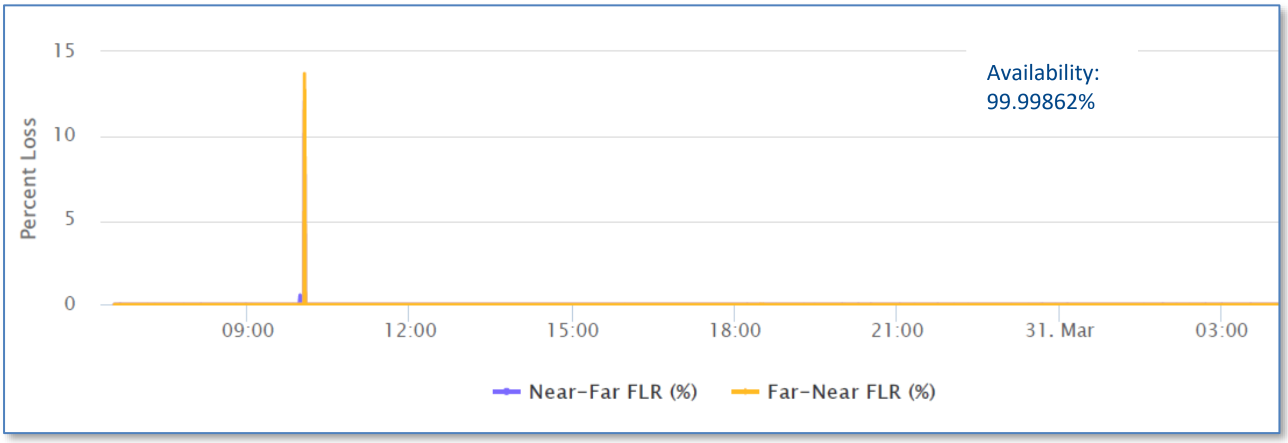


Figure 143. UC13a VR L2/L3 KPIs Transport path up to Fastmile UE.



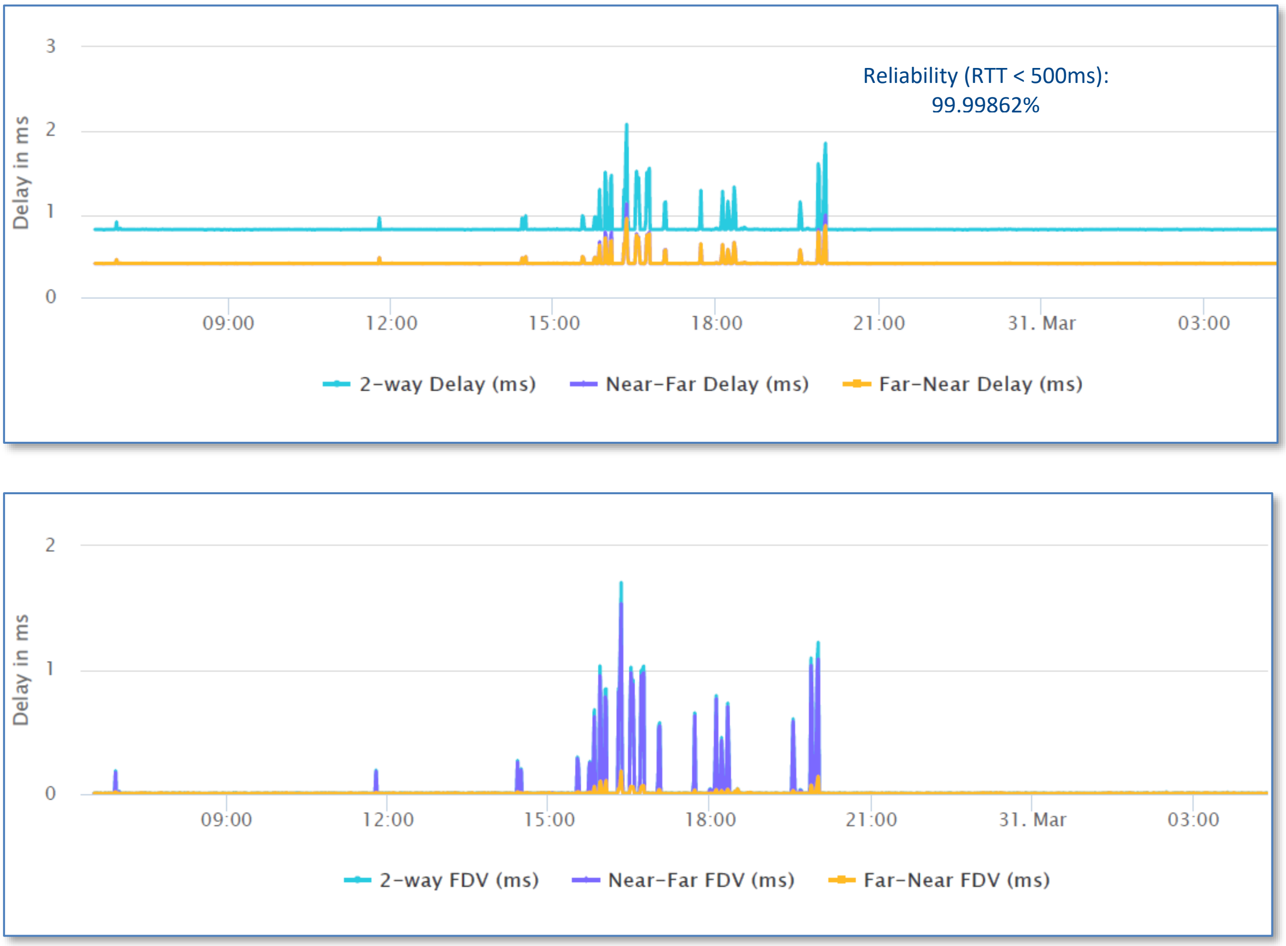
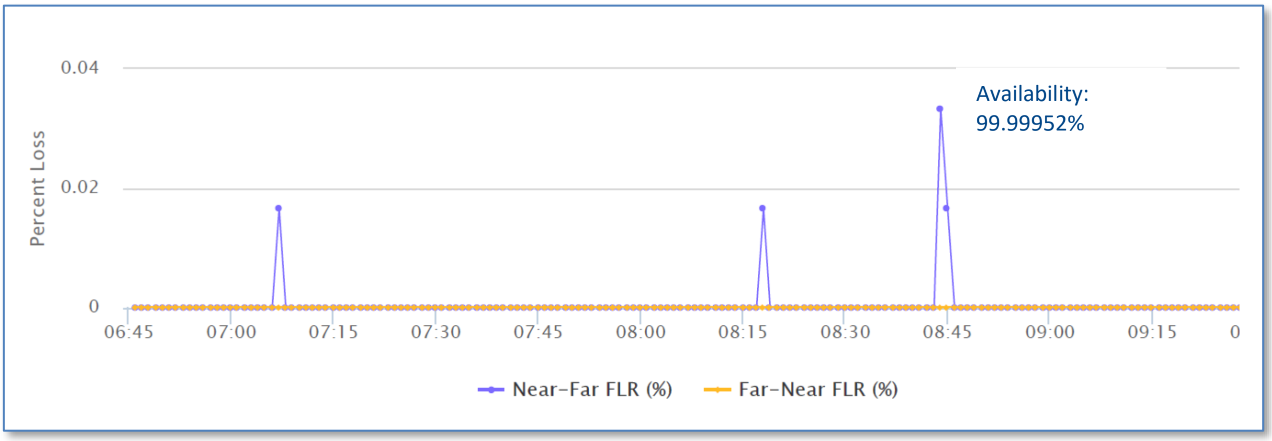


Figure 144. UC13b AR L2/L3 KPIs Transport path up to BBU.



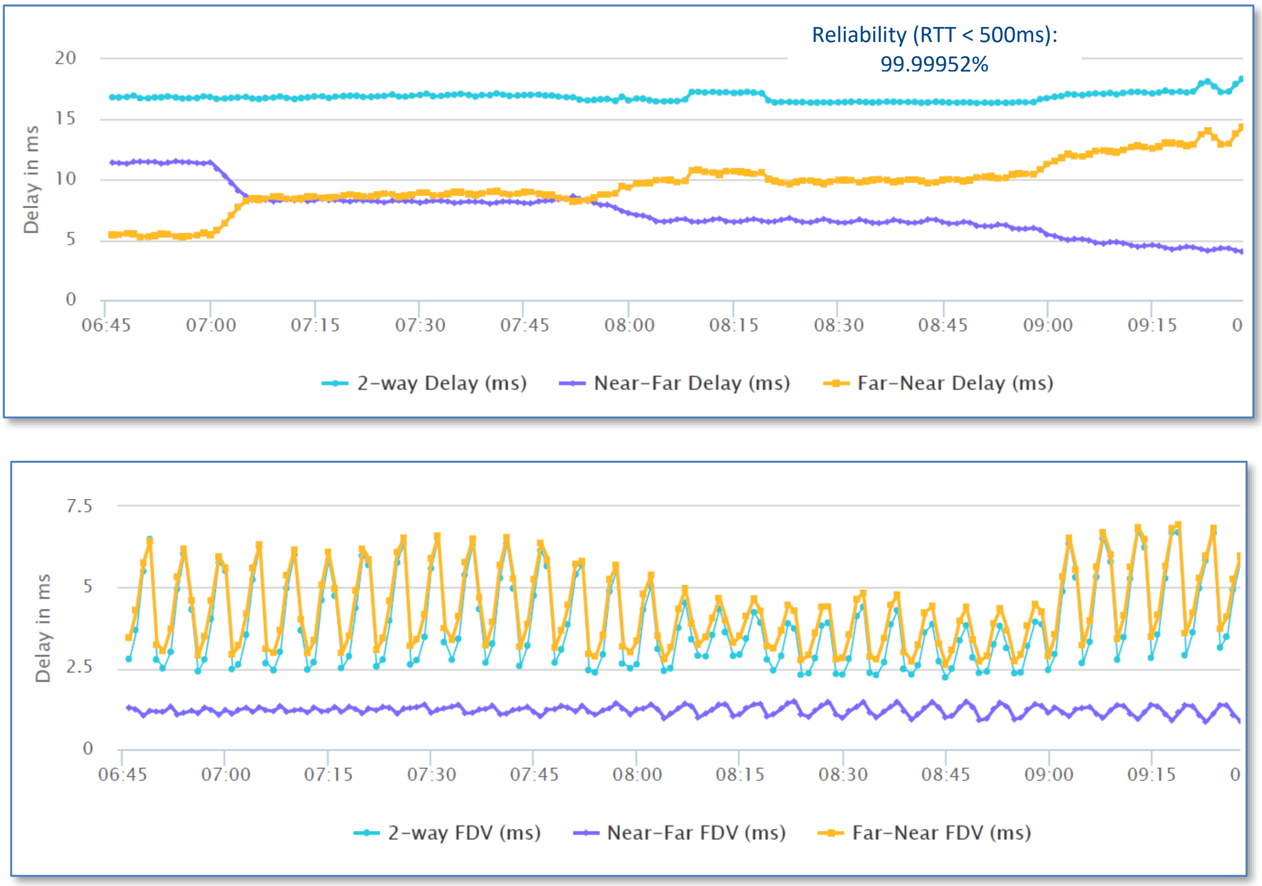


Figure 145. UC13b AR L2/L3 KPIs Transport path up to Fastmile UE.

The overall conclusion is that the L2/L3 Network KPIs of Latency, Availability and Reliability comply with the targets set in Table 7 (respectively KPIs 1, 5 and 4). An added benefit is that the RAN Latency (KPI 2 in Table 6) which is characterised as “difficult to be demonstrated”, can be indirectly measured by subtracting the respective latency values of the transport part from the end-to-end part.

Overall latency remains within the specified limits (below 50 ms for RAN latency and 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).

6 Other hosted UCs

6.1 UC6 and UC9

UC6 “Remote health monitoring and emergency situation notification” as well as UC9 “Optimal Ambulance routing” were initially scheduled to be executed in Rennes. Due to only commercial network availability in Rennes for these two use cases; their trials were decided to be performed in the Athens site. Detailed descriptions and corresponding results from the conducted trials on the two use cases can be found in D5.4 [33]. More detailed validation results are available in D7.4 [32].

6.2 Multisite UC

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 undergo a cardiac intervention procedure based on live, simultaneous X-Ray and ultrasound imaging.

The procedure follows an accident that was in fact due to an acute heart failure happening to the tourist patient secondary to a rupture from an acute heart rhythm dysfunction. The interventional procedure starts with a 3D Angiography X-Ray acquisition enabling the doctors to obtain the 3D volume of the heart auriculum. Then, a radiofrequency ablation is performed, guided by fluoroscopy, complemented by doppler ultrasound to estimate the blood flow, and superimposed on the fluoroscopy image, using advanced segmentation and matching algorithms with an Augmented Reality application that generates a guidance image displayed on a wireless tablet. The use of complementary imaging sources is justified to limit the use of X-Ray and contrast product at the minimum.

The tourist patient has been previously operated on in his country, Greece, by a cardiologist who is so able to interact with his Rennes colleague to improve the quality of the procedure, via a teleconference performed using smart glasses.

Finally, a HD camera captures the cardiologist’s hands to help the scrub nurses prepare the instruments and to enable students to follow the operation in the amphitheater close to the TherA-Image room.

All these video or live medical imaging are transferred as wireless video over IP, thanks to the recent DICOM-RTV standard, enabling synchronized real-time communication of video and associated metadata.

The overall architecture was firstly designed as shown in Figure 146. Four video sources (X-Ray, ultrasound, smart glasses and camera) and two displays (augmented reality and mosaic) were considered, all connected over a 5G wireless network.

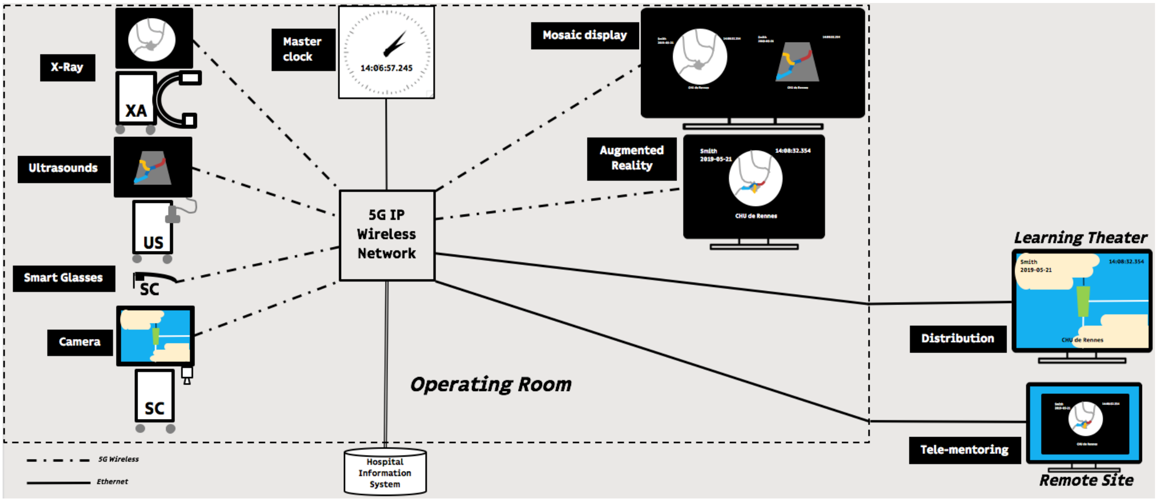


Figure 146. Wireless Operating Room (operation site in Rennes and tele-monitoring site in Athens).

After a more detailed analysis of the operating room equipment and of the available communication bandwidth, a refined architecture has been proposed (Figure 146).

Regarding this multisite UC, the following inter-site network topology is setup as depicted in the picture below (Figure 147).

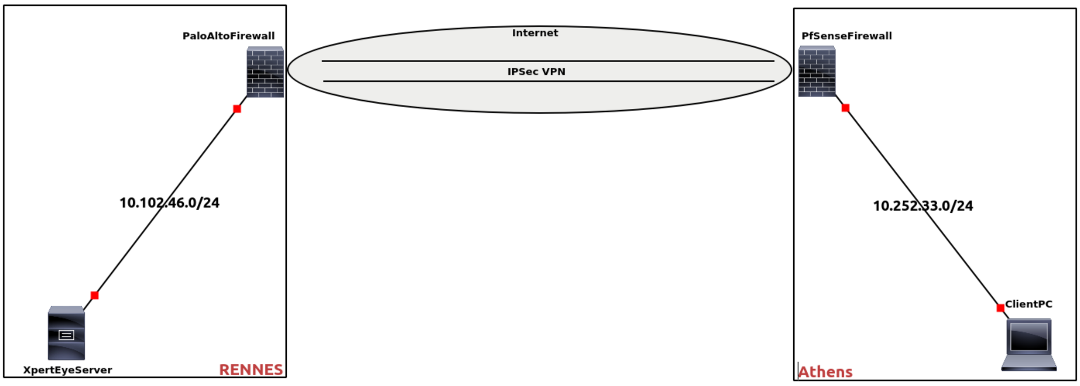


Figure 147. Interconnection topology between Greek Athens node and Rennes node, through VPN secure tunnel.

At OTE premises there is a PfSense firewall installed configured in such a way to create an IPSec connection to Rennes premises where a Palo Alto Firewall is also installed and configured to create the tunnel between the two sites. Both sites have been configured with IPSec protocol in order to secure the communication between the two sites and assure the encryption and authenticity of traffic.

In Rennes there is a server hosting the Xpert EyE application software that the monitor client from Athens can join and participate in a web call. The doctor at Rennes wears smart glasses when performing the surgery and the video from the glasses is transmitted through the vpn tunnel in Athens where the client resides.

The client at Athens is a laptop device with correct credentials and certificates needed from the XpertEyE app to join the call. After the client connected to the XpertEyE site using a compatible browser (Chrome), could then create or join a conference call with the doctor that performed the surgery and monitored with him the entire procedure.

Below are some captures taken from Rennes during the demo surgery through a conference call between Athens and Rennes (some photos from the multisite trial are depicted in (Figure 148).

Figure 148. photos from the trial of Multisite UC8 between Athens and Rennes.

6.3 Slicing

6.3.1 Network Infrastructure

The mobility efficient city network deployment offers two 5G network architectures, NSA (which thoroughly described in chapter 7 and especially in paragraph 7.1.1) and SA which has been deployed as part of phase 2 network implementation.

The SA architecture has been deployed as described in Figure 149 by Nokia-GR with the integration of a 5G Core Network and the RAN infrastructure in OTE Psalidi premises. 5GC consists of AMF, SMF, UDM, AUSF and NRF The 5GC has been connected with 5G RAN acting in SA mode.

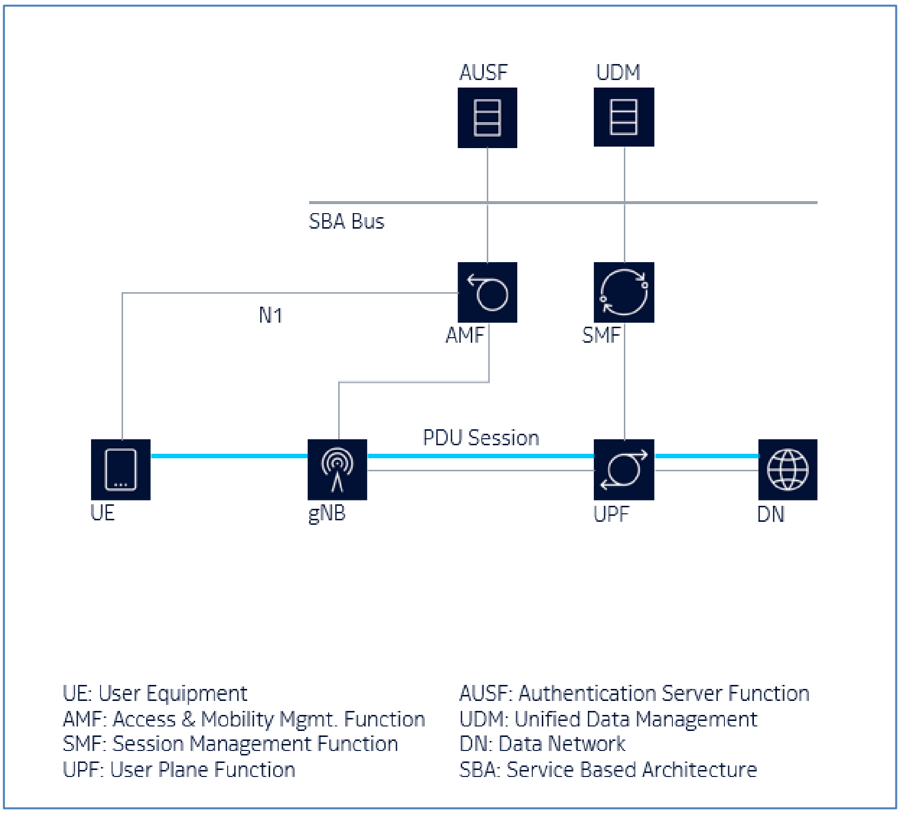


Figure 149. SA (phase 2) Core Network deployment for the Mobility-Efficient City.

In this SA solution different subscription profiles are created in UDM simulator, each associated with a Mobility-Efficient City Use Case. Each subscription profile is provisioned with dedicated DNN, QoS and S-NSSAI.

Both the NG-RAN and the 5GC (the AMF and the SMF) of the deployed 5G network were configured to support the S-NSSAI(s) as defined in sim-UDM for the various subscription profiles. During service invocation, the AMF used NRF service to do SMF discovery using DNN, S-NSSAI and TAI as discovery criteria in accordance to 3GPP requirements and then SMF/UPF and the NG-RAN enforced the subscribed QoS as part of QFI setup.

6.3.2 Network slicing scenario

In order 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”.

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 Fastmiles devices 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. The topology of the network is illustrated in Figure 150.

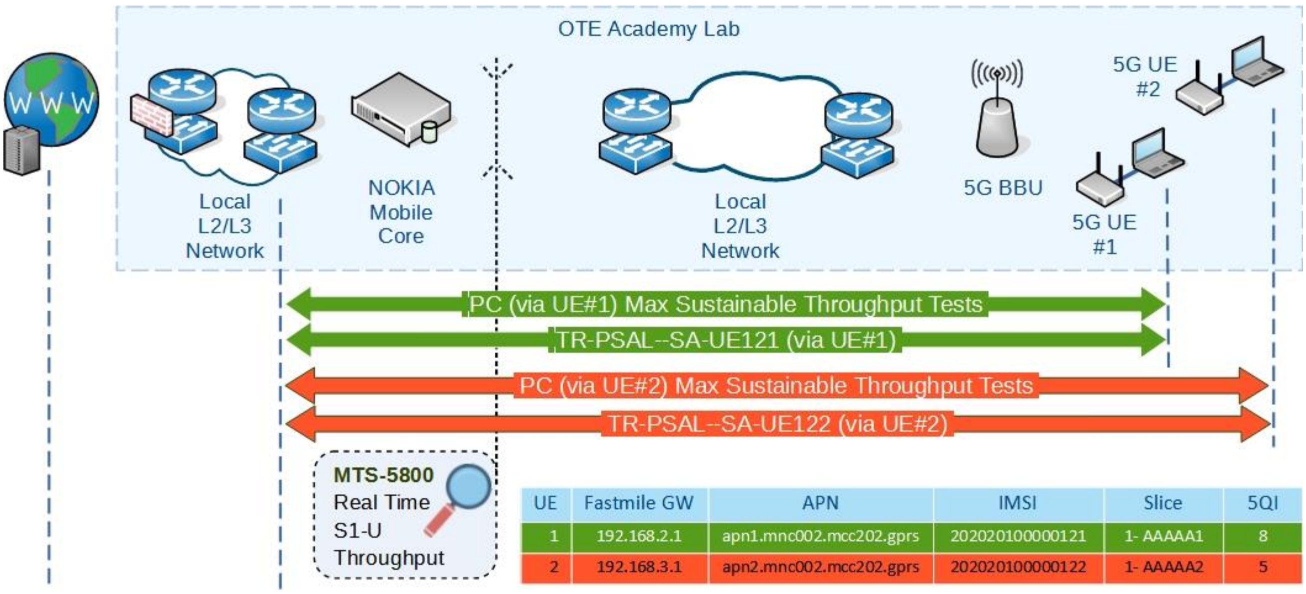
During the trial, both UCs were initiated, and traffic was injected in the 5G network in both network slices. In detail, UC6 (critical service) generated small packets in the uplink direction, while UC9 (not critical service) generated both service requests/response and video flows on both directions.

Several network and applications metrics were collected, analysed, and evaluates during the trial. The network performance metrics are presented in the next subsection.

Regarding the application metrics, as initial result 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, while the time needed for the realisation of the whole service functionality (request/routing/video generation/video received/response) was about 6s. The applications related results will be presented in detail in D7.4.

6.3.3 Network Performance Monitoring

The actual testing took place at OTE Labs on 26/04/22. It started around 12:57 and lasted ~15min. The setup of the measurements environment is shown in Figure 150 below.



UE	Fastmile GW	APN	IMSI	Slice	5QI
1	192.168.2.1	apn1.mnc002.mcc202.gprs	202020100000121	1- AAAAA1	8
2	192.168.3.1	apn2.mnc002.mcc202.gprs	202020100000122	1- AAAAA2	5

Figure 150. Probes and Endpoints for the Athens 5G-TOURS network Slicing Tria.l

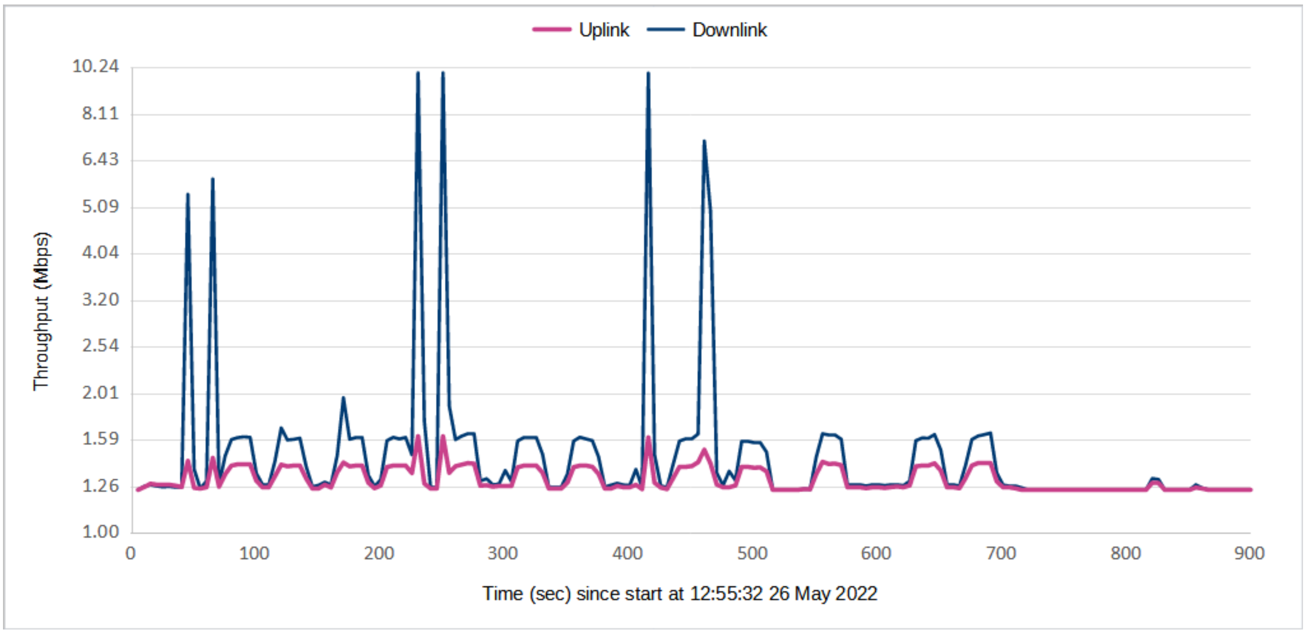


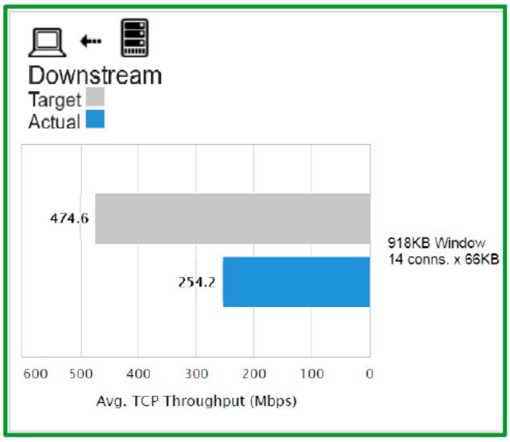
Figure 151. Real Time Throughput Measurements of both slices in parallel.

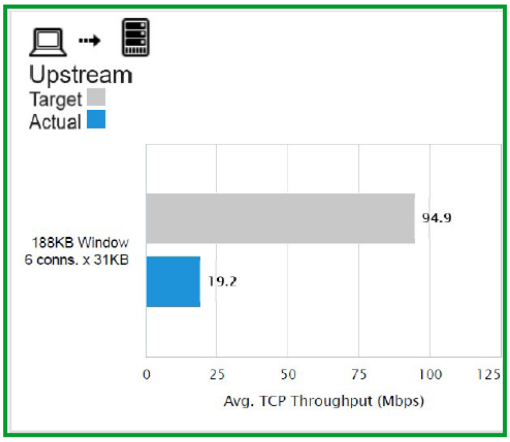
In Figure 151 slices running in parallel are depicted. The total traffic throughput was measured, which does not exceed 10 Mbps, as the setup was experimental.

Moreover, we can see the Throughput (maximum sustainable) for the two slices, as experienced by the end users with FastMile router UEs, in Figure 141 below. As a reminder:

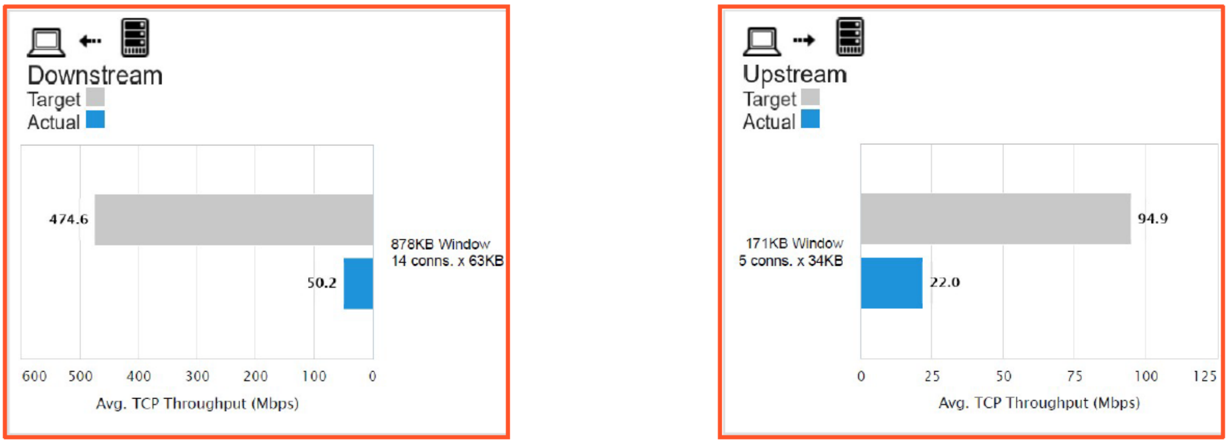
ue1 → “Slice 1” limited to max 300mbps DL, by the network.

ue2 → “Slice 2” limited to max 50mbps DL, by the network.





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 152. Slice1 & 2 Max Throughput Measurement results.

While the download metric stays around 20Mbps for both slices, the upload metric reflects the network capability of each slice.

In the above figures, 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.

Let us now turn our attention the Latency, Loss and Jitter L2/L3 KPIs measured for each slice. The first two are also being used to calculate Network Availability and Network Reliability as discussed in Section 7.2.5.

More Specifically:

<u>Slice 1</u>

- Loss remaining 0 %
- Latency below 12ms
- Jitter (delay variation) below 4 ms
- Availability 100%
- Reliability 100%

<u>Slice 2</u>

- Loss remaining 0 %
- Latency around 11ms
- Jitter (delay variation) around 3 ms
- Availability 100%
- Reliability 100%

Graphs detailing the above results for each slice are provided below in Figure 153 and Figure 154 below.

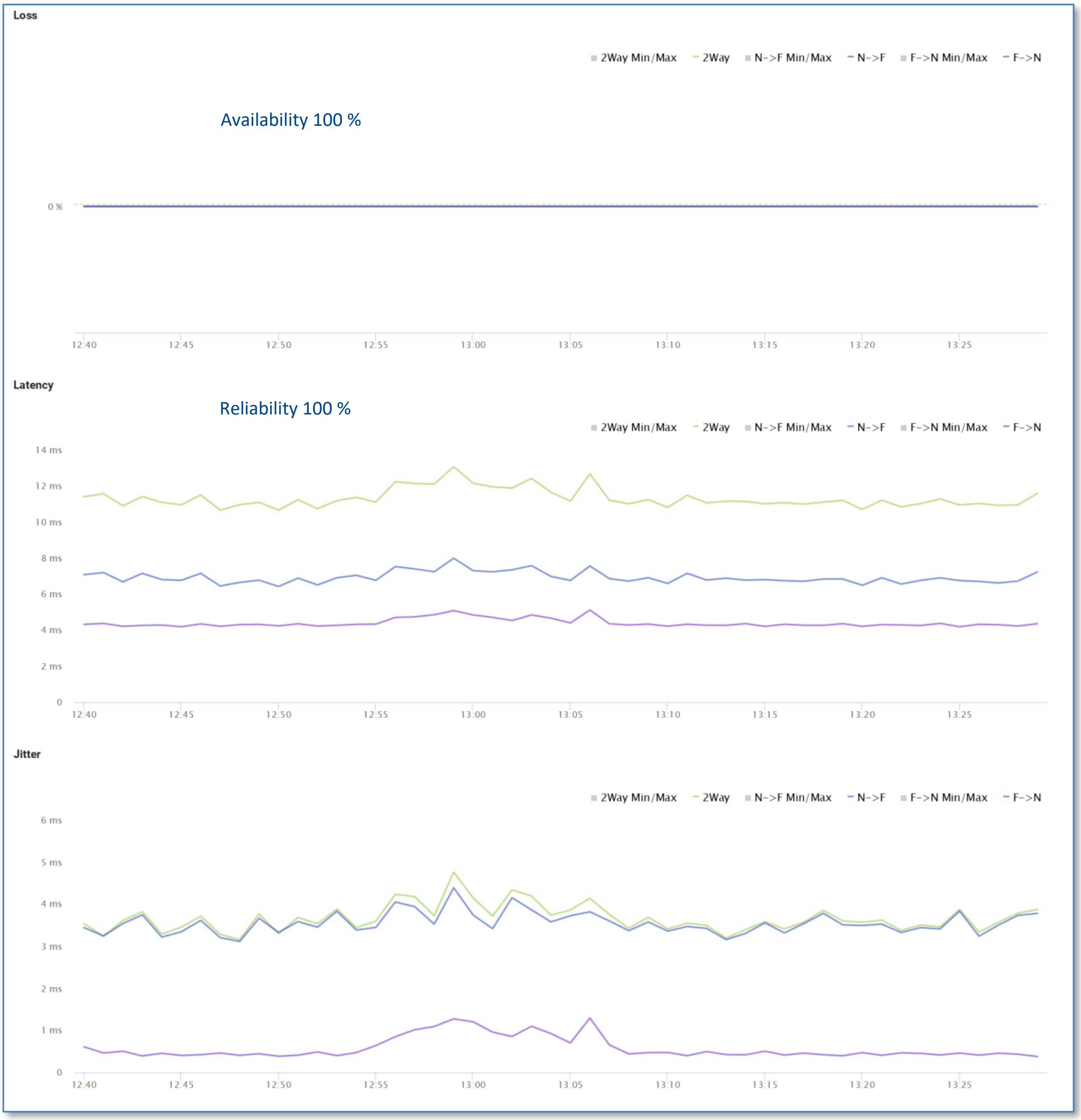


Figure 153. Slice 1 L2/L3 KPIs up to Fastmile UE.

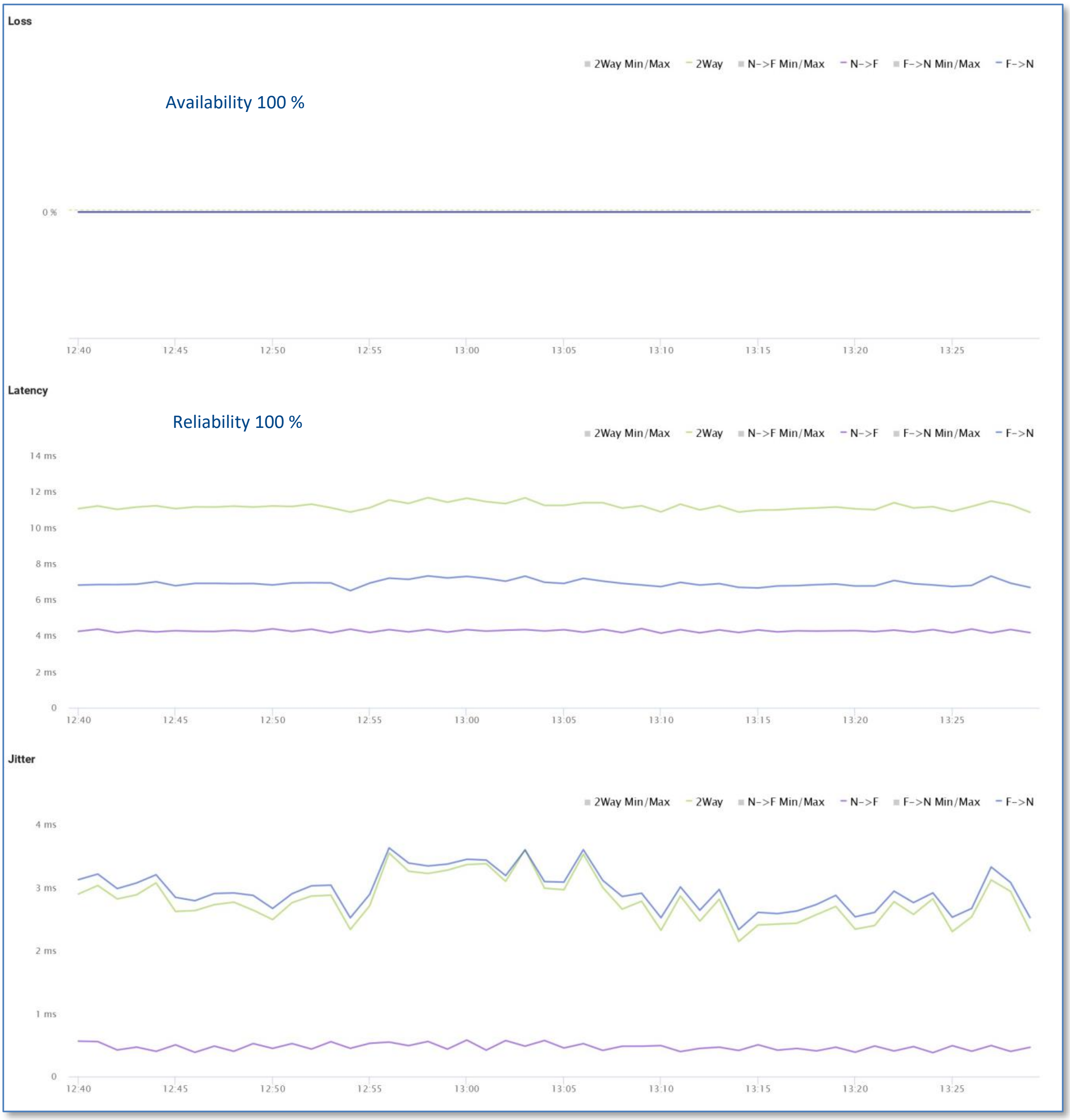


Figure 154. Slice 2 L2/L3 KPIs up to Fastmile UE.

The overall conclusion is that the L2/L3 Network KPIs of Latency, Availability and Reliability comply with one would expect from a controlled experimental setup and are very stable and low in value.

7 Network Implementation Aspects

7.1 Network Deployment

The mobility-efficient city presents a set of use cases that improve the tourism and tourism-related experiences from various perspectives. The implementation of the four UCs relies on 5G EVE Greek site infrastructure and on the extension that is implemented at the AIA premises during the 5G-TOURS project.

The final implementation of the Athens node spans two main areas. One in OTE's Labs facilities at Psalidi (suburb of Athens) where the previous infrastructure of 5G-EVE exists; the other at Athens International Airport where the extension site exists. The overall implementation comprises of the following components:

In OTE facilities:

- A fully functional 5G NOKIA 5G NSA core at OTE Labs facilities in Psalidi area (suburb of Athens)
- A NOKIA 5G SA core at OTE Labs
- 2 NOKIA outdoor pair 4G/5G antennas at OTE Labs facilities, upgraded to support 5G SA core
- One OSM (Orchestrator) interconnected to NOKIA's cores (NSA/SA). The OSM is also fully interconnected with the Interworking Layer (IWL) in Turin 5G EVE site through a secure tunnel. Moreover, OSM is interconnected with WINGS' IoT platform
- An AI-Enhanced Mano and Diagnostic Tool for the needs of the innovation (network application resources dynamic reallocation)
- A Kafka bus server, for the needs of keeping the metrics of the KPIs, is installed, configured, and interconnected to the central Kafka of 5G-EVE project, Clouds and VMs
- A Server farm and probes for real-time KPI measurements
- A TWAMP/VIAVI software for real-time measurements. The server is connected with Kafka and sends network application measurements in real-time
- E2E site interconnection with Portal in Spain Site, where blueprints are uploaded
- E2E site interconnection with 5G-EVE IWL (interworking layer in Turin)
- E2E site interconnection with Rennes Site for the need of running a multisite UC
- For the needs of all the above in OTE's facilities, data centers, racks, servers, UPS, power supply, internet access and telecommunication infrastructure are used

In the extended site at Athens International Airport:

- 2 NOKIA's BBUs
- 2 pairs of 4G /5G outdoor and 4 pairs of 4G/5G indoor antennas. All the 5G antennas utilize the spectrum band 3.4-3.6GHz, while the 4G antennas the 2.5 GHz. However, since there was interference with commercial COSMOTE 5G at the AIA, a restricted band of frequencies are used from 3450 MHz – 3500 MHz, with 50 MHz bandwidth
- All the antennas are connected through fiber optics to the NOKIA-GR's BBUs at the airport. From there, the data are forwarded through an OSN OTE switch which is connected to the OTE IP Core, using a 10 Gbps line, to interconnect to the 5G EVE Greek site infrastructure at OTE Labs in Psalidi
- License from the Greek National Regulator Authority (EETT) was needed for utilizing the 5G spectrum band. Furthermore, AIA obtained a second license from CAA (Civil Aviation Authority) for installing antennas at the International Airport of Athens. Safety plans and technical studies were also needed for the antennas installations

- Probes for the need of real-time KPI measurements (24x7) are installed between BBUs and the OTE switch, as well as between NOKIA-GR's 5G platform and WINGS IoT platform at Psalidi. These probes are used for measuring metrics in real time in order to validate the KPIs of the network
- A Media-streaming server for the needs of the UC11
- 3 Pepling 5G Routers and 3 Fastmile NOKIA 5G routers are used for the UC trials and for taking measurements in real-time from the network
- A 10GBps line which interconnects the AIA facilities with OTE Labs facilities
- UE equipment. For the needs of implementation of the four UCs, smart devices are used and specific innovative applications have been developed (30 Samsung Galaxy S20 mobile devices, tablets, Samsung AR/VR headsets, UHD cameras, Sequans and Quectel BG96 chipsets, sensors, etc.). Final versions of the applications have already been developed and are used to trials, according to the overall WP6 time plan
- The 30 Samsung Galaxy S20 mobile devices are configured to be connected to the trial 5G NOIKIA's NSA core using a specific PLMNid
- COSMOTE's data rooms and data centers, servers, poles of antennas, racks, switches, routers, UPS, power supply, e.tc, are used for supporting the overall infrastructure
- 50 SIM cards for NOKIA's NSA core for the needs of the UCs. Moreover, about 75 SIM cards from OTE for the needs of the UCs
- The overall infrastructure supports 7 UCs of 5G-TOURS (described in detail in chapters 2-6). Four of them belong to WP6 (Smart Parking, Ground-based vehicles, Airport Evacuation, AR/VR student bus excursion), the other two belong to WP5 and are hosted to Athens node (Remote Health Monitoring, Optimal Ambulance Routing), while the remaining one "wireless operating room" belongs also to WP5 and run as a multisite UC (see section 6.2 and [30])

The final interconnection diagram/architecture of Athens node as it is implemented for the mobility efficient city is depicted in Figure 155 below.

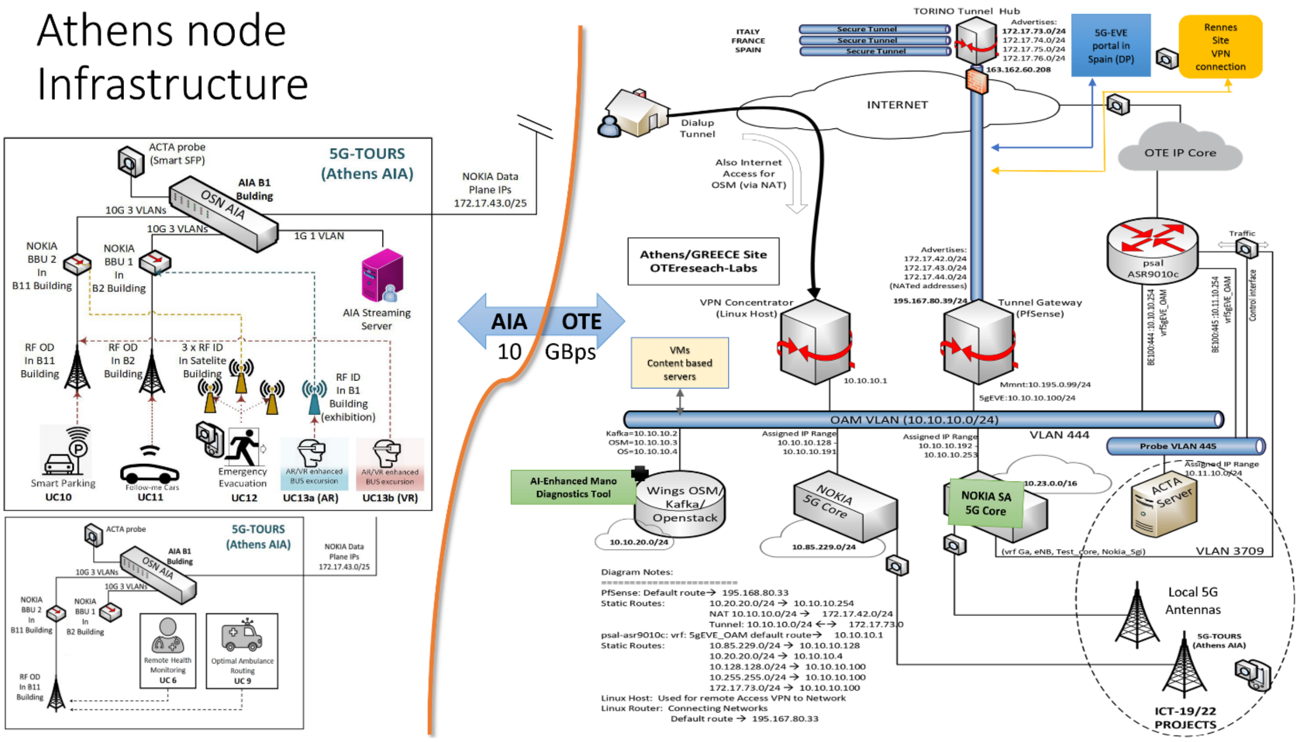


Figure 155. 5G-TOURS Athens node platform.

7.1.1 Network Deployment for UC10

Figure 156 below highlights the network deployment that is applied to cover UC10 Smart Airport Parking Management use case.

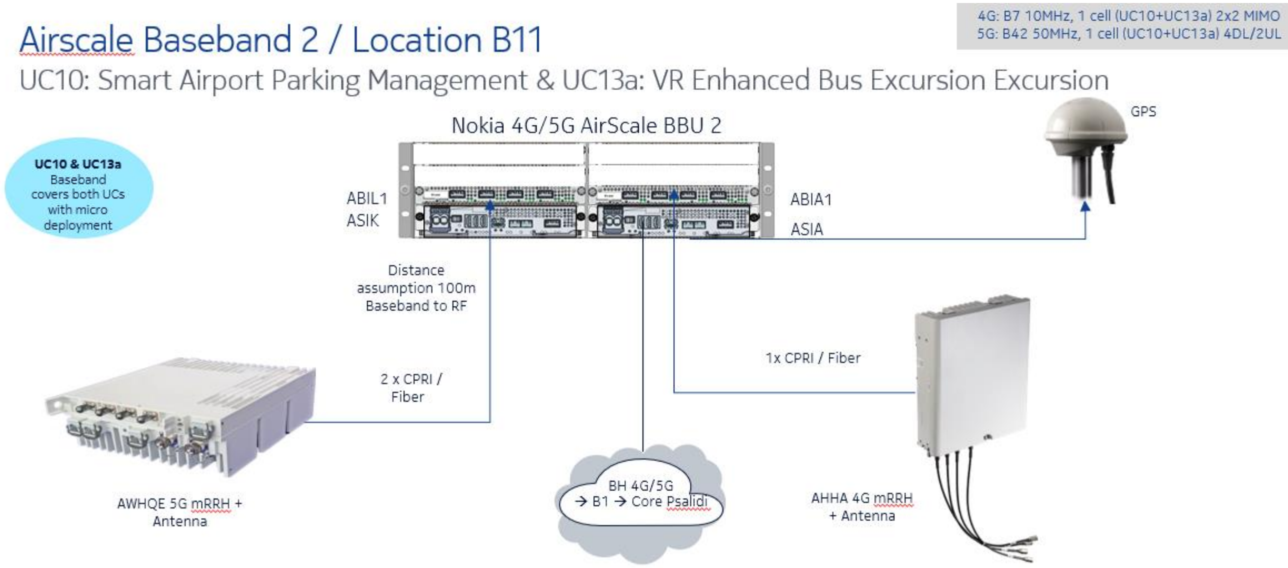


Figure 156. Smart parking management network deployment.

An Airscale BBU has been placed in the control room of building B11 in AIA (Figure 3). One pair of 4G/5G outdoor antennas (non-standalone deployment solution) is connected on the roof-top of the same building. A backhaul connectivity is established from B11 to the main control room of the airport (Building M2). From there, a 10Gbit Ethernet connects to the Packet Core network. Figure 157 illustrates the control room of building B11 and the antenna mast at the rooftop of the same building.

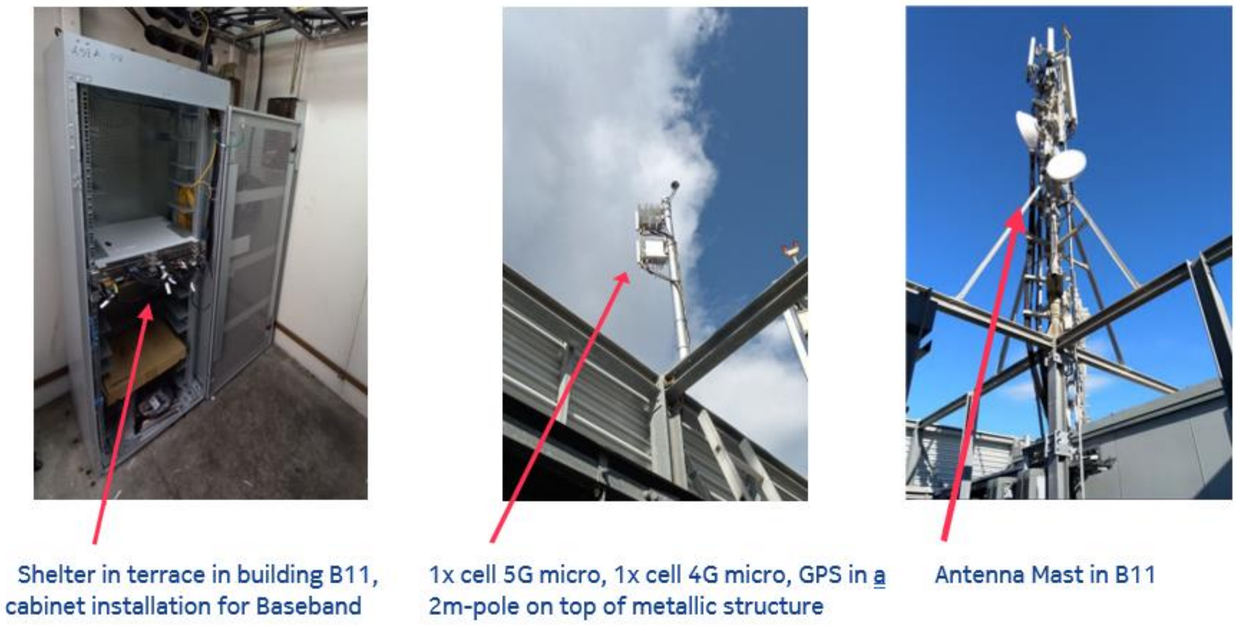


Figure 157. Control room of building B11 & the antenna mast.

Core Network of 5G EVE

The mobility efficient city network deployment largely relies on the available Core Network infrastructure from 5G EVE Athens for the vertical trials. It relies on 4G (and eventually 5G) equipment provided by NOKIA-GR. The infrastructure consists of RAN, offering 5G NSA (Option 3X) support for phase 1 and 5G SA support for phase 2 of the 5G-TOURS project, vEPC Core Network (phase 01) and 5GC (phase 02) Core Network elements and tools for the management and orchestration of the NFV infrastructure. Functional behavior is the same as with non-virtualized nodes. CMM VNF is composed of multiple internal components (VNFCs).

5G-TOURS Core Network reuses the 5G EVE Core Network deployment for both phase 1 and phase 2. Regarding phase 1 deployment, vEPC Core Network is used and connected with 5G NSA RAN as described in deliverables D3.1 [3], D3.2 [4] and shown in Figure 158. Note that vEPC is deployed at OTE premises in Psalidi, Attika.

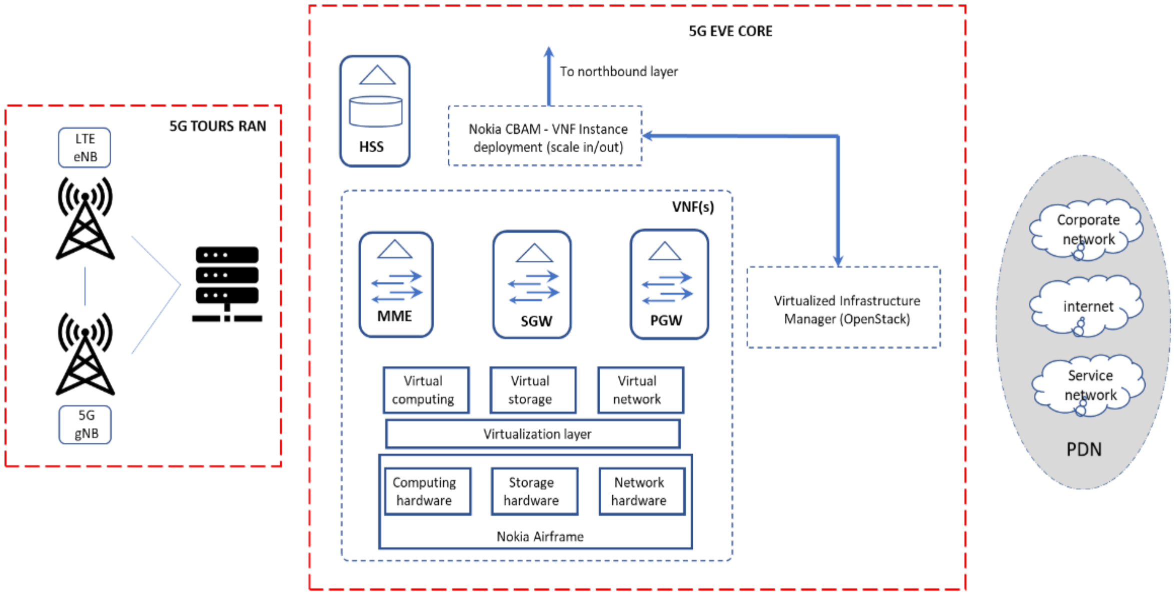


Figure 158. NSA (phase 1) Core Network deployment for the Mobility-Efficient City.

Regarding phase 2 deployment, vEPC is replaced by 5GC consisting of AMF, SMF, UDM, and NRF, as shown in Figure 149. The 5GC has been connected with 5G RAN acting in SA mode.

All modifications and enhancements required in the Core Network infrastructure to extend the 5G EVE network from Psalidi to AIA as well as the RAN infrastructure, the installation of the antennas to be used in the context of 5G-TOURS in AIA has been completed succesfully.

7.1.2 Network Deployment for UC11

As it is mentioned in the previous chapter OTE and COSMOTE in co-operation with NOKIA-GR organized all the designation and implementation part of the infrastructure for the needs of the four UCs of the mobility efficient city. During the last period of the project for the better organization of the WP6 infrastructure designation and installation and in order to reach smoothly the MS3, many teleconferences or online-meetings and on site F2F meetings took place and organized between OTE, COSMOTE mobile team and NOKIA-GR, where many decisions were taken as they have been mentioned before. In section 2.2.1 we have described in detail the existing extended infrastructure of Athens node. Figure 159 highlights the network deployment which is applied to cover the Video-enhanced ground-based vehicles use case.

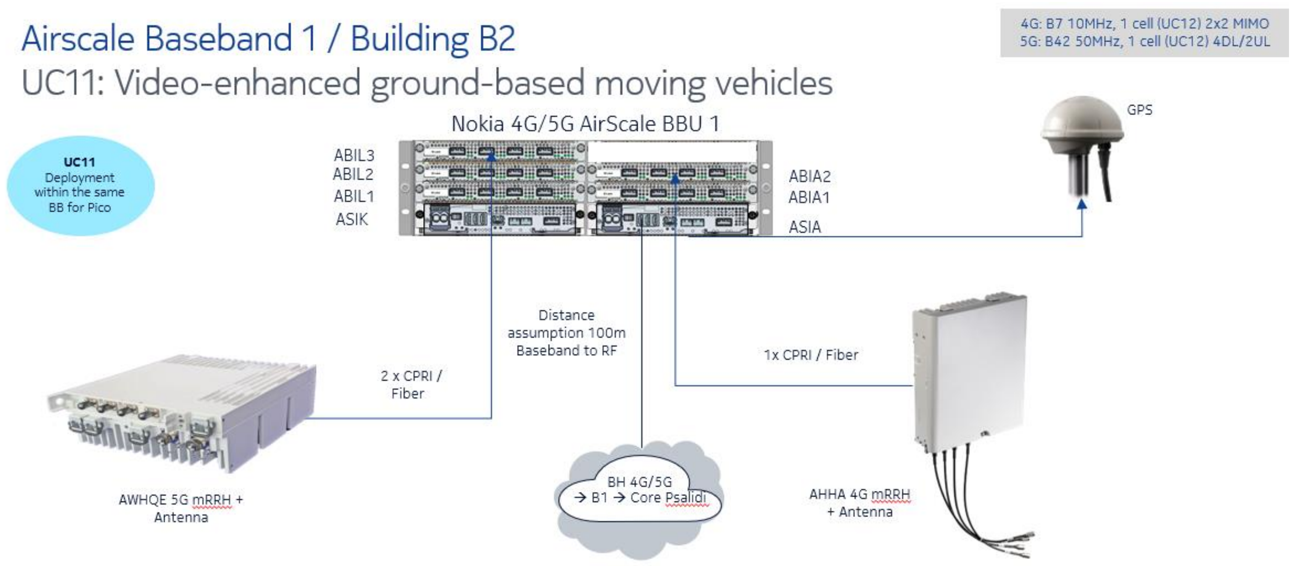


Figure 159. Network deployment for video-enhanced ground-based vehicles use case.

An air scale BBU is placed in the control room of building B2 in AIA. One pair of 4G/5G outdoor antennas is placed on the rooftop of the same building. A back-hall connectivity is established from B2 to the main control room of the airport (Building M2). From there a 10 Gbit Ethernet connects airport to the Packet Core network.

Figure 160 illustrates the control room of building B2 and the antenna mast in the rooftop of building B2.

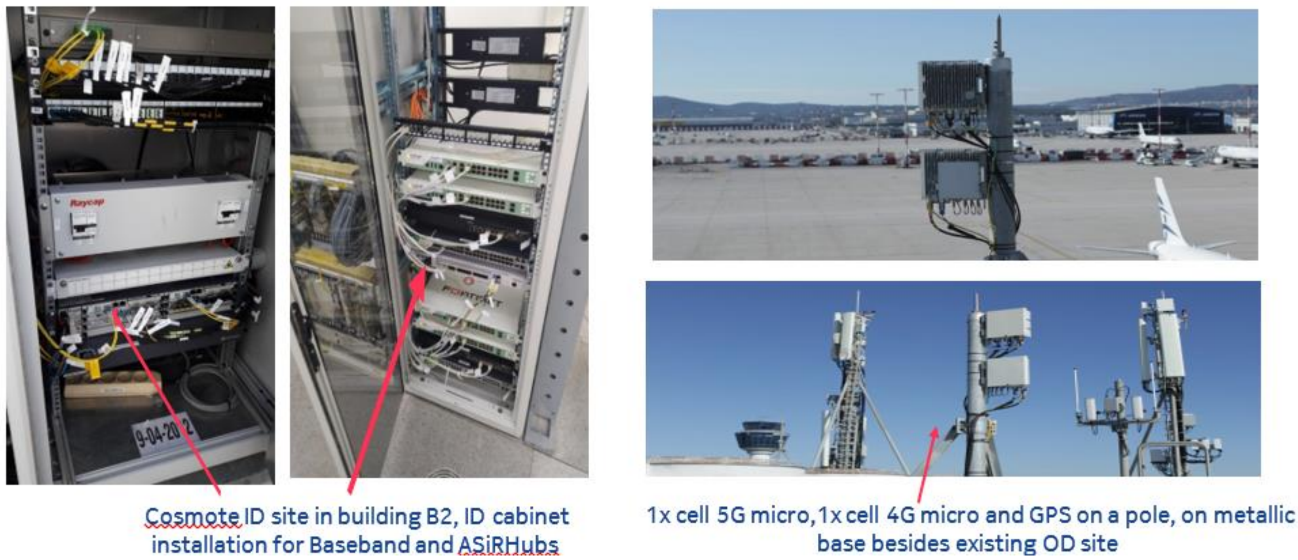


Figure 160. The control room of building B2 & the antenna mast.

For the Core Network of 5G EVE see section 2.2.1.

7.1.3 Network Deployment for UC12

For the implementation of UC12 OTE and COSMOTE in co-operation with NOKIA-GR organized all the designation and implementation part of the infrastructure for the needs of the four UCs of the mobility efficient city. During the last period of the project for the better organization of the WP6 infrastructure designation and installation and to smoothly reach the MS2, many teleconferences or online-meetings and on site F2F meetings took place between OTE, COSMOTE mobile team and NOKIA-GR, where many decisions were taken as mentioned before. In section 2.2.1 the existing extended infrastructure of Athens node is described in detail. Figure 161(red square) highlights the network deployment which is applied to cover the airport evacuation use case.

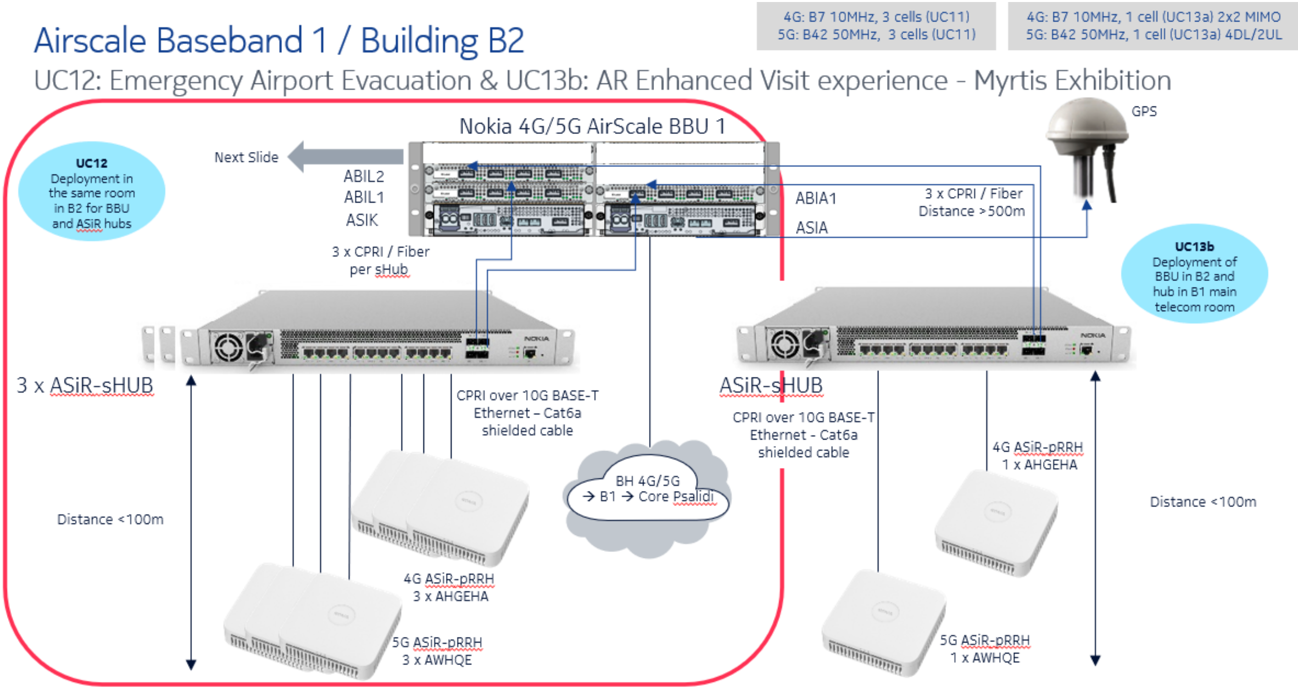


Figure 161. Network deployment for airport evacuation use case.

An AirScale BBU is placed in the control room of building B2 in AIA (Figure 162). Three pairs of 4G/5G indoor antennas are placed on the second floor of the same building. A backhaul connectivity follows from B2 to the main control room of the airport (Building M2). From there a 10 Gbit Ethernet connects to the Packet Core network.

Figure 162. Control room of building B2. The space where BBU (floor installation) and ASiR HUBS (3X1 RU) are installed.

In Figure 163 we can see a 2D/3D model of the indoor area (second floor of building B2) where the evacuation scenario took place. It can also be seen the location of small cells in the building.

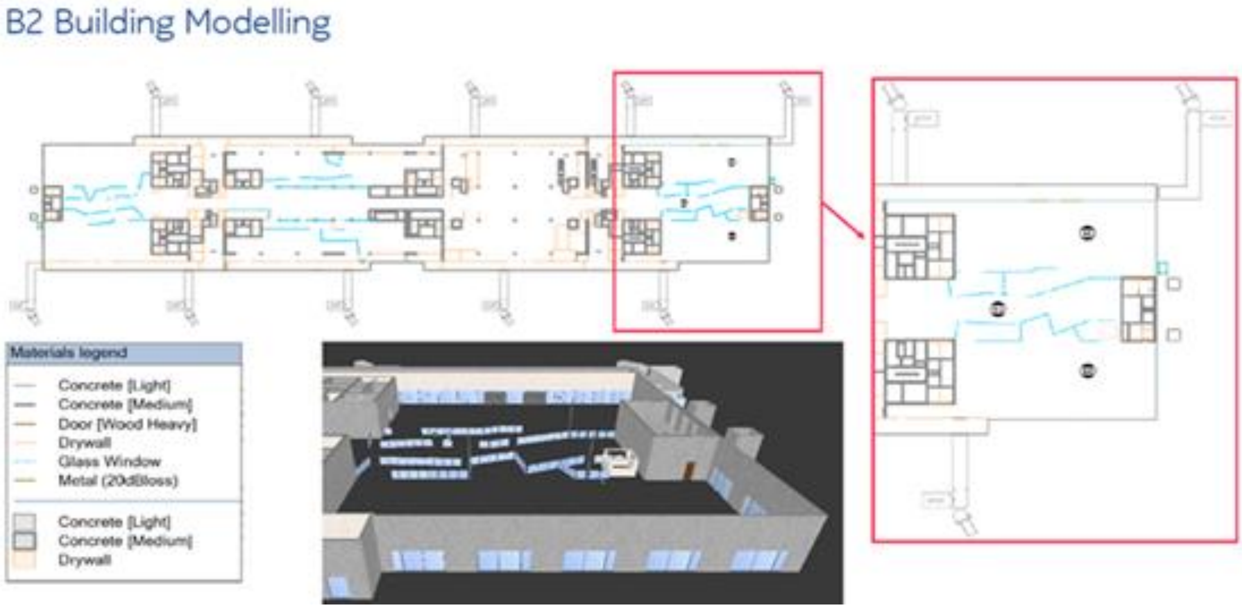


Figure 163. B2 building modelling.

For the Core Network of 5G EVE see section 2.2.1.

7.1.4 Network Deployment for UC13

The Athens site also supports the implementation of the UC AR/VR student bus excursion. Toward this need OTE and COSMOTE in cooperation with NOKIA-GR organized all the designation and implementation part of the infrastructure for the needs of the four UCs of the mobility efficient city. During the last period of the project for the better organization of the WP6 infrastructure designation and installation and to smoothly reach MS2, many teleconferences or online-meetings and on site F2F meetings took place and organized between OTE, COSMOTE mobile team and NOKIA-GR, where many decisions were taken as they have been mentioned before. In chapter 2.2.1 all the needed existing of Athens node is described in detail.

This Use case is a combination of an indoor and outdoor scenario. Network deployment for the indoor scenario can be seen in the Figure 164(red square). The outdoor scenario is implemented by using the radio equipment defined for UC10.

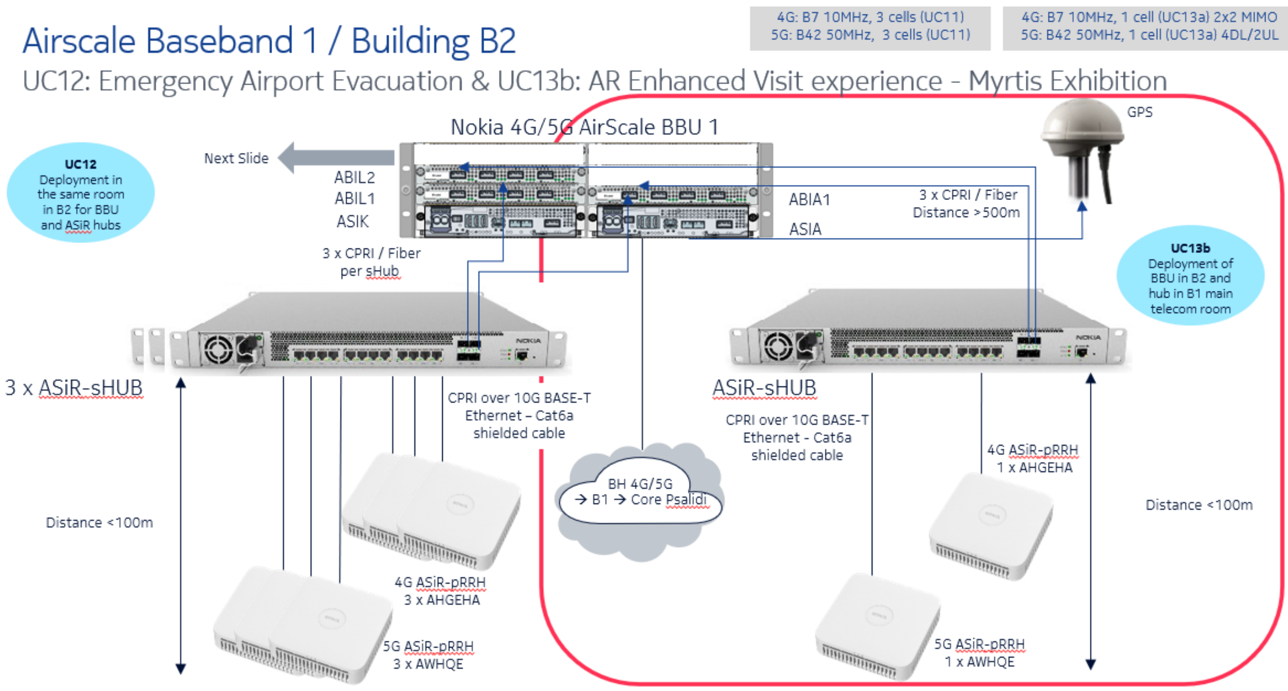


Figure 164. Network deployment for the AR/VR bus excursion use case (indoor).

An ASiR-sHUB has been installed in the control room of airport's main terminal building (M2) as shown in Figure 165.

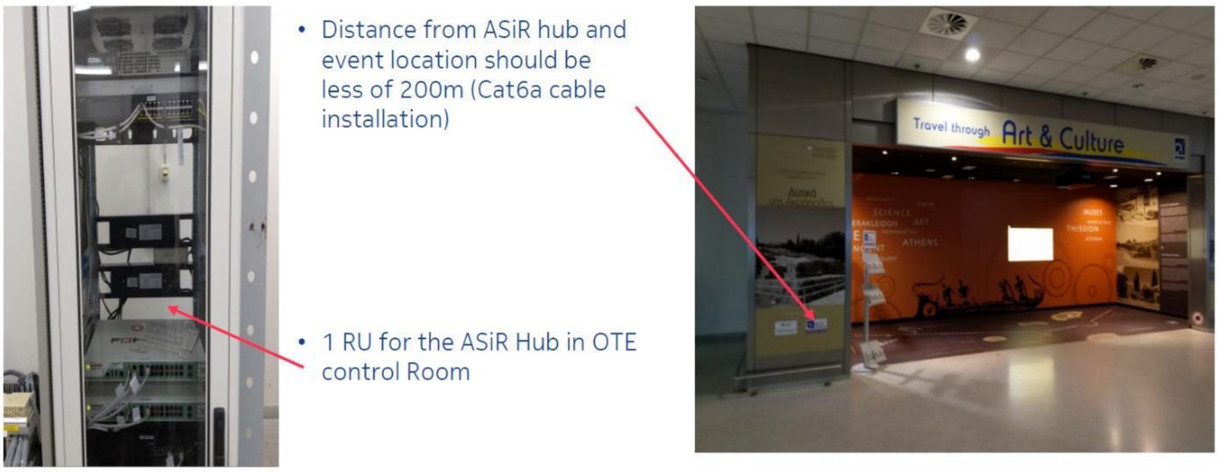


Figure 165. Illustration of the Rack where NOKIA-GR's Hub was installed.

One pair of 4G/5G indoor antennas is connected to the Hub and from there connected to NOKIA-GR's AirScale BBU. BBU resides in a satellite building, it is the low budget terminal of the airport, building B2.

In Figure 166 2D/3D illustration of the indoor area, where the Myrtis exhibition took place, is highlighted.

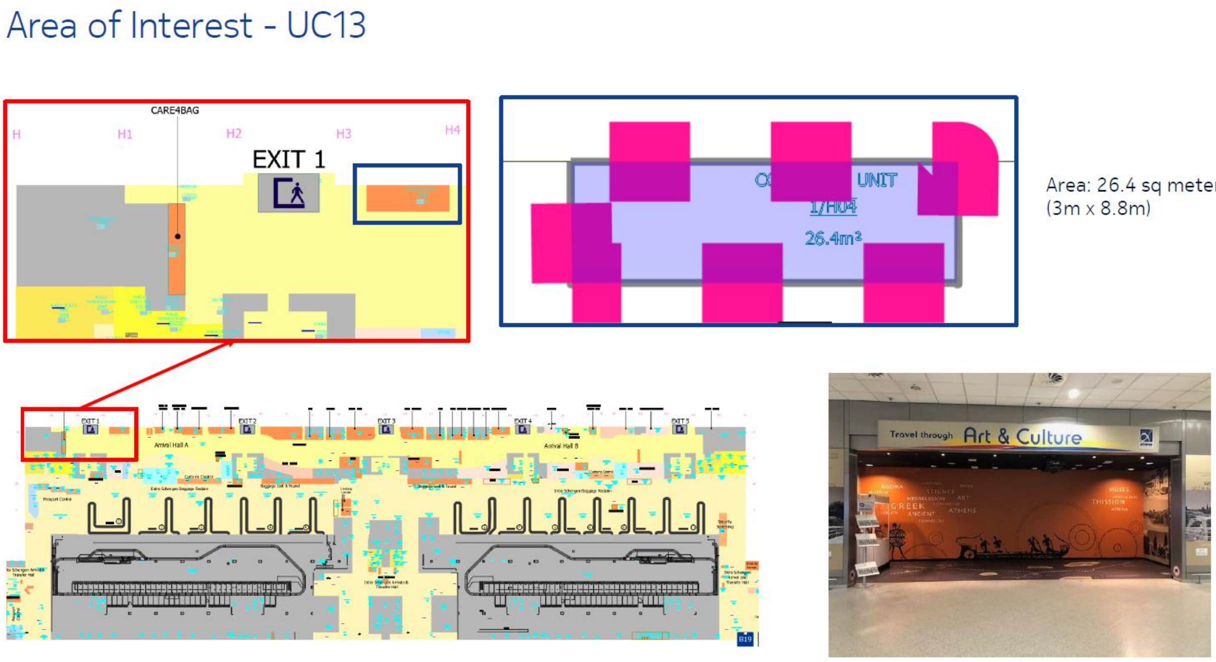


Figure 166. Illustration of the indoor area.

Network deployment for the outdoor scenario (Bus Excursion) is shown in Figure 167:

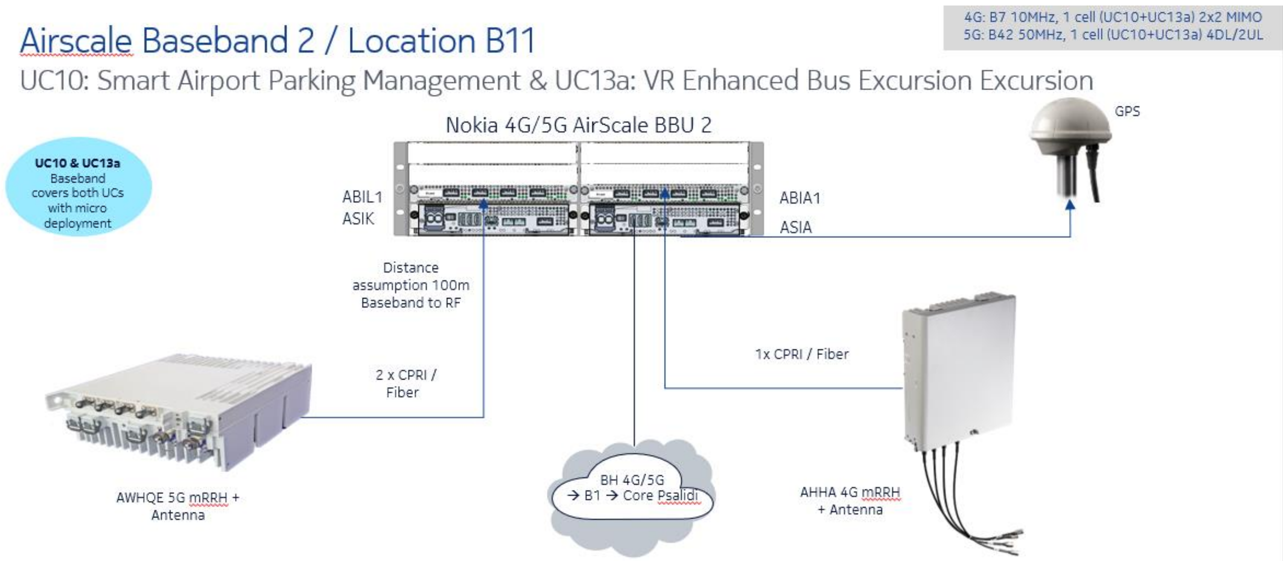


Figure 167. Network deployment for the AR/VR bus excursion use case (outdoor).

An Airscale BBU is placed in the control room of building B11 in AIA (Figure 168). One pair of 4G/5G outdoor antennas is placed on the rooftop of the same building. A backhaul connectivity is established from B11 to the main control room of the airport (Building M2) and from there a 10 Gbit Ethernet connects to Packet Core network.

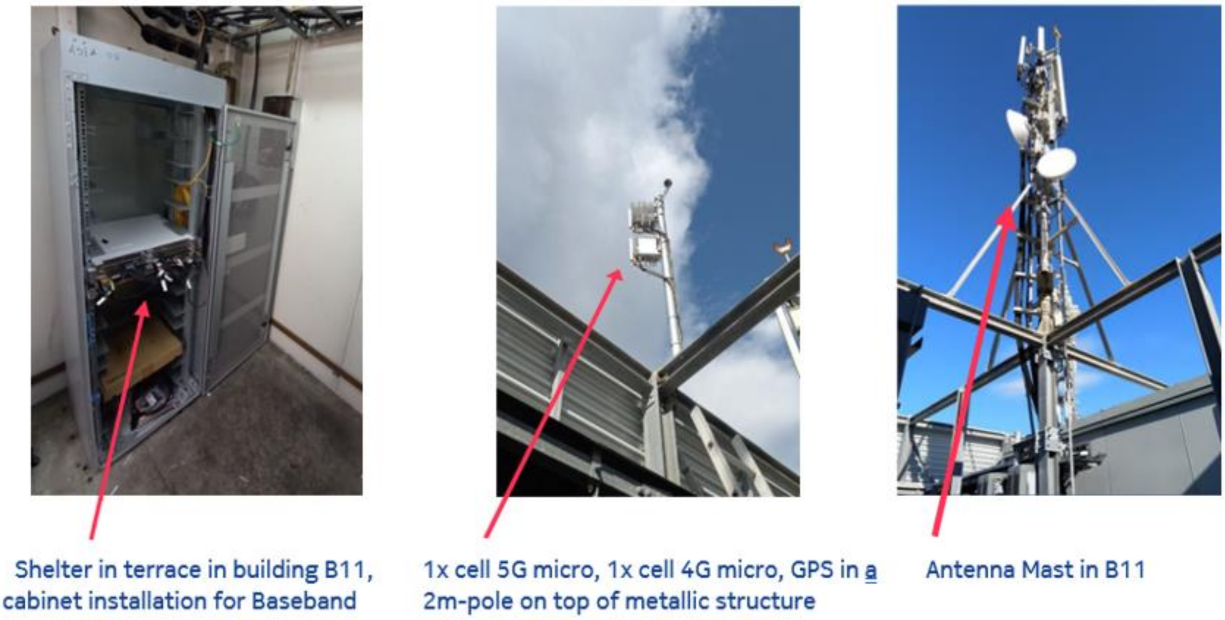


Figure 168. The control room of building B2 & the antenna mast.

For the Core Network of 5G EVE see section 2.2.1.

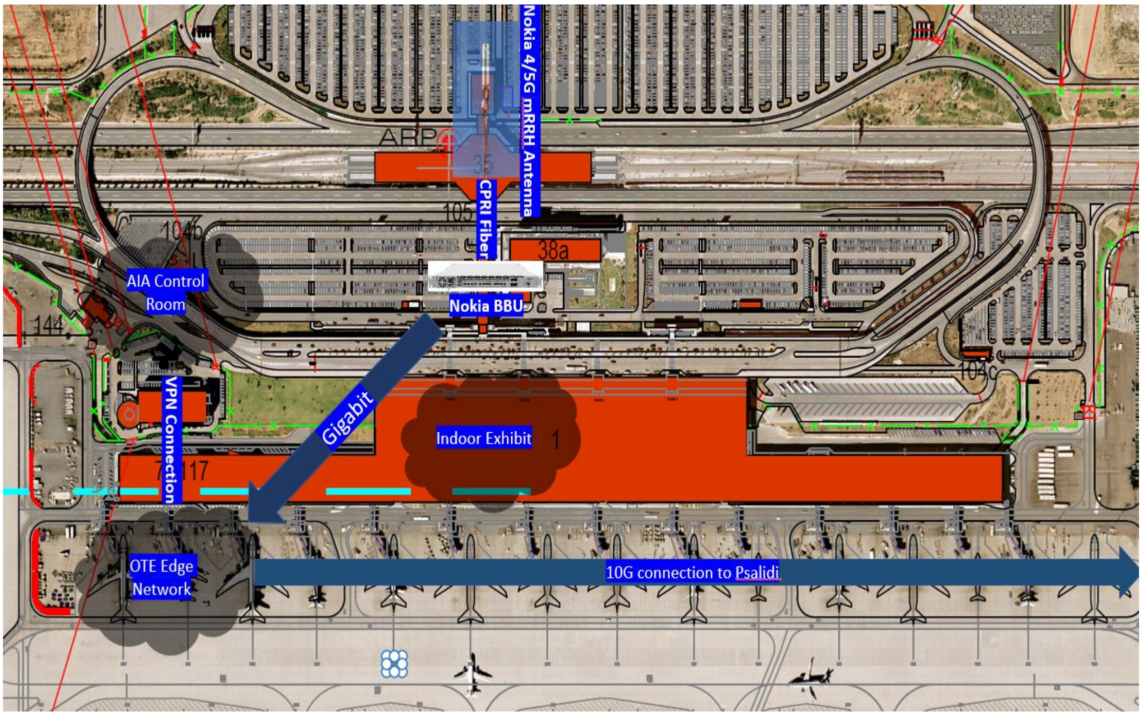


Figure 169. The RAN coverage of AIA for the Myrtis Exhibition use case.

7.2 Network Equipment

7.2.1 Network Equipment for UC10

The proposed solution for the Smart Parking Use Case is a fully 3GPP gNB compliant small cell solution using NOKIA-GR's Flexi Zone platform [6]. Key benefits of the proposed solution are as follows:

- Uniform user experience across the network through tight integration and feature parity[7] with the macro network;
- Total cost of ownership (TCO) benefits due to macro parity, common NetAct [29] OSS with macro, complemented with heterogeneous network features;
- Unrivalled small cell baseband capacity in the market;
- Enabled for evolution to Zone [6] architecture for extremely high small cell cluster capacity and Multi-access Edge Computing (MEC) for local breakout additional services such as augmented reality.

Flexi Zone Small Cell future-proof product family and its most innovative small cell architecture provide new capabilities and versatile approach to address the varying deployment needs and business cases and fulfil the requirements of the UC in terms of density, latency, performance, and throughput.

The solution selected consists of:

Baseband HW[8]:

- AMIA AirScale Subrack
- ASIA Air Scale Common
- ASIK Air Scale Common
- ABIA Air Scale Capacity
- ABIL Air Scale Capacity

RF HW:

- AHHA Air Scale Micro 4T4R B7 20W
- AWHQE Air Scale Micro 4T4R n78 B42 40W

ANCILLARIES:

- FOSP Optical SFP P 1310nm 9.8Gb 10km SM
- FUFBH SM OD fiber LC OD-LC OD dual 100m
- FOTB Optical SFP+ 10GBase-LR 1310nm SM
- FMFA FLEXI MOUNTING KIT FLOOR/WALL/POLE
- AOQA Air Scale Optical QSFP Adapter
- OCTIS Plug Kit DC Power
- OCTIS Plug Kit SFP
- AMBA Air Scale Micro Bracket Assembly Kit

GPS:

- FYMA GPS MOUNTING KIT
- FTSH GPS cable assembly 100m

[7] Tight integration stands for using "only one of anything" component in the 5G network, where feature parity stands for covering the concept of having the exact same functionality as the macro network.

[8] These are Nokia products and information on them can be found in Nokia's site.

- FYGC GNSS Receiver Antenna
- FTSF Sync Cable F

The aforementioned network equipment was deployed in AIA surrounding area (Logical Network View) as highlighted in Figure 170.

Figure 170. RAN coverage of AIA (physical view).

7.2.2 Network Equipment for UC11

The following network equipment was used for Video Enhanced Ground Based Vehicles. It belongs to the same product "family" as the chosen equipment for Smart Parking UC and fulfils all the requirements and needs of the UC.

It consists of:

Baseband HW:

- ABIL AirScale Capacity
- Viavi network performance probes (see Section 2.4.2, 2.4.3)
- 3x MikroTik RBLtAP-2HnD&R11e-LTE Router

RF HW:

- AHHA AirScale Micro 4T4R B7 20W
- AWHQE AirScale Micro 4T4R n78 B42 40W

ANCILLARIES:

- FOSP Optical SFP P 1310nm 9.8Gb 10km SM
- FUFBH SM OD fiber LC OD-LC OD dual 100m
- OCTIS Plug Kit DC Power
- OCTIS Plug Kit SFP
- AMBA AirScale Micro Bracket Assembly Kit

The Network Equipment was deployed in AIA surrounding area (Logical Network View) as Figure 171 highlights.

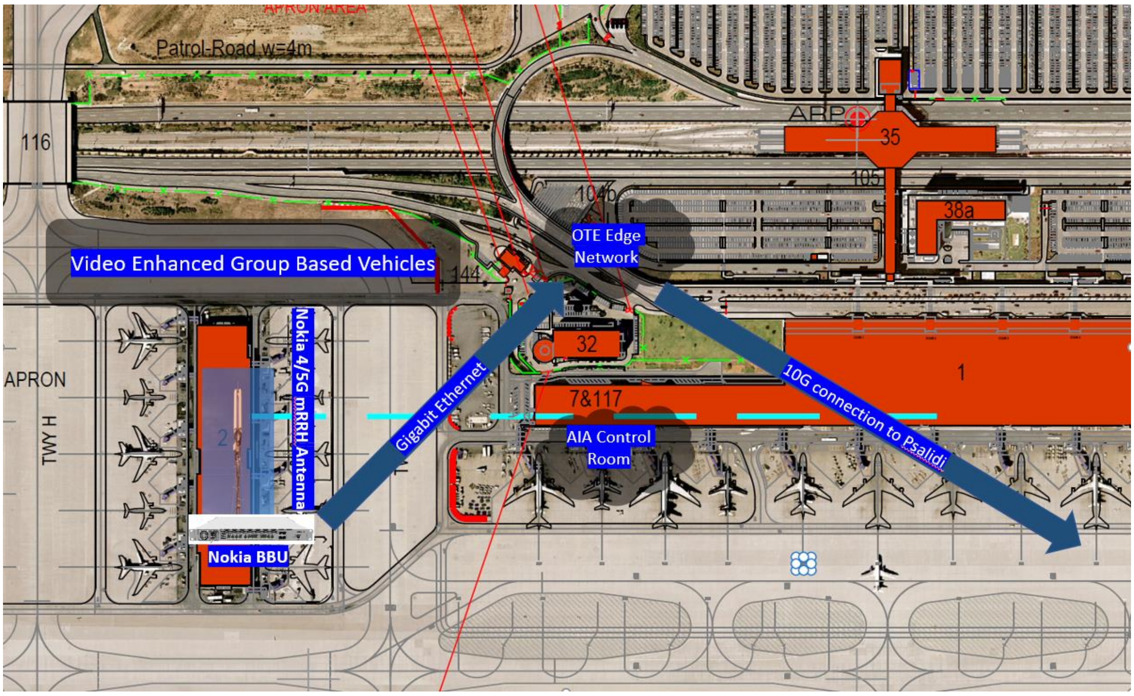


Figure 171. RAN coverage of AIA.

7.2.3 Network Equipment for UC12

The proposed solution for the Airport Evacuation Use Case is a fully 3GPP gNB compliant indoor small cell solution using NOKIA-GR’s Flexi Zone platform. Key benefits of the proposed solution are as follows:

- Centralized flexible architecture enabling graceful 5G insertion.
- Best performance vs. size.
- High capacity.
- Carrier-grade software quality (macro parity).
- Proven plug & play for light touch install.
- Enhanced scaling via SFN.

Flexi Zone Small Cell future-proof product family and its most innovative small cell architecture provide new capabilities and versatile approach to address the varying deployment needs and business cases and fulfil the requirements of the UC in terms of density, latency, reliability, mobility, and throughput.

The solution selected consists of:

Baseband HW:

- AMIA AirScale Subrack
- ASIA AirScale Common
- ASIK AirScale Common
- ABIA AirScale Capacity
- ABIL AirScale Capacity

ASIR HUB:

- APHA ASiR-HUB 12-port

RF HW:

- AHGEHA ASiR-pRRH B1 + B3 + B7
- AWHQE ASiR-pRRH n78 B42

ANCILLARIES:

- FOSO Optical SFP O 1310nm 9.8Gb 1,4km SM
- FUFBG SM OD fiber LC OD-LC OD dual 10m
- FOTB Optical SFP+ 10GBase-LR 1310nm SM
- ASiR Dual port power extender
- FMFA FLEXI MOUNTING KIT FLOOR/WALL/POLE
- AOQA AirScale Optical QSFP Adapter

GPS:

- FYMA GPS MOUNTING KIT
- FTSH GPS cable assembly 100m
- FYGC GNSS Receiver Antenna
- FTSF Sync Cable F

Performance HW:

- Viavi network performance probes (see Section 2.4.2, 2.4.3)

The aforementioned Network Equipment is deployed in AIA surrounding area (Logical Network View) as Figure 172 highlights.

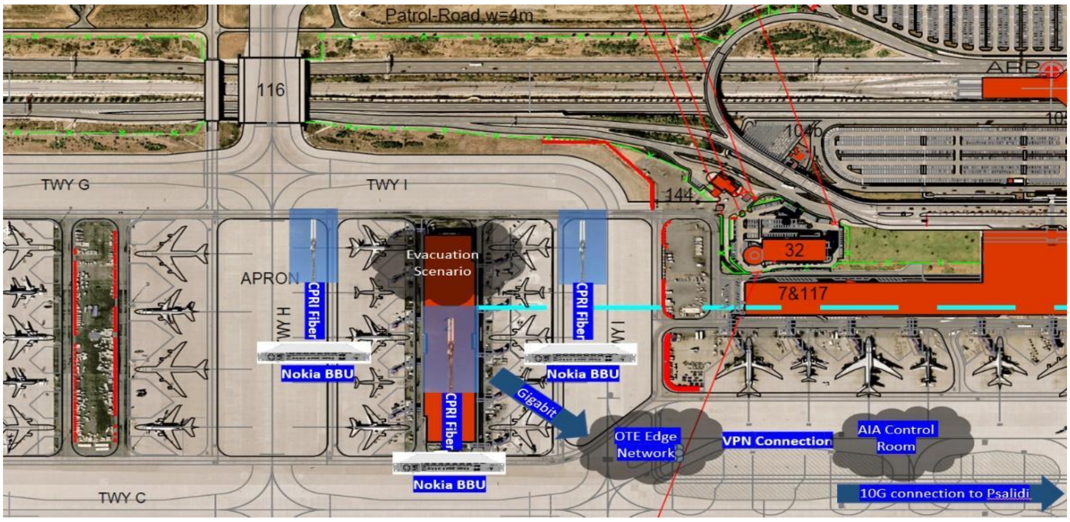


Figure 172. The RAN coverage of AIA.

7.2.4 Network Equipment for UC13

The following network equipment was used for the indoor scenario, Myrtis Exhibition, of the AR/VR bus excursion use case. It belongs to the same product “family” as the chosen equipment for Evacuation UC and fulfils all the requirements and needs of the Use Case:

It consists of:

ASIR HUB:

- APHA ASiR-HUB 12-port

RF HW:

- AHGEHA ASiR-pRRH B1 + B3 + B7
- AWHQE ASiR-pRRH n78 B42

ANCILLARIES:

- FOSO Optical SFP O 1310nm 9.8Gb 1,4km SM
- ASiR Dual port power extender

Network equipment for outdoor scenario of AR/VR bus excursion use case:

RF HW:

- AHHA AirScale Micro 4T4R B7 20W
- AWHQE AirScale Micro 4T4R n78 B42 40W

ANCILLARIES:

- FOSP Optical SFP P 1310nm 9.8Gb 10km SM
- FUFBH SM OD fiber LC OD-LC OD dual 100m
- OCTIS Plug Kit DC Power
- OCTIS Plug Kit SFP
- AMBA AirScale Micro Bracket Assembly Kit

Performance HW:

- Viavi network performance probes (see Section 2.4.2, 2.4.3)

The Network Equipment is deployed in AIA surrounding area (Logical Network View) as the Figure 173 and Figure 169 highlight:

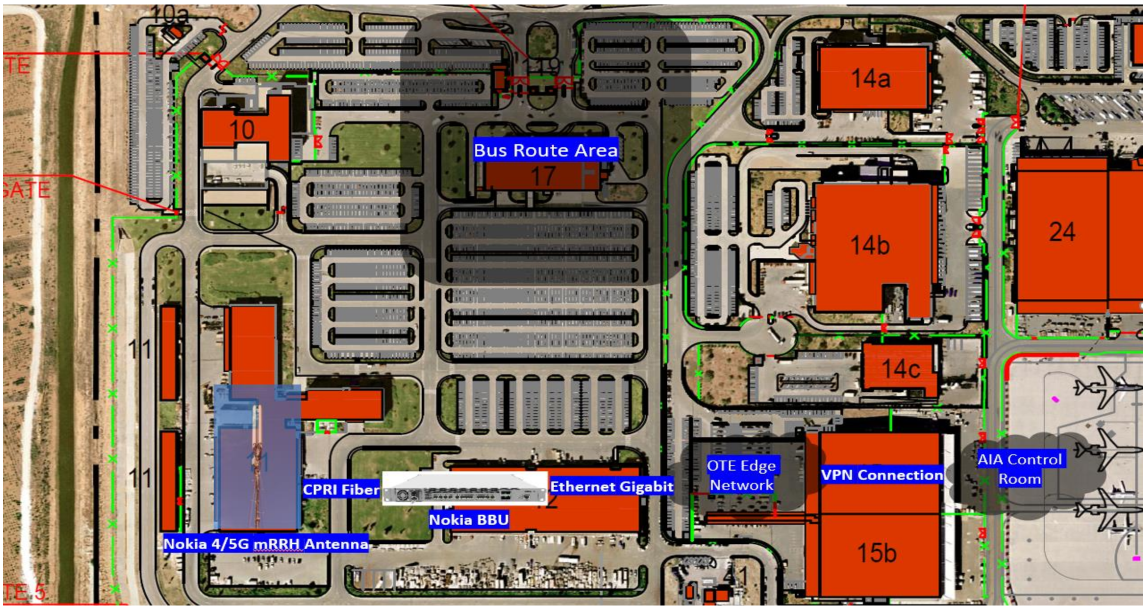


Figure 173. The RAN coverage of AIA for the AR/VR Bus Excursion use case.

7.2.5 Network Performance Monitoring

ACTA have assisted in the network rollout, activation, and UCs trialing, by measuring network KPIs and validating the level of performance achieved. These KPIs comprise of metrics related to the service provided to the end-users (such as latency, data rate, etc.) as well as others related to the operation of the network (such as deployment time and scalability).

ACTA's platform has both the ability to monitor the traffic passing through the network (user traffic) and extracting important KPIs such as bandwidth utilization and transfer speeds per service, as well as active testing (generate test traffic) which is used to measure packet loss, delay and jitter information for selected network paths.

For the needs of the UCs and the corresponding test and trials, OTE as site manager provides all the telecommunication infrastructure at OTE Labs in Psalidi (OTE Academy's facilities) and AIA (data rooms, poles for antenna mounting, racks, switches, routers, etc.) for the implementation of the UC in cooperation with NOKIA-GR, as well as for implementation of KPI validation in cooperation with ACTA. In addition, OTE, for the needs of the interconnection of AIA with Psalidi (5G EVE infrastructure) has established a 10 Gbit line.

7.2.5.1 ACTA Network Probes and Management System

ACTA's implementation is based on both hardware and software probes managed by a dedicated cloud platform. These elements are described in the following sections.

The following Viavi [22] hardware network probes are deployed in key positions in the network (Figure 174).

MTS-5800 Handheld Network Tester

Figure 174. The Viavi M TS-5800 probe.

The Viavi MTS-5800 handheld network tester can test throughout the service life cycle, including, service activation, troubleshooting, and maintenance. Advanced Ethernet test features such as throughput testing with TrueSpeed per RFC 6349 have also been employed.

Fusion JMEP

Figure 175. Viavi SFP network probe.

The VIAVI JMEP micro Ethernet probe for Ethernet and IP performance assurance, are gigabit Ethernet smart SFP transceivers, available in two varieties, a 1 Gbps JMEP3 and a 10 Gbps JMEP10, that both can seamlessly be deployed inline into existing network devices. The SFP main capabilities are:

- Fully compatible with RFC 2544 and Y.1564 test methodologies
- Activates test loopbacks (L2/L3)
- TWAMP-Light (RFC 5357)
- Measures throughput, availability, frame loss, frame delay, and frame delay variation.

These probes are being complemented with SW based measurements and virtual probes that reside in the ACTA KMVaP cloud platform, described in the following section.

The KMVaP is the central management system for the multitude of probes that are installed in the network and are responsible for collecting data from measurements of network KPIs. These additional probes include (and are not limited to):

Fusion TrueSpeed VNF

Throughput testing as a virtual network function based on RFC 6349.

Based on the IETF RFC 6349 TCP throughput testing methodology, Fusion TrueSpeed VNF performance tests serve as a neutral 3rd-party evaluation of network quality. Operating as a virtual network function (VNF) in conjunction with VMware hypervisors, Red Hat Linux, and x86 compute resources, Fusion TrueSpeed VNF deploys quickly and tests reliably in all parts of the network.

VCPE1 Software based probe

The hardware of VCPE1 probe consist of a SUPERMICRO SERVER 5019D-4C-FN8TP
CPU: INTEL SoC Intel® Xeon® processor D-2123IT, 4-Core, 8 Threads, 60W
RAM: 16GB DDR4-2666 2Rx8 ECC REG DIMM
DISK DRIVE: Samsung PM883 240GB SATA 6Gb/s V4 TLC 2.5" 7mm (1.3 DWPD

Figure 176. The Virtual CPE/ Software Probe hardware used in the KMVaP platform.

Being a virtual software probe, a VCPE can host a number of different probe functionalities tailored to the measurements required by the network operator and/or Vertical user. Here we have:

-vPMA : Performance Monitoring Probes

-vTA: Testing Probes, employing the TWAMP sw, which is explained in the coming sections.

The network probes and their measurements are managed via ACTA's in-house developed KPI Measurement and Validation Platform (KMVaP). The interconnection of the platform with OTE's LAB infrastructure is shown in Figure 177 together with the Public IP address that is used for Remote Management, Remote Configuration and Access to the collected data by third parties.

For security and full redundancy, the platform can also accommodate interconnection, access and remote management and configuration using a 4G/LTE router connected to the PFsense [24] Firewall/proxy/gateway. Due to the interconnection of the KMVaP with Data Plane of the Pilot 5G TOURS Network as well as the public internet, the use of a Firewall for both secure remote access and configuration, and for public access to the gathered data/measurements the use of Pfsense is considered essential.

The overall placement of the KMVaP platform and the probes is shown in Figure 177.

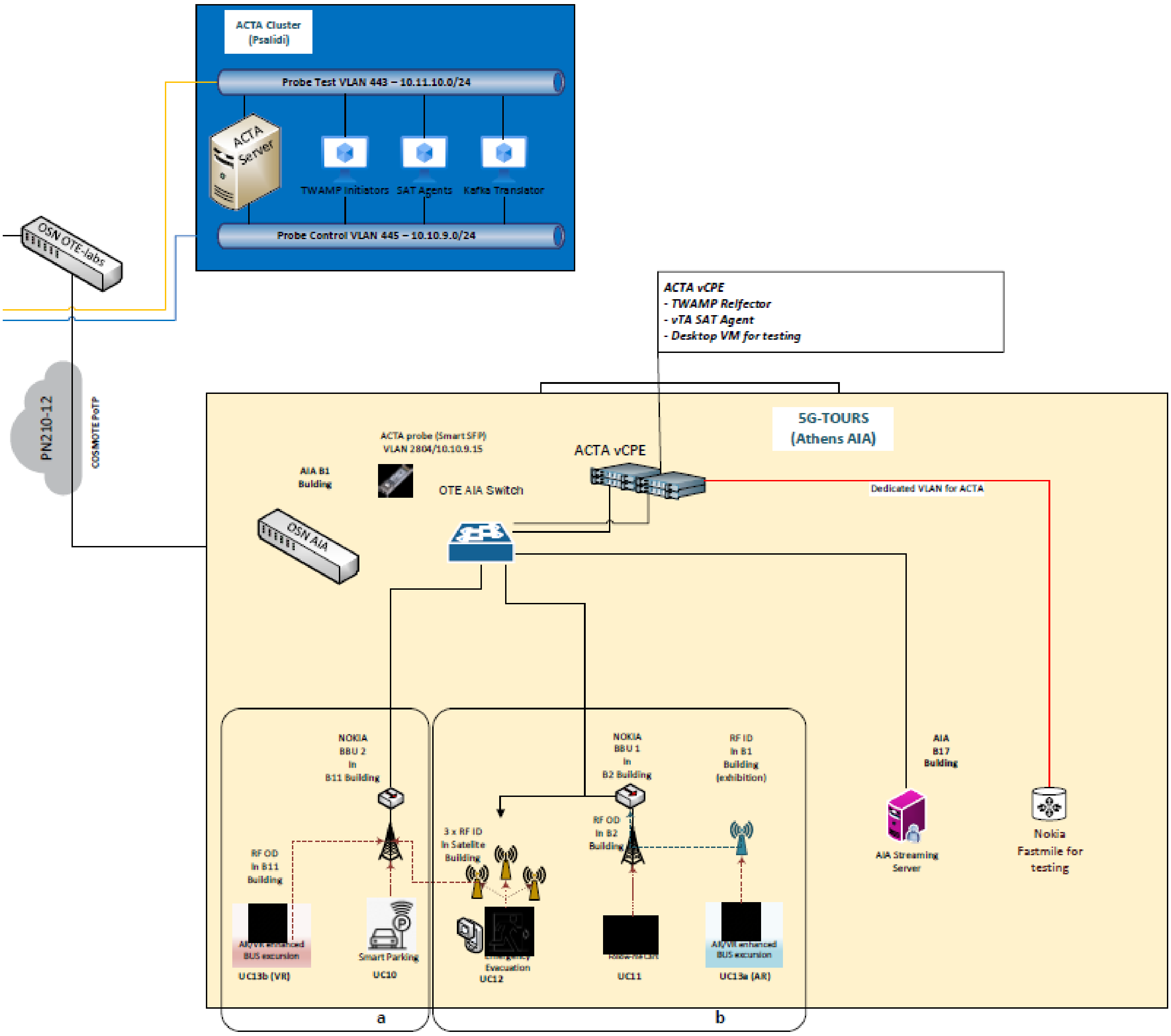


Figure 177. Overall network architecture of ACTA KMVaP network interconnections.

The actual ACTA installation at OTE Labs and AIA, can be seen in the photos of Figure 178 below.

Figure 178. ACTA's KMVaP ecosystem at OTE Labs and probes at AIA.

The internal Architecture of the KMVaP (KPI measurement and validation platform) that is installed in OTE-group R&D Laboratories is shown in Figure 179 below.

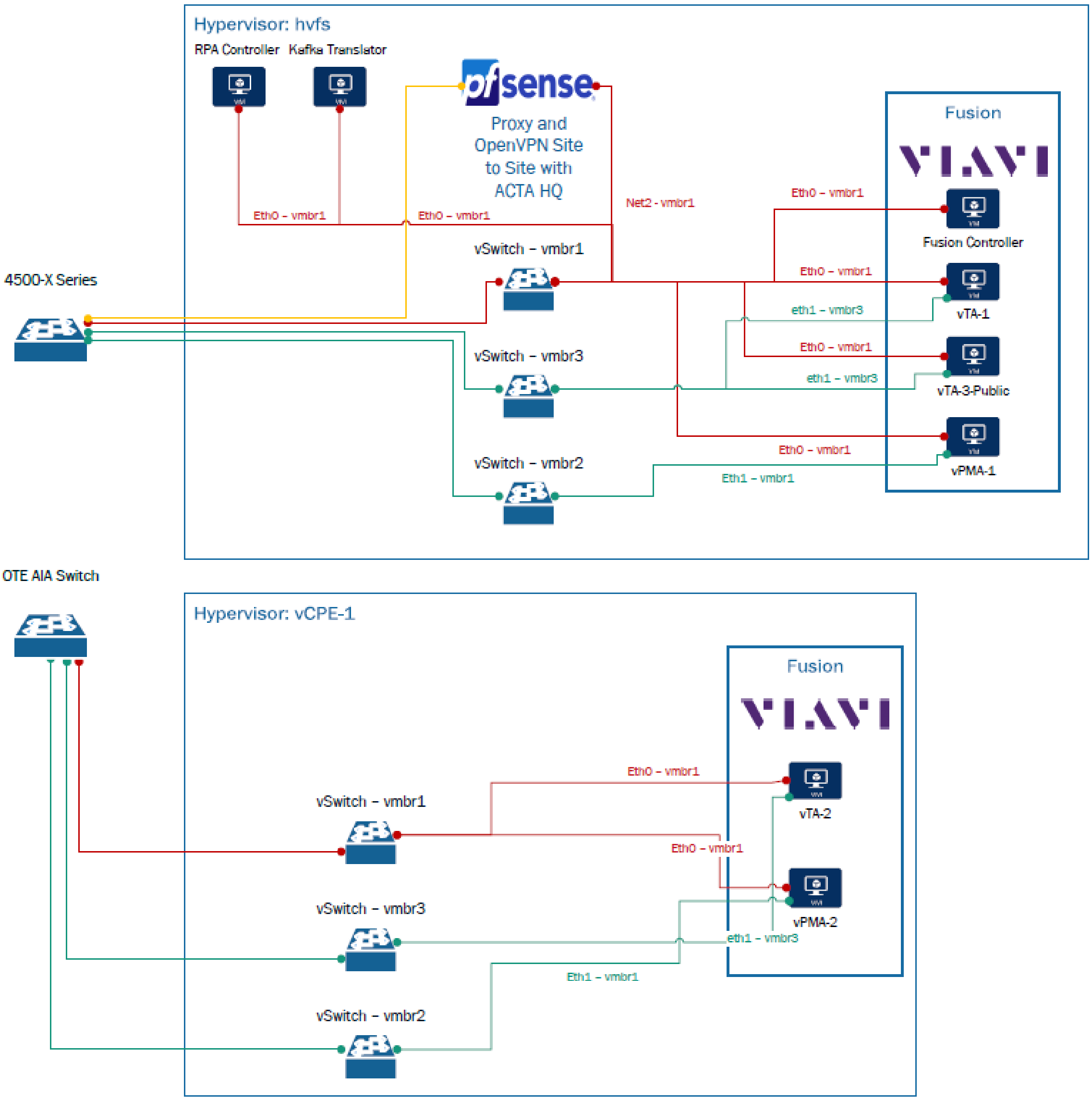


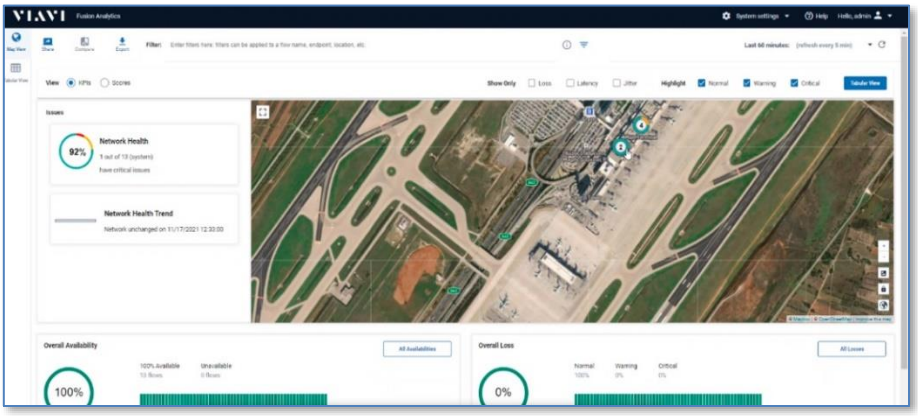
Figure 179. ACTA's KMVaP ecosystem for KPI measurement and validation.

The core part of the KMVaP cental management system is based on VIAVI's Network Integrated Test, Real-time analytics and Optimization (NITRO) platform. This is augmented by open source components and ACTA developed software in order to become a complete KPI validation system.

All the components of the KMVaP platform are Virtual Machines using a VM Hypervisor (hvfs). A hypervisor [25] (or virtual machine monitor, VMM, virtualizer) is computer software, firmware and hardware that creates and runs virtual machines. A computer on which a hypervisor runs one or more virtual machines is called a host machine, and each virtual machine is called a guest machine. The hypervisor presents the guest operating systems with a virtual operating platform and manages the execution of the guest operating systems. Multiple instances of a variety of operating systems may share the virtualized hardware resources: for example, Linux, Windows, and macOS instances can all run on a single physical x86 machine. This contrasts with operating-system-level virtualization, where all instances (usually called containers) must share a single kernel, though the guest operating systems can differ in user space, such as different Linux distributions with the same kernel.

A KAFKA interface is enabled in the the KMVaP management Platform that is delivering the measurements in real-time to the KAFKA topic defined in the KAFKA server with IP address 10.10.10.2 (shown in Figure 49 above). With the translation of the measurement data from the ACTA VIAVI Fusion Kafka topics format to the 5G-EVE KAFKA topic format, we achieve to use the 5G-EVE environment Analysis and Diagnosis software components developed by WINGS. Also, the EVE KAFKA s/w modules are used by many Projects. The collection of data is an automated process running 24x7, with 1min monitoring granularity and 10 ms sampling granularity.

Typical views are shown in the images of Figure 180 below that allow the operator to monitor in real time the progression of the selected KPIs along the selected flows (network segments). Certain thresholds can be set to allow for cockpit view of KPIs, in accordance to the 5G TOURS specified performance targets.



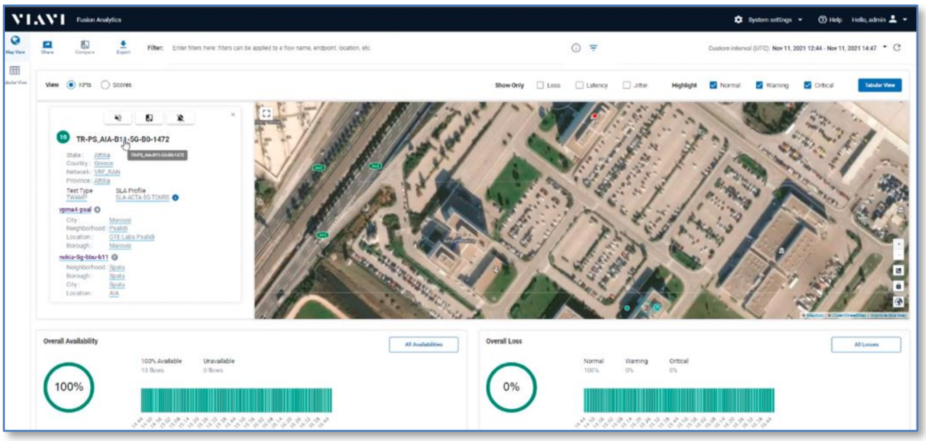


Figure 180. ACTA KMVaP User Views for Performance Management

7.2.5.2 Probes network topology and KPI extraction methodology

The schematic topology diagram of the KPI measurement probes and server for control and data collection and analysis is shown in Figure 51 below. The blue probes are HW based while the green ones are SW based and closer to the end-user and the Service Delivery Platforms.

One probe is connected via Ethernet through configuration between the NOKIA-GR's Airscale BBU and the Backhaul of the telecom network at the AIA, as shown in Figure 181. A second probe is installed via Ethernet through configuration at the Backhaul of the telecom network in the OTE labs.

The NOKIA-GR BBUs are installed in the Athens International Airport (AIA). They also act as TWAMP reflectors. The Backhaul network equipment is installed in the control room of building M2 of AIA. The Nokia Packet Core network is in OTE labs. The large amount of network KPI data were analyzed and presented in a user-friendly format, to identify possible weak points of the network which indicate the need to undertake corrective action for optimization and performance improvement. During the setup and verification phases, the results of the measurements allowed the team to fine-tune various network parameters that led us to maximise the stability and performance under the given network configuration.

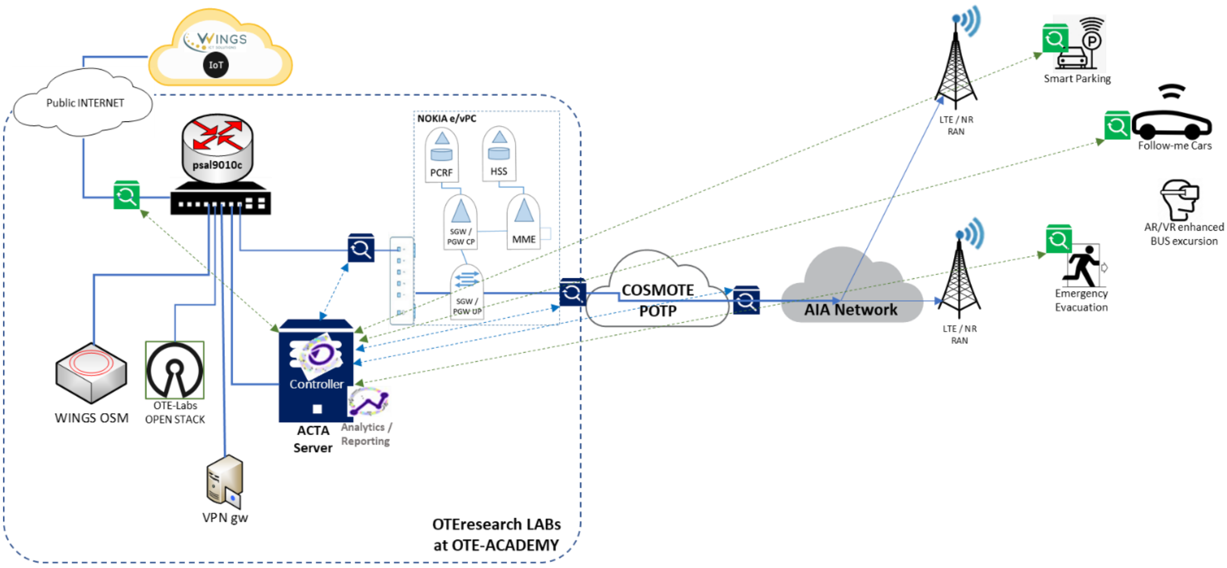


Figure 181. Overall network topology for the Athens 5G-TOURS site together with the KPI probes and server.

The proper placement of the probes allows for network segmentation measurements. Figure 182 is a schematic presentation of the flows monitored.

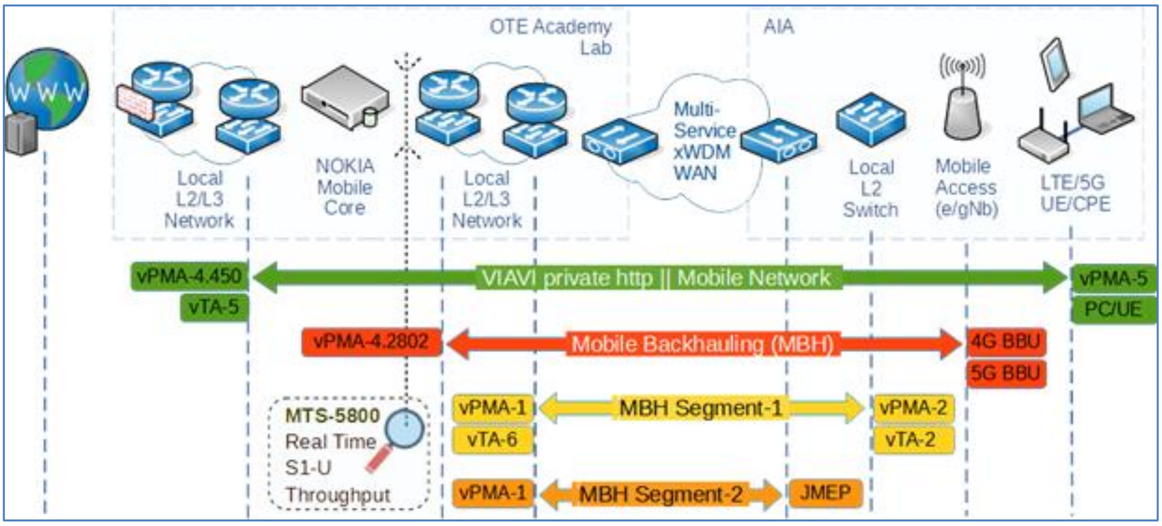


Figure 182. Probes and Endpoints/Network Segmentation for the Athens 5G-TOURS network.

The KPIs measured for the 5G TOURS UCs, are:

- Throughput – real time (mainly relevant for the BW demanding UCs)
- Max Sustainable Throughput (Attainable Bitrates UDP/TCP)
- Latency end-to-end (Min/Max/1-min-Average)
- RAN latency (approximately through deduction of metrics between e2e and backhauling segments)
- Jitter (Min/Max/1-min-Average)
- Packet Loss (Min/Max/1-min-Average)
- Availability
- Reliability

<u>Throughput (probe-based measurements)</u>

- The Throughput is bidirectional:
    a) From the end-point to the App Server (mainly video and voice traffic)
    b) From the App Server to the end-point (mainly control and voice traffic)
- The sustainable Throughput between the end-user (e.g. camera inside the vehicle) and the NOKIA's ePC (located at OTE-labs premises can be monitored)
- The probes can provide information about the traffic throughput that corresponds to the E2E of the network (COSMOTE Core IP network, AIA, network, etc.)

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

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

Availability (network layer)

Network availability measures the amount of uptime in a network system over a given time period, according to [31]. Uptime refers to the amount of time a network is fully operational. Network availability is measured as a percentage and is monitored to ensure that the service being offered continues to operate for end-users (= Uptime/ (Uptime + Downtime) x 100%). It is, however, difficult to measure it in some use cases since it requires large operational times. Therefore, in 5G TOURS, availability is calculated as the percentage of Network layer packets successfully delivered out of all Network layer packets sent.

Reliability (network layer)

Network reliability is defined as likelihood of a failure occurring in a system, again according to [31]. In this case, reliability tracks how long a network's infrastructure is functional without interruption where in a fully reliable system has 100% availability. Again, network reliability requires large operational times. In cases of small or medium operational times, network reliability can be estimated using analytical calculations of the reliability of each network component.

In 5G TOURS, network reliability is calculated, as the percentage of Network layer packets successfully delivered within the predefined Network layer KPI limits (e.g. latency and/or jitter) out of all Network layer packets sent. ACTA KMVaP system calculates these values automatically, given that the KPI thresholds are properly configured in the monitoring system (SLA definition). Table 7 below summarizes the protocols and KPIs that are monitored.

Table 7. Summary of network protocols and KPIs.

Type	Probe type	Direction	KPI L2/L3	KPI L4
SAT - RFC2544 - Y.1564	MTS 5800	Bidirectional		Service Activation Testing
			Throughput	peak throughput
			Latency	Latency
			packet loss	packet loss
				Availability
PM - TWAMP - RFC5357	SFP & Virtual	Bidirectional		
			Latency	
			packet loss	
			Delay variation (jitter)	
WireSpeed - RFC6349 (TrueSpeed)	MTS 5800 & Virtual	Bidirectional		peak throughput (TCP)

The use of the improved TWAMP protocol provides better accuracy compared to the widely used ICMP [19][20][21] for the active measurements.

For time related KPI measurements like latency (one-way or round-trip), jitter, etc. it is very common to use ICMP based packet (most commonly referred to as PING). This is mostly a connectivity tool when the network infrastructure is being established or a new node is installed and configured. For more accurate time measurements, the Two-Way-Active-Measurement Protocol (TWAMP) is more appropriate. The TWAMP protocol is used by Network equipment manufacturers (Cisco, Nokia, Huawei, Ericsson, Juniper etc.). The official RFC5357 can be found in the IETF repository here [23]

A brief table overview of the comparison between PING and TWAMP is show in Table 8 below.

Table 8. TWAMP vs. PING comparison for time based measurements.

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

The TWAMP protocol was implemented in conjunction with the NOKIA Fast Mile UE, which through its Ethernet ports was connected to the ACTA TWAMP servers installed at AIA premise (OTE equipment room) (Figure 164).

Nokia Fast Mile 5G Gateway is a 5G high gain antenna with innovative design, automated alignment 5G speeds and Wi-Fi coverage. The radio is dual band, 802.11b/g/n 3x3 2.4 Ghz and 802.11ac 4x4 5GHz.It has cellular WAN and the following connectivity interfaces Wi-Fi, three RJ-45 GigE LAN ports and USB 3.0 Type A port (Figure 183).

Figure 183. Nokia Fast Mile 5G Gateway.

The use of real-time network and service KPI acquisition, together with the subsequent analysis of the measurements, allows for pre-emptive resolution of network and service delivery issues. **This approach together with the AI based Orchestration for network resources is part of the innovation(s) suggested for the 5G-TOURS project implementation. (Section 7.3).**

7.2.5.3 Backhaul (Transport) Network Measurement Results

The probes measuring the backhaul traffic between AIA and OTE Labs can provide Throughput and the Frame Loss Rate for the network between AIA OSN and OTE Labs OSN (10Gbps optical backhaul network). (Cosmote POTP cloud in Figure 51). These are "turn up" (acceptance) type of measurements, according to ITU-T protocol Y1564. Figures 52 & 53 below show the test configuration and the measurement results.

Test Configuration

Test Point A

Name PSALIDI-MTS5800 Version: 1.0	Management Address 10.11.10.116	Management Port 0
Test Address 10.10.9.18	Test Subnet Mask 255.255.255.0	Test Gateway 10.10.9.254

Test Point B

Name AIA-MTS5800 Version: 1.0	Management Address 10.10.10.55	Management Port 0
Test Address 10.10.9.17	Test Subnet Mask 255.255.255.0	Test Gateway 10.10.9.254

Test Setup

Test Mode Concurrent Bidirectional	Layer to Test Layer 3	Suppress Loop Commands false
Stream Rate Convention L1 Mbps (ULR)	Service Configuration Test Enabled	Steps 25% 50% 75% 100%
Step Duration 10 seconds	Service Performance Test Enabled	Performance Test Duration (HH:MM:SS) 00:15:00

Figure 184. End Points for OTE – AIA backhaul Measurements.

As shown below, we achieve 1 – 1.5 Gbps per stream and when the link was loaded with 9 streams the nominal capacity of 10 Gbps was reached. The Frame Loss rose to around 2,3% because of the attempted excess in throughput with all streams in parallel.

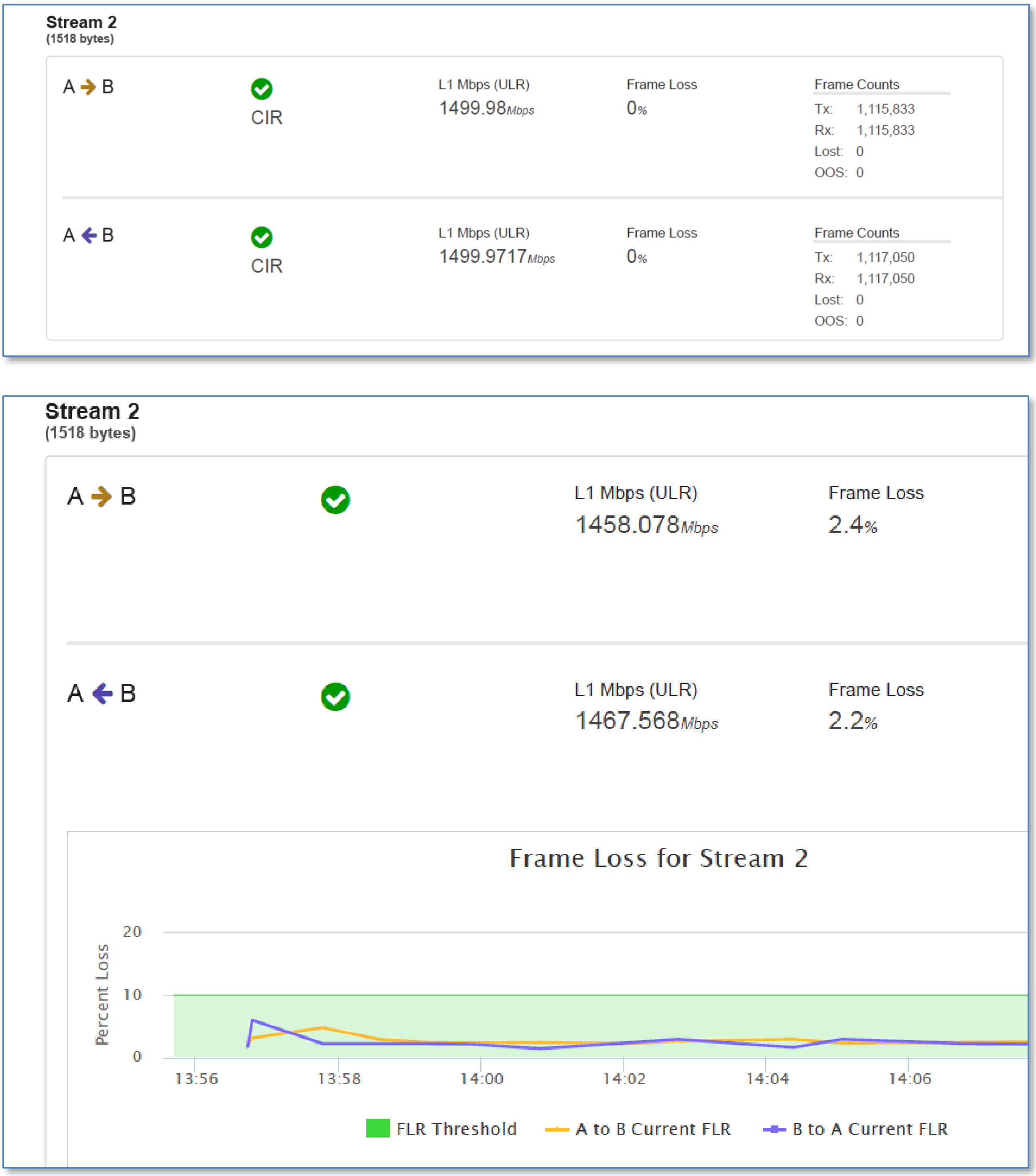


Figure 185. OTE Labs – AIA backhaul metrics.

Furthermore, the maximum sustainable TCP Throughput for the mobile backhauling segment, between OTE Labs switch and AIA Switch (1 Gbps capacity), is measured at 930 Mbps, very close to the theoretical maximum as can be seen in Figure 186 below:

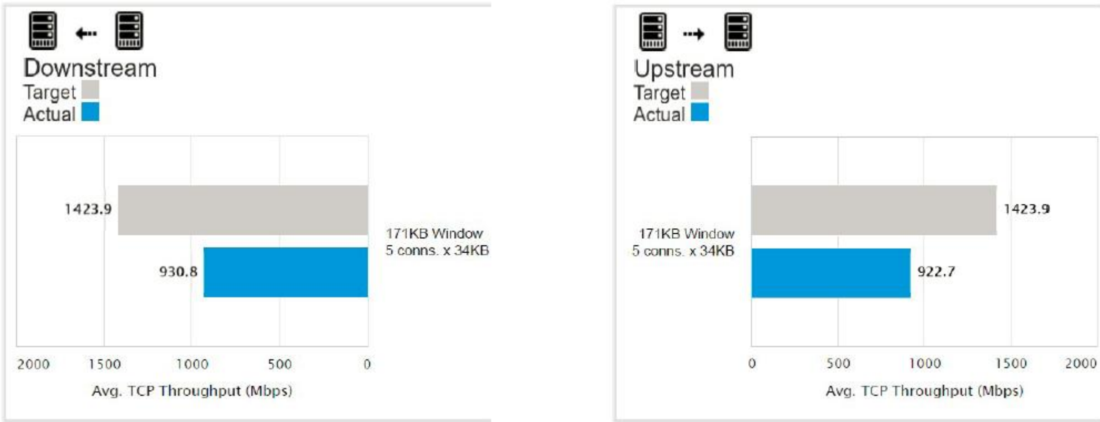
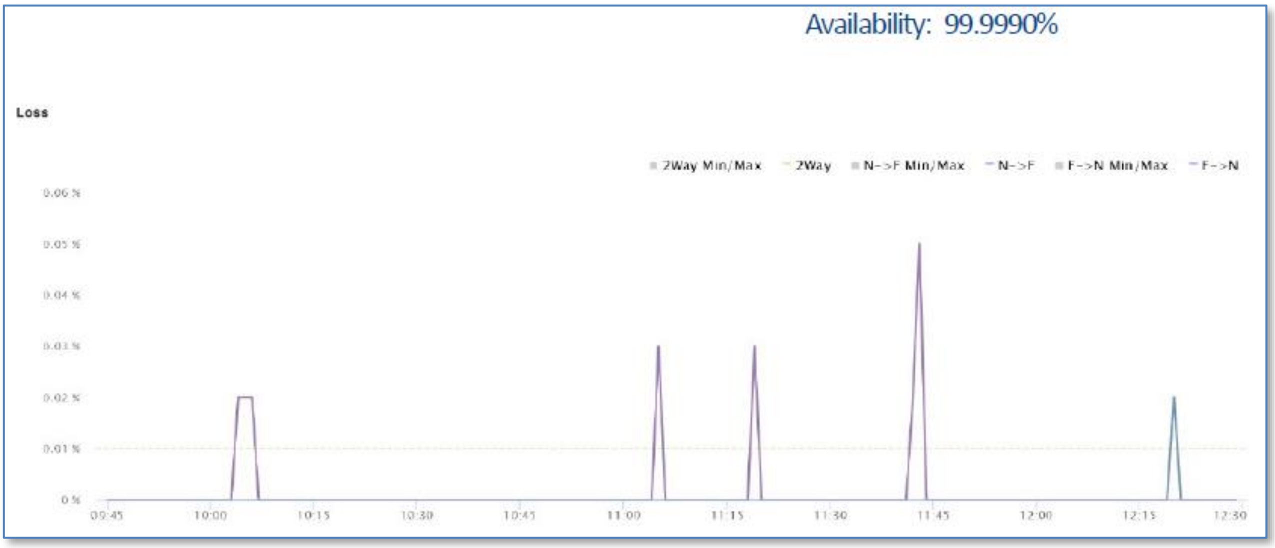


Figure 186. OTE Labs – AIA switch maximum sustainable throughput.

The L2/L3 KPIs of the backhaul network (Loss, Latency, Jitter) and the corresponding Availability & Reliability metrics can be seen in the figures below. Loss is max 0,05%, latency 0,9 ms and jitter 50 µs! Availability and Reliability stay with confidence at 99,999 %.



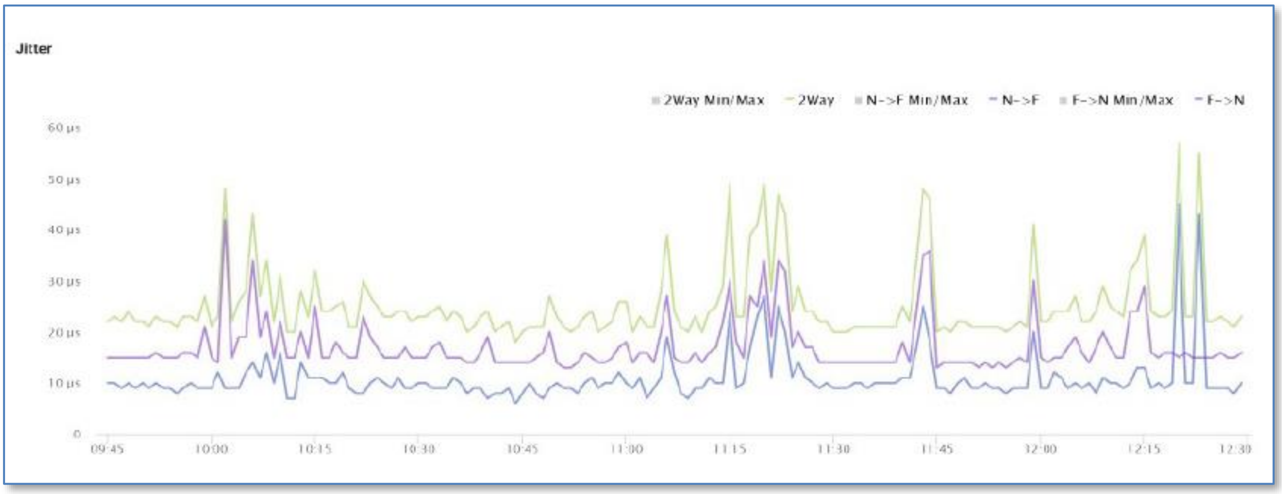


Figure 187. OTE Labs – AIA switch transport network KPIs.

7.2.6 Radio Network RF Measurement Results

In addition to the Network Performance Measurements, ACTA provided VIAVI ONA 800 RF measurement equipment which was used together with NOKIA and AIA to identify and resolve coverage and interference issues in the AIA outdoor and indoor areas (Figure 188).

Figure 188. RF Measurements at AIA.

Measurements were taken in April, September and December 2021, following reconfigurations of the network. Sample graphs are shown in Fig. 184. The main results were:

- ✓ the elimination of a timing error,
- ✓ and the reduction of the available 5G spectrum from 100 MHz to 50 MHz within the 3450-3500 MHz band (to avoid interference from commercial 5G networks in the area).

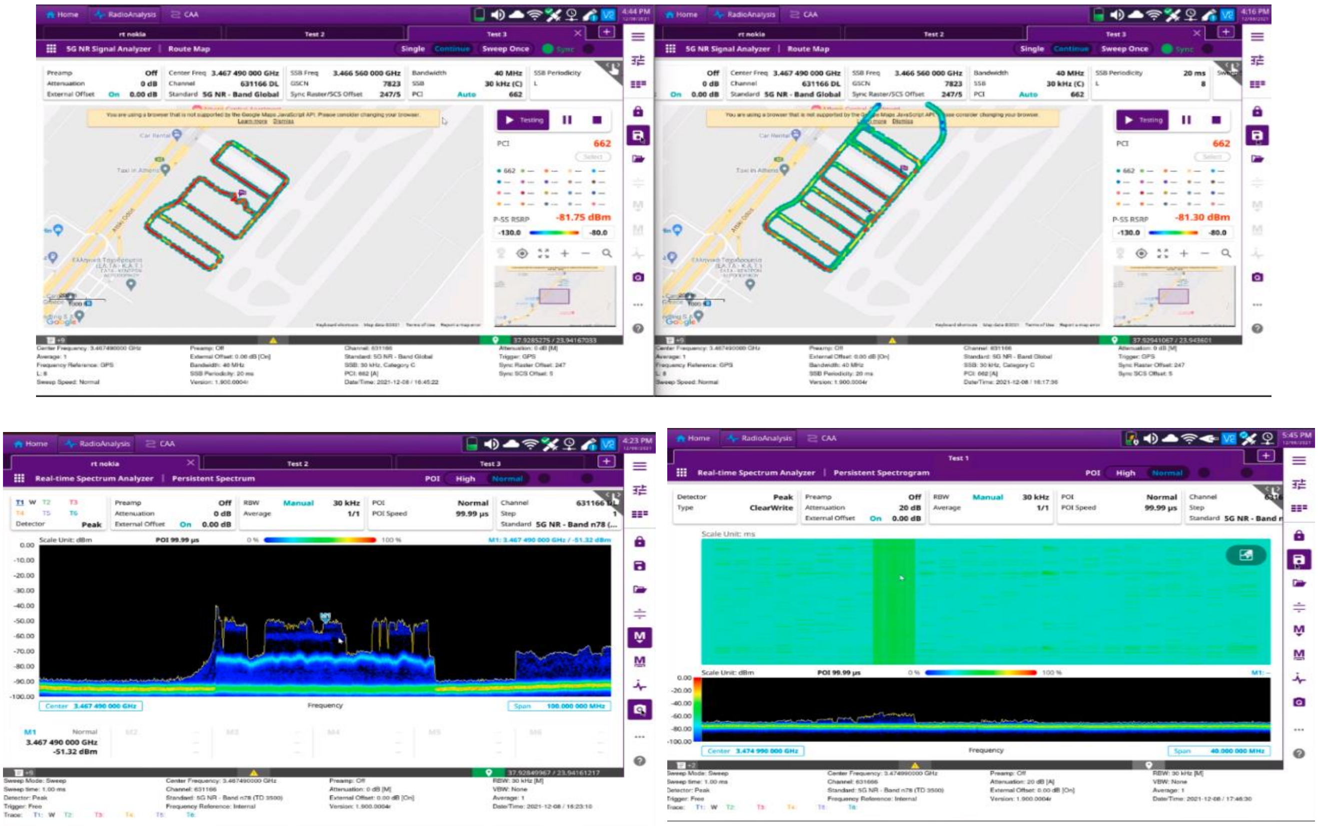


Figure 189. Coverage and Interference Measurements at AIA.

7.3 Network and Application Innovations Aspects

The 5G-TOURS architecture provides an improved responsiveness for real-time consumer applications and provide 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 applications 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 deployed 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 technology used in the use cases of the Greek node is orchestration.

Table 9. WP6 UCs mapping (use of blueprints in phase 2).

UC	Phase 1				Phase 2				
WP6	**Reference Network**	**Service Accessibility**	**Objectives**	**Availability target dates**	**Reference Network**	**Service Accessibility**	**Objectives**	**PoC/Additional development**	**Availability target dates**
UC10	Outdoor extended 5G EVE NOKIA-GR / OTE infrastructure	Direct request*	Obj1	MS3[9] (31/03/2021)	Outdoor extended 5G EVE NOKIA-GR / OTE infrastructure	5G EVE portal / Direct request	Obj1+ Obj2	Addition of AI-based intelligence in the Greek site orchestrator	MS5[10] (31/3/2022)
UC11	Outdoor extended 5G EVE NOKIA-GR / OTE infrastructure	Direct request*	Obj1	MS3 (31/03/2021)	Outdoor extended 5G EVE NOKIA-GR / OTE infrastructure	Direct request*	Obj1	Real-time KPIs measurements and validation using probes	MS5 (31/3/2022)
UC12	Indoor extended 5G EVE NOKIA-GR / OTE infrastructure	Direct request*	Obj1	MS3 (31/03/2021)	Indoor extended 5G EVE NOKIA-GR / OTE infrastructure	5G EVE portal / Direct request	Obj1+ Obj2	Addition of AI-based intelligence in the Greek site orchestrator	MS5 (31/3/2022)
UC13	Indoor extended 5G EVE NOKIA-GR / OTE infrastructure	Direct request*	Obj1	MS3 (31/03/2021)	Indoor extended 5G EVE NOKIA-GR / OTE infrastructure	Direct request*	Obj1	Real-time KPIs measurements and validation using probes	MS5 (31/3/2022)

* Portal usage is not precluded
Obj1: Validate the need of 5G networks
Obj2: Demonstrate the benefits of 5G-TOURS innovations

For the implementation of the four Athens node UCs the existing infrastructure of 5G EVE Greek site with the OTE-NOKIA-GR's vEPC is used with an extension of NOKIA-GR's antennas and BBUs at the AIA facilities. This implementation followed two phases. During the first phase, the start/stop or enable of the Smart Parking service was run with direct connection to the 5G EVE infrastructure at Psalidi (5G EVE Greek site). During the second phase the start/stop or enable of the service was run using blueprints and the Portal of 5G EVE (see Table 9).

According to Table 9 only two of the mobility efficient city UCs was run using blueprints in a Phase 2. UC10 and UC12.

According to Table 10:

- UC10 (mMTC and eMBB) requires a very high accuracy and a very low latency.
- UC11 (eMBB) requires a very large throughput and a very high reliability level.
- UC12 (URLLC) requires a very high accuracy for the location of the end-users as well as a very high level of reliability.
- UC13 (eMBB) requires a large throughput and a very low latency. Moreover, edge computing technology may be leveraged to bring the AR/VR server close to the end-users.

Table 10. Service types/slices for mobility efficient city UCs.

Areas	Use cases	URLLC	mMTC	eMBB
	Smart airport parking management		X	X

[9] MS3: Use case first implementation tested on initial network infrastructure
[10] MS5: Final implementation of all UCs, updates, optimization in infrastructure and use cases

Mobility-efficient city	Video enhanced ground-based moving vehicles			X
	Emergency airport evacuation	X		
	AR/VR enhanced bus excursion			X

The Athens node innovation comprises of two parts (see Table 11):

- To implement Real-time KPI measurements and feeding the measurement values to Kafka
- To add smartness AI-enhanced MANO to OSM (5G EVE orchestrator) and a diagnostics module for taking the Kafka measurements to dynamically control reallocation of the resources for the running applications.

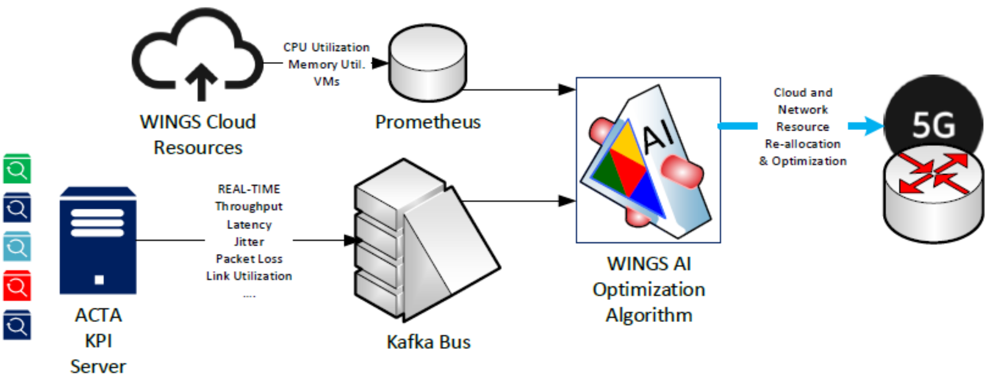


Figure 190. 5G-TOURS network innovations high level view (ACTA KPI measurements server and Kafka bus).

The following table describes the two parts of the Athens node innovations:

Table 11. 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, was 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).

In more details the following paragraphs describe the content of Table 11 and what exactly is implemented as innovation for the needs of 5G-TOURS Athens node.

AI-enhanced MANO (Orchestration)

The motivation for the development of this innovations is based on the fact that the configuration for deployment of network functions and applications is fixed for the whole lifecycle. In addition, changes in deployment of a network function or applications are difficult, time consuming and cause excessive expenditures or service outages. Many times, the information about the availability of resources in the infrastructure is not known, while the metrics from applications, VNFs, infrastructure are not considered after the deployment of a service.

In this direction, the proposed solutions target automated operations such as deciding the deployment location of a NS and resource utilization in a highly heterogeneous cloud infrastructure. In addition, during the service operation, is enabled: a) real-time monitoring and collection of various metrics for multiple attribute decision making; b) automated and optimized network resource utilization, monitoring of SLA under 5G networks and c) automated and optimized network resource utilization, monitoring of SLA under 5G networks.

Figure 191 illustrates the steps and processes that the AI-enhanced MANO component is able to retrieve metrics from MECs, VNFs in real time and evaluate them in order to make any migration decisions. Some of the steps are:

1. NS, VNF unique IDs and other critical info is exported from the OSM and fed to the AI module.
2. The AI component triggers the metrics exporters/ shippers of the MEC platform and the MEC's VNF instances, to evaluate the metrics in real time
3. The metrics (network metrics, MEC metrics, VNF metrics) are shipped to the Kafka broker
4. The collected metrics are then pushed to the Elastic Search platform using Logstash. The Diagnostic component gets the metrics data from the Elastic Search module.
5. The Diagnostics component communicates with the AI component to provide the diagnosis results.

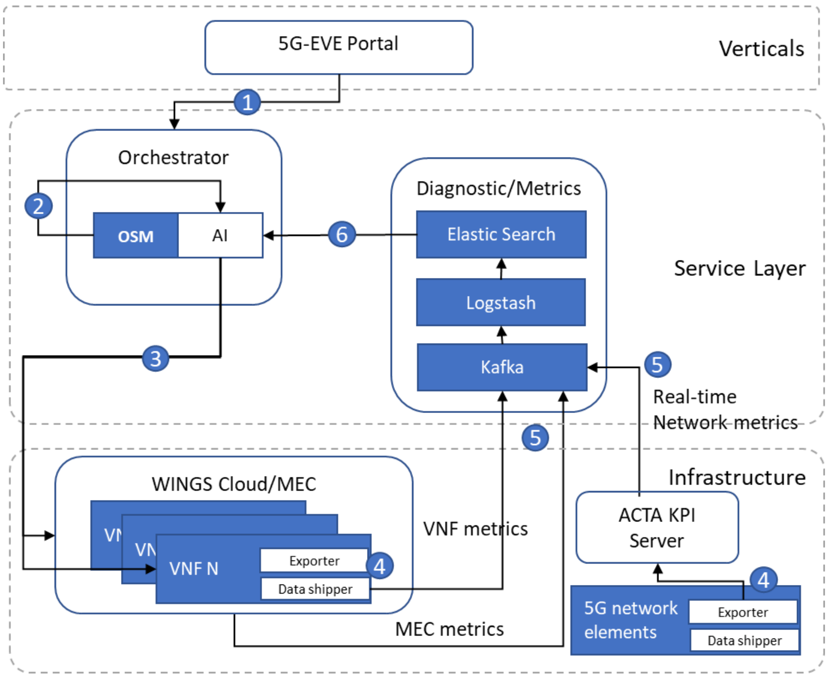


Figure 191. 5G-TOURS network innovations detailed view.

New Interfaces are designed and being developed to support AI at the OSM level (Figure 192).

- Interface with Verticals
- Interface with Infrastructure
- Interface with Vertical Applications
- Interface with Diagnostic component

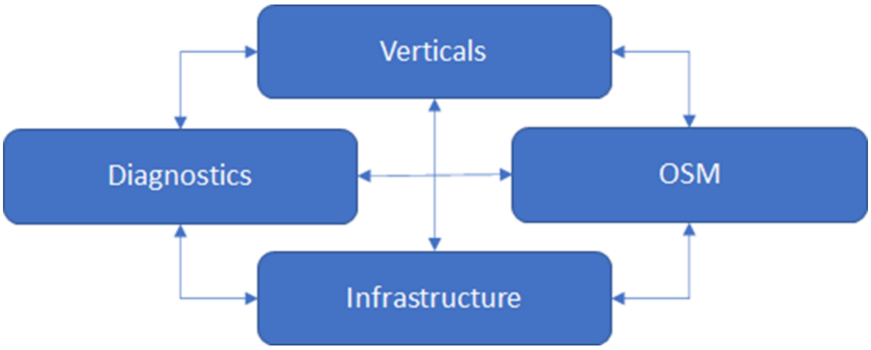


Figure 192. Enhancements on Interfaces.

Performance diagnostics module

The motivation for developing a performance diagnosis tool is stemmed from vertical requirements. Verticals require automated tools to ensure the reliability and high performance of the services running on top of the 5G network. In addition, verticals require effective methods and tools for the appropriate allocation of virtual resources fine-tuned to the needs of their 5G services. Therefore, it is a need for tools for automated prediction and localization of faults and service degradations, which then trigger the generation of automated decisions for improving the performance or mitigate the possible faults.

In this direction, the performance diagnosis module is responsible for realizing two critical tasks: Anomaly detection and Root Cause Analysis (RCA). During the anomaly detection task, Machine Learning algorithms are used to identify any anomalies in the collected metrics that need to be considered further. The core of the performance diagnosis mechanism is the RCA module. The RCA module is responsible to predict and localize faults and service degradations, so that in a next step the engineers and technicians can take decisions on how to improve the system or mitigate the possible faults. The RCA module uses diverse information including correlated network/service events and E2E service graphs. By correlated network or applications events, we mean events generated by different sources that can be related e.g., in a temporal or spatial way. In addition, service graphs are used as additional knowledge for the RCA algorithms in order to correlate nodes or link along a network path.

Two RCA algorithms are realized that are operated in a real time manner. The first is using statistical learning and it is characterized by low complexity and high speed in finding the root cause. The second algorithm is using machine learning approaches (Self Organizing Maps - SOMs) and it is characterized by medium complexity and the requirement of a long training data set.

The developed module is based on the 5G EVE performance diagnosis module [5G EVE D5.5], appropriately extended in order to: a) operate in a real time manner as explained below; b) communicate with the AI enhanced MANO module in order the decisions of performance diagnosis module to be realized and optimized in the actual development using the OSM.

Real-Time KPIs monitoring

In the context of 5G-TOURS ACTA proposes the use of real-time KPI measurements (in addition to the offline measurements that are used currently in the 5G EVE Athens site).

Offline (also referred to as Activation) measurements are usually performed using iPerf and Ping/ICMP based tools. They are very good in measuring network KPIs / metrics during and after the implementation phase and prior to Service Delivery. Currently they are used and are very well suited in assessing the infrastructure's readiness (in this case the 5G EVE network instance) to deliver a Service.

Real-time measurements (also referred to as Active), can monitor the KPIs after Service Activation and while the Service is being delivered (sometimes they are referred to as service performance measurements).

The innovation we suggest here is to implement Real-time (Active or Service Performance) measurements while the 5G-TOURS Use Cases are active and running. Analysis of the collected measurement also provides a better insight with respect to the network and other components (servers, devices) behavior while the Services are running.

These include TWAMP (two-way active measurement protocol) that is better than the ICMP protocol [1] & [20] as well as non-invasive (passive) throughput traffic measurements. They are implemented using properly placed network probes of three different categories:

a) Software based on open source tools

b) Hardware SFP based for network elements and

c) Commercial software based ones.

The acquired data can be fed and analyzed in real time to improve the stability and performance of the aforementioned innovation (by WINGS) with respect to the improved (AI based) orchestration.

In a simplified manner, the real-time active KPI measurement and acquisition can be thought as a feedback loop for the Management and Orchestration of the overall Network and Service delivery platform. This concept is shown in Figure 193:

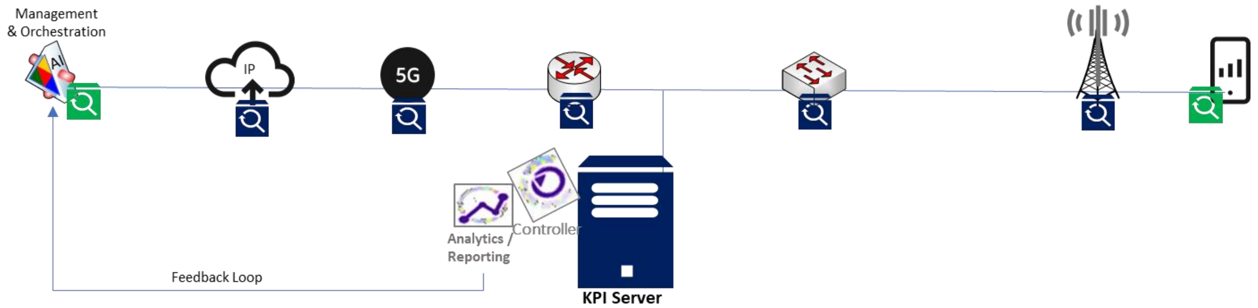


Figure 193. 5G-TOURS innovation concept of Real-Time KPI monitoring and Analysis.

Summarizing the suggested innovations, these include the following aspects (in conjunction with the innovation that is presented in the previous section).

- Real-time monitoring of network KPIs (plus some Service KPIs) in parallel
- Utilization of both active and passive monitoring tools
- Integration of existing (legacy) as well as new / open-source tools for measurement acquisition
- Continuous feed of the measurements for analysis and decision making
  (i.e., deploy a new slice, or establish a new VNF to the edge-cloud etc.)
- Extension of the above approach even to end-user-devices/CPEs like smartphones & APP servers

Application of innovations in UCs

All aforementioned three innovation modules (described in the above paragraphs) were integrated and applied in two UCs of the Athens site (UC10 and UC12 running in parallel). The architectural diagram of this application is highlighted in Figure 194. The Real-Time KPIs monitoring tool collects both general, accumulated, specialized and end-to-end networks metrics (denoted with the blue dot). These metrics are further aggregated and analyzed in the ACTA Server. In addition, system metrics from VMs/containers (denoted with green dots) and applications metrics (yellow dots) are collected from WINGS agents. Both ACTA and WINGS are using tools to collect a number of end-to-end metrics using agents (pink dots).

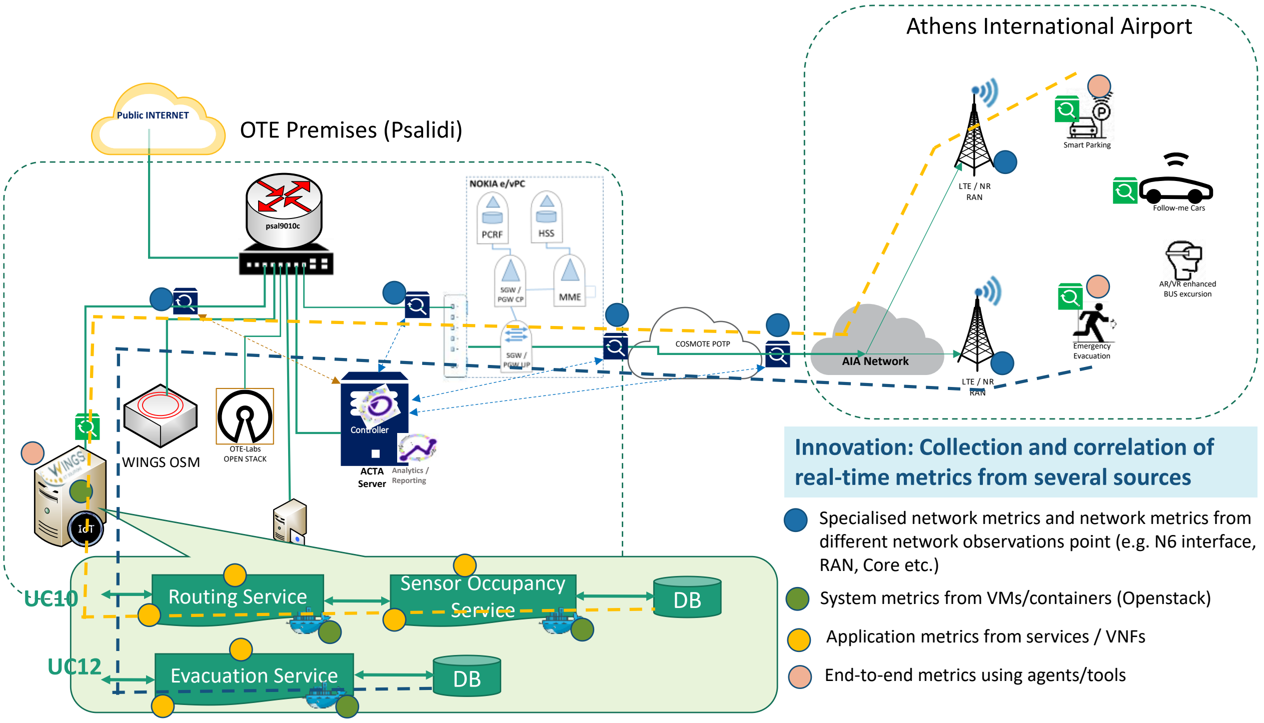


Figure 194. Application of innovations in UC10 and UC12.

All the aforementioned metrics are provided to the performance diagnosis module which correlates and analyses the data. Then, the performance diagnosis module executes online performance diagnosis and RCA on the correlated data. It identifies any impairment or performance degradation and in this case the RCA algorithm is executed to identify the source (cause) of the problem. The RCA can discriminate between three types of impairments/degradations: a) Network problem (e.g., performance degradation due to low coverage); b) System problem (e.g. low resources in Openstack instances); c) Application problem (e.g. high latency because of misconfigurations).

Figure 195. Performance diagnosis module – Topology chart.

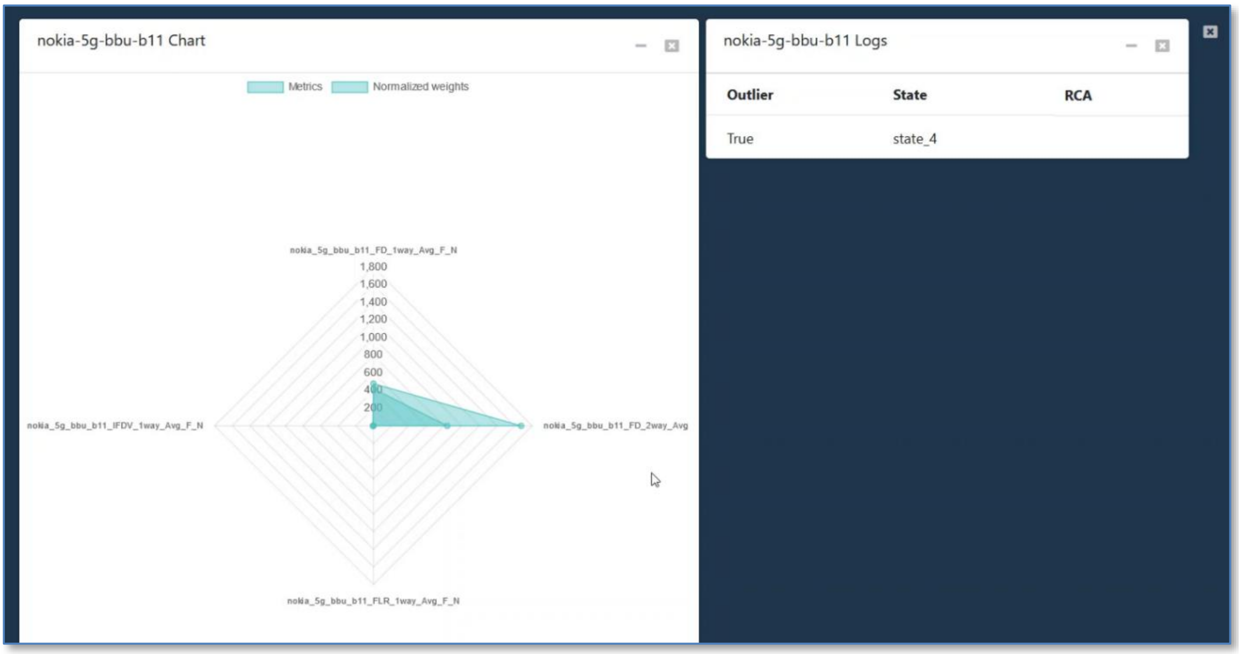


Figure 196. Performance diagnosis module – Anomaly detection outcome.

The dashboard of performance diagnosis module is illustrated in Figure 195, Figure 196 and Figure 197. In Figure 195 the dashboard presents the service graph including both the network components (BBU, 5G Core) and the application service components (VNFs). In Figure 196 the outcome of the anomaly detection process is illustrated. The figure presents the identification of an impairment/degradation (outlier) after the analysis of the correlated metrics and the execution of anomaly detection process. In Figure 197 the outcome of the RCA algorithm is presented. In this specific scenario the nokia-bbu is identifies as the problematic node which affects also the UE (high RRT latency in UE).

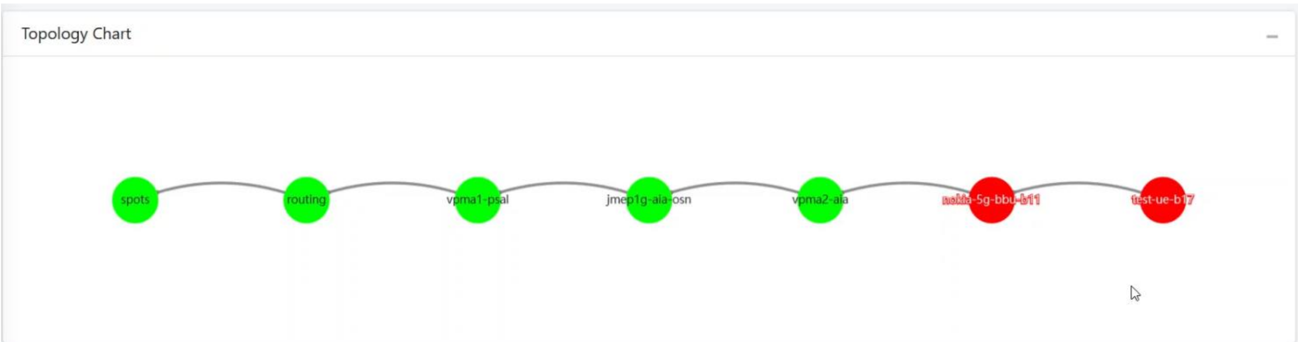


Figure 197. Performance diagnosis module – RCA outcome.

In cases of type (b) impairments/degradations, the performance diagnosis module further triggers the AI enhanced MANO module, which is responsible to reallocate system resources and alleviate the problem. The reallocations are realized by deciding and realizing the redeployment of selected services (based on the cause of the problem, the service requirements and the service priorities) in the Openstack.

The dashboard of AI enhanced MANO module is illustrated in Figure 198. In the specific scenario, the problem is caused by a high utilization of infrastructure RAM (identified by the diagnostic tool) cause by the allocation of high number of resources to Airport Parking service. After the problem is identifies by the performance diagnosis module, the AI enhanced MANO module is triggered, which downgrade Airport Parking service and in parallel deploy the new Airport Evacuation service.

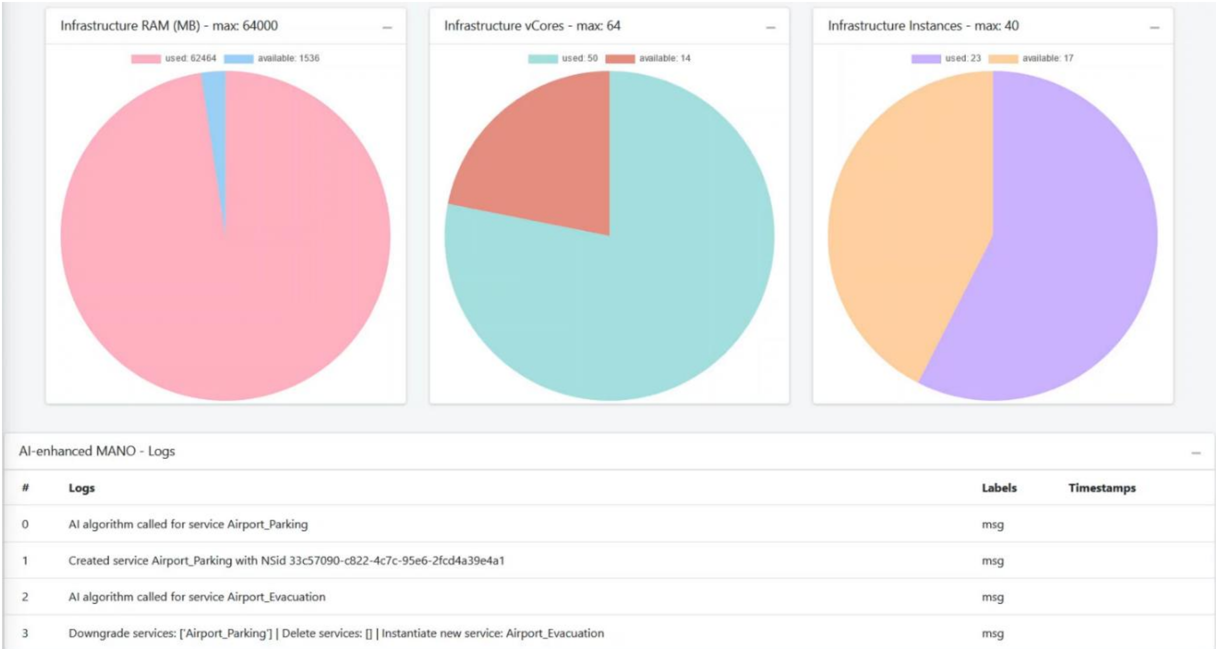


Figure 198. AI Enhanced MANO – Reallocation of resources.

8 Conclusion

This deliverable provides a detailed description of the final status of the design and implementation of the Athens node 5G network infrastructure and gives details of the development of the four main 5G-TOURS UCs in terms of definition, implementation, application development, network equipment and KPI validation. All the implementation of the mobility efficient city took place in Athens OTE and AIA facilities.

For each UC, this document presented the final version of the architectural design, the network design and respective equipment that has been deployed and implemented as an extension of the 5G-EVE Greek Site. In addition, the overall final implementation of all the applications for each one of the trials is presented. Furthermore, the final metric/KPI (QoS) results together with their analysis are presented in detail for each UC in the current document.

In UC10 "Smart parking management", 50 parking spots were deployed at AIA, which were tested with the final version of WINGSPARK platform and the mobile application running on UEs. A lot of tests for the mobile application have been executed on site and the UC is completed. KPIs are measured and analyzed.

For UC11, the final network equipment is presented, installed configured and checked. A media server has been set up at AIA and the last version of the web based interface for the AIA apron monitoring has been completed successfully. Final trials took place using FHD cameras that send FHD video to the streaming server. Moreover, a new 5G Pepling router (5G Transit by Peplink - MAX-TST-5GD-T-PRM, which is car mountable, see Figure 51), was used for the trials. KPIs are measured and analyzed.

For UC12, airport evacuation, the definition and all the implementation details are presented for the network and for the application. A 3D model of the airport terminal has been created into the application. The application and the optimal route to the exit have been run successfully during the trials. An LBS algorithm was developed and evaluated. From the network perspective 3 indoor cells are used for this UC. Moreover, probes have been installed and configured for measuring real time KPI metrics for the needs of this UC.

For UC13, AR/VR bus excursion, the implementation is also completed successfully. Implementation of the network and the AR/VR applications deployment has been described and developed. In summary, the content to be used in the AR applications of ATOS and WINGS and the VR application of SRUK was generated and integrated successfully into the applications. The used equipment S20s Samsung Galaxy mobile devices, as well as Gear VR was configured and tested successfully. Moreover, probes have been installed and configured for measuring real time KPI metrics for the needs of this UC.

In addition, 2 more UCs, from WP5 are hosted and run using the infrastructure of the Greek Athens node. All the trials were completed successfully. Moreover, one more UC, from WP5 (UC8) run as a Multisite UC between two interconnected sites: Rennes and Athens.

In all the aforementioned UCs, the trials were realized based on the decided plans, all the metrics/KPIs defined in D6.2 and D7.2 were collected, most of the analysis and validation process is completed and the results will be presented in D7.4. In summary, the KPI results demonstrates that most of the requirements were fulfilled. The few subcases that do not meet selected KPI targets are explained in D7.2. In addition, in all UCs the user experience was high as reflected from the filled questionnaires (both from AIA visitors and the AIA staff). The QoE (questionnaires) results which are already collected during the trials and the final QoS/QoE validation results will be reported in D7.4.

Furthermore, the innovations for each use case that was planned to be trialed in the Athens node as well as the relationship with the overall 5G-TOURS architecture has been presented and completed. More specifically, the innovation concerning the AI-based intelligence was integrated in the Greek node orchestrator, the diagnostics module (part of the 5G-TOURS service layer) as well as the real time KPIs monitoring have been integrated. More specifically, real time KPI measurements are given as input into the AI-based enhanced MANO and a decision is taken dynamically for resource reallocation concerning the needs of the running applications.

With the above, this document presented that all the planned functionalities were developed and integrated successfully into the different UCs of WP6, therefore fulfilling the objectives of milestone MS5. All the work progressed according to the decided starting plan with only minor delays due to covid pandemic and minimal differentiation from in starting scope concerning the number of volunteers in evacuation process, the number of students in AR/VR bus excursion, etc.

Acknowledgment

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

References

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

[2] 5G-TOURS, D6.1 "5G enabled solutions for mobility efficient Cities"

[3] 5G-TOURS, D3.1 Baseline architecture and deployment objectives, October 2019.

[4] 5G-TOURS, D3.2 Technologies, architecture and deployment initial progress, July 2020

[5] What is mMTC in 5G NR, and how does it impact NB-IoT and LTE-M. October 2019. [online]. Available: https://enterpriseiotinsights.com/20191016/channels/fundamentals/what-is-mmtc-in-5g-nr-and-how-does-it-impact-nb-iot-and-lte-m

[6] Nokia's Flexi Zone, 2020. [online] Available:https://www.nokia.com/networks/products/flexi-zone/https://www.nokia.com/networks/products/flexi-zone/

[7] Samsung Galaxy S10 5G. 2020. [online]. Available: https://www.samsung.com/us/mobile/galaxy-s10/

[8] LIS2MDL, digital magnetic sensor. 2020. [online]. Available: https://www.st.com/en/mems-and-sensors/lis2mdl.html

[9] LTE BG96 Cat M1/NB1/EGPRS Module. 2020. [online]. Available: https://www.quectel.com/product/bg96.htm

[10] Netty project. 2020. [online]. Available: https://netty.io/wiki/

[11] Apache kafka, a distributed streaming platform. 2020. [online]. Available: https://kafka.apache.org/

[12] Django web framework. 2020. [online]. Available: https://www.djangoproject.com/

[13] Nginx web server. 2020. [online]. Available: https://www.nginx.com/

[14] Angular web and mobile framework. 2020. [online]. Available: https://angular.io/

[15] https://iperf.fr/

[16] Indoor Localization: Which Technology For Each Use?, Bonzom Pierre, 2019. Available: https://elainnovation.com/indoor-localization-which-technology-for-each-use.html

[17] Cooperative localization in 5G networks: A survey, section 2.1, Ping Zhang et al, 2017

[18] RSSI-Based Indoor Localization With the Internet of Things, Sebastian Sadowski, Petros Spachos, 2018

[19] Introduction to TWAMP: https://www.slideshare.net/nirc1963/what-istwamp

[20] Kahraman Zaim, Cemal Kocak, "*Performance Analysis of IP Network Using Two-Way Active Measurement Protocol (TWAMP) and Comparison with ICMP (Ping) Protocol in a Saturated Condition*," 4th International Symposium on Innovative Technologies in Engineering and Science (ISITES2016) 3-5 Nov 2016 Alanya/Antalya – Turkey

[21] Cemal Kocak, Kahraman Zaim, Performance measurement of IP networks using Two-Way Active Measurement Protocol, May 2017, DOI: 10.1109/ICITECH.2017.8080008, 8th International Conference on Information Technology (ICIT).

[22] https://www.viavisolutions.com/en-us/product-category/network-test-certification/multi-protocol-field-test

[23] https://tools.ietf.org/html/rfc5357

[24] https://www.pfsense.org/getting-started/

[25] https://en.wikipedia.org/wiki/Hypervisor

[26] [5G EVE D5.5] 5G EVE D5.5 “Performance diagnosis mechanism and reporting methodology document”, June 2020.

[27] 5G- TOURS, D6.2 First Mobility Efficient Cities Use cases implementation results, Dec 2020.

[28] EETT : https://www.eett.gr/opencms/opencms/EETT_EN/index.html

[29] NetAct : https://www.nokia.com/networks/solutions/netact/

[30] Deliverable D5.2 First safe city use cases implementation results

[31] D7.2 First Integrated 5G-TOURS Ecosystem

[32] D7.4. “Final integrated 5G-TOURS ecosystem and technical validation results”

[33] D5.4 "Final Safe City use case results"

[34] D2.3 “Technical requirements of the use cases, economic and deployment implications”