5TH GENERATION END-TO-END NETWORK, EXPERIMENTATION, SYSTEM INTEGRATION, AND SHOWCASING

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Deliverable D4.6

The Málaga Platform (Release C)

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LIST OF ACRONYMS

Acronym	Meaning
3GPP	3rd Generation Partnership Project
5G PPP	5G Infrastructure Public Private Partnership
5GC	5G Core
AMF	Access and Mobility Management Function
ANDSF	Access Network Discovery and Selection Function
API	Application Programming Interface
AS	Application Server/Service
AUSF	Authentication Server Function
CA	Consortium Agreement
CME	City Emergency Center
CN	Core Network
CNF	Core Network Functions
CORD	Central Office Rearchitected as Data Center
COTS	Commercial off-the-shelf
DHCP	Dynamic Host Configuration Protocol
DUT	Device Under Test
E2E	End to End
ELCM	Experiment Life-Cycle Manager
eMBMS	Evolved Multimedia Broadcast Multicast Service
EMS	Element Management System
EPC	Evolved Packet Core
ePDG	Evolved Packet Data Gateway
FCAPS	Fault, Configuration, Accounting, Performance and Security
GA	Grant Agreement
GUI	Graphical User Interface
HSS	Home Subscriber Server
IMS	IP Multimedia Subsystem
KPI	Key Performance Indicator
LBS	Location Based Services
LTE	Long Term Evolution

MANO	Management and Orchestration
MCPTT	Mission Critical Push-to-Talk
MCS	Mission Critical Cervices
MME	Mobility Management Entity
MNO	Mobile Network Operator
MOCN	Multiple Operator Core Network
MONROE	Measuring Mobile Broadband Networks in Europe
MTIP	Multi-connection Tactile Internet Protocol
NFV	Network Function Virtualization
NFVI	Network Function Virtualization Infrastructure
NFVO	Network Function Virtualization Orchestrator
NMS	Network Management System
NRF	NF Repository Function
NSA	Non-StandAlone
NSSF	Network Slice Selection Function
OAI	OpenAirInterface
OAM	Operations, Administration and Management
OLT	Optical Line Termination
OSM	Open Source MANO
OSS/BSS	Operations Support System and Bussiness Support System
OTT	Over The Top
PCF	Policy Control Function
PCRF	Policy and Charging Rules Function
PGW	Packet Gateway
PNF	Physical Network Function
PoP	Point of Presence
QCI	QoS Class Identifier
QoS	Quality of Service
RAN	Radio Access Network
RO	Resource Orchestration
RRH	Remote Radio Head
SA	Standalone
SCPI	Standard Commands for Programmable Instruments
SDK	Software Development Kit

SDN	Software Defined Network
SDR	Software Defined Radio
SGW	Serving Gateway
SMF	Session Management Function
SNMP	Simple Network Management Protocol
SoC	System on a Chip
SON	Self-Organized Network
TAP	Test Automation Platform
TI	Tactile Internet
UDM	Unified Data Management
UDR	Unified Data Repository
UE	User Equipment
UPF	User Plane Function
VCA	VNF Configuration and Abstraction
VIM	Virtualization Infrastructure Manager
VLAN	Virtual Local Area Network
VNF	Virtualized Network Function
WAN	Wide Area Network
WIM	WAN Infrastructure Manager
X-PON	Any PON technology (G-PON, XGS-PON, NGPON2)

List of Figures

List of Tables

Executive Summary

5GENESIS project has built a 5G experimentation facility composed of six platforms, distributed in Europe, with the major task of validating the 5G KPIs (Key Performance Indicators) defined by the 5G PPP[1]. The five main platforms have been developed in Athens, Berlin, Limassol, Málaga and Surrey, while the sixth one serves as a portable demonstrator. All of them are instances of a common reference architecture already defined in deliverable D2.2[2] "Initial overall facility design and specifications" in response to the project requirements, identified in deliverable D2.1[3] "Requirements of the facility". Timewise, the 5GENESIS project is split into three integration cycles, each one lasting 6 months and followed by a testing cycle of 3 months. The platform result of an integration cycle is called a platform Release, named Release A, B and C for each integration cycle. Integration cycles are also named as phases, namely Phase 1, 2 and 3.

This deliverable focuses on the instantiation of the reference architecture made specifically for the 5GENESIS Málaga Platform, describing all the elements that compose the platform and highlighting the improvements and additions made during the Phase 3 of the project. This is the last phase of the project and the final release (Release C) of the Málaga Platform.

The main challenge of the Málaga Platform[4] has been to build a 5G multi-technology, multi-domain End-to-End (E2E) platform that enables to validate the 5G PPP KPIs for 3GPP Mission Critical Services (MCS) offered over E2E network slices. The main technologies combined for that are the 5G New Radio (NR), the edge computing at the Radio Access Network (RAN) and the flexible orchestration of network functions and services at the core of the network.

The 5GENESIS Málaga Platform has been deployed in two main areas of the city of Málaga: the campus of the University of Málaga (UMA), nearby the research building Ada Byron; and the old historical center of the city, where the Police Department operates surveillance cameras. Additionally, the City Emergency Center (CME), where those cameras are monitored, serves as a support site for the platform. The sites are directly connected to the main data center and the core network at the UMA research building Ada Byron. Additional connections with the premises of a commercial Mobile Network Operator (MNO) in Madrid and with the 5GENESIS Athens platform through GÉANT[5] have been setup too. The first one of those additional connections allowed the sharing of the MNO network in the city center with the Málaga Platform; while the second one allowed the testing of two interconnected 5GENESIS platforms.

For the delivery of the Release C of the platform, several improvements have been applied to the platform's components and technologies with major target to enable the validation of the corresponding KPIs. Among those improvements, the major ones are the extension of the RAN deployment, the addition of 5G SA capable equipment to operate this 5G mode, the interconnection of Málaga and Athens platforms through GÉANT, and the integration of an LBS (Location Based Services) system. Apart from those, use case specific enhancements have also

[1] https://5g-ppp.eu/kpis/
[2] https://5genesis.eu/wp-content/uploads/2019/12/5GENESIS_D2.2_v1.0.pdf
[3] https://5genesis.eu/wp-content/uploads/2019/12/5GENESIS_D2.1_v1.0.pdf
[4] https://5genesis.eu/malaga-platform/
[5] https://www.geant.org/

been applied, which have allowed the execution of preliminary tests to assist the use case trials that will take place under WP6 context in the last months of the project lifetime.

With all the work done in the 3 phases of the project, the 5GENESIS Málaga Platform currently serves as a functional 4G and 5G testing facility focused on Mission Critical Services but that offers an interesting opportunity in the present 5G testing context in general, and which will continue to expand and improve to keep up with the necessities of experimenters and stakeholders involved in 5G and beyond.

Table of Contents

1. Introduction

1.1. Purpose of the document

This deliverable provides a detailed description of the deployment and the functionalities of the 5G experimental platform built in the city of Málaga in the context of the H2020 project 5GENESIS.

The document is the last of a series of three deliverables whose main goal is to report on the status of the 5GENESIS Málaga Platform, in line with the three experimentation cycles defined in the project: April-June 2019, January-March 2020, October 2020-June 2021. These experimentation cycles target the validation of relevant 5G KPIs in a full end-to-end network and follow an integration cycle where new or upgraded components are integrated into the platform.

The following table shows the set of deliverables with which the present one shares dependence. It is advisable to check them to better understand the Málaga Platform status and evolution.

Table 1: Dependencies with previous 5GENESIS documents

id	Document Title	Relevance
D2.1 [1]	Requirements of the Facility	The document establishes the ground for the first set of requirements to be supported by the testbed for the realization of the planned Use Cases.
D2.2 [2]	5GENESIS Overall Facility Design and Specifications	The 5GENESIS facility architecture is defined in this document. The list of functional components to be deployed in each testbed is defined.
D2.3 [3]	Initial planning of tests and experimentation	Testing and experimentation specifications that influence the testbed definition, operation and maintenance are defined.
D3.1 [4]	Management and orchestration (Release A)	The document presents the MANO solutions that are integrated in the infrastructure. Interfaces and deployment options are also described.
D3.3 [5]	Slice management WP3 (Release A)	The document details the Slice Manager solution, its interfaces towards the MANO and NMS components in Release A.
D3.4 [6]	Slice management WP3 (Release B)	The document details the Slice Manager solution, its interfaces towards the MANO and NMS components in Release B.
D3.5 [7]	Monitoring and WP3 analytics (Release A)	The document details the Infrastructure Monitoring components and the interfaces with infrastructure elements.

D3.9 [8]	5G Core Network WP3 Functions (Release A)	The document details the 5G Core network functions and provides input on their integration with the infrastructure and management components for Release A.
D3.10 [9]	5G Core Network WP3 Functions (Release B)	The document details the 5G Core network functions and provides input on their integration with the infrastructure and management components for Release B.
D3.11 [10]	5G Access Components and User Equipment (Release A)	The document details the 5G Radio Access components and UE devices for Release A.
D3.12 [11]	5G Radio Components and User Equipment (Release B)	The document details the 5G Radio Access components and UE devices for Release B.
D4.4 [12]	The Málaga Platform (Release A)	This document summarizes the sites and components that will form the Málaga Platform and sets the ground for D4.5 and D4.6.
D4.5 [13]	The Málaga Platform (Release B)	This document summarizes the sites and components that were part of the Málaga Platform for Release B and the roadmap for the last release. D4.5 has been the baseline for D4.6 content.
D5.1 [14]	System-level tests and verification (Release A)	Midterm report with detailed analysis of the results from the system-level tests and the verification trials.
D6.1 [15]	Trials and experimentation - cycle 1	This deliverable includes the trials and experimentation executed on the 5GENESIS platform as well as the initial results of the first integration cycle.

1.2. Structure of the document

The structure of this document is as follows:

Section 2 includes the most technical part of the document. In the first subsection of Section 2, an overview of the sites that host the components of the Málaga Platform is provided. A second subsection outlines the different functional setups that are part of the platform. Then, the third subsection depicts the overall architecture of the platform in detail, splitting the characterization of the components in three logical layers, as per defined in the reference architecture:

- The low-level Infrastructure Layer is composed of all the physical components that provide service to the entire platform.
- The Management and Orchestration (MANO) layer controls the configuration of the physical and logical elements of the setup and is responsible for the creation and management of the different slices.

- The Coordination Layer is the high-level component responsible for the synchronization of the rest of the elements including the monitoring tools of the platform.

As a complement to Section 2, Appendix 1 includes deeper technical and architectural details on the different subsystems that compose the platform, covering aspects that range from the indoor deployment of base stations inside the laboratory of the University of Málaga to the interconnection between the police cameras used in the use-cases through a commercial MNO network. Appendix 1 can be used as a reference point for those interested in the technical details of the components of the Málaga Platform.

Section 3 is devoted to the three use cases that were planned for the platform, describing their components, the integrations done to support them, and the expected outcome that will be gathered once executed.

Finally, Section 4 describes the evolution of the platform during its consecutive cycles of developments and integrations, highlighting the accomplishments and milestones reached for this last Release C of the platform.

1.3. Target Audience

This deliverable detailing the Release C of the Málaga Platform is released as a public document depicting the platform final status and the integration activities that took place until the present date. As such, the target audience of the deliverable include both European Commission and technical experts in the area as well as general audience/verticals interested in using the Málaga Platform for experimentation.

The deliverable provides valuable inputs for analysis and decision making in relation with future developments, integration, experiments, requirements, and, in general, for improving the roadmap of this platform specifically and of the 5GENESIS framework. We hope that the content allows non-expert/general public to understand what the platform offers and its possibilities in relation to the 5G-oriented experimentation.

2. MALAGA PLATFORM OVERVIEW

The 5GENESIS Málaga Platform is an extension of the previous 4G platform deployed at UMA and result of different European projects like FLEX, Fed4Fire, Fed4Fire+[6], TRIANGLE[7], Q4Health[8] and NRG5[9]. The latest instance of this previous platform is the testbed TRIANGLE, which became a platform for validation of KPIs of devices and applications over mobile networks. The TRIANGLE testbed was the starting point for the 5GENESIS Málaga Platform development.

The new platform in 5GENESIS is composed of the resources coming mainly from UMA, Telefonica I+D (TID), Police Department of Málaga City, ATOS, Athonet (ATH), RunEL (REL) and Eurecom (ECM). The platform is oriented to validate KPIs for verticals related to Mission Critical Communications, which require Enhanced Mobile Broadband and Low Latency Communications, and that are supported by Airbus (ADS) and Nemergent (NEM) in the context of 5GENESIS. The platform combines i) an infrastructure located in Ada Byron Research building (previously present as part of the indoor TRIANGLE testbed - one of the EU FIRE research testbeds), ii) an outdoor deployment at the University campus (which has evolved through 5GENESIS different phases), iii) an outdoor deployment in the city center of Málaga (property of TID), iv) TID Edge infrastructure, v) the Open5GENESIS framework for the management, orchestration, and coordination functionalities, and finally vi) Athonet's EPC and 5GCore. Figure 1 depicts the main sites of the platform and where the major components are deployed in the field.

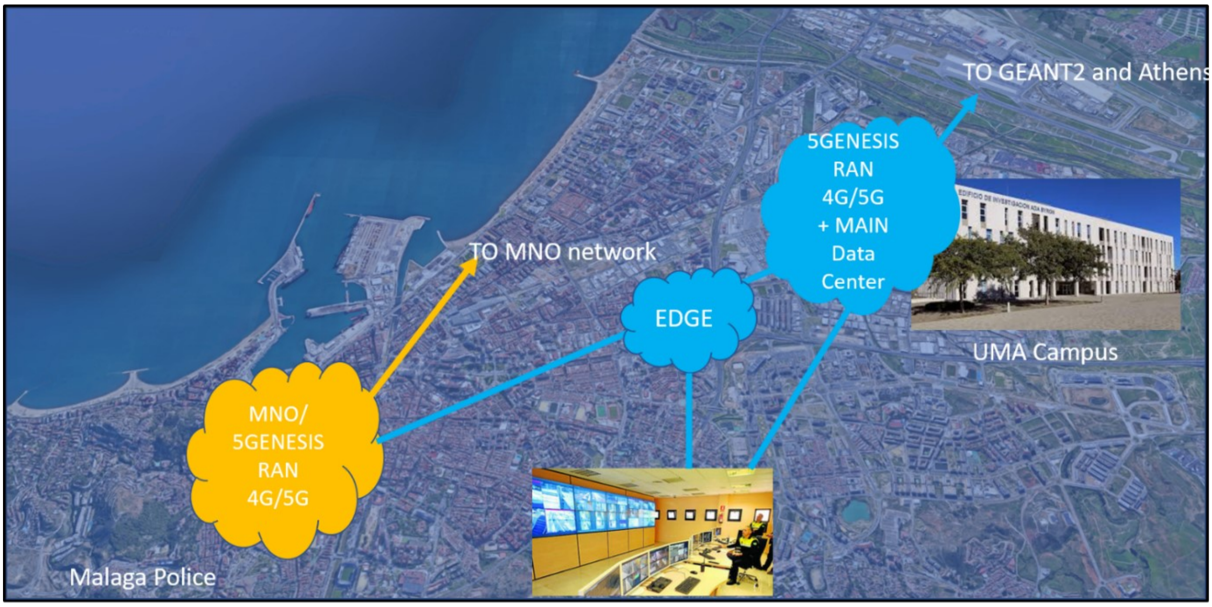

Figure 1: Picture of 5GENESIS Málaga Deployment

[6] https://www.fed4fire.eu/
[7] https:// www.triangle-project.eu
[8] http://q4health.eu/
[9] http://www.nrg5.eu/

2.1. Platform Sites Topology

2.1.1. Overview

The Málaga Platform of 5GENESIS facility is physically distributed in three different locations, belonging to three different domains of the network:

- Ada Byron Research building hosts the core network as well as the main Data center infrastructure and the Edge and RAN infrastructure. Two main sites reside at the Ada Byron area, namely the ***Site 1: indoor UMA Lab*** (section 2.1.2) and the ***Site 2: UMA outdoor deployment*** (section 2.1.3).
- The police facilities across the city center, host wiring and other equipment, that serve as an interconnection point between surveillance cameras, base stations, and the Ada Byron Research building. It is noted that the ***Site 3: Málaga city center*** (section 2.1.4) is co located with the infrastructure of the MNO (Site 5) in the city i.e., the ***TID labs in Málaga*** (section 2.1.6). Actually, in the framework of 5GENESIS, Telefonica set up additional 5G cells allowing the data flows from the experimenters to pass through a hybrid commercial/experimental deployment.
- The ***Site 4: City Emergency Center***, located on the outskirts of the city and connected through a fixed radio link with the rest of the police facilities, has the role of the remote end-user that consumes the video from the cameras and assesses the performance of the entire platform in a real-world public safety environment.

Commercial users in the Málaga city center are connected to the premises of the MNO (Site 5) in Madrid (*TID labs in Madrid*) as explained in section 2.1.6. This allowed the evaluation of the impact of the Edge infrastructure on the network.

As depicted in the Figure 1, an interconnection between Málaga and Athens platforms has been set through a high-capacity link from the GÉANT network. All the sites of the Málaga Platform and the interconnections among them, are depicted in Figure 2 as well. It shows a schematic distribution of the physical deployment that was targeted initially for the Málaga Platform, which has been accomplished completely at the end of the project. The diagram includes the functional components of the different sites involved in the platform, most of which were integrated in the Release B of the platform, with some final integrations and extensions performed for the Release C, as described in the following subsections.

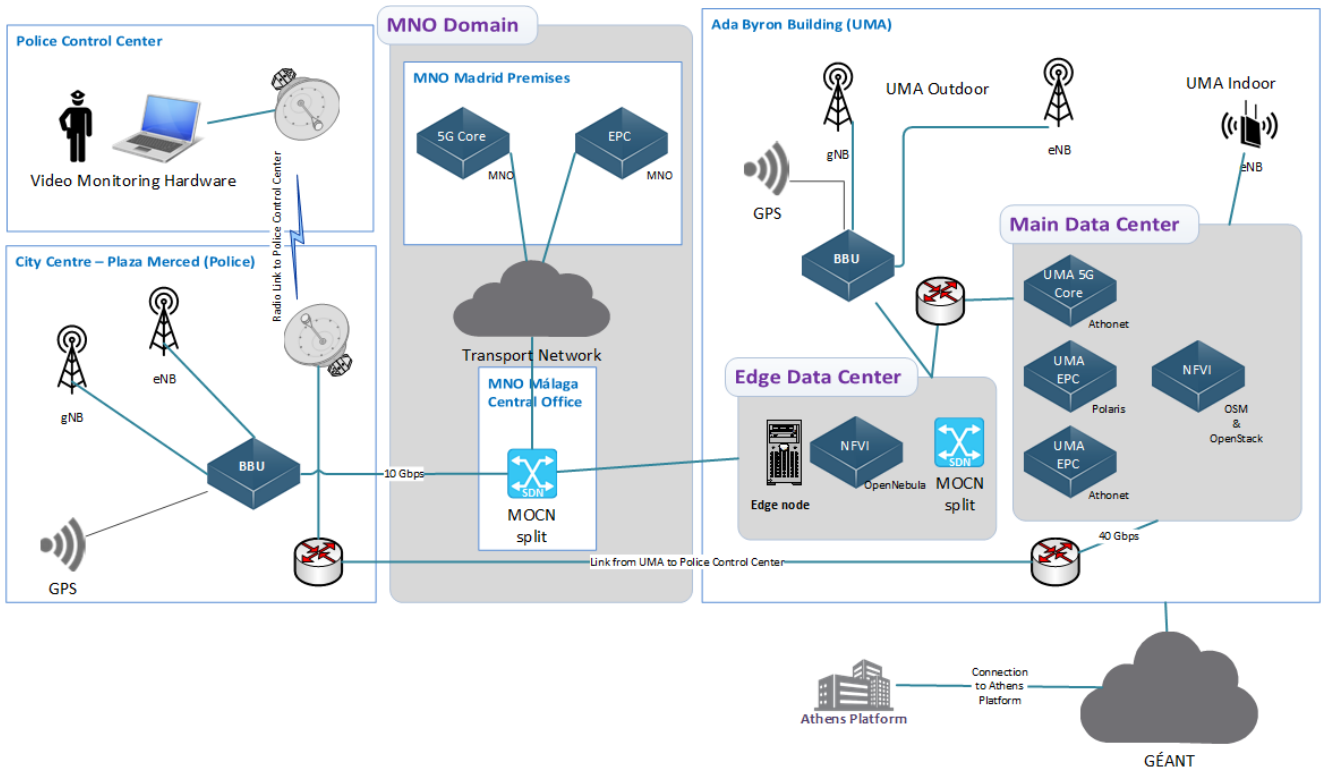

Figure 2: Overview of the Málaga Platform Infrastructure

From the implementation perspective, where possible, the interconnection between the different sites of the platform has been done using optic fiber links. Critical aspect was the interconnection with the MNO's premises (TID) that provided connectivity to 5GENESIS users in Málaga city center. This happened thanks to the sharing of TID's city center deployment and the capacity of splitting commercial users from the experimental 5GENESIS ones using the same spectrum. The 5GENESIS users´ traffic is routed to the Ada Byron building, where the core network used by 5GENESIS is located. The user´s traffic is routed then back to the Málaga City Center and to the Police Control Center using a radio link between the two locations.

A brief description of the sites involved in Málaga Platform can be found in the following subsections. Specific diagrams detailing the architecture of all the sites and the setups, along with Main Data Center and Edge Data Center diagrams, can be seen in Appendix 1: MALAGA Platform Components and Architecture details.

2.1.2. Site 1: Indoor UMA Lab

The MORSE research group of the University of Málaga operates the TRIANGLE testbed, which is the result of the H2020 project TRIANGLE, as previously mentioned. The TRIANGLE testbed was one of the examples considered as 5G European platforms in the 5G-PPP Trials Roadmap Version 2.0[10]. The testbed offers a realistic experimentation environment covering LTE, LTE-A and 5G features, and it is based on commercial off-the-shelf solutions (both in the radio and core network), software defined radio equipment and conformance testing equipment.

[10] https://5g-ppp.eu/5g-trials-roadmap/

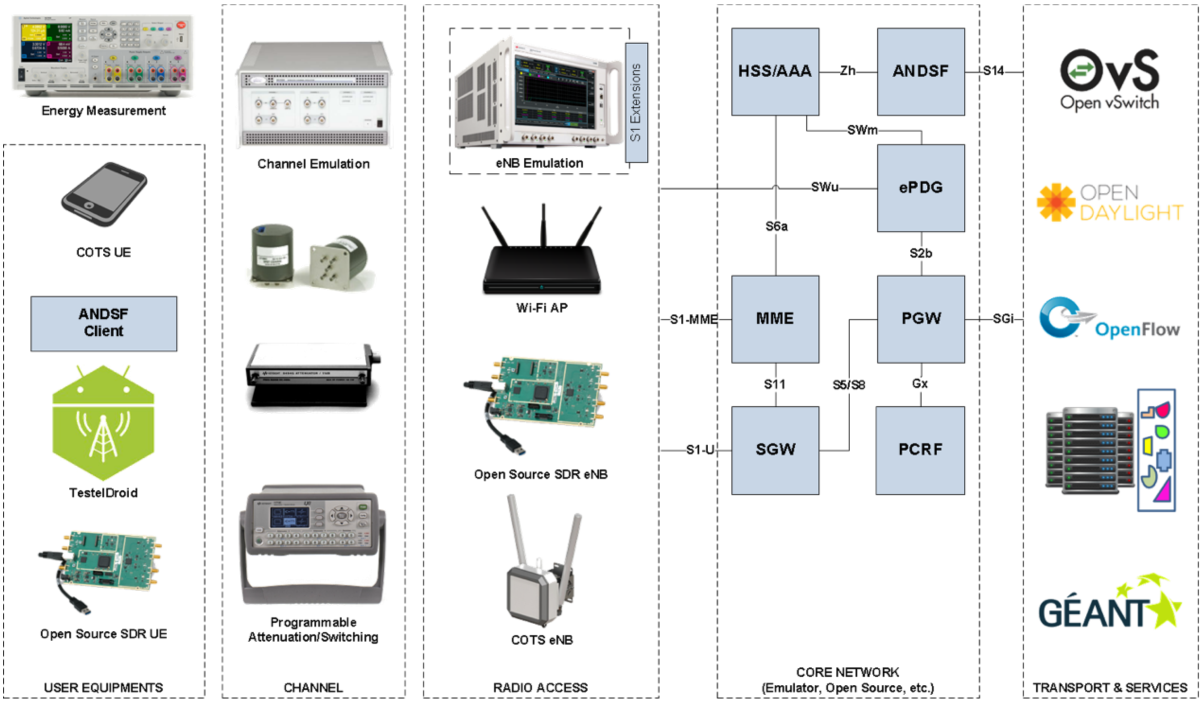

Figure 3: UMA Lab Testbed Components associated to TRIANGLE

Figure 3 depicts the different components of the testbed per category, whereas Figure 4 shows part of the actual indoor laboratory. Details regarding the equipment currently available are provided in section 2.3.1.

Figure 4: Part of Indoor UMA Testbed

Besides the TRIANGLE testbed components, Málaga Platform also integrates 5G NR RAN equipment, 5G compatible UEs, 5G NSA compatible EPC and different services to support the use cases. The indoor RAN deployment present at this site has been extended for the platform's Release C with the addition of 2 pico RRH for 5G under 6GHz, which can be seen in Figure 5, along with the inclusion of new 5G software core networks and new UEs supporting 5G SA mode. All these components will be described accordingly in section 2.3.1.

Figure 5: Indoor pico RRH for 5G under 6GHz

Two setups present at the indoor lab, corresponding to the 5G prototypes of ECM and REL can be seen in Figure 6.

Figure 6: 5G prototype setups at UMA Testbed

2.1.3. Site 2: UMA Outdoor deployment

UMA has extended the indoor lab deployment adding an outdoor deployment to cover the outside area around the Ada Byron research building as represented in Figure 7. Further extensions have happened during the project lifetime, for instance, the integration of mmWave gNBs during this last phase, and new extensions may take place after the project's finalization. The current outdoor deployment consists in 4 small cells or remote heads (RRH) with the latest radio release available for 4G, other 4 for 5G under 6GHz, and 2 more for 5G at mmW. Such equipment has been provided by vendors through a public procurement launched by UMA, including both 5GENESIS and UMA specific budget. The spectrum is provided by Telefónica that also supply the required equipment. The Spanish regulator is also willing to authorize the use of spectrum for mmWave. Details on the specific components for the outdoor deployment are provided in section 2.3.1.1. .

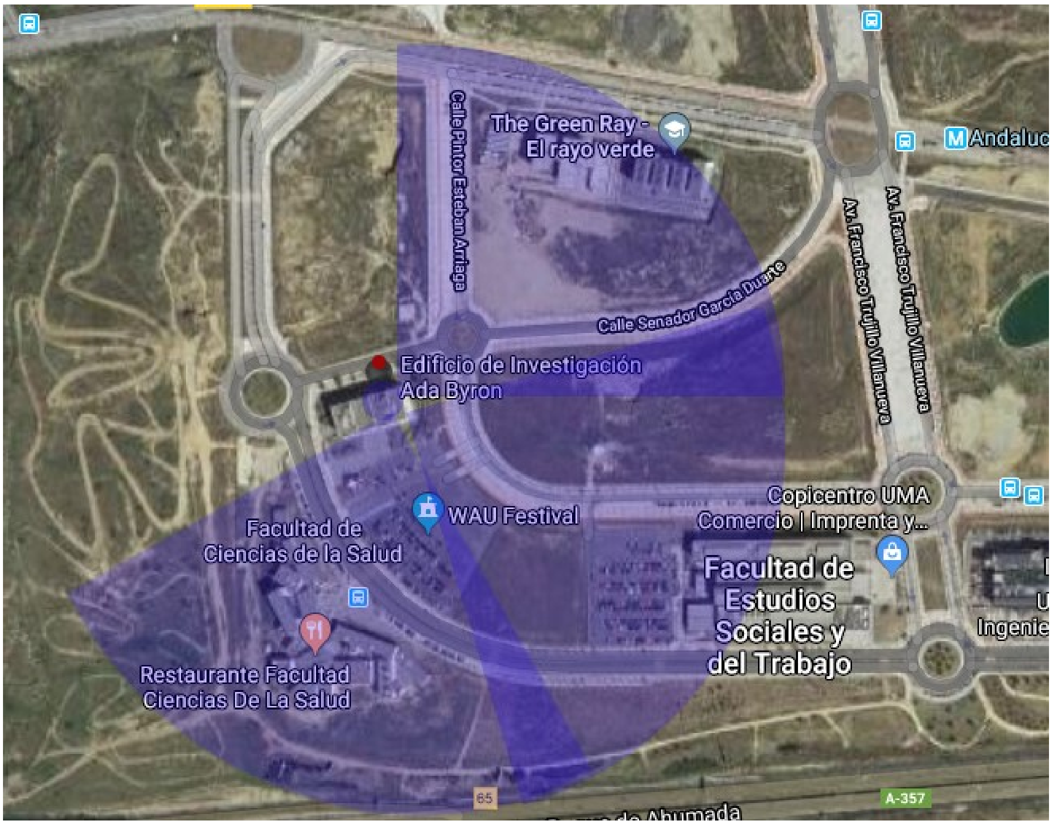

Figure 7: UMA outdoor deployment estimated coverage around Ada Byron building

2.1.4. Site 3: Málaga City Center

The 5GENESIS Málaga Platform has also been extended during the project to cover the area of Málaga City center to support the validation of Mission Critical Communications in the context of both periodic big events (i.e., annual fairs, parades or shopping holidays) and singular events in dense areas. Málaga city provides locations for small cells with backhaul and energy supply. The provision and installation of those small cells has followed the same approach as in UMA campus. Figure 8 depicts some of the locations (blue area) that are being used now and the connection of this area with the CME. This site has been completely interconnected with the rest of the platform during the last phase, and it has been completely tested to validate its successful integration for the platform's release C.

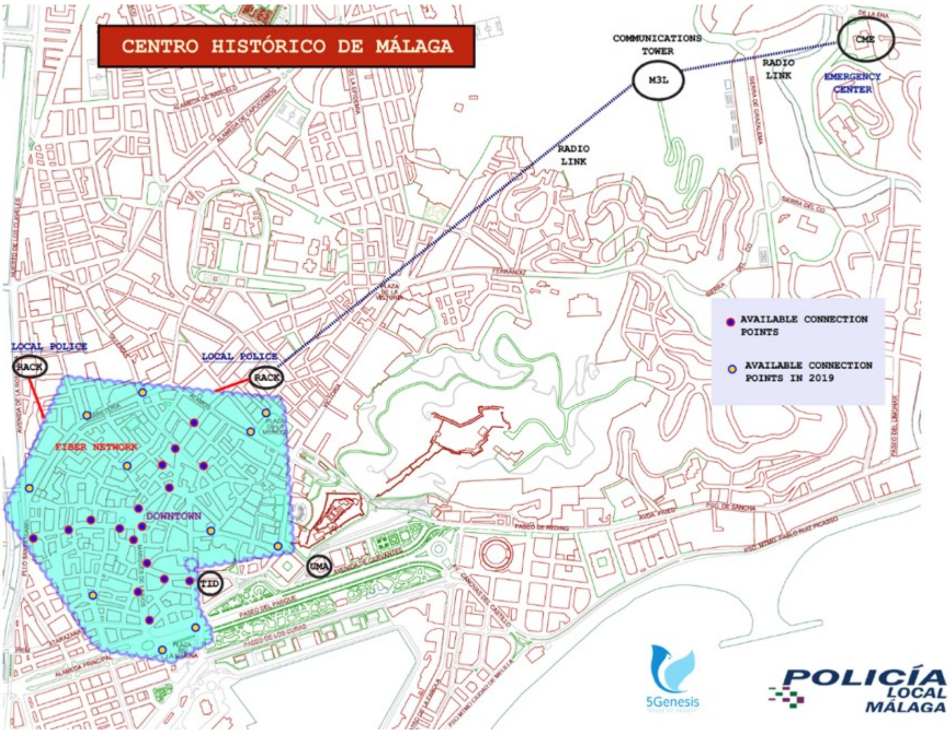

Figure 8: Area of Málaga City center with locations for small cells

2.1.5. Site 4: Málaga Police Emergency Center

Málaga Police department has a control room in the Málaga CME to monitor and control the existing cameras in the city (Figure 9). Currently, all the cameras are connected with a fiber network to a central point at Plaza de la Merced (mentioned previously as police facilities across the city). Two radio links are in place to perform the interconnection between the Emergencies Center and Plaza de la Merced (Figure 10). As mentioned previously, this site acts as end-user for one of the use cases of the platform, consuming real-time video from cameras and 5GENESIS users located at both the city center and the UMA lab deployments. The interconnection between this site and the UMA lab has also been performed during the last phase and has been tested to check the correct execution of the corresponding use case for this last Release C of the platform.

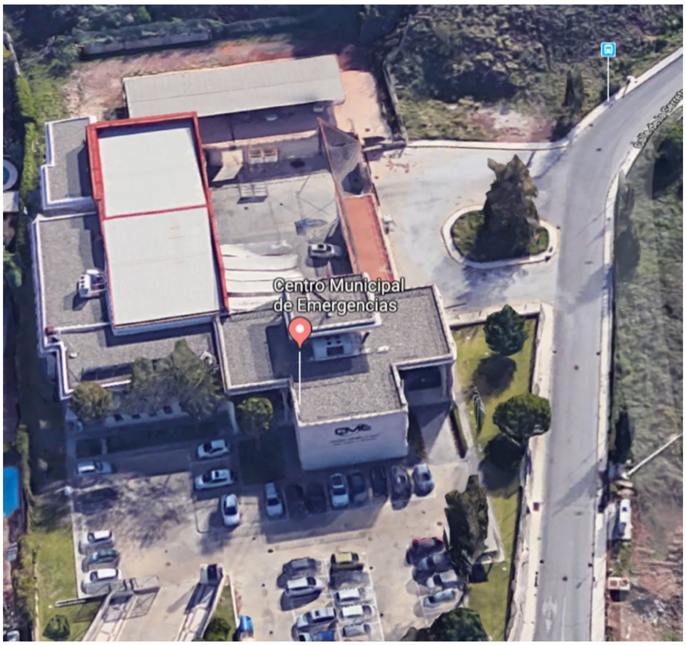

Figure 9: Málaga Emergency Center

Figure 10: Radio Link Repeater close to Emergency Center

2.1.6. Site 5: Telefónica I+D Lab in Málaga/Madrid

Telefonica provided their mCORD-like installations in Málaga to include Edge functionality into the platform. Telefónica also has built a new Lab during 2021 in Madrid in Sur 3 building at Telefónica campus (Ronda de la Comunicación sn, 28050, Madrid, Spain). This new Lab includes the following equipment relevant for 5Genesis:

- Nokia AirScale indoor Radio (ASiR) System Module Indoor. BaseBand Unit, composed by:
    - AirScale Subrack AMIA 5GC000623 (subrack).
    - AirScale Capacity ABIL 5GC000276 (Capacity Unit).
    - AirScale Common ASIK 5GC000275 (Common Unit).

- ASIR Smart Hub
- Nokia ASiR-pRRH

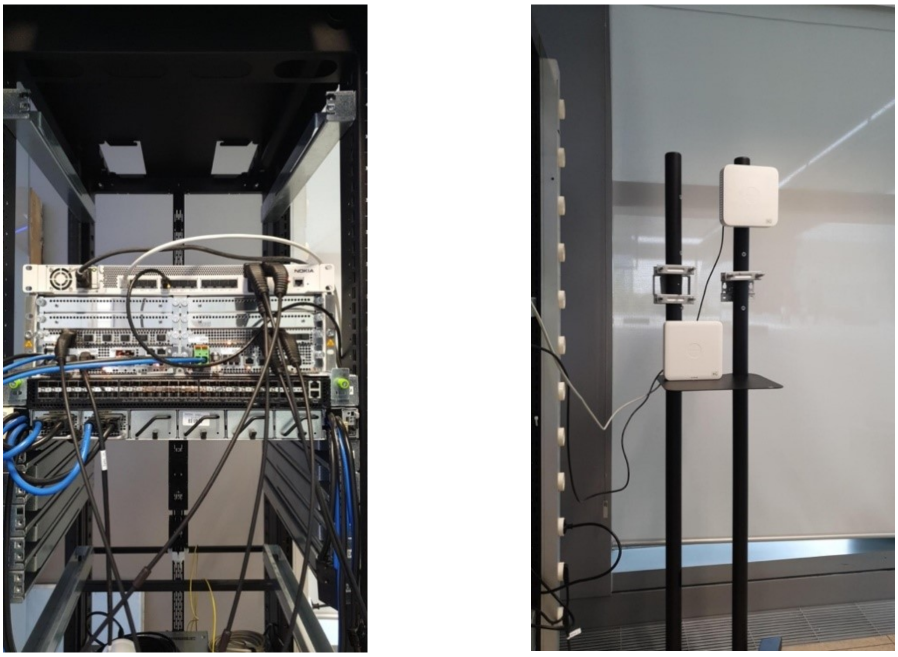

Figure 11: New Nokia 5G RAN at Telefónica I+D Lab

2.2. Platform Deployment Setups

The following Table 2 depicts the initial roadmap for the different radio setups planned for the Málaga Platform. In Release B setups 1 to 5 were completed, while the NSA option of the setup 8 (setup 8.1) was ready as well. Release C was concentrated to setup 6 and the SA option of 8 (setup 8.2). It is noted that the initially planned setup 7 was skipped due to critical interoperability issues between the REL and OpenAirInterface[11] systems, and the availability of the commercial solution from Nokia. However, in Release C setups created beyond the initial roadmap have been added, based on combinations of all the available ones and the addition of emulators and other prototypes. More precisely, Release C included the following four setups (Table 3):

- A setup including both indoor and outdoor radio deployment for LTE, 5G NSA and 5G SA. This setup is the result of the evolution and merge of the setups displayed at Table 2 as number 2, 5, 8.1 and 8.2.
- A setup composed by a new instance of the Keysight emulator for 5G NSA and SA, which can be considered an extension and evolution of setup 1 of the table.
- A setup composed of the ECM 5G prototype based on OpenAirInterface, which has evolved from setup 3 to what is depicted as setup 6 in the table but supporting also 5G SA mode partially (and fully in the near future).
- A setup composed of the REL 5G prototype based on RunEL solution, which is an evolution of setup 4.

[11] https://openairinterface.org/

Table 2: 5GENESIS Málaga Platform 5G Technology and roadmap for Release B

	#	Description	Mobile Core Product	Radio Access Products	UE	3GPP Option
Phase 1 (Release A)	1	TRIANGLE testbed	Polaris EPC	Keysight 4G Emulator	Commercial 4G	LTE
	2	Indoor E2E	Athonet EPC	Nokia eNodeB	Commercial 4G	LTE
	3	Indoor 5G ECM no core	-	OAI gNodeB	OAI	Only basic DL
Phase 2 (Release B)	4	Indoor 5G REL no core	-	RunEL gNodeB	RunEL UE Emulator	Only basic DL
	5	Full E2E 4G with VIM	Athonet EPC	Nokia eNodeB	Commercial 4G	LTE
	8.1	Full E2E 5G (including outdoor)	Athonet EPC Rel 15 Polaris EPC Rel 15	Nokia gNodeB	Commercial 5G	NSA
Phase 3 (Release C)	6	Indoor 5G ECM NSA	Athonet EPC Rel. 15	OAI gNodeB	OAI	NSA
	7	*Full E2E Indoor 5G*	*Athonet 5G Core*	*RunEl gNodeB*	*OAI 5G UE*	*SA*
	8.2	Full E2E 5G (including outdoor)	Athonet 5G	Nokia gNodeB	Commercial 5G	SA

Table 3: Málaga Platform final deployed setups detail for Release C

Deployment Parameters	5G Products/Technologies Options			
Setup ID	1. Full E2E 4G & 5G	2. Keysight 4G & 5G emulator	3.Indoor 5G ECM	4.Indoor 5G REL
Description	Indoor & outdoor E2E 4G & 5G (NSA and SA)	Indoor full 4G & 5G network emulator	5G setup with ECM OAI solution	5G setup with RunEL solution
Core Cloud	Yes - OpenStack	No	No	No
Edge Cloud	Yes - OpenNebula	No	No	No
# Edge Locations	1	NA	NA	NA
Slice Manager	Yes - Katana	NA	NA	NA
MANO	OSM v6	NA	NA	NA

NMS	TAP	TAP	TAP	TAP
Monitoring	Prometheus	NA	NA	NA
3GPP Technology	4G LTE+, 5G NSA, 5G SA	4G LTE+, 5G NSA, 5G SA	5G	5G
3GPP Option	NA	NA	NA	NoS1
Non-3GPP Technology	NA	NA	NA	NA
Core Network	Athonet Rel. 15 vEPC and 5GC Polaris NetTest EPC and NetCore 5GC Rel. 15	Keysight 4G and 5G UXM wireless test platform	Athonet Rel. 15 vEPC Polaris NetTest EPC Rel. 15	No Core
RAN	Nokia Airscale System (indoor and outdoor)	Keysight 4G and 5G UXM wireless test platform	OAI eNB/gNB	RunEL eNB/gNB
UE	COTS UE	COTS UE	COTS UE	RunEL UE Emulator
Relevant Use Cases	Use Cases 1, 2, 3	NA	NA	NA

2.3. Platform Implementations

This section highlights the new components and the ones that have been upgraded in Release C; however, it includes descriptions of all the components of the platform in order to keep the document self-contained. The section is structured in three subsections, each one dedicated to one of the three different layers of the platform architecture, as defined in D2.2 [2], namely ***Platform Infrastructure layer*** (Section 2.3.1), ***Management & Orchestration layer*** (Section 2.3.2), ***Coordination layer*** (Section 2.3.3).

2.3.1. Platform Infrastructure Layer

This section is focused on the physical components used to provide the services of the platform, including the devices and networking elements that form the core infrastructure used for experimentation. This layer is subdivided into different components, each one described in a dedicated subsection for clarity. Table 4 below summarizes all the technologies that compose the infrastructure layer, highlighting in bold the new components integrated for Release C.

Table 4: Infrastructure Layer Technologies

Component	Product/Technology	Mode of Implementation
Radio Access – LTE	Nokia small cells deployed indoor and outdoor Commercial LTE smartphones	LTE base station and UEs

Radio Access – 5G	Nokia Airscale System, 5G micro RRHs, **5G mmW RRHs deployed outdoor, 5G pico RRHs deployed indoor** Prototypes from REL and ECM Commercial 5G smartphones	5GNR prototypes, base stations and UEs
Mobile Core Network	ATHONET's EPC Polaris' Rel. 15 EPC solution for Edge environment **ATHONET's 5GCore** **Polaris' NetCore5 5GCore**	Instances of the core network with different capabilities
Main Data Center	Commercial servers	OpenStack
Edge Data Center	TID Edge solution	OpenNebula
Transport Network	Copper and fiber optic cabling, switching and routing equipment	Copper and fiber optic supporting 1 Gbps and 10 Gbps
Monitoring & Measurements	Custom traffic and functionality probes	Distributed tools across all the layers of the stack, controlled by a single monitoring entity

Before describing each component of the infrastructure layer, it is important to mention that the equipment that formed the TRIANGLE Testbed as part of the indoor UMA laboratory is now part of the 5GENESIS Málaga Platform, acting as baseline components and extending the possibilities of the platform. A brief description of the TRIANGLE components follows:

Conformance Testing Units. T2010 unit is a conformance testing equipment formerly implemented by AT4 Wireless and now part of Keysight Technologies. The unit is designed to provide conformance testing both at protocol and physical level of LTE user equipment of Release 8. This technology belongs to "eNB Emulation" present in Figure 3.

Keysight UXM. A very-high-performance LTE-A emulator, supporting functionality like carrier aggregation (4CC DL and 2CC DL) with data rates of up to 600Mbps. The unit has been extended over the course of the TRIANGLE project to support the standard S1 interface, thereby enabling experiments involving commercial core networks. As in the Conformance Testing Units case, this belongs to "eNB Emulation" part in Figure 3.

LTE Small Cells. Pico-cells of Athena Wireless working in band 7 with a maximum transmission power of 2W. The cells can be configured via a standard configuration interface (TR-069). The testbed also features indoor Nokia Small Cells working on band 7. The cells integrate Wi-Fi access and offer carrier grade performance, being part of the deployment of many different Tier 1 mobile operators.

Channel Emulation. The Spirent Channel Emulator SR5500 emulates complex wideband channels characteristics like time-varying, multi-path, delay spread, fading and channel loss offering a programmable SCPI (Standard Commands for Programmable Instruments) interface.

Radio interconnection infrastructure. The testbed also features programmable RF switches and attenuators, which can be used to have variable attenuation and RF outputs, useful to generate controlled handover scenarios.

LTE core network. Polaris core network implements the basic LTE core network elements (MME, SGW, PGW, HSS, PCRF) plus functionality to support Wi-Fi offloading (ePDG and ANDSF). The EPC supports features like negative testing, protocol monitoring and advanced KPIs. This core network supports all the standard functionality and can be used to deploy multiple instances of any of the available components, which enables very complex scenarios. The EPC components can be deployed as VNFs.

LTE User Equipment. Málaga University has many User Equipment samples working in different frequency bands, and covering several UE speed categories supporting from IoT devices to high performance connections. Additionally, there are several SDR cards that can be used to provide UE functionality deploying OpenAirInterface (OAI) or srsUE.

Power Analyzer and other instrumentation. The power analyzer unit N6715B can act as a 2-quadrant DC voltage and current source, but it's also able to generate arbitrary waveforms. It features an integrated oscilloscope and a remote programming interface, which can be used to mimic certain special behavior like battery chargers or even a battery emulator to connect to the DUT (Device Under Test).

Automation and measurement support. UMA has developed a web portal and several automation tools to control the experiments in the testbed in order to ensure their repeatability in the same conditions. This feature, that can be exploited remotely, is very valuable to measure KPIs and to compare technologies.

2.3.1.1. Mobile Network Technology

(a) Radio Access

The following Table 5 summarizes the Radio Access components currently deployed as Release C of the Málaga Platform, again highlighting in bold the additions made in the last phase.

Table 5: Málaga Platform radio access equipment deployed

Site	Deployed Radio Access Equipment
UMA Lab indoor	• 2 Nokia 5G pico RRH AWHQB 474754A • Keysight 5G Wireless Test Platform ○ E7515B UXM 5G Wireless Test Platform ○ E7770A Common Interface Unit ○ M1740A mmWave Transceiver for 5G • 4 FlexiBTS Nokia 4G Small Cell • Keysight T2010 and UXM LTE eNB emulators • Prototype 5G RAN setups from OAI and RunEL
UMA Lab outdoor	• 2 Nokia 5G mmW RRH AEUB 474608A • 4 Nokia 5G Micro RRH 5GC001274 • 4 Nokia 4G Micro RRH 474147A • Nokia Airscale BBU
Málaga City Center	• 6 Nokia 5G Micro RRH 5GC001274 • 5 Nokia 4G Micro RRH 474147A • Nokia Airscale BBU

Indoor LTE deployments

The Málaga Platform uses an existing 4G deployment for integration, experimentation and KPI baselines extraction. It consists of two different sets of devices:

- Two successive generations of the Keysight UE Conformance Testing Equipment for 4G networks, pictured in Figure 12. This is the kind of equipment that manufacturers use to test new radio and baseband chipsets before launching them to market. It acts as an eNodeB to the UE, giving complete control of the signaling and the radio stack to the operator. Thanks to its configurability, it is possible to test different frequency bands, bandwidth and resources assigned to the UE in the standard conditions stablished by 3GPP (clean or noisy environment, static or moving UE with different speeds, etc.)[16][17].

Figure 12: Conformance Testing Equipment available in the Málaga Platform

- Alongside the conformance testing equipment, a number of indoor commercial 4G small cells from Nokia are also used in order to obtain realistic baselines for the KPIs analyzed during the entire project. These base stations, depicted in Figure 13, provide the same characteristics and performance available to commercial MNO, and some advanced features like eMBMS support or carrier aggregation that will be used for the use cases.

Figure 13: FlexiBTS Nokia 4G Small Cell

Indoor 5G deployments

OpenAirInterface RAN (OAI-RAN) solution provided by Eurecom is an open-source software and hardware platform providing a standard-aligned implementation (3gpp Rel. 10/14) for the LTE UE and eNB. Currently, OAI has been extended to support 5G-NR UE and gNB [18], as per Rel.15 standards.

The current OAI setup integrated in the Málaga Platform can be seen in Figure 14. The protocol stack extensions for both 5G-NR UE and gNB have become gradually available throughout the different phases of 5GENESIS, starting from the physical layer (phase 1) and continuing with the rest of the RAN protocol stack (MAC, RLC, RRC, PDCP). The OAI UE can be launched and configured easily through a Command Line Interface (CLI). Based on this CLI, the UE can also be controlled remotely through external software.

Figure 14: OpenAirInterface setup 3 at Málaga Platform

For the previous releases of the platform, Eurecom had provided an intermediary version for a NSA setup based only on Openairinterface gNB and UE components. In this version, there was no Core Network and eNB, and all required configuration that would normally take place over the LTE and X2 links to establish a 5G connection was preconfigured, so that data plane IP traffic over the 5G NR stack could be demonstrated.

For release C of the platform, Eurecom has provided the OAI components supporting the real 3gpp aligned NSA setup (Rel.15-16) based on the OAI eNB and gNB, OAI or other Core Network and COTS UEs. OAI supports NSA architecture option 3a as per 3gpp Rel.15. As depicted in Figure 15, according to this deployment, all the control plane traffic is exchanged with the UE through the eNB. In order to add successfully the COTS UE to the NR cell (gNB), the eNB acts as the intermediary node that communicates with the gNB over *X2-C* interface to convey all required NR configuration to and from the UE. *S1-C* interface is responsible for the exchanges between the eNB and the 4G EPC (MME component) for the successful attachment of the UE. Once the UE is attached to the CN and connected to the 5G cell, the end-to-end user-plane traffic is delivered to the UE and the core network (*S1-U* interface to the SGW) exclusively through the gNB. It is noted that as per this architecture option, there is no delivery of user-plane traffic through the X2 interface (i.e., no split bearer option).

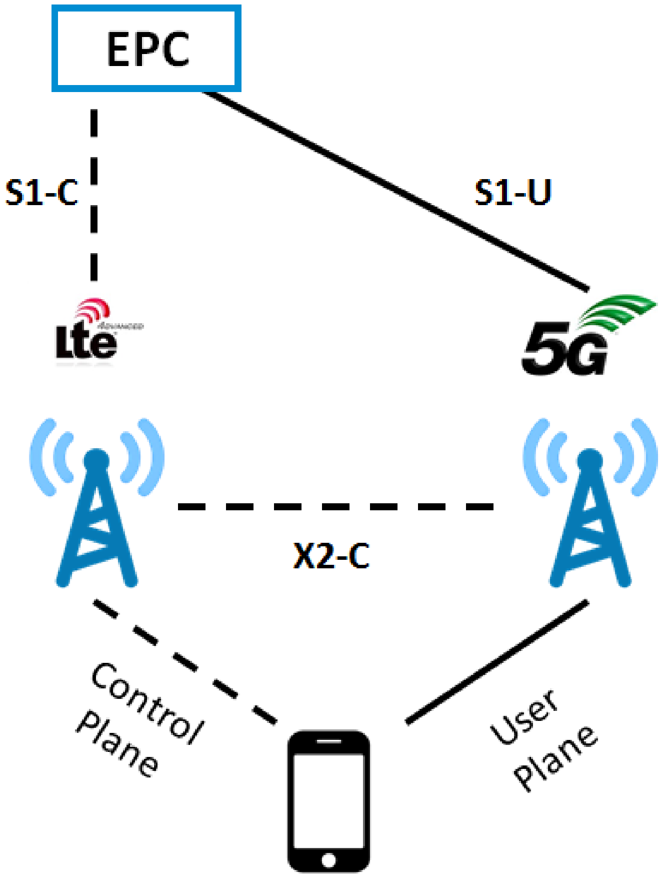

Figure 15: NSA architecture deployed in OAI

Based on the OAI NSA setup, the most stable performance at the gNB is achieved for *40 MHz channel bandwidth*, reaching up to *75 Mbps downlink* and *7.5 Mbps uplink* throughput and ~15msec round-trip time latency between the COTS UE and the core network. The goal is to achieve performance improvements in the upcoming contributions (100-200Mbps downlink, 15-30 Mbps uplink) and ensure stable performance for 80 and 100 MHz channel bandwidths. When such performance improvements become available through the OAI software, they can easily be integrated at the platform by updating the version of OAI components.

During the phase 3 of 5GENESIS project, Eurecom has been working on the OAI support for the 5G SA setup. The target was to deliver an OAI gNB, able to support an end-to-end SA setup based on a *5G CN* (OAI or other) and *SA capable COTS UE* devices. At the same time, the OAI UE has also been extended to support SA. A first version of the SA setup became available at the end of phase 3 of the project allowing for a successful end-to-end 5G connection and some first user-plane traffic tests. Compared to NSA setup, in SA the gNB needs to also implement the complete RRC layer and handling of all the associated messages as well as the NGAP to interface with AMF (N2 interface) and UPF (N3 interface), as shown in Figure 16.

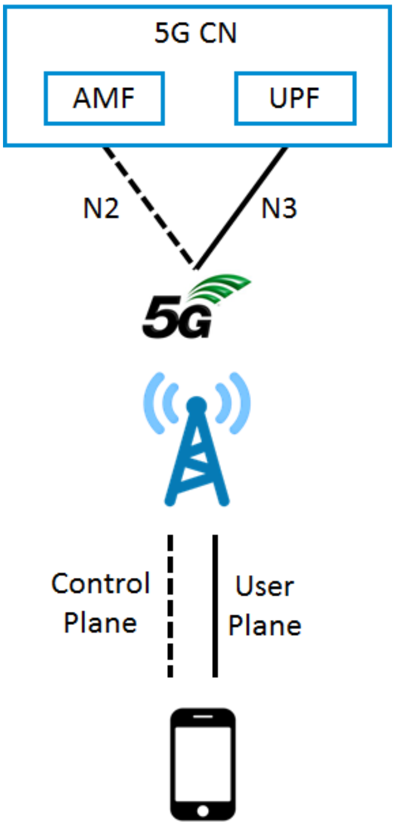

Figure 16: SA Architecture deployed in OAI

After the release of the first OAI SA version, there have been continuous efforts for stabilizing the performance of the SA setup, expanding the range of configurations it can support and validating interoperability with different COTS UE devices and Core Networks (besides the OAI 5G Core Network). With respect to KPI performance improvements, the work conducted is mostly common with the work for the NSA setup as described above. The target is to integrate the SA setup as well at the Málaga Platform until the end of 5Genesis project.

RunEL has also provided a 5G Infrastructure to the 5GENESIS Málaga Platform including 5G New Radio (PHY and MAC) already optimized for Ultra Reliable Low Latency Communication (URLLC), as can be seen in Figure 17. The RunEL gNB includes advanced features such as: 2 frequency bands 3.5GHz and 28 GHz, Beam Forming, MIMO, flexible frames, 200MHz BW and more.

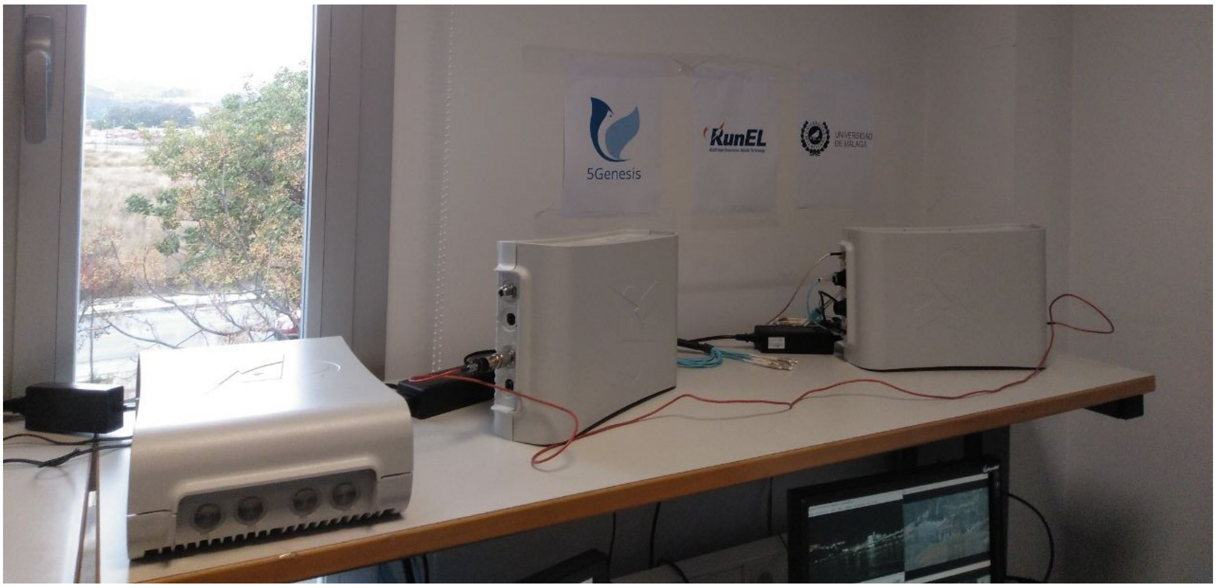

Figure 17: RunEL setup 4 at Málaga Platform

The RunEL equipment provides a 5G physical layer implementation. The setup includes the main two units which comprise the physical layer: the DRAN (Distributed RAN) unit and the RRH (Remote Radio Head) unit. To enable testing of this units, the setup includes also a UE emulator and software for a basic MAC layer and a video server. The RunEL setup is shown in the following Figure 18.

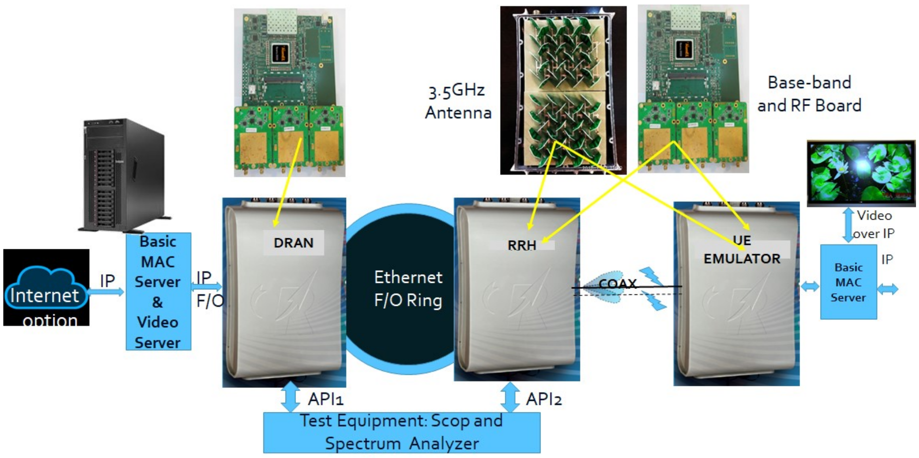

Figure 18: RunEL 5G setup architecture

During phase 3 the RunEL prototype setup has not suffered many changes. RunEL provided an upgrade of the RRH firmware that added the missing uplink communications support for this setup, thus allowing to measure the round-trip time latency of this 5G deployment.

More detail about both OAI and RunEL equipment and setups can be found in Appendix 1: MALAGA Platform Components and Architecture details and deliverable D3.12 “5G Radio Components and User Equipment (Release B)” [11].

Apart from the specific ECM and REL setups, UMA has also improved its indoor RAN deployment with the integration of new equipment, which can be separated into two different extensions:

- Keysight UXM 5G Network Emulation Solution

Figure 19: Keysight UXM 5G setup 3 at Málaga Platform

The Keysight E7515B UXM 5G wireless test solution is an integrated test platform for 5G network emulation which includes a wide variety of capabilities allowing deep and flexible testing of RF characteristics, protocol compliance, and functional KPI. The latest 3GPP Release 15 is supported, and the solution works with both NSA and SA 5G modes as well as both FR1 and FR2 frequency bands, in addition to LTE and C-V2X signaling formats.
Some of its specific capabilities include:

  - 5G NR 8CC DL, 4 CC UL 2x2, with LTE 2CC.
  - Wide bandwidth in each RF port.
  - Multiple angle of arrival (AoA) test.
  - Internal fading for 5G NR and LTE formats.
  - Frequency extensions to high IF and millimeter-wave with the use of a common interface unit and remote radio heads (RRH).

In addition to the E7515B UXM unit, an isolation chamber and two other instruments have also been integrated into the Málaga Platform to allow the solution to work with higher frequencies: the M1740A mmWave Transceiver (usually called the Remote Radio Head or RRH) and the E7770A Common Interface Unit (CIU). mmWave can also be tested with this solution thanks to those additional units, and using the chamber functionality to move and rotate the DUT through remote control of its moving platforms, even precise DUT positioning for the mmWave beamforming use cases can be performed.

- Nokia RAN extension

Málaga Platform's indoor radio deployment has also been expanded with new Nokia equipment. It consists of the Nokia's ASiR-pRRH AWHQB 5G n78 product. The corresponding equipment has been added to our BBU, and two new pico RRH for under 6 GHz have been installed in the indoor spaces of the platform's premises at Málaga, as previously illustrated in Figure 5. Some of its specific capabilities include:

- 5G Access: n78 Band 43 Frequency range
- Band Frequency:
  - UL: 3600-3800 MHz
  - DL: 3600-3800 MHz
- RF Output Power: 50mW to 250mW per Tx path
- RF Bandwidth:
  - OBW: 800 MHz
  - IBW: 1400 MHz
- Carrier Bandwidth: 50MHz, 100MHz
- Synchronization: via CPRI timing recovery
- Antenna:
  - Configuration: 4 Tx/4 Rx (per band)
  - Integrated Omni
  - Nominal Gain: -0dBi

Figure 20: Nokia pico RRHs

Outdoor LTE and 5G deployments

UMA and TID have designed the expected outdoor deployments for UMA campus and the city center to be covered within the 5GENESIS budget, as was depicted in Figure 2 in the platform overview. The technology integrated in the platform for the outdoor deployment is the Nokia AirScale Solution, which can be seen in Figure 22 and Figure 23.

This solution includes the following components:

- Common equipment
  - Nokia AirScale System Module Indoor. BaseBand Unit, supporting a variety of technologies as GSM, WCDMA, TDD-LTE, FDD-LTE and 5G NR, and a capacity of up to 10 Gbps per system module with up to 96 LTE cells.
- 5G equipment
  - Nokia Micro RRH 5GC001274. RRH for 5G under 6 GHz.
  - Nokia Micro RRH AEUB MMA 8T8R 512AE n257.RRH for 5G at mmW.
- LTE equipment
  - Nokia Micro RRH 474147A. RRH for LTE.

For Release C, new Nokia equipment has also been integrated into Málaga Platform's outdoor radio deployment. For the outdoor case a mmWave deployment has been added, composed by Nokia's AEUB AirScale MMA 8T8R 512AE n257 8W product. The corresponding equipment has been added to our BBU, as well as two new RRH for mmW. Some technical specifications of this product are:

- 5G Band/Frequency: n257, n261
- RF Output Power: BRP 60 dBm 2T2R
- RF Bandwitdh:
  - OBW: 800 MHz
  - IBW: 1400 MHz
- Carriers: Up to eight 100 MHz 5G NR carriers
- Synchronization: via AirScale BBU
- Antenna:
  - 2Tx/2Rx, 2 single polarized 16x16 arrays
  - Horizontal Coverage Angle +/-45º
  - Vertical Coverage Angle +/-45º
  - Horizontal BW: 6º
  - Vertical BW: 6º

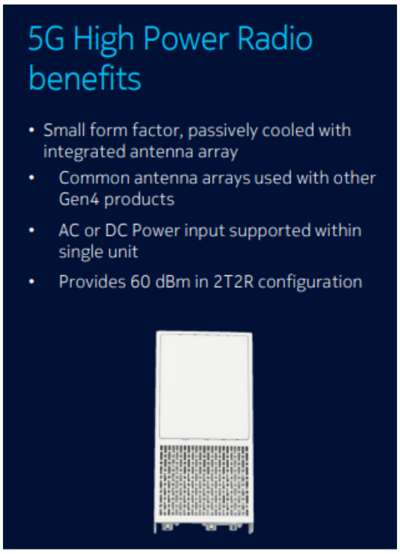

Figure 21: Nokia mmW RRHs

Technical details about the AirScale System integrated in the Málaga Platform are available in Appendix 1.

Figure 22: Nokia 5G and 4G micro RRH in Ada Byron building rooftop

Figure 23: Nokia 5G mmW RRH in Ada Byron building rooftop

Figure 24: Nokia Airscale BBU at Ada Byron site

(b) Mobile Core

5Genesis Málaga Platform has integrated two new core solutions in order to deploy 5G SA option into the platform. As outlined in Table 4, the two core solutions are new products from the already present core solutions for 4G and 5G NSA: Athonet provided their new 5G core product for its integration in the Main Data Center of the platform, while Polaris provided its NetCore5 5G core to be used both at the Main Data Center and at the Edge Data Center.

Athonet's mobile core for 4G/5G-NSA is based on a highly efficient and effective software-only implementation. The expensive, proprietary, hardware centric CAPEX of traditional mobile core solutions has been replaced with a wholly software-only product that runs on standard off the shelf servers or in a virtualized environment since its first release in 2010. The solution has a reduced footprint that can run on x86-based as well as on ARM-based platforms.

The platform is a full 5G-NSA mobile core that implements 3GPP Release 15 defined network functions, including 5G-NSA support for 3, 3a and 3x configurations, 5G extended bandwidth support for uplink/downlink bearers and dual registration.

For Release C of the platform Athonet has evolved its 4G/5G-NSA Software Mobile Core towards a full-fledged 5G SA core network. In fact, in the Málaga Platform, the 4G-5G-NSA and 5G-SA core networks are currently deployed independently. The 5G-SA Software Mobile Core by Athonet is compliant to 3GPP Rel-15 and newer technical specifications from Rel-16. The apparatus is based on an extremely flexible software architecture on top of which the 3GPP network functions (NFs) are implemented. The new 5G core network brings, among other functionalities, the separation of the user and control planes to ease flexible and agile deployments as required by specific 5G use cases (e.g., URLLC and TSN). Furthermore, virtualisation and distribution to the edge of the core network functionalities allows running networks with applications as close as possible to the users, improving service delivery and quality of experience. More details can be found in Deliverable 3.10 [9].

The 5G-SA Software Mobile Core encompasses the fundamental NFs that are inherited (and evolved) from the 4G/5G-NSA Software Mobile Core (that are AMF, SMF, UPF, UDM/AUSF/UDR) and needed for the scope of 5GENESIS, while more NFs are provided along with the project activities and advances, such as PCF, NSSF.

The MCPTT applications provided by the partners have been successfully integrated with the core network functions described above and tested with the real UEs and RAN equipment present in the platform and outlined along section 2.3.1 of this document.

While Athonet's solution is the mobile core for the Main data center, Polaris's LTE NetEPC is the chosen one for being used in the Edge. Polaris NetEPC, which includes MME, SGW, PDN-GW, HSS, PCRF, makes possible the use of the components individually to create a testbed with a mix of real and emulated EPC elements, as well as the use of all the Polaris elements together to have a complete LTE/5G-NSA EPC. The components support all the 3GPP defined network interfaces and implement all the protocols required for an EPC to operate in an LTE/5G-NSA network.

In a similar way that with Athonet's products, a 5G SA mobile core solution from Polaris has been integrated into the platform for Release C. Polaris NetCore5 is a lightweight 5G Core Network that is able to deliver 5G services such as eMBB (enhanced Mobile Broadband), mMTC (massive Machine Type Communications) and URLLC (Ultra-Reliable Low Latency

Communications), thanks to its scalable, cloud-native architecture. This carrier-grade solution is suitable for commercial public networks, private enterprise networks and emergency networks deployed by Public Safety agencies.

NetCore5 includes all Core Network Functions (CNFs) – Access and Mobility Management Function (AMF), Authentication Server Function (AUSF), Network Slice Selection Function (NSSF), Unified Data Management (UDM), Unified Data Repository (UDR), Session Management Function (SMF) Policy Control Function (PCF), NF Repository Function (NRF), and User Plane Function (UPF) – along with a Network Management System (NMS) and a web-based Console to manage and operate the 5G core network.

Some highlights of the NetCore5 5GC are:

- 3GPP Release 15 compliant 5G Network Functions, with plan to support Release 16 and future specifications.
- New 5G features such as Network Slicing, different Service and Session Continuity modes, and different types of PDU Sessions are supported.
- Flexible deployment options allowing NFs to be co-located on one system or distributed on multiple systems, as well as the possibility of using COTS hardware, virtual machines, or containers for its deployment.
- High scalability capabilities with support for 10 and 40 Gbps user-plane throughput and millions of subscribers on a single-CPU system.
- High-availability features.
- Full interoperability with NFs from other vendors.
- RESTful API for the NF management via third-party OSS/BSS.
- Support for third-party Cloud Infrastructure Managers such as OpenStack and Service Orchestrators such as Kubernetes and ONAP.
- Flexible licensing options based on number of NF instances and Subscriber capacity.

More detail about the Mobile Core solutions can be read in Appendix 1: MALAGA Platform Components and Architecture details.

2.3.1.2. Main Data Center

The main data center is used for the physical composition of the NFVI. We have chosen to extend the minimum configuration (i.e., one server that contains everything) to a more distributed one, where each server has its own functionality. Adding an extra server for storage relieves the load of the controller, taking care of the volumes of persistency which might also be useful for the next phases in case we want to enhance the platform capabilities with instance migration, redundancy or we need to deploy services that require volume persistence. For such reason, the server that is dedicated to host the volumes has been equipped with extra storage.

Connectivity between the different elements of the Main Data Center and also with the rest of the platform, outlined in Figure 62(Appendix 1: MALAGA Platform Components and Architecture details), will use high-capacity switches with a base bandwidth of 10 Gbps for general interconnections and specific 40 Gbps links for the backhaul between remote sites.

More details on the equipment and networking present in the Main Data Center can be found in Appendix 1: MALAGA Platform Components and Architecture details.

2.3.1.3. Edge Data Center

Telefónica Edge Data Center has been reconfigured to adapt it to the new network infrastructure and design in the transport network of the UMA. Also, virtual networking in Open Nebula has been revisited and adapted accordingly.

2.3.1.4. Transport Network

Málaga Platform's transport network has been improved with new switching and routing equipment supporting 10 Gbps, needed to deal with the expected throughput of 5G SA. Some of the new equipment installed in the platform include Netgear ProSafe XS716T and Netgear ProSafe M4300-12X12F switches, which present both RJ-45 and SFP+ ports.

2.3.2. Management & Orchestration Layer

As explained in deliverable D2.2 [2], most of the 5GENESIS components in the management and orchestration layer are also common to the six platforms in the project, and they are described in the deliverables of WP3, as for example D3.2 for the MANO or D3.4 [6] for the slice manager. However, there are some variants in the MANO and the NMS systems due to the hardware/software installed in each platform and also due to the previous existence of some MANO solutions.

For the Release C of the Málaga Platform, the Málaga team has installed and configured Open Source MANO release SEVEN (OSM7) as NFVO, upgrading from the SIX version previously installed. Along with the NFVO upgrading, the core VIM has also been reinstalled and upgraded to the Openstack Rocky version. The Edge VIM remains untouched from Release A and keeps the Open Nebula 5.8.1. The first stable release of the Katana Slice Manager has been installed and integrated with the rest of the existing components and also the configuration of the NMS to support hardware coming from TRIANGLE and from radio vendors have been done.

The following table shows a brief description of all the components of the management and orchestration layer.

Table 6: Monitoring and Management Tools

Network/Element Management Systems	Description
4G/5G Legacy EMS	Most Mobile Network elements deployed in the platform provide proprietary solutions that allow operations like configuration and monitoring for the respective devices. These systems are exploited to perform configuration management and retrieve status information per case.
WIM	WIM is the WAN infrastructure Manager, a component that has the overview of the Wide Area Network (WAN), the physical network that is used to provide connectivity to any physical and virtual

	component of the platform. It keeps track of the way on which all networking devices (SDN switches, routers), NFV Infrastructures and physical devices of the platform are connected, in the form of a network graph.
OpenTAP	OpenTAP is an open-source test sequencer developed by Keysight Technologies which can be extended using custom plugins. Several TAP plugins have been developed within the 5GENESIS project for the automation of the different components of the platforms.
Monitoring Tools	**Description**
Prometheus	Prometheus servers deployed in hierarchical mode are collecting aggregated time series data from a larger number of subordinated servers and can be used to take measurements from any device on the platform by creating custom exporters that use the SNMP protocol.
Grafana	Used for the visualization and analytics of the Prometheus metrics. Additionally, Grafana supports a lot of presentation dashboards.
NFV MANO	**Description**
OSM	OSM[12] is an open source MANO aligned with the ETSI framework for NFV. OSM is an orchestration and management system which manages life-cycle and configuration aspects of the hosted virtual network functions (VNFs) that are deployed on the wide number of supported NFV Infrastructure (NFVI) platforms. These MANO capabilities are critical to implement the sophisticated services expected by the 5G communication systems and utilize the underline management systems and tools. For the purpose of the 5GENESIS Platform, the deployed OSM is of release 7 and is already integrated with the Element management systems and monitoring tools as well as the Virtualisation Infrastructure Managers (Openstack).
Slice Manager	**Description**
Katana	Release A implementation of the 5GENESIS reference architecture Slice Manager implementation (WP3 component).
Traffic Generators	**Description**
iPerf	iPerf is a cross-platform network performance measurement tool that can produce standardized measurements on any network. iPerf agents have been deployed for PC and Android devices, allowing the automation of the iPerf tool. More information about these agents can be seen in Deliverable D3.5.

[12] OSM, https://osm.etsi.org/

Ping	Ping is a round trip time measurement tool available in most operating systems. Like in the case of iPerf, PC and Android agents have been deployed in the platform in order to automate the use of this tool. More information can be seen in Deliverable D3.5.
Exoplayer	Exoplayer is a library and media player for Android that provides support for DASH, SmoothStreaming or HLS adaptive playback. The source code of this application is available and designed to be easily customizable and extensible. The Exoplayer instances deployed in the Málaga Platform have been adapted for automation and result retrieval.

NFV Management & Orchestration

The Málaga Platform NFVI will be managed by two different technologies distributed in two different domains: OpenStack for the Core NFVI and Open Nebula for the Edge infrastructure.

In the Main data center, located at the UMA campus, there are three dedicated servers to host and manage the network service instances using OpenStack (Rocky release): the controller, the compute and the storage nodes. As stated in the previous section, this component has been upgraded to a newer version for the Release B.

In the Edge NFVI, an Open Nebula (v5.8.1) portal and a controller are available.

On top of the infrastructure management, there is a single orchestrator handling the NFV deployments in both the Core and the Edge. In this case, the edge orchestrator will not be actually necessary as these functionalities are delegated to the Core NFVO, which has been implemented with OSM Release SEVEN in Release C. On top of that, we have developed and integrated a wrapper to perform the necessary actions over the NFVO and the VIM, on top of the security introduced by the components themselves, simplifying the usage to adapt it to 5GENESIS and enhancing some features like the advanced descriptor validation

A simplified network diagram of the above deployment is shown in Figure 25.

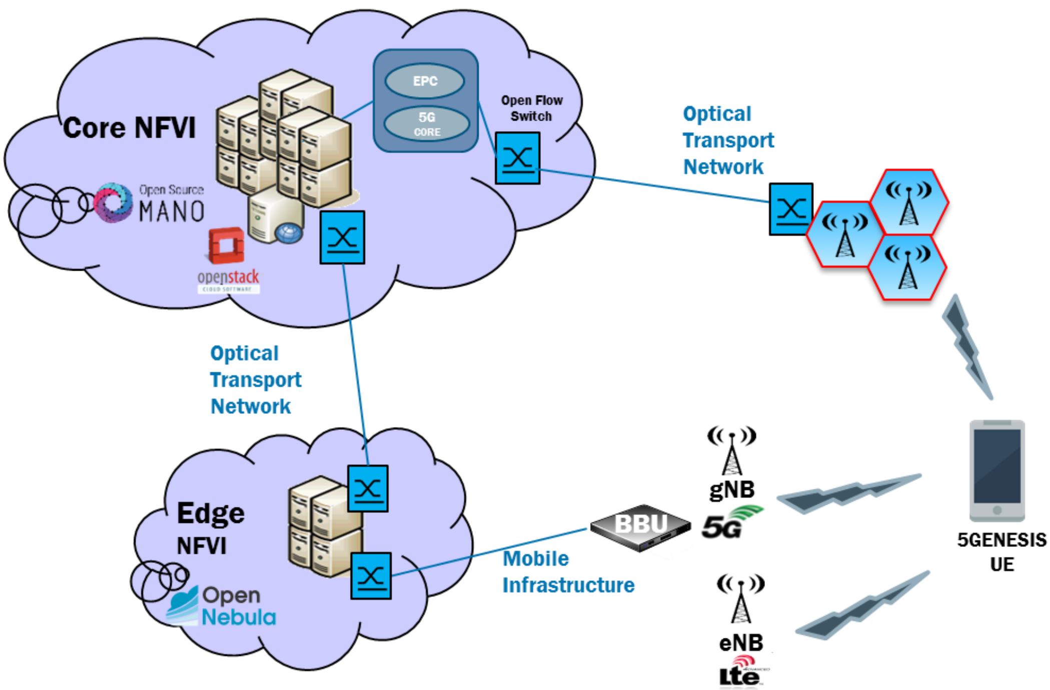

Figure 25: Core NFVI and Edge Composition

In order to properly communicate the infrastructure management (OpenStack) with the NFVO (OSM), we needed to set a specific configuration for OpenStack and the networks it manages in order to:

1. Guarantee that OpenStack API endpoints are reachable from OSM (particularly from Resource Orchestration (RO) container).
2. Create a management network, with DHCP enabled, reachable from OSM (particularly from VNF Configuration and Abstraction (VCA) container).
3. Create a valid tenant/user with rights to create/delete flavors.
4. Modify the default security group or create a new one. By default, OpenStack apply the "default" security group that blocks any incoming traffic to the VM. However, *ssh* access might be needed. Therefore, we had to modify the default security group to allow TCP port 22 or create a new security group and configure RO to use it when a data center is added.

Slice Manager

The Katana Slice Manager was introduced as part of the Málaga Platform Release A, and it has been updated to a newer version for Release B. Its focus is to deal with the experiment slices, taking over the command of instantiation of network services in the NFVO. Katana is installed in a dedicated server with network access to the NFVO. As explained in D3.3 [5], the Slice Manager for Release B provides the following functionalities:

- VIM user and project management, creating a new user and project for each deployment to improve the isolation (operations supported for OpenStack and OpenNebula VIM types).
- NFVO VIM management, creating a new VIM in the NFVO to complement the above bullet point.

- NS service deployment as part of a new slice, making use of all the items created in the mentioned points.

To carry out the previous features, the Slice Manager needs to be preconfigured with information such as the available PoPs, the network services that are going to be deployed and where (PoP), the type of slice, etc.

Network Management Systems

The NMS is being implemented using the TAP framework [19][20] already used in TRIANGLE project to support full automation of all the hardware and software components. In order to accomplish this level of automation, we are developing TAP plugins for controlling the different components of the platform. Each TAP plugin will communicate with the component using the most appropriate interface available, for example, several instruments expose an SCPI interface for control, while others can be controlled by sending commands through *ssh*.

TAP includes a generic SCPI instrument that can be used out of the box, but we have developed a new generic TAP instrument that is able to send commands and transfer files through *ssh*. These instruments can be extended, which will allow us to create specific instruments for a particular component of the platform. This, in turn, will help to create more fine-tuned steps for controlling the different actions that an instrument can perform. Details about the implementation of this TAP plugin can be seen in section 4.3 of deliverable D3.15.

In a similar way, we can develop generic plugins for communicating with components that can be only controlled using a different interface. For instance, we can create a generic REST instrument using the libraries already available for C# and possibly extend it to better support a specific component of the platform if necessary.

For the Release B of the Málaga Platform, multiple TAP plugins have been integrated for automation of different equipment.

2.3.3. Coordination Layer

As detailed in deliverable D2.2, devoted to the architecture, the 5GENESIS coordination layer is common to all six platforms in the project; their components have been described in the deliverables D2.2 and D2.3. The implementation of these components is described in the deliverables D3.X provided in Work Package 3 (WP3). Each platform shall instantiate a number of these components depending on the features supported per platform. In the case of Málaga Platform, it integrates all the components, including interconnection with the 5GENESIS Athens Platform through the Dispatcher component, which has been developed to serve as the entry point to the platform, abstracting the features of the subjacent components via the Open APIs.

Release B of the components provided by WP3 have already been deployed in the Release C of the Málaga Platform. Components that are part of the coordination layer of the Málaga Platform are summarized in the following table:

Table 7: Coordination Tools

Experiments Coordination	Description
5GENESIS Portal	WP3 Release A implementation. The 5GENESIS Portal is a custom web application developed in Python + Flask that provides an easy to use point of entry for external users, allowing them to run experiments in the different platforms. More information about the 5GENESIS Portal can be seen in Section 4 of Deliverable D3.7.
Experiment Life Cycle Manager	WP3 Release A implementation. The ELCM is a custom application developed in Python that oversees the execution of concurrent experiment in the 5GENESIS platforms, communicating with the layers below so that the actions required by an experiment are correctly coordinated and executed. More information about the ELCM can be seen in Deliverable D3.15.
Results Repository	InfluxDB is the open-source storage engine provided within the InfluxData framework, and handles in particular time series data and is used to store all monitoring events and metrics that are necessary for the generation of the end-reports and KPIs validation.
Analytics	Custom Python scripts are developed to support the statistical analysis requirements for results presentation and KPI validation. The scripts are utilizing the native Influx DB capabilities to support Python. More information can be seen in Deliverable D3.5.
Dispatcher/ Open APIs	WP3 Release B implementation. The Dispatcher secures the components located behind, exposing a set of APIs (Open APIs) to authorized users to work with the platform. The Dispatcher is also in charge of analyzing and redirecting the Experimenter requests to the appropriate component. Through the Validator (one of the features of the Dispatcher), the system assures that the involved resources provided for the execution of the experiment are well formed for a successful experimentation. Moreover, the Dispatcher is responsible for the Experiment Distribution, allowing the communication between platforms, and the retrieval of the joint experiment.

Monitoring & Measurements

The monitoring and analytics framework at the coordination layer is common for all platforms; however, the actual probes to get measurements are platform-dependent because they are coupled with the current infrastructure. Málaga Platform will integrate probes in all the relevant points in the E2E path: UE, BBU, transport network, Edge, EPC/5GCore, NFVI, MANO, and, in general, in all the components of the 5GENESIS architecture where radio or IP level information can be retrieved. Some interesting locations to include the probes are the

OpenFlow switches and the BBUs, provided that the vendors offer these features. The platform will also integrate the tools identified in the 5GPPP TMV WG, including MONROE [21] nodes and TRIANGLE tools where applicable. All the probes will be automated via TAP so that they can be integrated in the NMS system.

For commercial Android UEs, UMA has developed and integrated a set of Android applications and TAP plugins for control and measurement retrieval for the Release B of the platform. These applications provide information about the usage of resources in the devices, as well as generating iPerf traffic and measuring round trip time using ping.

Málaga Platform Monitoring Tool

A new tool focused on monitoring has also been integrated into the Málaga Platform. This Platform Monitoring Tool is based on Zabbix, which is an open-source monitoring software solution that allows the collection of different metrics. The monitoring capabilities of Zabbix can be enhanced installing a Zabbix agent in the host to be monitored, offering a greater set of metrics and statistics. For operation of this Platform Monitoring Tool, Zabbix offers a web interface where configuration of all the capabilities can be done, as for example the addition of new hosts to monitor and new metrics to measure for every host, or the configuration of triggers to raise events with different severity.

In addition to the configuration side, the web interface provides dashboards that can be customized through different widgets and modules to divide the screen into many sections, and each of those sections showing a selected graph, event, map, or other specific components. In Figure 26 below an example of the dashboard for the Málaga Platform can be seen, where a network map shows the different network components and its status, a module in the higher right part shows also the status of each component in relation with a set of triggers, another module under it list the problems raised over time and its severity, and in addition two graphs are shown, one for one EPC network traffic, and another one for a 5GC response time. Apart from the customized dashboards, every host has a specific page where all its metrics and graphs can be seen. An example of this is shown in Figure 27 for one of the platform's EPCs.

Figure 26. Málaga Platform Monitoring Tool main dashboard

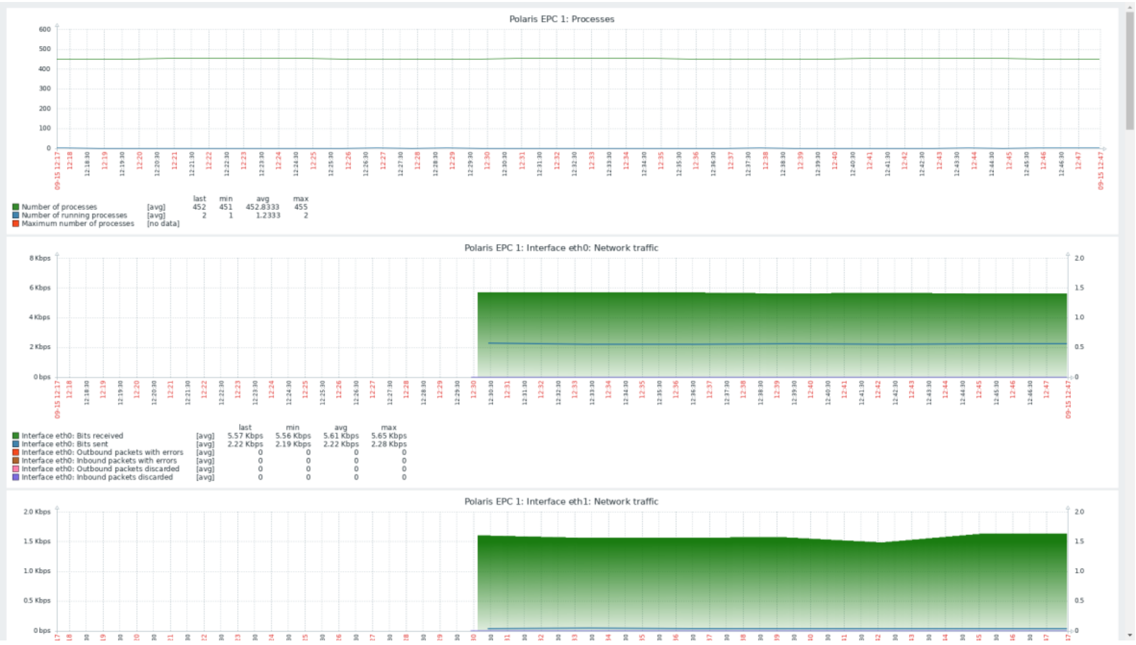

Figure 27. Specific graphs for the Polaris EPC 1 shown in the Málaga Platform Monitoring Tool

With this tool the focus is to have a place where one can check the status of the whole platform quickly, and also trace a problem in a specific part of the network or a specific component. This will help greatly not to miss any problem in the platform and also with the corresponding troubleshooting. The Málaga Platform Monitoring Tool has been designed and integrated in the Málaga Platform as an extension of the initial monitoring planned, and it will be extended as new components join the platform, and it will also be tailored to the specific monitoring needs the platform has at any given time.

3. MALAGA USE CASES-SPECIFIC EXTENSIONS

Each 5GENESIS platform focuses on the validation of a subset of 5G KPIs. In particular, as introduced in deliverables D2.1[1], D2.2[2] and D2.3[3], Málaga Platform focuses on measurements on latency, capacity, speed, availability, and service creation time. The setups described in previous sections are oriented to analyze these KPIs in controlled environments. The three uses cases defined in the Málaga Platform will conduct the validation of relevant 5G KPIs in realistic scenarios, which will involve both the Málaga Police Department and final users. Such validation is part of WP6 responsibilities, including the experimentation and showcasing activities.

3.1. Use Cases Target Deployment

3.1.1. Use Case 1 – Wireless Video in Large Scale Event

This use case intends to enhance the functionality of the video security service that Málaga Police Department manages in the city center. Málaga Police operates a set of video cameras deployed in the city that are connected to a main control room, providing additional security to the areas where the Police acts. 5GENESIS' Málaga Platform has been working on two scenarios to enhance this service.

The first one consists in the deployment of portable cameras with 4G/5G capability, which allows to easily extend and improve the fix cameras coverage for specific events. The second scenario included in this use case consists in the access of the policemen to the real-time video of the cameras while they are on the street and not in the control room. For this matter, the cameras must be able to offer the high-quality video in the platform's network, and policemen must have UEs (such as tablets or smartphones) with 4G/5G connectivity to watch the real-time video of the different cameras.

With Release B, this use case started to include some interaction with the city center while making use of an indoor deployment at Ada Byron building for experimentation while the final setup was completely developed and ready. For Release C some improvements and additions have taken place, finishing the use case integration into the platform. Those can be summarized as follows:

- Interconnection of UMA lab (site 1) with city center police video cameras and Police Emergency Center (site 4).
- Integration of new software and equipment to allow the achievement of both scenarios, which will be detailed below.
- Experimentation and validation of both scenarios of the use case using both smartphones and portable LTE cameras, as can be seen in Figure 28 and Figure 29.
- Use case demonstrated as part of a preliminary showcase in Málaga city center with the participation of UMA, TID, and MOM. More details on this will be part of the corresponding WP6 deliverable.

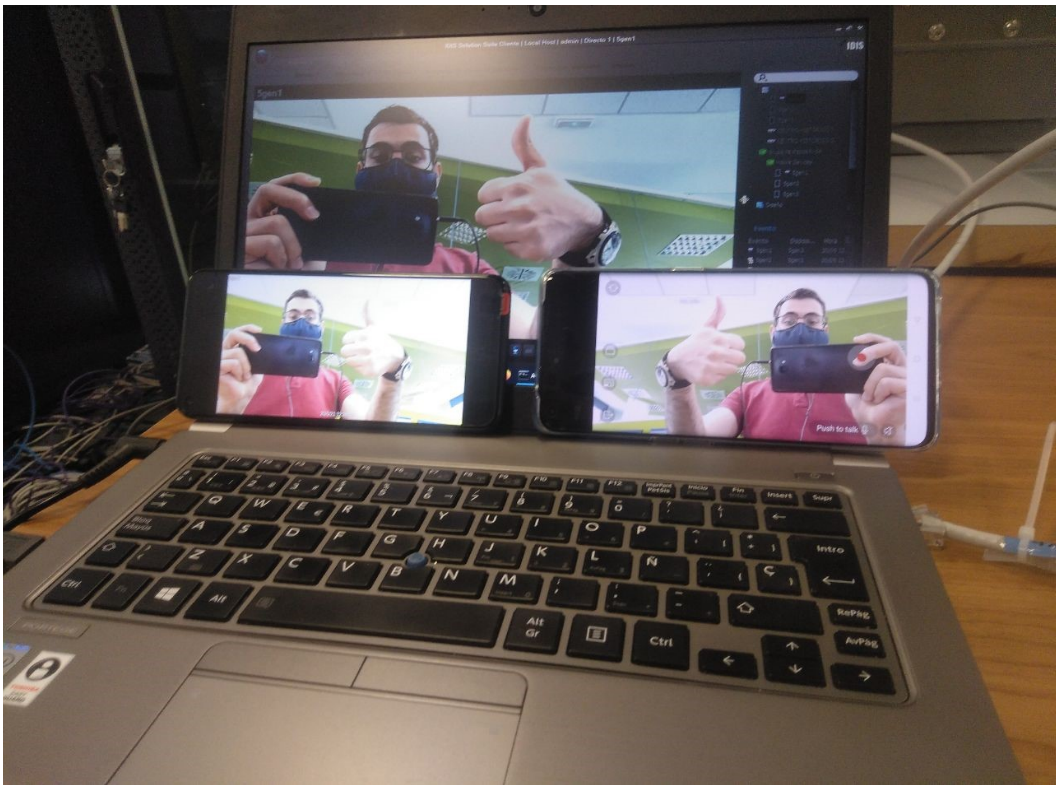

Figure 28: Experiment showing video streaming from 5G NSA smartphone (right) to PC and 5G NSA smartphone in Málaga Platform's 4G/5G network.

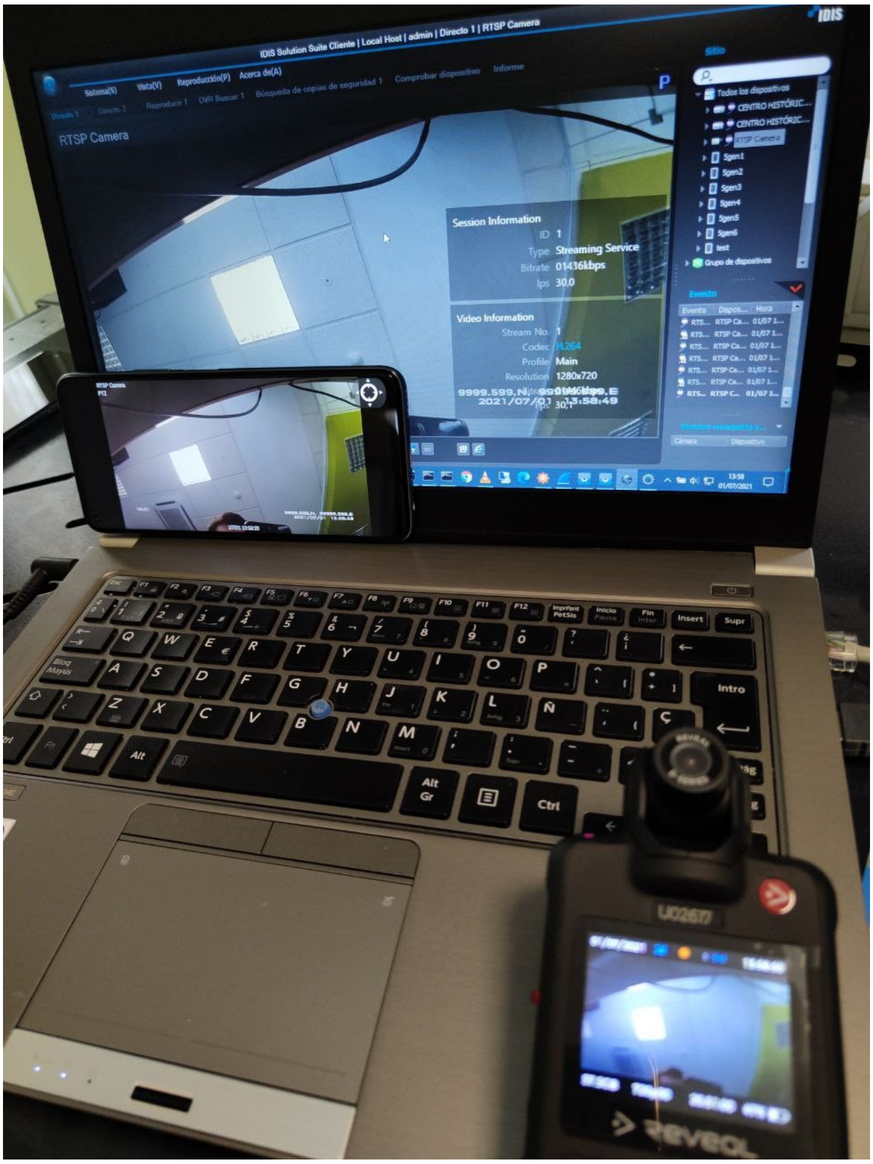

Figure 29: Experiment showing video streaming from LTE portable camera (lower right) to PC and smartphone in Málaga Platform's 4G/5G network.

Use Case 1 Components and Technology

As mentioned, a number of components have been added to the Málaga Platform in order to fully support this use case, including some new additions for Release C to finish its complete readyness. All the components related to the use case, highlighting the ones included for Release C, are detailed below:

- **IDIS video cameras.** Fixed IP video cameras for outdoor operation, which include capabilities such as video resolution up to 4k UHD or H.265/H.264/JPEG compression. These cameras are part of the existing Police surveillance system in the city center, a portion of which has been interconnected to 5GENESIS Málaga Platform for the execution of this use case. In previous releases of the platform one unit of these cameras was deployed indoor in the lab environment for its testing, but since the interconnection with the city center camera deployment is now in place, it is not necessary anymore and now the experimentation takes place with the real Police's outdoor deployment in the city center.

Figure 30: IDIS video camera

- **IDIS Solution Suite and IDIS Solution Suite Mobile**. IDIS, as CCTV solution provider for the Málaga Police, offers a set of software to manage the video cameras deployment. Specifically, IDIS Solution Suite is the software used at the Police Emergency Center to monitor and manage the different cameras installed through the city. This software includes some interesting capabilities such as recording service or video analitycs service, but those are out of the scope of this use case. In addition, IDIS Solution Suite Mobile is an application for smartphones that allows to connect to any IDIS Solution Suite running in the network and watch in real-time any of the cameras available in that instance of the Solution Suite. This application has been tested successfully in the platform and is the one used to support the second scenario of the use case, that is, to provide the capability to access the real-time video to any UE connected to Málaga Platform 4G/5G network.

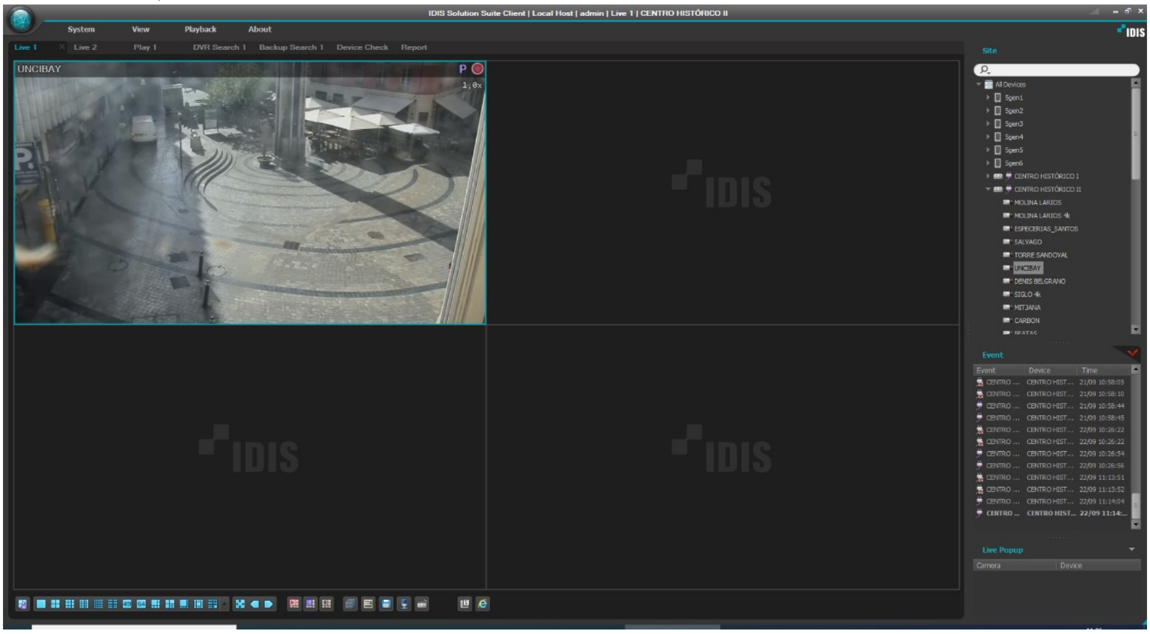

Figure 31: IDIS Solution Suite main screen

- **IDIS Mobile Camera app**. This application developed by the same vendor allows to use a smartphone as a source of video streaming, which makes feasible the use of UEs as portable 4G/5G cameras, covering the first scenario of the use case. UEs using this app can be registered as video devices at the IDIS Solution Suite available in the network so the video that the smartphone is recording can be received in real-time at the PC running the Solution Suite or any UE running the Solution Suite Mobile as if it was a normal fix camera.

- **4G/5G Portable cameras.** This equipment also covers the support for the first scenario of the use case. Apart from the use of 4G/5G smartphones using the IDIS Mobile Camera app previously explained, Málaga Platform has also tested an LTE portable camera as specific equipment for this scenario. This testing has been done with a Reveal D7 LTE capable portable camera, which can be seen in Figure 32, and the suitability of this equipment for the use case has been validated using the platform's 4G/5G network. In fact, the LTE portable camera can be registered at IDIS Solution Suite to be seen along the rest of the cameras, which also allows for a UE running IDIS Solution Suite Mobile to see the portable camera's video streaming, so it has been checked that the Reveal D7 camera can be completely integrated with the rest of the use case setup.

Figure 32: LTE portable camera tested at Málaga Platform

Use Case 1 Topology and Architecture

The target final deployment of Use case 1 is presented in Figure 33. It represents both scenarios previously explained in the beginning of this section, including the deployment of portable cameras and the streaming of the video to UEs, along with the commercial users that will use the network at the same time (but managed by their MNO). Figure 34 shows more detail about the architecture in the UMA Lab for this use case. This target deployment has not changed since its initial design, and in Release C the platform has achieved to be compliant with what was designed to fully support the use case. The use case has been tested using the main setup of the platform, named setup 1. Full E2E 4G & 5G in Table 3.

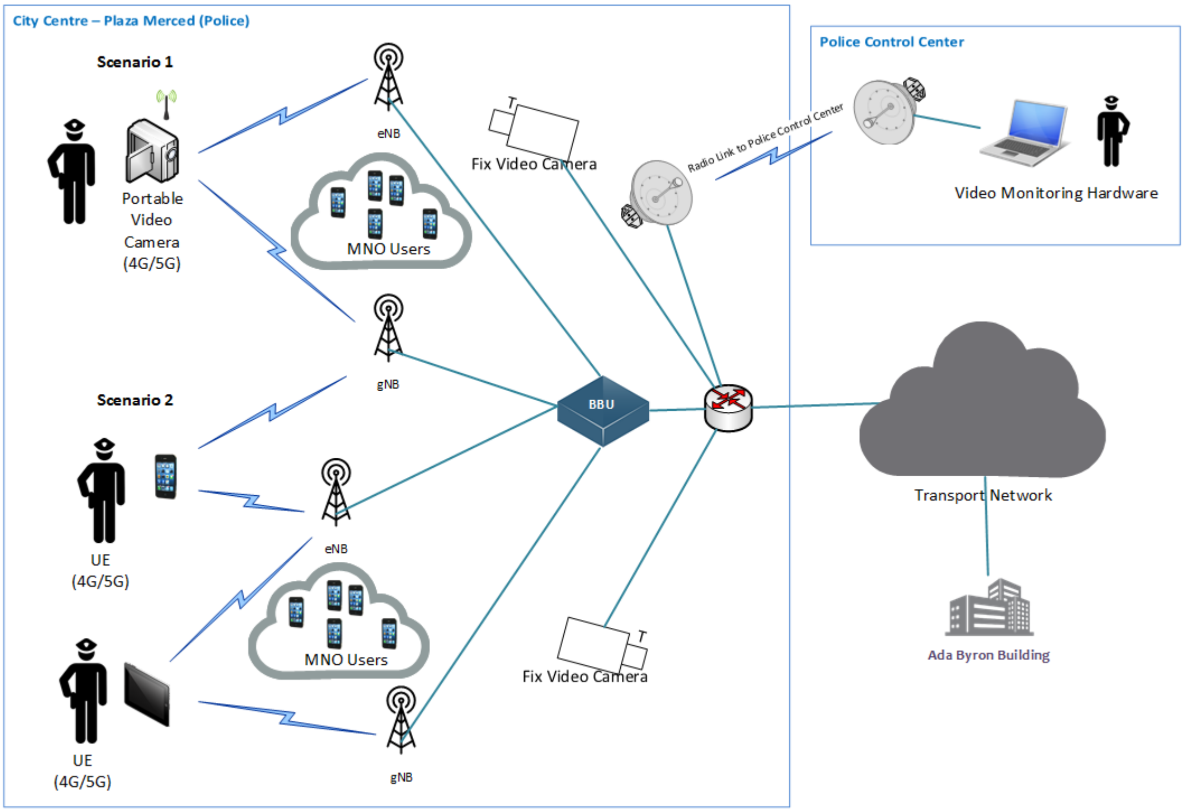

Figure 33: Use case 1 Final Deployment

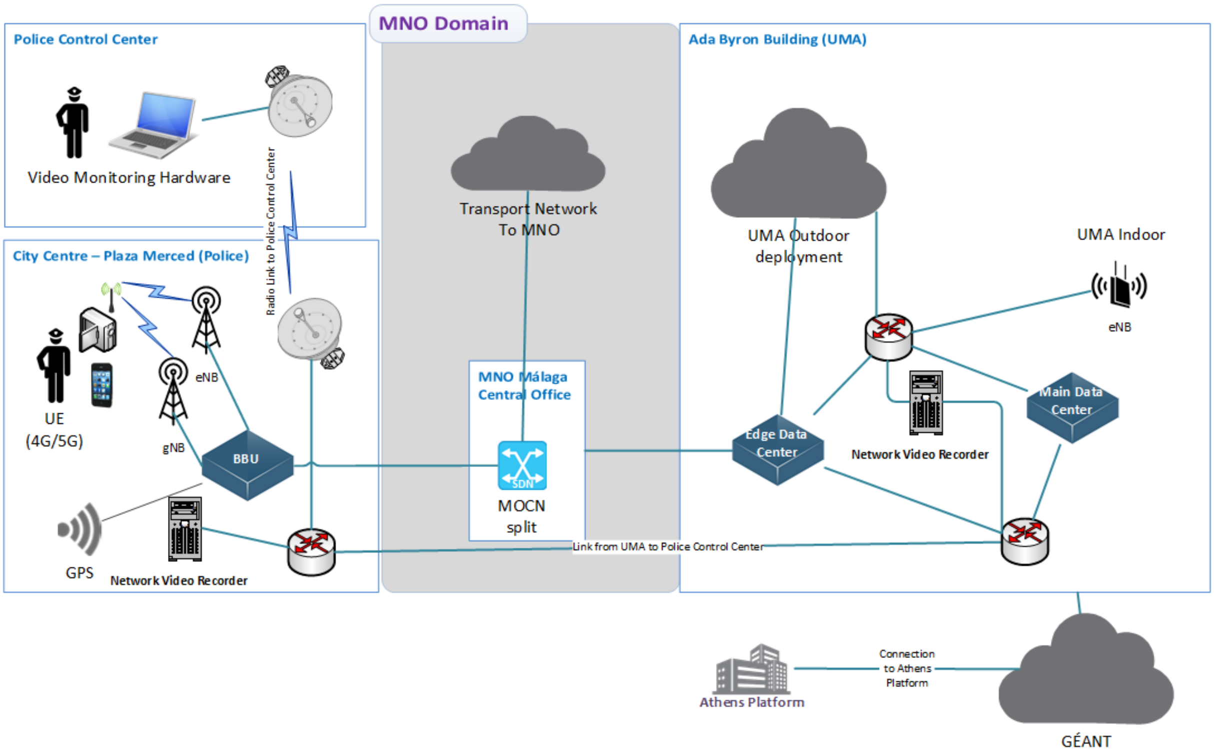

Figure 34: Use Case 1 outdoor experiment setup

3.1.2. Use Case 2 – Multimedia Mission Critical Services

Use Case 2 Components and Technology

This subsection describes the components and technologies to support the Mission Critical Services (MCS) Use Case 2 which, using voice services, instant messaging, video communication and emergency calls, will provide the means to validate some of the Málaga Platform targeted 5G KPIs.

The 5G components which are deployed on the Málaga Platform to support this use case are described in the following section.

Infrastructure components

- **MCS Server:** the MCS Server provides the control and management of voice, video and data communications for both private and group calls. This functionality is divided into Controlling Server(s) and Participating Server(s):
  - The MCS Controlling Server is responsible for:
    - Communication control (e.g. policy enforcement for participation in the MCS group communications) towards all the MCS users of the communication group (i.e. a group of users capable to communicate with the rest of users at once), as well as private communication;
    - Managing floor control entity for a group communication and private communication;
    - Managing media handling entity.
  - The MCS Participating Server is responsible for:
    - Communication control (e.g. authorization for participation in the MCS communications) to its MCS users for group communication and private communication;
    - Relaying the communication control and floor control messages between the MCS client and the MCS server performing the controlling role;
    - Media handling for its MCS users for unicast media;
- **Identity Management Server (IdMS):** this server is provisioned with the user’s MC ID, MCPTT ID and password. The user is also provisioned with its MC ID and credentials. The IdMS authenticates an MCS user by verifying its credentials.
- **Key Management Server (KMS):** this server stores and distributes the security information such as encryption keys for private and group calls to the key management client on the UE, to the group management server and to the MCS servers. It enables integrity and confidentiality of the signaling and media flows. The encryption keys are generated by a separate tool and imported to the KMS.
- **Group Management Server (GMS):** this server is used to perform the management of communication groups. It manages the group call policy information and media policy information to be used by a given UE.
- **Configuration Management Server (CMS):** this server is used to configure the MCS application with non-group management related information and configure data on the configuration management client. The configuration management server manages MCS

configurations (e.g. user profile, UE configuration, functional aliases and service configuration).

- **SIP Core:** it is the entity responsible for registration, service selection and routing in the SIP signaling control plane.
- **HTTP Proxy:** acts as the proxy for all hypertext transactions between the HTTP clients (on the mobile device) and HTTP servers. The HTTP proxy terminates the TLS session with the HTTP client of the MCPTT UE in order to allow the HTTP client to establish a single TLS session for hypertext transactions with multiple HTTP servers.
- **MCS Configuration Server:** it is used by the MCS system administrators for the management of tactical and technical configuration information.
- **IP Networking Services:**
  - STUN Server: it enables MCS clients to discover the IP addresses and ports that must be used for MCS services in case of NAT traversal.
  - DNS Server: it is used by MCS servers to resolve IP addresses of hosts.
  - DHCP Server: it is used to provide IP addresses to the MCS servers.
  - NTP Server: it is used for time synchronization of MCS servers.

Client components

- **MCS Dispatcher application:** it runs on any devices with a standard web browser such as Firefox or Google Chrome. Thanks to the MCS Dispatcher application, PPDR dispatcher users are able to use and experiment with Mission Critical Services (MCS) enabling the following functionalities:
  - Group and individual voice calls.

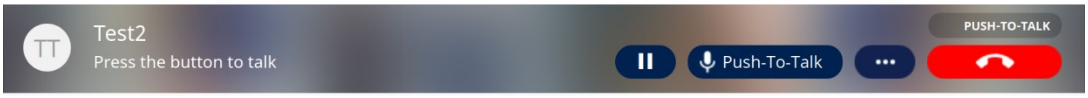

Figure 35: Airbus MCS Dispatcher MCPTT command

  - Group and individual multimedia messaging.

Figure 36: Airbus MCS Dispatcher multimedia messaging

- Individual video calls.

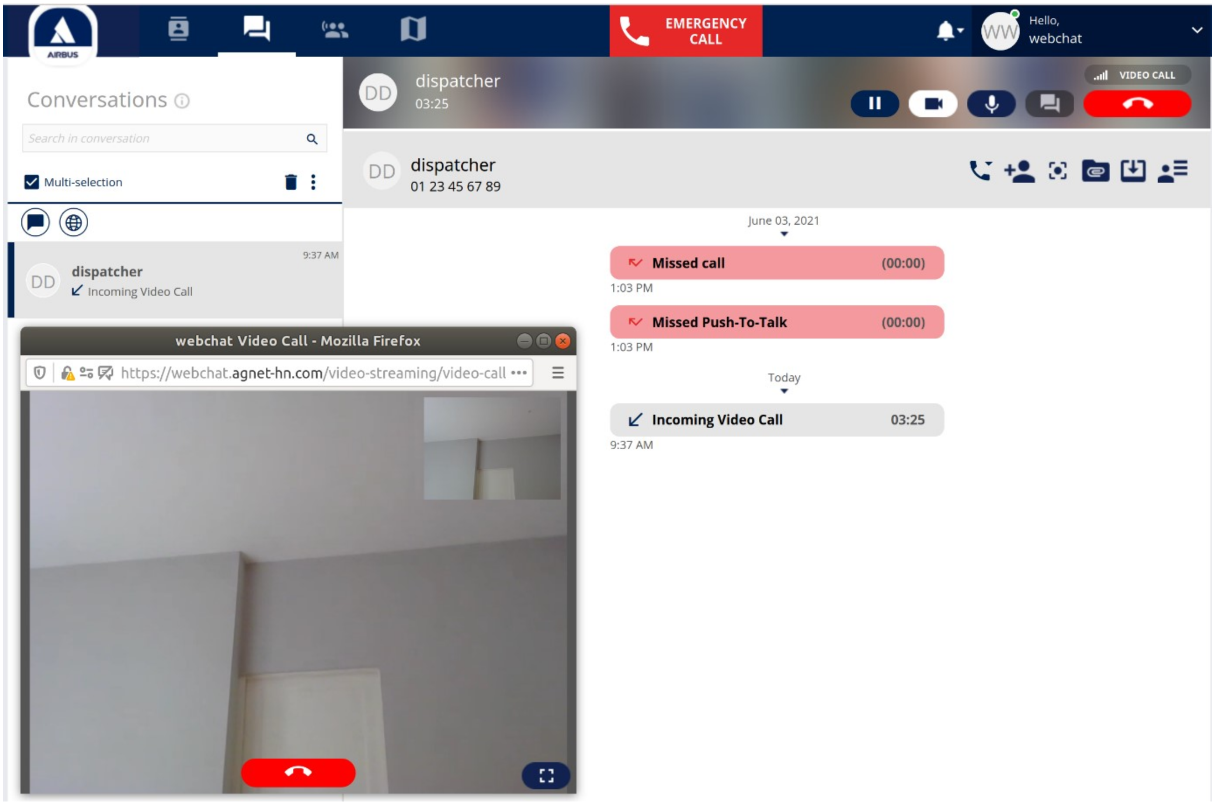

Figure 37: Airbus MCS Dispatcher Video call

- Emergency calls.

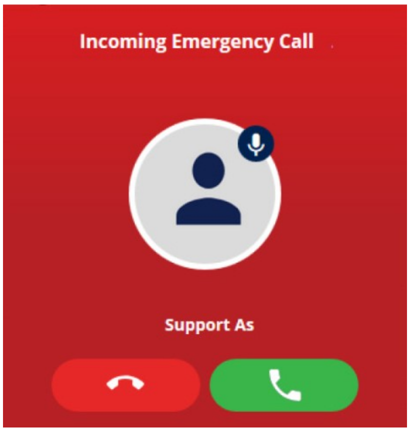

Figure 38: Airbus MCS Dispatcher Incoming Emergency call user interface

Figure 39: Airbus MCS Dispatcher Emergency call commands

- o Location and map services.

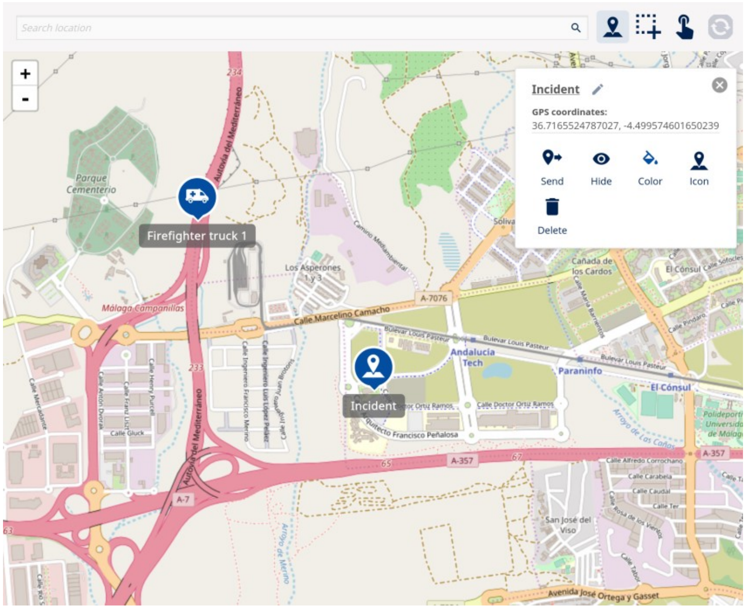

Figure 40: Airbus MCS Dispatcher map with units and points of interest

- **MCS Client application:** it runs on the mobile device. It implements the MCS protocols, the MCS client entities which are communicating with the servers, and the graphical user interface. Thanks to the MCS Client application, PPDR mobile users are able to use and experiment with Mission Critical Services (MCS) application enabling the following functionalities:
  - o Group and individual voice calls.

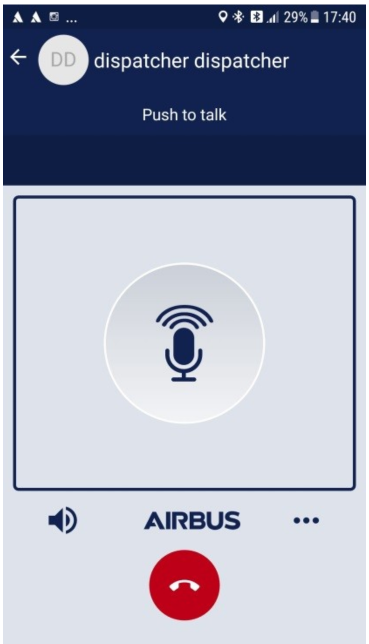

Figure 41: Airbus MCS Client MCPTT call

- Group and individual multimedia messaging.

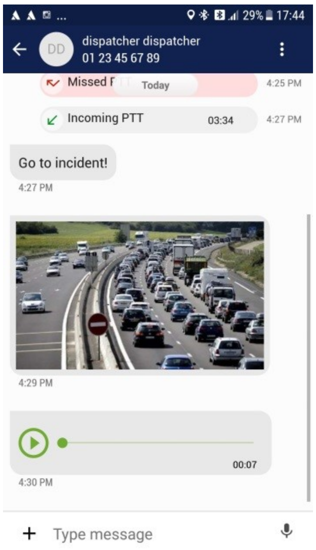

Figure 42: Airbus MCS Client multimedia messaging

- Individual video calls.

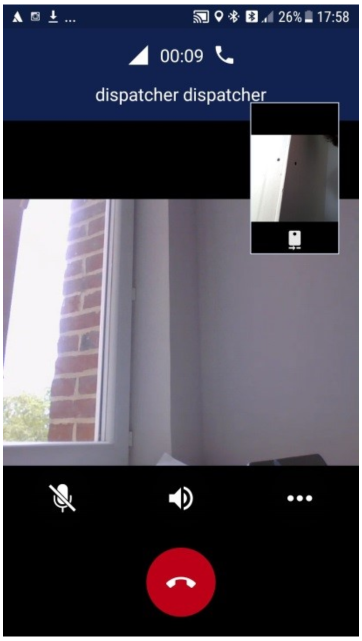

Figure 43: Airbus MCS Client video call

- Emergency calls.

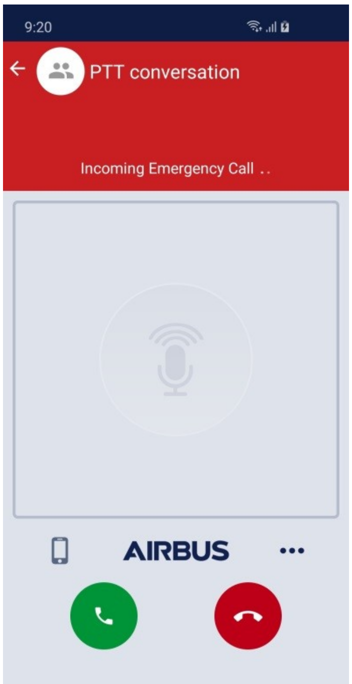

Figure 44: Airbus MCS Client emergency call

- Location and map services.

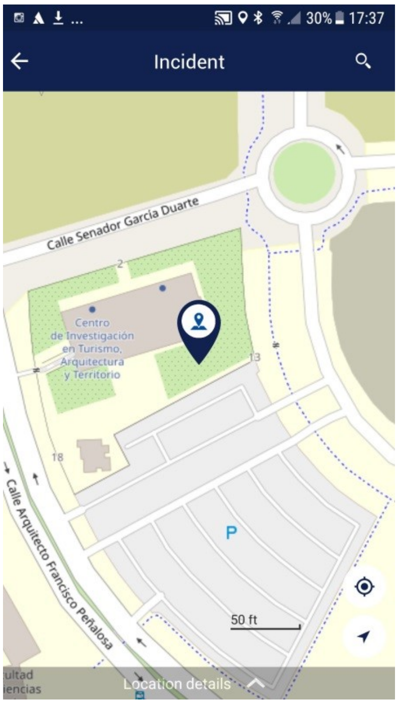

Figure 45: Airbus MCS Client location and map

- Mobile Devices:
  - Samsung Galaxy S8 running the MCS Client application.

Figure 46: Samsung Galaxy S8 running the MCS Client Application

- 5G UEs, as the Xiaomi Mi Mix 3 5G and Samsung S10 5G, will be tested with the MCS Client application.
- The Airbus Tactilon Dabat is a rugged smartphone which supports both broadband and TETRA networks. In the scope of this project, only the broadband functionality will be used. The Airbus Tactilon Dabat runs the Android operating system and mobile applications, such as the MCS client application.

Figure 47: The Airbus Tactilon Dabat Device running the MCS Client Application

Several components and functionalities have been added or enhanced on the Málaga Platform in Release C in order to complete use case 2. The new components are detailed below:

- **MCS Map Server:** this component stores the map information and delivers the map static tiles in real-time to MCS mobile user and dispatcher applications. The following picture shows the geolocation of units and points of interest:

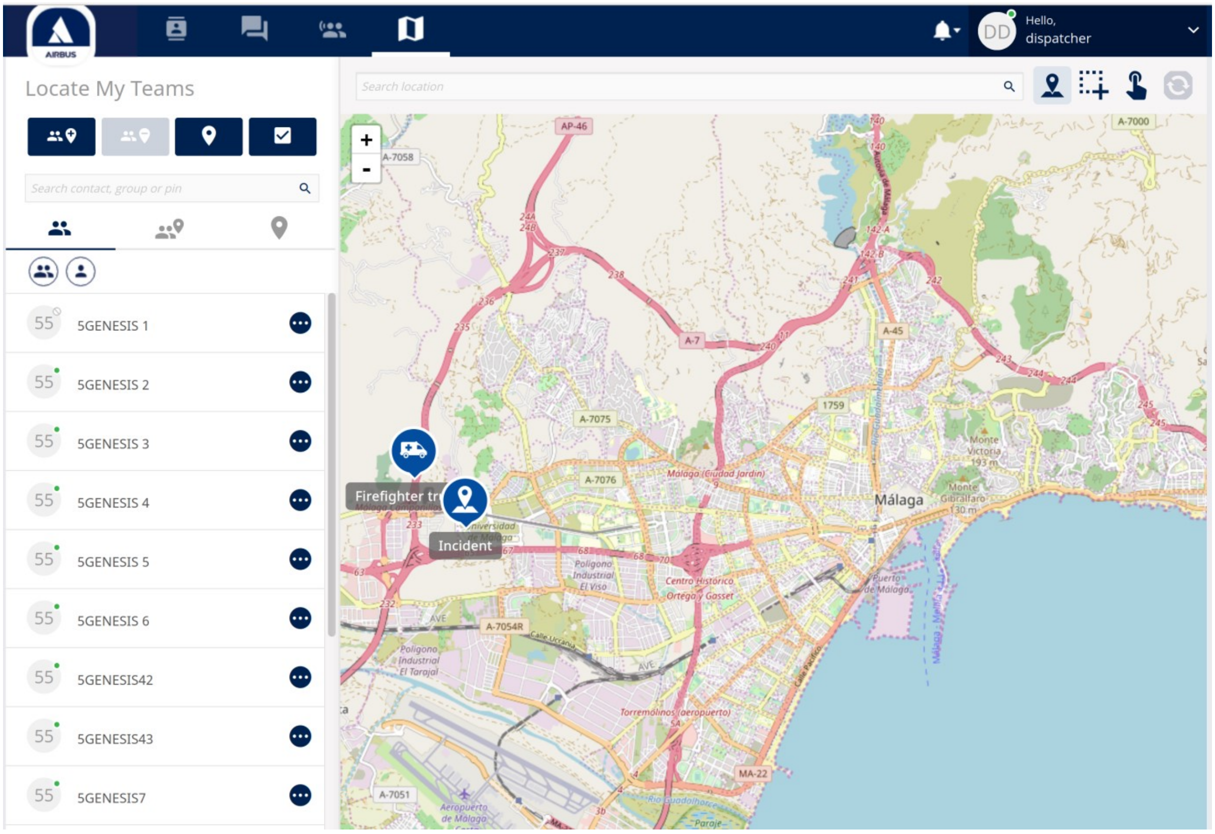

Figure 48: Airbus MCS map

- **MCS QoS Management module:** this module implements the Diameter protocol messages as defined for the 3GPP Rx interface and enables the integration with the Policy and Charging Rules Function (PCRF). Successful quality of service (QoS) management has been demonstrated and dedicated bearers with QCI 65 are established each time an MCPTT user takes the floor in a call.

- **MCS Server VNF:** the MCS server has been deployed as a VNF. The MCS Server VNF runs as an Openstack image as shown in the following Figure 49:

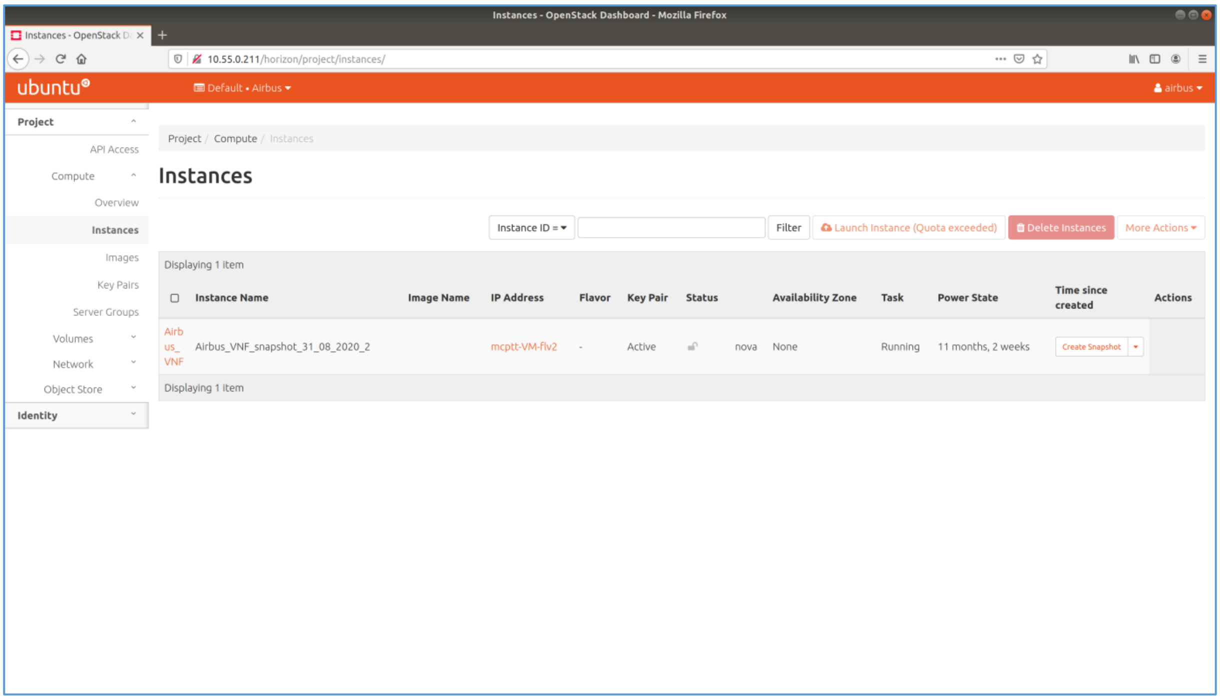

Figure 49: Airbus MCS VNF instance in Openstack

- **MCS Server client – server interface interoperability:** the Airbus MCS Server was configured in order to test the interoperability with the Nemergent client for MCPTT group calls. The support of chat and group calls was tested successfully.

Use Case 2 Topology and Architecture

The Use case 2 deployment architecture for release C is shown in Figure 50. The figure shows where the components, which have been described previously, are installed. The MCS infrastructure components have been deployed as both virtual machines on a hardware server and as a Virtualized Network Function (VNF) using Openstack.

During the course of the project, the MCS services have been able to run over both 4G and 5G in order to perform KPIs measurements and comparison between 4G and 5G.

The MCS services have been enabled on both the UMA indoor and outdoor setup.

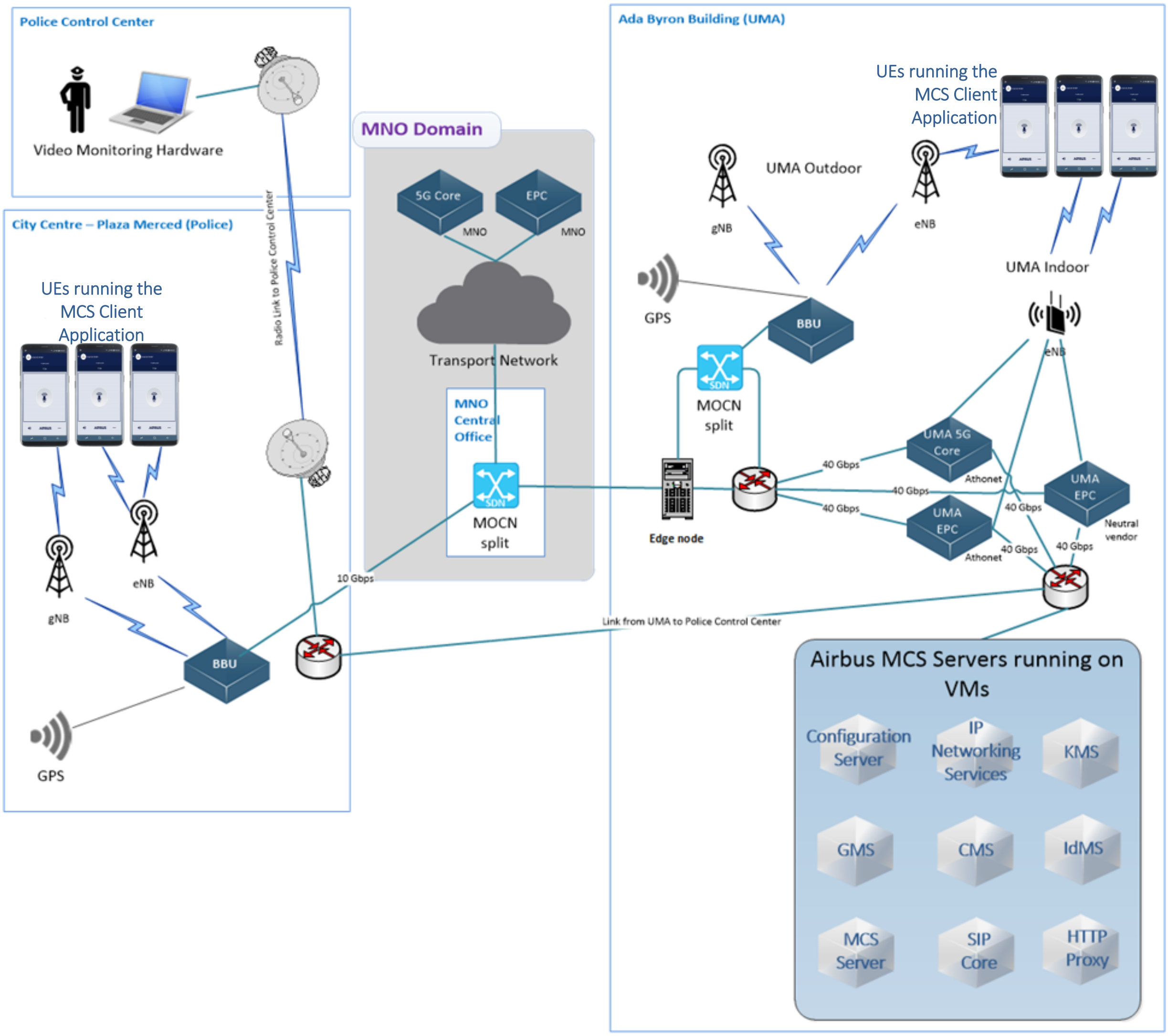

Figure 50: Use Case 2 Deployment Architecture

3.1.3. Use Case 3 – Edge-based Mission Critical Services

Use Case 3 Components and Technology

In the Use case 3, Nemergent provides its technology to run standardized mission critical services, both behind the core network or having an Edge infrastructure in place. The provided and integrated products can be divided in two main sides: the server-side and the client-side.

Server-side

The Nemergent MCS/MCX server-side provides the application-level components required to deploy the full 3GPP Rel15+ Mission Critical Push-To-Talk (MCPTT) service, together with Mission Critical Video (MCVideo) and Mission Critical Data (MCData) services. The main standardized mission critical architecture and components were first described in 3GPP Rel13 MCPTT definition and later inherited in following releases. This architecture comprises MCPTT/MCS application servers (ASs) –both controlling and participating - and MCPTT/MCS UEs deployed over a MCPTT-compliant SIP Core (e.g. IMS core) and a professional LTE access network that supports QoS-enabled unicast connectivity with PCC and native multicast support with eMBMS.

Other basic nodes and interfaces, such as MCPTT/MCS configuration and management servers, are also included in the solution, namely the Identity, Group, Configuration and Key management servers. Even though the Nemergent solutions could work as a simple E2E OTT solution (without network coupling interfaces), the Málaga Platform supports Public Safety requirements in terms of QoS.

The server-side of Nemergent's mission critical solution also includes mechanisms more related to administration and management and all the underlying procedures to support this management appropriately. Being more precise, the solution also includes user registration, authorization, affiliation, location configuration provisioning and location reporting.

These features enable that authorized MCS users (e.g., system administrator, dispatcher…) can manage the system configuration. To this end, the solution also includes an OAM interface intended to provide easy OAM and configuration/troubleshooting operations and being capable of managing MCS users and groups creation, deletion, modification and configuration (implements the CSC interfaces according to 3GPP, and private OAM interfaces for provision the IMS system).

The Nemergent MCS system is deployed as a series of server components, each of them fulfilling a different functional role. All the server components may be deployed as standalone services in the host system, as an all-in-one Virtual Machine or a VNF (desired setup in Málaga Platform).

The following figure contains the explained components and the target interfaces to be integrated with the LTE or 5G (the final way to interconnect still needs to be standardized) side to be considered standardized mission critical services, highlighting in orange the modules provided by Nemergent in this Use case 3.

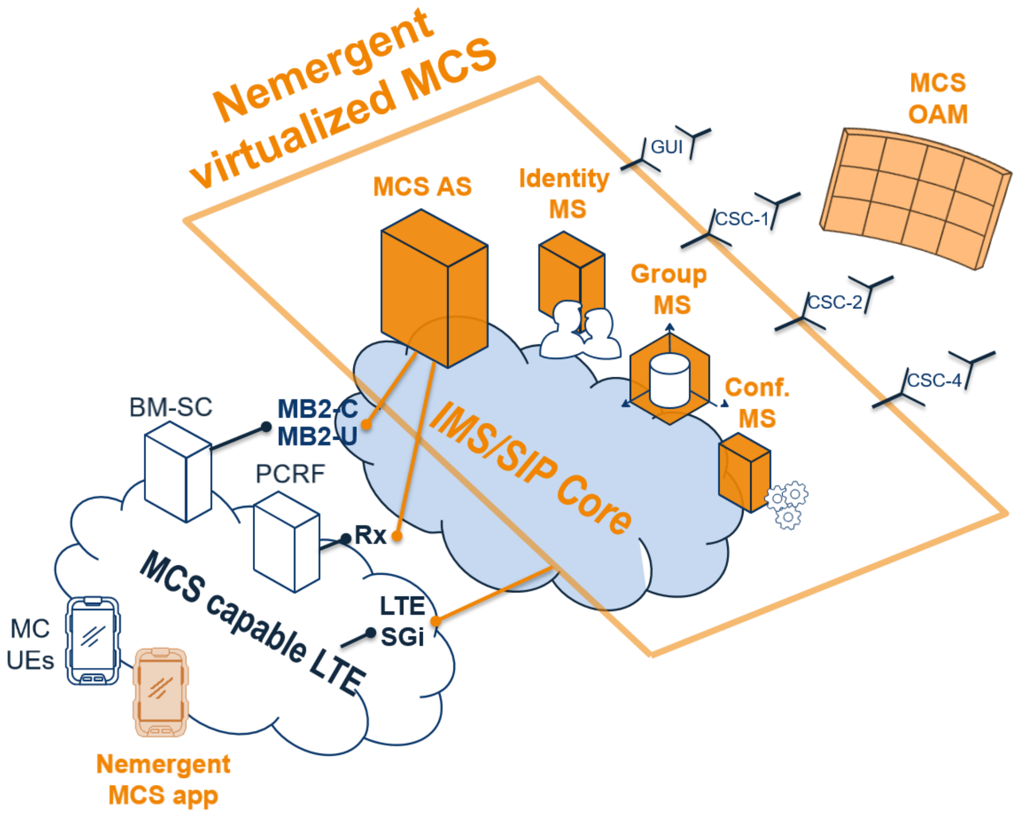

Figure 51: MCPTT/MCS Basic Components and Integration Interface

Release C has included changes in the VNF to make it work in two different scenarios or conditions:

- Single IP or all-in-one deployment of all components (Release A and B)
- Multi-IP support in an automatic way in deployment time and adjustment and auto-configuration of components based on assigned interfaces. This method is used to divide the components and their tasks of protocols in different subnets. Thus, being able to configure the VNF to have 5 subnets in total: QoS management subnet, internal subnet, external subnet towards the UEs, management subnet and finally the interconnection subnet with other MCS instances server-to-server using MCX-1 interface.

The interconnection capability has been included in Release C to deploy cross-platform MCS. The current state is that the feature is integrated but lacks validation at this point.

Client-side

The Nemergent MCS client-side is divided by two main components: the selected UE (HW) and the MCS client App running on it (SW).

Taking into account the specific needs of Use case 3 in Málaga Platform, Sonim XP8 [13] devices were provided in release A. This UE version is tough and endurable in its form and fully supports the required frequency bands, QCIs and eMBMS in order to be 3GPP compliant. Release B and Release C have been responsible for adding new 5G NSA/SA UEs where the same MCS client

[13] https://sonimtech.com/xp8/

will be run, so that 4G and 5G UEs communicate with each other using the same Nemergent MCS client SW.

As for the MCS client, Nemergent introduces all the functionalities with 4 different components. Thus, a whole MCS Client System consists of a GUI, an SDK and two service plugins.

- MCS SDK: Main component of the client-side that carries the majority of the workload and abstracts the logic for the upper and below components through its northbound and southbound interfaces.
- MCS GUI: It is the GUI whereby the user could use the preselected client and all the functionalities offered by the App (enabled by the supporting SDK and plugin layers).
- Provisioning Tool App: It allows the user to select one of the pre-loaded client's profiles. Moreover, the user is able to edit the proxy of the IMS core address and port so as to reach the MCPTT/MCS Servers.
- eMBMS middleware: It makes possible the communication and synchronization between the eMBMS API of the UE and the MCS SDK.

In order to better understand the relation between the abovementioned components, the following figure represents the relation between them and the existing communication interfaces.

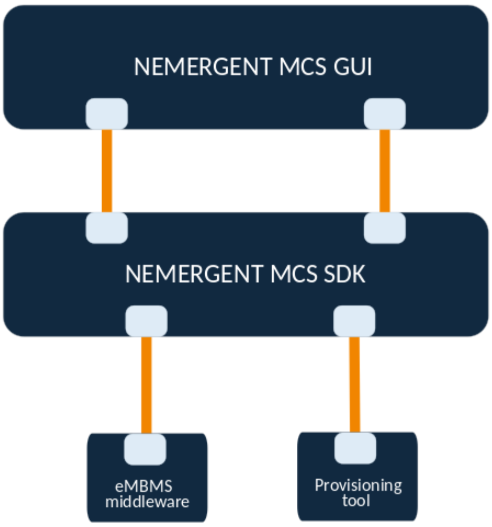

Figure 52: MCS Client Building Blocks

Due to the full support of 3GPP standardized QCIs in all HW and SW components, the MCS system can establish the DIAMETER connection (Rx interface) to the PCRF to handle QoS in default and dedicated bearers.

Release C has included upgrades of the client to support MCVideo with standardized 3GPP-compliant Transmission Control in addition to many additional re-branding or App formatting changes and product evolutions to improve experience such as seamless reconnection, adjustments to Police of Málaga needs and easier interaction in general.

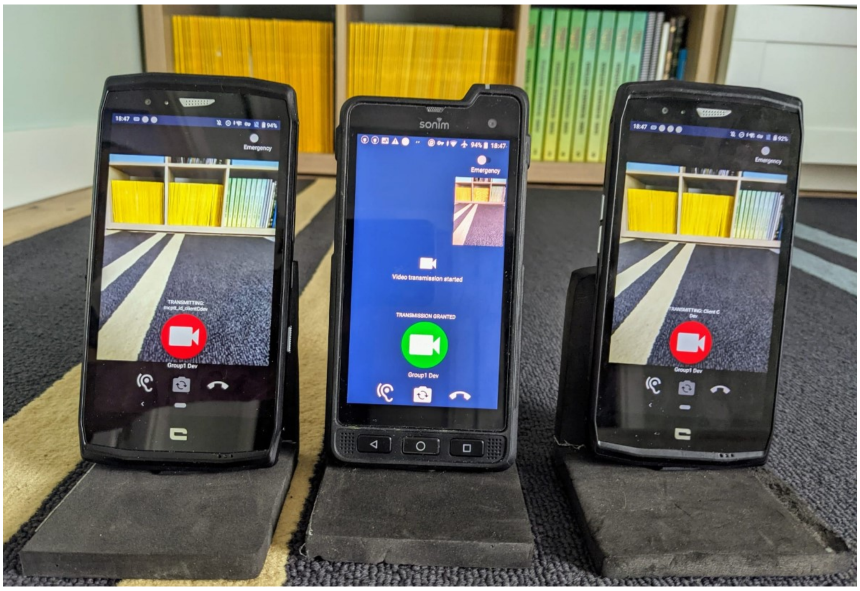

Figure 53: Video transmission with transmission control (overall view)

Use case 3 Topology and Architecture

The Use case 3 topology and architecture has evolved throughout the different releases. While the last objective is the full 5G integration and orchestration of the services outdoor in real-world scenarios where the first responders most require the involvement of new public safety technology, the release A focused on the integration of Nemergent's MCS server-side, the Athonet's EPC, the Nokia's small cell and the Nemergent's MCS client-side indoor in the Ada Byron building. Release B was responsible for introducing new 5G components and evolving the NSA mode of the platform while the Use Case 3 functionalities are tested and validated. Release C is responsible for introducing new 5G components evolutions towards SA mode of the platform while the Use Case 3 functionalities are tested and validated.

The idea of the Use Case is to evolve to outdoor deployment little by little by integrating with the available 5G equipment. Besides, the MCS service has been deployed and validated behind the Edge server in order to ensure high bandwidth to MCS with high demand such as MCVideo. The final Use Case 3 setup looks as the following integrated figure:

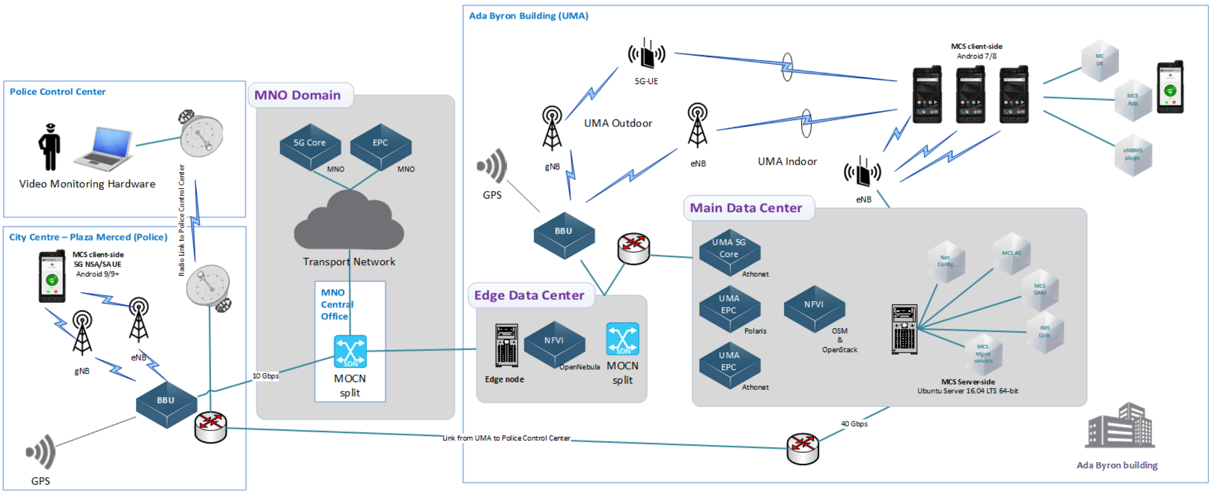

Figure 54: Advanced Use Case 3 Deployment

4. MALAGA PLATFORM EVOLUTION IN 5GENESIS

4.1. Evolution Timeline

4.1.1. Instantiation of the 5GENESIS Architecture

Through the proposition of an experimentation reference architecture common to all the platforms that are members of the project, 5GENESIS aims at establishing a 5G Experimentation Facility that spans over this set of fully interoperable platforms with diverse capabilities.

The diagram below, Figure 55, outlines the reference architecture planned for all of the 5GENESIS facilities. The figure is colored showing the instantiation evolution during the three integration cycles of the project.

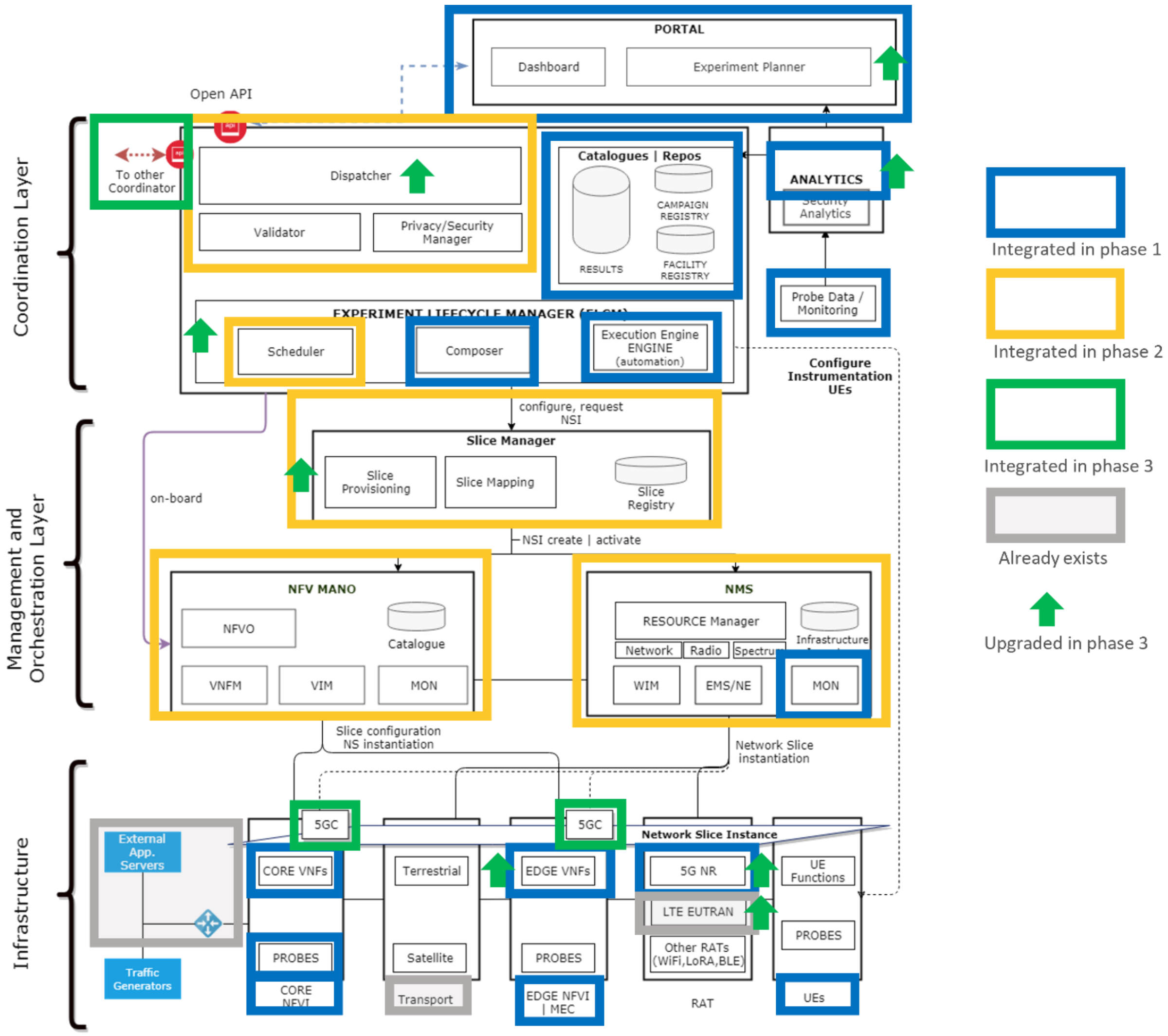

Figure 55: The Málaga Platform Evolution based on 5GENESIS Reference Architecture

The blue boxes of the diagram represent the integrations done during phase 1, which focused on the support of the main functionality in the coordination layer, that is, the required functionality to run experiments with the infrastructure already present in the platform. Included in that release were an initial version of the portal and the ELCM capable of defining and automating the execution of experiments, along with a basic result monitoring capability and the possibility of presenting KPIs to an experimenter. Finally, some servers, edge nodes and 5G NR equipment was integrated into the Málaga Platform as part of this first phase in relation to the infrastructure expansion.

The integrations that took place during the second phase and that were included in the Release B of the platform are marked in yellow boxes. In that release most of the expected components for the final E2E platform were introduced, including support for slicing with 5G NR and 5G core thanks to the slice manager integration, support for automation and KPI computation through the NMS, and management & orchestration through MANO NFV. Additionally, some previously missing parts of the coordination layer were added, such as Dispatcher or the ELCM scheduler.

For the last phase, phase 3, which gives as result the Release C of the platform, integrations are marked with a green box. The only pending integrations for this last release were the interconnection of the Coordination layer with other platforms in 5GENESIS, which has been completed accordingly towards Athens Platform, and the integration of 5G SA supporting infrastructure, as represented by the 5GC boxes, which has also been achieved.

Apart from the integrations present in the reference architecture diagram, some improvements and enhancements have also been performed to the platform, as was stated in previous sections of this document. Some achievements are strictly related to the use cases defined for Málaga Platform, and those have their own subsection below.

4.2. Phase 3 Accomplishments

As previously outlined, the work on the Málaga Platform during phase 3 has been focused on finishing pending integrations, such as the 5G SA mode support as well as on updating and refining some already existing integrations. In addition, some further integrations and updates have taken place to complete the deployment for the 3 use cases planned for the Málaga Platform as well as the interconnection with the Athens Platform. On top of these integrations, the platform has been expanded with new features, like the new transport protocol MTIP for exploiting several paths to improve reliability and latency. The list of accomplishments completed during phase 3, is as follows:

- Interconnection between Málaga and Athens Platforms
- Upgrade of 4G and 5G setups including addition of 5G Standalone Mode
- Integration of LBS system
- Integration of Open5Genesis Suite Release B
- MTIP protocol design and initial validation
- Use case 1 “Wireless video in Large Scale Event” achievements
- Use case 2 “Multimedia Mission Critical Services” achievements
- Use case 3 “Edge-based Mission Critical Services” achievements

Details on the accomplishments can be found in the following subsections. It is noted that all the achievements will be further tested during the following months and as such they will be reflected in different experiments that will take place under the WP6 tasks and they will be reported in corresponding deliverables. The achievements related to the use cases will additionally be proven successful through different trials and demonstrations, some of which have already taken place and have validated the current and complete status of the use cases implied.

4.2.1. Interconnection between Málaga and Athens Platforms

The support of Cross-Platform Experimentation was one of the pending developments and integrations for 5Genesis. To achieve this, Málaga and Athens Platforms have worked in collaboration to perform an interconnection between both of them that allows the execution of distributed experiments. The distributed experiments execution involves a set of specific actions that must be performed between the two platforms implied, including:

- Cross-platform experiment customization, request from Platform A for the execution of an experiment to Platform B,
- Experiment customization, definition of a custom cross-platform experiment by an experimenter,
- Execution synchronization, request from Platform A of information about the experiment status on the side of Platform B,
- Information exchange, request from Platform A of information about specific parameters configured in Platform B,
- Results retrieval, request from Platform A of results generated by Platform B.

The Cross-Platform experiments result of this work will be reported in the future Deliverable D4.6 “Multiplatform trial and interworking experimentation”.

The sites of both platforms that have been interconnected are the Ada Byron Research building for Málaga Platform, and the NCSRD Campus premises for Athens Platform. The interconnection has been made through GÉANT, and a set of tests making use of ping, UDP and TCP Iperf have confirmed the network performance of the link and the success of the interconnection. The results of the network performance tests have shown a mean of 60ms of delay for the ping, a maximum UDP throughput of 600 Mbps without loss for the UDP Iperf, and a TCP Throughput of between 400 and 600 Mbps. The results are detailed below in Table 8.

Table 8. Málaga and Athens Platforms interconnection network performance tests

Test	Source	Destination	Results
Ping (RTT)	Málaga	Athens	63 packets transmitted, 63 received, 0% packet loss, time 62083 ms RTT min/avg/max/mdev = 57.783/58.628/60.203/0.665 ms
Iperf UDP (UDP Throughput)	Málaga	Athens	600 Mbps with 0% loss 650 Mbps with 0.5 % loss 700 Mbps with 17 % loss 800 Mbps with 30 % loss
Iperf TCP (TCP Throughput)	Málaga	Athens	200 Mbps with 1 connection 400 – 600 Mbps with 5 simultaneous connections

4.2.2. Upgrade of 4G and 5G setups including addition of 5G Standalone Mode

The work on the 4G and 5G setups has been one of the main tasks for the infrastructure layer of the Málaga Platform, and it has given as results the final set of deployments shown previously in Table 3. The progress made in every one of the 4 final setups can be considered a separate achievement, and as such they will be briefly described separately in this subsection. A detailed description of the components and functionalities of the 4 final setups has already been provided in section 2.

The first and main setup in the platform is the called “Full End-to-end 4G & 5G”, which comprises both indoor and outdoor coverage for 4G, 5G NSA and 5G SA modes. During phase 3 this setup has integrated new equipment including network cores for 5G SA mode, new radio equipment for 5G SA sub-6Ghz indoor and for 5G SA mmW outdoor, and additionally the platform has integrated new 5G SA capable smartphones. The current status of this setup allows the concurrent operation of the different cores and radio equipment with different configurations, enabling experimentation with independent deployments inside this setup.

A new setup that has been integrated from scratch into the platform in this phase 3 is the Keysight 4G & 5G Wireless Test Platform. This deployment provides 4G, 5G NSA and 5G SA, supporting both sub- 6GHz and mmW for 5G, and its main interest for being added to the platform resides in its low-level customization capabilities. The Keysight Test Platform allows to configure and modify a great set of parameters, including some low-level ones related to the PHY layer of the protocol stack, and it also offers the possibility to emulate channel conditions for example. All those capabilities and the flexibility it provides for testing, allow to test easily and quickly configurations with different combinations of cells being aggregated, channel conditions, or LTE/5G stack parametrization, makes this a very interesting testing setup for internal research and development and also for testing very specific scenarios that would be difficult to achieve with a more commercial and much less customizable setup, such as the "Full End-to-End 4G & 5G" previously stated.

The other 2 remaining final setups in the platform are the prototypes from ECM and REL. Both of them have progressed in their development and have added new functionalities that have allowed for new testing in the platform. In the case of the ECM setup, the OpenAirInterface software it is based on, has seen much progress in different areas, but as a summary it now supports COTS UEs connections for 5G NSA and SA modes. The last and most stable release of this software has been integrated into the platform's equipment and its correct operation has been tested. For the REL setup, the equipment has also been upgraded with a new software version that now allows both DL and UL communications, and this new functionality has also been validated through tests done in the platform. Both ECM and REL setups, as prototypes in constant development, are oriented mostly to internal testing and validation of their evolution. A proof of this continuous effort on both setups development and its prototypes nature are the initial plans of interoperability among them, that needed to be dropped after some work in previous phases of the Málaga Platform, resulting in the current focus of the two setup's development as completely independent. The motivation for dropping such interoperability plans came from the involved partners analysis of the effort needed to solve some blocking issues that appeared after some initial work, being such effort excessive for the project's duration and the interest of the specific task.

4.2.3. Integration of LBS system

Since one of the KPIs associated to the Málaga Platform under the umbrella of WP6 is location accuracy, the platform's plans included the integration of some tool or system that allowed the measurement of such indicator. As part of phase 3 the platform has finally integrated an LBS solution, Creativity Software's LocationWise [22]. This solution includes all the LTE core network elements needed for LBS, along with an EMS that allows to interact with the system as a client and perform location requests along with other management operations for the system. An example of the solution's EMS showing a location estimation in a map and some other locations results can be seen in Figure 56.

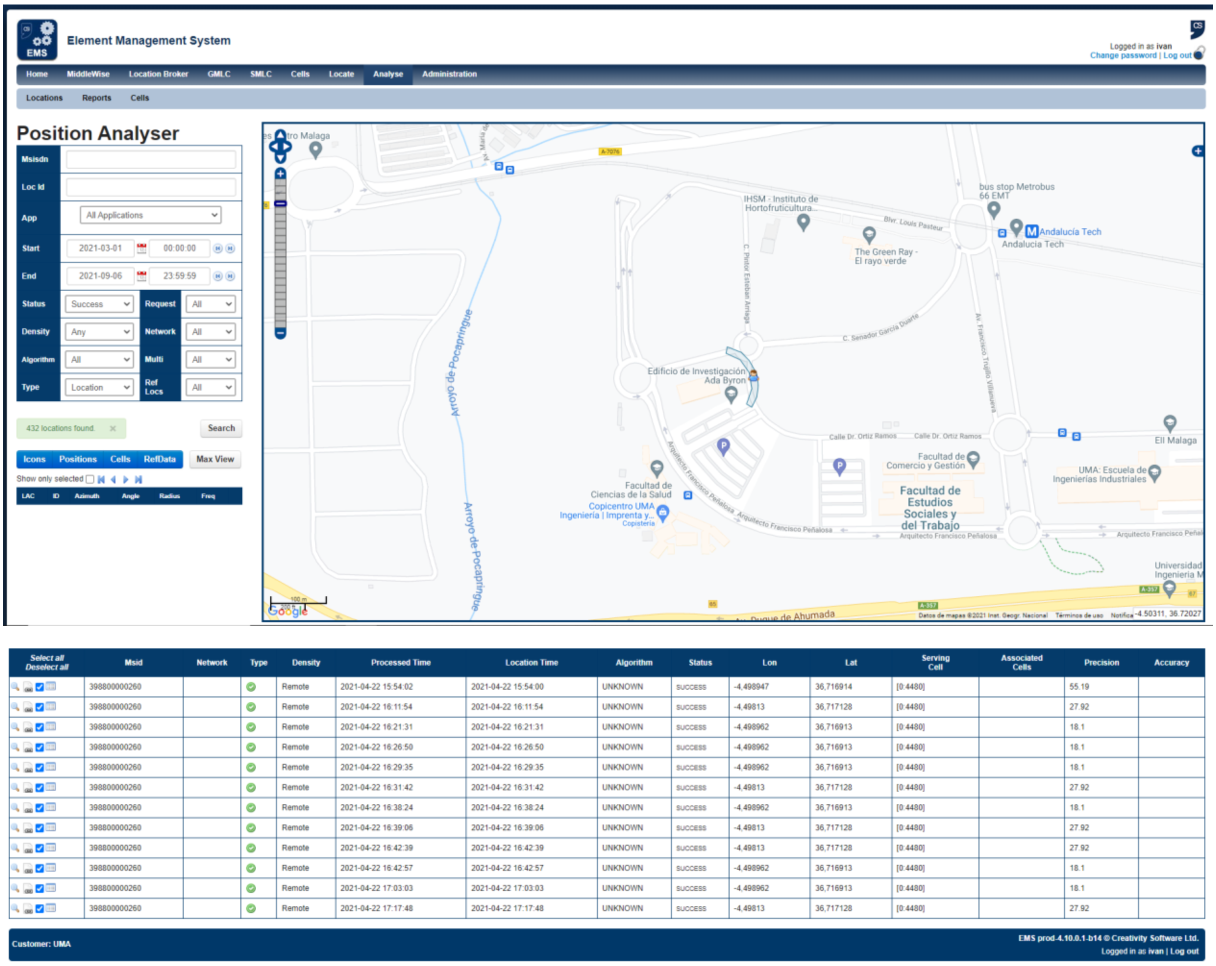

Figure 56: Example of location estimation report using LocationWise EMS

This product has been completely integrated with the platform and its EPCs, and some tests have been performed to validate its correct performance. The results of experimentation related to a new test case created to measure the associated KPI will be reported in WP6.

This integration expands the platforms functionalities with a very interesting new one, the subscriber location through LTE, including different positioning methods such as Enhanced Cell-ID (E-CID) and some of its subtypes. The successful collaboration of the Málaga Platform with Creativity Software for this integration has led to a mutual interest in a future integration of an LBS system supporting 5G related positioning technology, which will further improve the Platform's capabilities.

4.2.4. Integration of Open5Genesis Suite Release B

During Phase 3, the existing Open5Genesis Suite deployment has been updated to the latest Release B versions. This includes the upgrade of the existing releases of the Portal (Figure 57), ELCM and Slice Manager, as well as the deployment of entirely new components such as the Dispatcher and Analytics Dashboards.

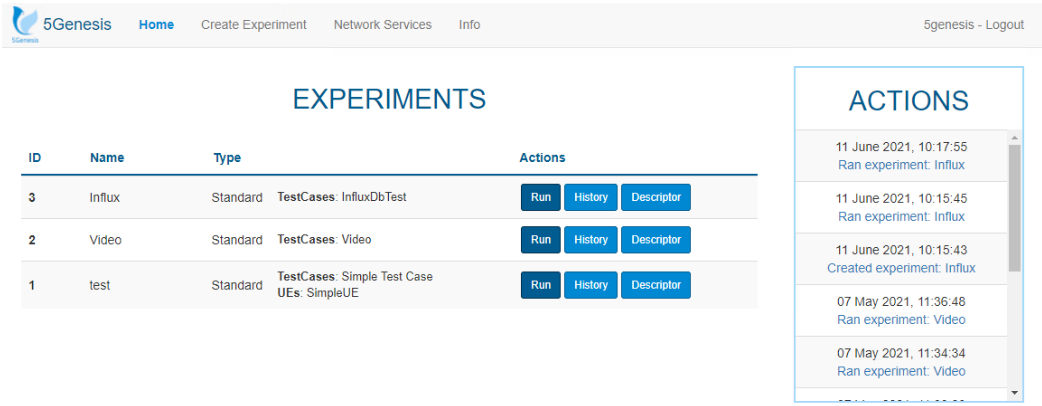

Figure 57: 5Genesis Málaga Platform portal

Some of the additional features supported by the upgraded coordination layer are:

- Platform-wide user authentication, provided by the Dispatcher and integrated in the Portal, and the possibility of accessing the functionality through the Open APIs.
- Support for the definition of additional types of experiments, as well as extended capabilities for the implementation of test cases within the platform.
- An improved network services onboarding interface.
- Additional experiment scheduling options available to the experimenters.

In addition to the results visualization capabilities provided by the existing Grafana installation, during Phase 3 the new Analytics Dashboard developed within the context of Work Package 3 has been deployed and integrated with the rest of the components of the Málaga Platform. This dashboard (Figure 58) provides enhanced visualization of all the experiment's generated results, while also providing capabilities for the statistical analysis of the data, including prediction, correlation and feature selection.

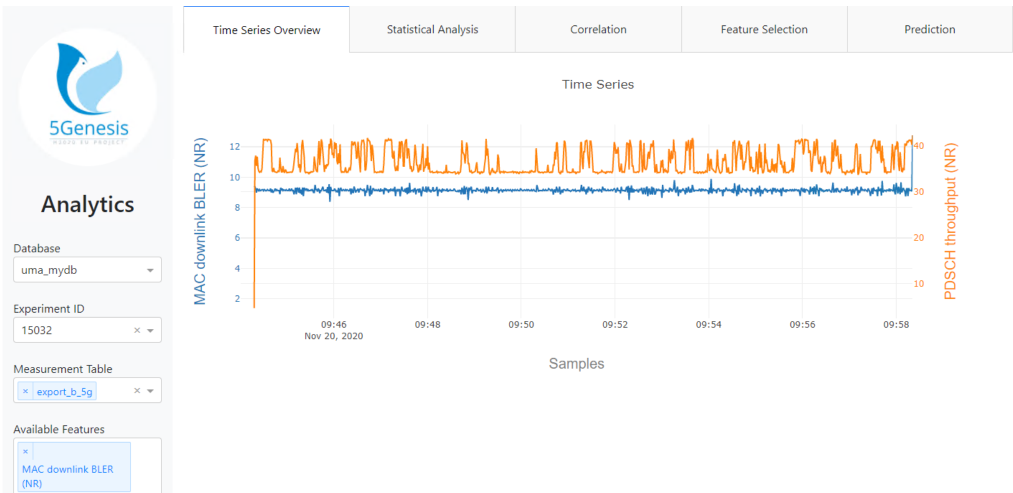

Figure 58: 5Genesis Analytics Dashboard

On the underlying execution layer, the measurement probes have been updated to their latest versions, which improve stability and solve some detected issues, and the OpenTAP Automation Framework (Figure 59) used as part of the experiment execution engine has been updated to release 9.13.

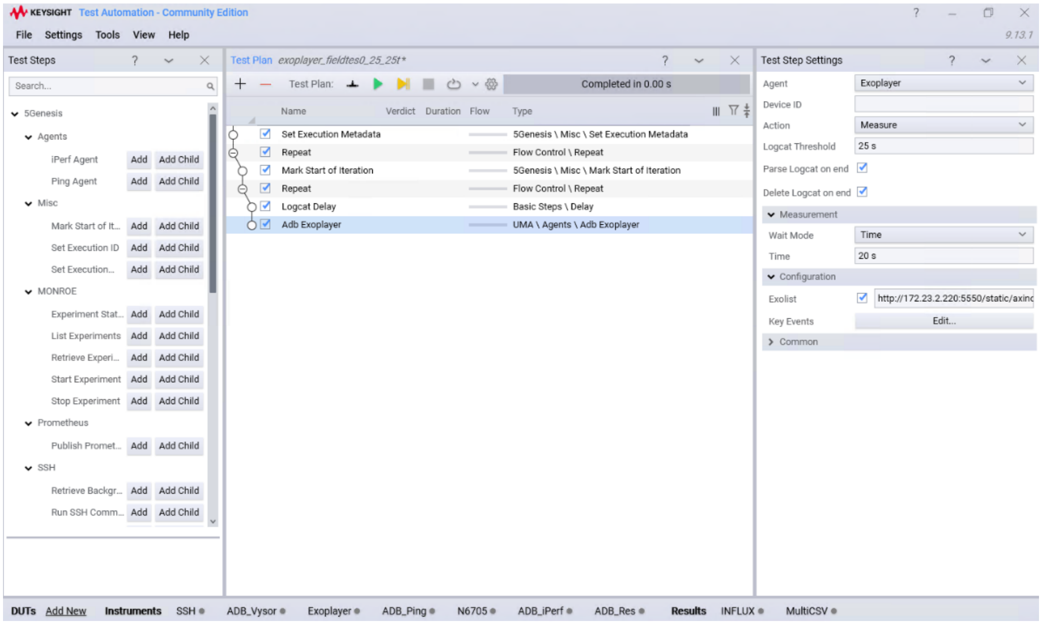

Figure 59: OpenTAP automation framework

4.2.5. MTIP protocol design and initial validation

In phase 3, UMA has addressed the expansion of the platform to support Tactile Internet (TI) applications. TI refers to the transmission of touch and the real-time control of applications like the remote control for teleoperation of machines, drones or vehicles. Traditional TCP and UDP protocols are not suitable for these applications, because they are mainly designed for content delivery for non real-time interactive applications. Some ideas from transport protocols for real-time multimedia like RTP are closer to TI; however, they do not satisfy requirements of low latency and high reliability. UMA has proposed the Multi-connection Tactile Internet Protocol (MTIP), a novel transport protocol on top of the Internet Protocol to support the reliability and latency for Internet applications over multi-homed devices connected to several wireless networks. In order to provide that service, MTIP is based on the combination of sequence numbers and timestamps in packets, enhanced with global clocks and context awareness. The work carried out in the context of 5GENESIS focuses on building a state machine based model of MTIP to prove the correct behavior of the protocol using the spin tool to verify a number of relevant correctness properties. This work will be presented at Q2SWinet '21 [23] and at MSWIM 2021 as poster presentation.

4.2.6. Use case 1 "Wireless video in Large Scale Event" achievements

Regarding the first use case corresponding to the Málaga Platform, it has seen much progress in phase 3 that has led to its full completion, as already commented in section 3.1.1. Firstly, the interconnection between the UMA lab at the Ada Byron research building and the police surveillance cameras at the Málaga city center was a critical step that was still pending in Release B of the platform. Now that link has been setup and the corresponding set of cameras are reachable from the Málaga Platform, which allows any UEs connected to the 4G/5G deployment to watch the cameras video streaming through the appropriate mobile app.

In addition to that, MOM has provided an LTE portable camera to be used as mobile video source. This equipment, along with normal 4G or 5G smartphones, plays the role of video source for police on the field to activate them and allow the corresponding police control center to expand the video surveillance area in a dynamic and on-demand way. The LTE portable camera provided has been configured and tested to work with the platform deployment and it has been confirmed that it works as expected.

Along with the testing of the interconnection and the LTE portable cameras, the rest of the use case and scenarios envisioned have also been tested, including mainly the reception of video from the surveillance cameras of the city in a smartphone using the platform's 5G deployment at the Ada Byron building, and the reception of video from a smartphone using the platform's 5G deployment at Ada Byron building at the Police Emergency Center.

The last achievement regarding this use case has been a demonstration as part of a showcase that took place in Málaga city center in June 2021 with the participation of UMA, TID, NEM and MOM, which involved use cases 1 and 3. In this demonstration the 4 partners coordinated some experiments making use of the two use case scenarios of use case 1, and MOM provided the resources to record this demonstration for future showcase purposes, as shown in Figure 60. This way the use case 1 and its two scenarios have been completely validated as were initially envisioned in the Málaga Platform plans.

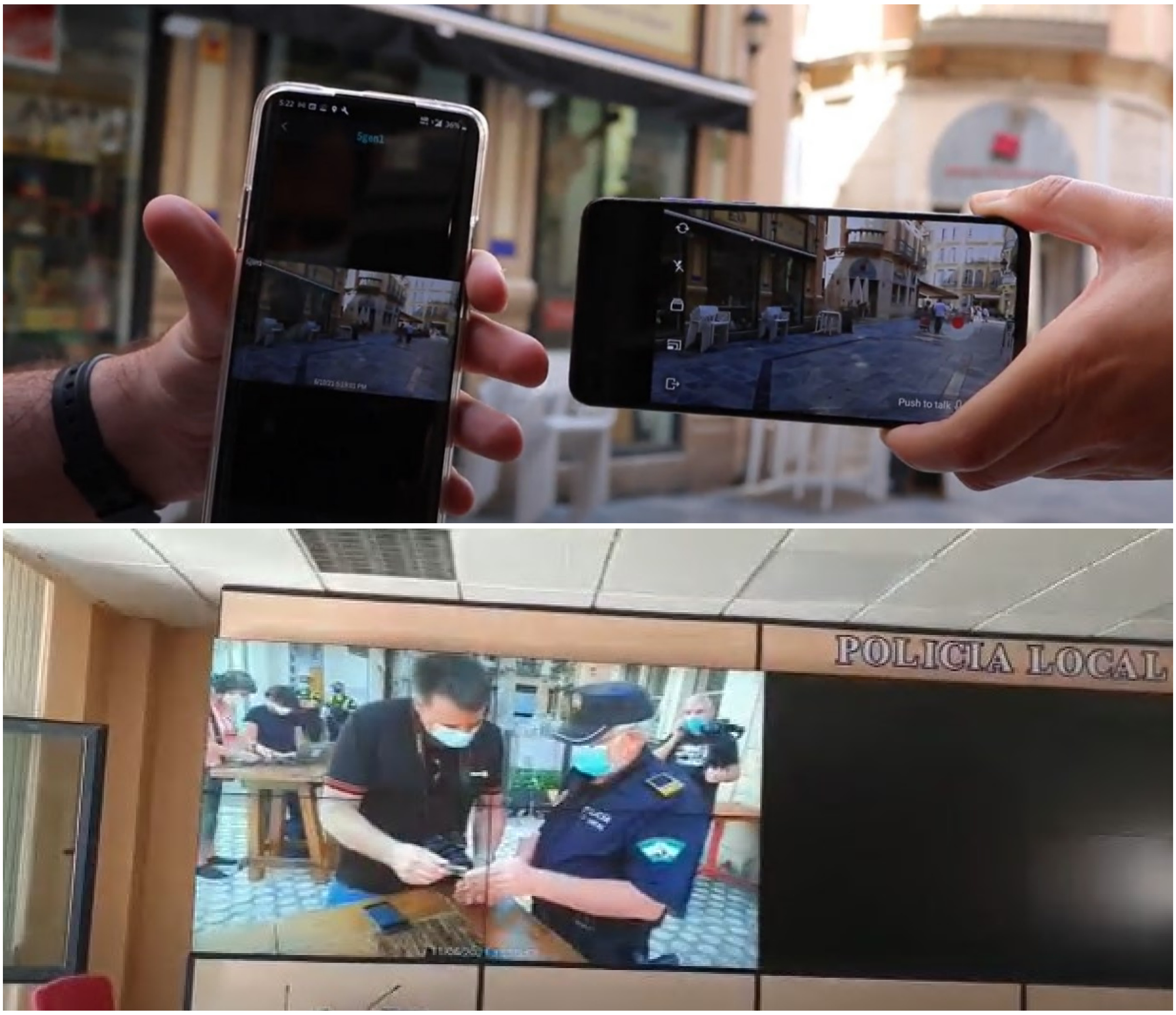

Figure 60: Tests of Use Case 1 during Málaga showcase in June 2021

4.2.7. Use case 2 “Multimedia Mission Critical Services” achievements

The second use case has also seen evolution in this last phase 3 up to its completion. One of the pending steps in Release B to fulfill the initial plans for this use case was the deployment of the ADS MCS service at the Main Data Center OpenStack instance as a VNF. In the current Release C this service has been correctly deployed as VNF as intended, and the correct performance of the ADS MCS VNF has been checked.

The deployment of the service as VNF has also brought a new upgraded version of it, which includes several additions of components and functionalities as previously detailed in section 3.1.2. Among those new additions are a new dispatcher application, map and location services making use of a new MCS map server, and a MCS QoS management module. In relation with the QoS management module, it has been integrated with the ATH EPC of the platform and successfully tested the dynamic request and grant of dedicated bearers with specific QCI for MCS communications.

Finally, the work on the interoperability between ADS and NEM MCS solutions needed to be concluded after some time. During that time, the interoperability support of chat and group calls was successfully demonstrated. Since this interoperability was not one of the initial objectives of the project’s work, it needed to be dropped off after the mentioned milestone.

4.2.8. Use case 3 “Edge-based Mission Critical Services” achievements

The last use case corresponding to the Málaga Platform can also be considered as completed after the work carried out during phase 3. The main step missing in Release B was the deployment of the NEM MCS service at the Edge setup of the platform. Such deployment has taken place in the Edge’s OpenNebula and the MCS server VNF has been checked to work properly, same as in the previous release for its deployment in the Main Data Center.

In a similar way that with use case 2, this new deployment has been made with an upgraded version of the MCS service, both at server and client sides as already detailed in section 3.1.3. The upgrade included new interesting functionalities such as multi-IP support for the deployment of the MCS components and also support for cross-platform MCS for the MCS server side, while for the client side support for MCVideo with transmission control has been added, as well as a reformatting of the app focused on a better user experience and interaction. For the user experience improvements of the MCS Client, MOM policemen have tested the application and have provided their feedback to NEM. Another important improvement, which is also shared with use case 2, is the integration with the ATH EPC for handling of QoS and the corresponding default and dedicated bearers through the Rx interface. This integration has been also tested and the dynamic request and setup of the default and dedicated bearers with the corresponding QCI for MCS communications has been validated for NEM’s MCS service.

As mentioned in the previous subsection, the work on the interoperability among NEM and ADS MCS solutions have reached some achievements, such as successful support of chat and group calls, but after those milestones this line of work needed to be concluded.

Finally, use case 3 has also been demonstrated in the showcase mentioned for use case 1. The showcase in which it was demonstrated involved UMA, TID, NEM and MOM as participants, being TID and MOM the partners making use of NEM’s MCS service in Málaga city center to validate its status once the service was deployed in the Edge. With this demonstration, use case 3 becomes completely validated as complying with its design and objectives for the project. Figure 61 shows a test taking place during said demonstration.

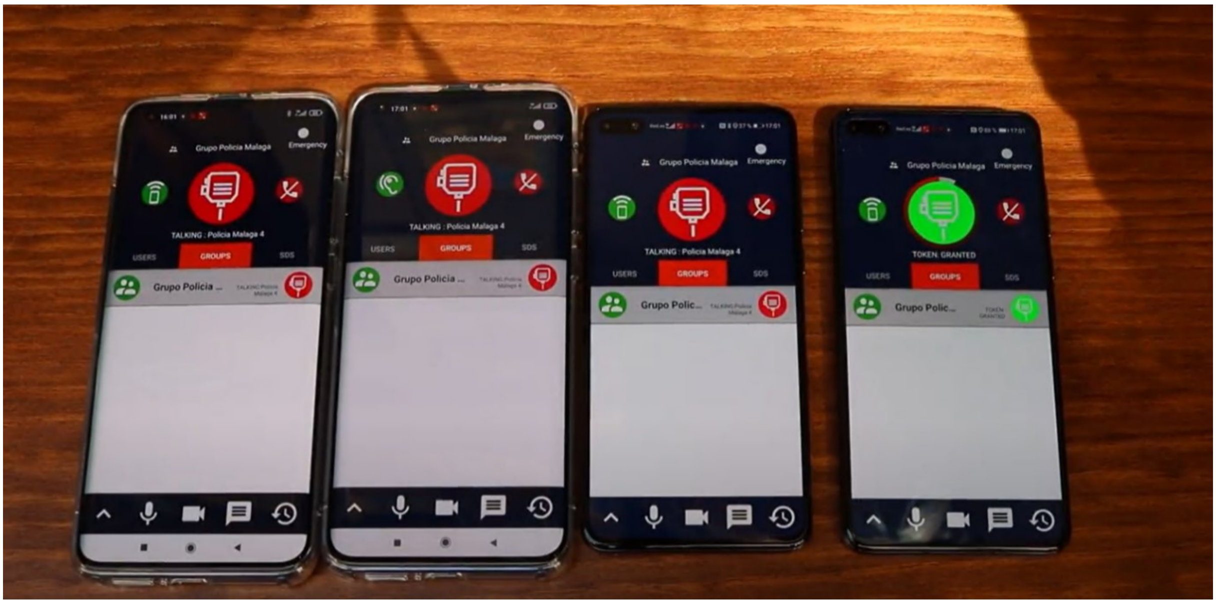

Figure 61: Tests of Use Case 3 during Málaga showcase in June 2021

5. CONCLUSIONS

This document presented the third and final phase of the work done towards the implementation of Release C of the 5GENESIS Málaga Platform. With the completion of Phase 3, all the developments and integrations led to a full instantiation of the reference architecture. The most important step taken in Phase 3 has been *the extension of the 4G and 5G deployment, by including the addition of new RAN and core equipment to support 5G SA mode*. Along with that, other important advancements were accomplished, such as i) the interconnection among sites not connected in release B, ii) the connection with the Athens platform, iii) the upgrade of the Open5GENESIS components and iv) the upgrade of the two 5G prototypes by OpenAirInterface and RunEL, setups which are meant to continue evolving with main focus on research activities.

The coming months will be dedicated to testing intensively the new components and functionalities in the context of the WP6 tasks. Additionally, the partners that contributed to the Málaga Platform development will continue working on the task of polishing and optimizing its components and the whole platform's operation.

With all the achievements accomplished within the 5GENESIS framework, the 5GENESIS Málaga Platform has become a reliable testbed providing end-to-end 4G and 5G experimentation allowing for automated KPI validation with a special focus on Mission Critical Services, whose capabilities and potential have been demonstrated in different use cases and related trials performed during the project lifecycle.

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6. Appendix 1: MALAGA Platform Components and Architecture Details

6.1. Main Data Center

Table 9: Main Data Center servers

Name	CPU	RAM	Networking	Disk	Usage
Master	Single socket 6 physical cores	8 GB	1x10 Gbps (plus 1Gbps for administration, or IPMI)	512 Gb SSD 4 Tb (RAID0)	NFVO (OSM)
Controller	Dual socket 24 physical cores each	64 GB	2x 1 Gbps 2x 10 Gbps (plus 1 Gbps or IPMI)	500 Gb SSD 4 Tb (RAID0)	OpenStack controller
Compute	Dual socket 24 physical cores each	64 GB	2x 1 Gbps 2x 10 Gbps (plus 1 Gbps or IPMI)	500Gb SSD (RAID0)	OpenStack compute
Storage	Single socket 6 physical cores	32 GB	2 x 10 Gbps (plus 1 Gbps or IPMI)	500 Gb SSD (OS, RAID0) 24 Tb (6x4Tb, Ceph replication)	Openstack Storage

The Main Data Center infrastructure, by design, must be reachable by the core network and the radio elements, as well as by the end-users to support low-latency services on the edge of the operator's domain. The following diagram shows the networks that will be used in the NFV deployment and their relation to the other elements of the platform:

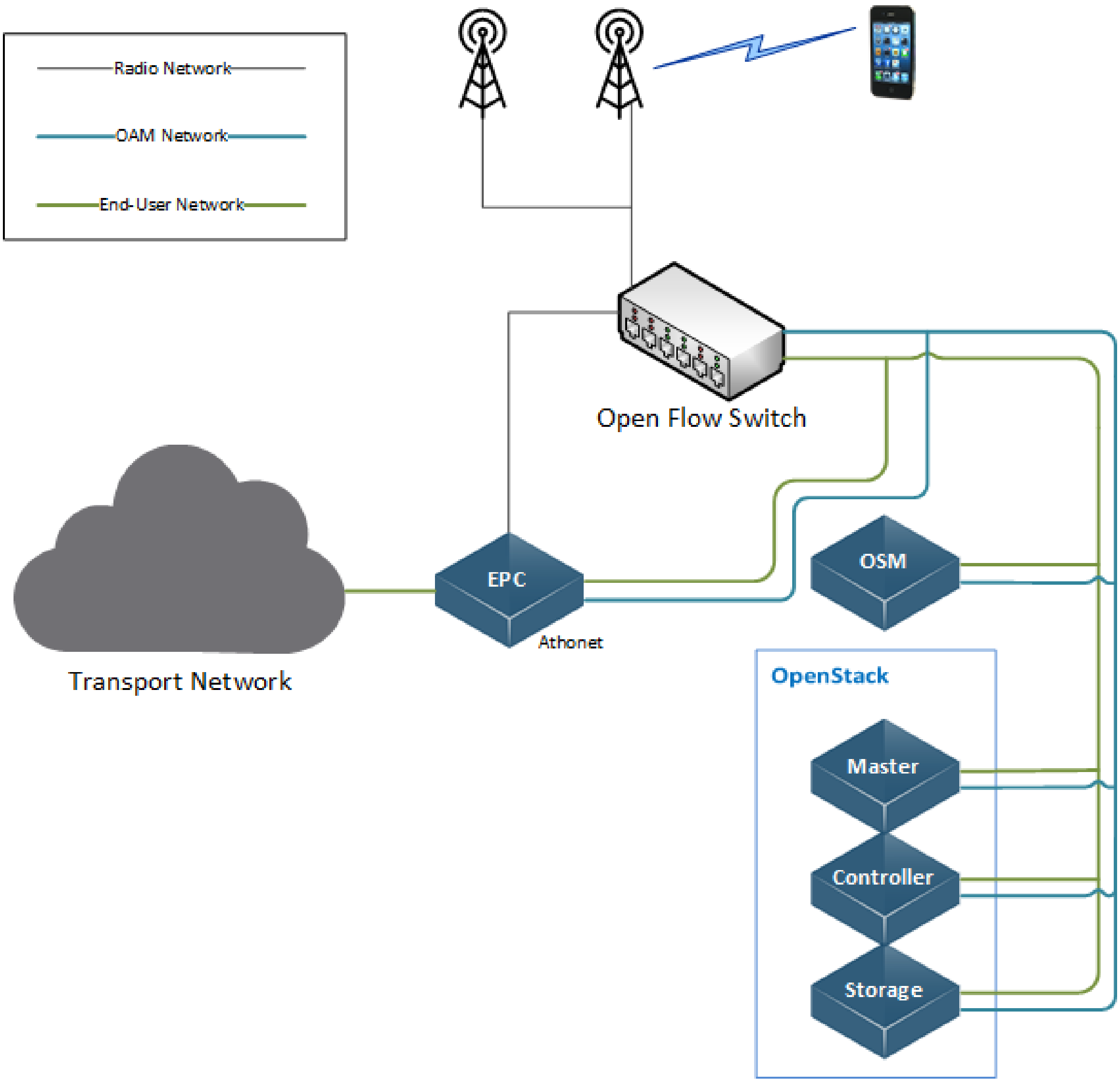

Figure 62: NFVI Deployment

6.2. Edge Data Center

Edge Data center includes the following components:

- **Computation Layer**: It comprises the following elements: 2x OCP server nodes with 2x Intel 6126 CPUs (12 Cores, 24 threads), Memory 128GB RAM, 500GB NMVe SSD and 2x 40Gb Mellanox NICs, 1x 1Gb management NIC, 1x console port.

- **Switching Layer:** This layer switches are based on the Broadcom BCM56870 Trident 3 chipset with 3.2 Tbps capacity and 48 QSFP + ports of 40Gbps each. There are 2 types of switches:
  - Leaf 1: D2060 Redstone XP, 48x10GbE ports, 6x40GbE ports.
  - Leaf 2, Spine: D4040 Smallstone XP, 32x40GbE ports.

  The switching fabric is comprised of 2 leaf and 1 spine switches.

- **GPON Optical Access Layer**: The unbundled OLT Ruby S1010 vOLT is used with 48 GPON ports of 2.5 Gbps and 6 QSFP ports of 40 Gbps. It uses the SoC (System-on-a-Chip) PAS5211 of MicroSemi. As such, it implements GPON media access control functions, OMCI GPON protocol management, IEEE 802.1ad VLANs, access control to the Ethernet medium.
- **Management switch**: Pebble D1050 switch will be used for management, it contains 48x1GbE ports and 4x10GbE ports.

Edge node has two physical networks cabled. The "Management Network" is a private IPv4 flat network that connects all elements through a management switch. This network carries only management traffic for OAM of the infrastructure. The following picture shows how all physical elements are connected:

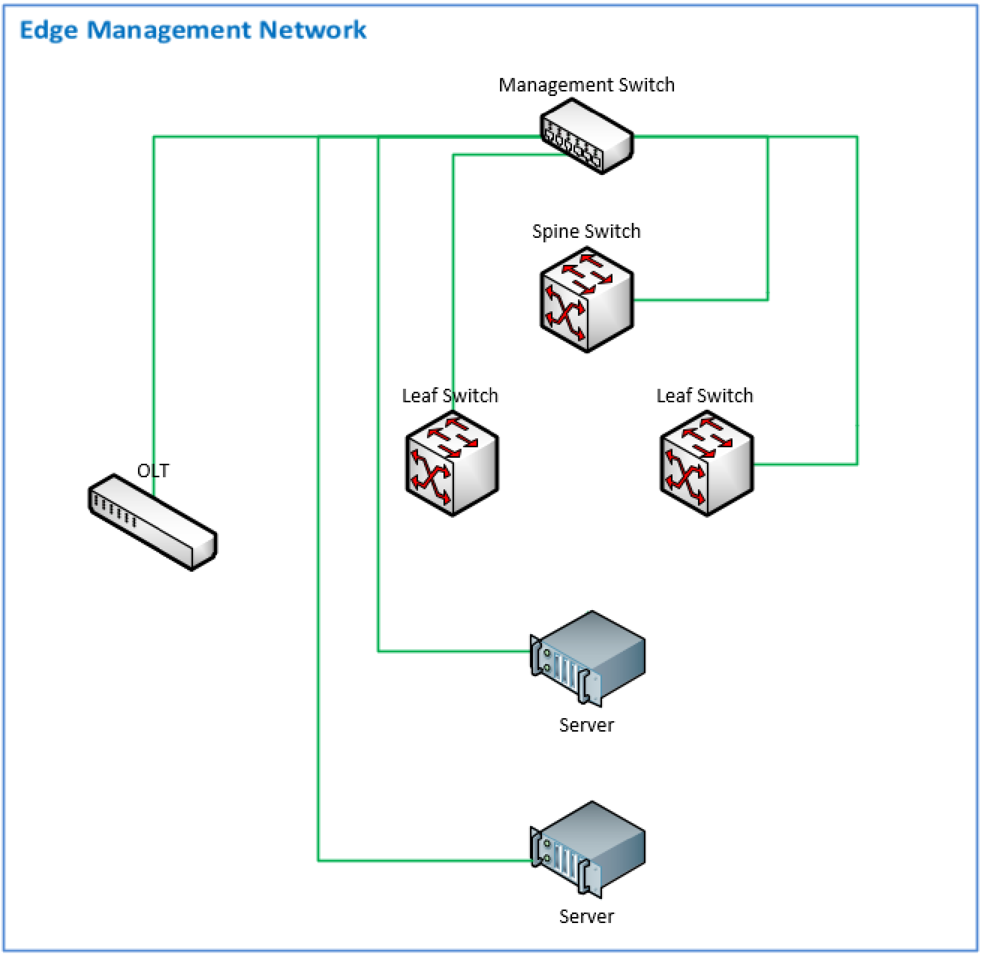

Figure 63: Edge Management Network

The second network is the called "Service Network". This network supports both IPv4 and IPv6 traffic and carries out both the Control plane (Signaling) and Data Plane (user´s traffic). The service network is controlled by an SDN Controller, and it is connected as displayed in the following picture:

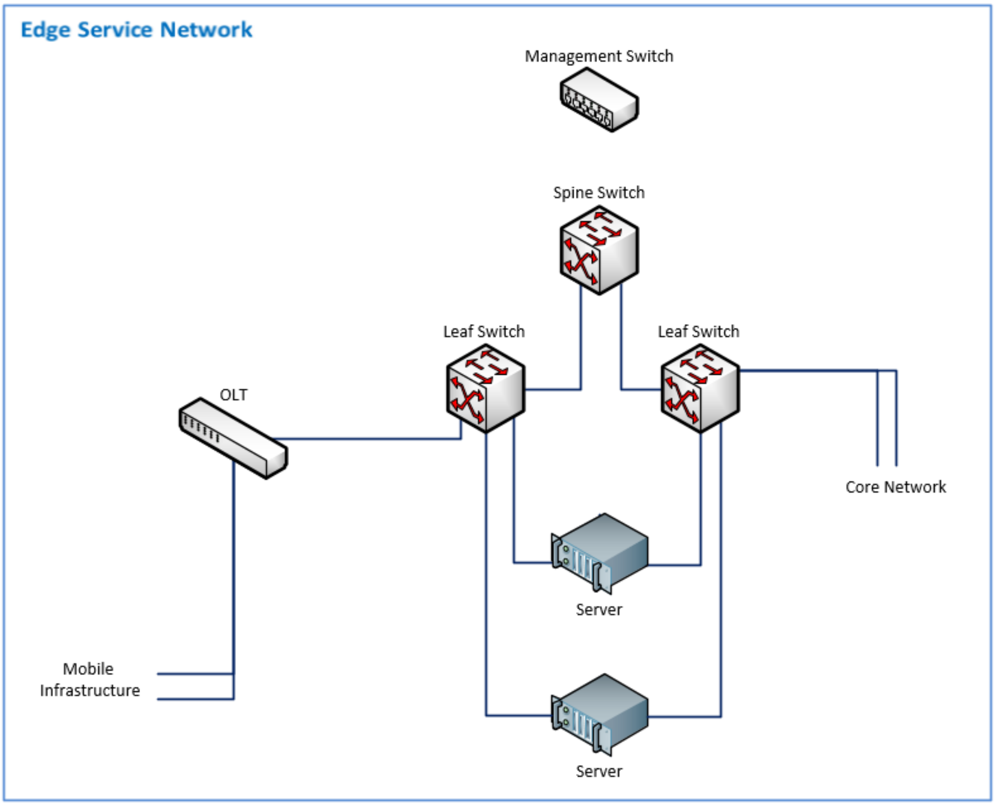

Figure 64: Edge Service Network

The distribution of the new components at the physical level is shown in the following picture:

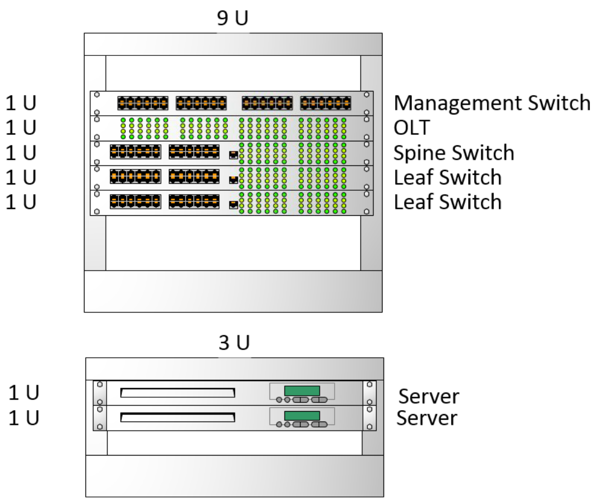

Figure 65: Edge Infrastructure Physical Layout

6.3. Mobile Core Network

6.3.1. Athonet Mobile Core

Being a commercial solution, Athonet's EPC can be connected to commercial OSS/BSS systems, which enforces regulatory obligations and billing by means of standard interfaces, i.e., X1, X2 and X3 for lawful intercept and Bx and Gy for charging.

In addition, Athonet mobile core is compliant with the 3GPP Release 13 MCPTT core network, as it includes the eMBMS system and supports QCI values for public safety MCPTT, i.e. 65, 66, 69 and 70.

Athonet has implemented a web-based Element Management System (EMS) that caters for performance, configuration and fault management. The EMS includes the following main features:

- System configuration for networking and 3GPP elements.
- User subscriber management and QoS profile assignment/management.
- Automated installation and insertion of license key.
- System configuration backup.
- Detailed user activity.
- Individual users monitoring and global system usage; historical data and statistics are also provided, based on different time granularity (daily/weekly/monthly/yearly).
- Secure access to the GUI via dual-authentication method based on TLS 1.2.
- Access and activity logging.

The following integration points are available for controlling the EPC using 3rd party management systems through the following integration items:

- SNMP for KPI and performance monitoring.
- SNMP traps for alarm indication.
- RESTful API is used for user provisioning and profile assignment in the HSS and other functions such as user enablement, examining users' CDRs (UL and DL traffic), enabling users for a certain traffic or time quota; the API is continuously evolving following customer requests and new functionalities are expected to be introduced.

6.3.2. Polaris LTE NetEPC

The solution deployed at the Edge as Mobile Core, Polaris NetEPC, provides some interesting features, including:

- Both control plane and user plane capabilities required to build an LTE network.
- Distributed scalable and cost effective architecture to meet requirements of different LTE networks.
- 3GPP Release 15 specifications alignment and clearly defined road map for later 3GPP releases.
- Availability on various carrier-grade platforms.
- Voice over LTE using IMS.

6.4. Indoor Radio Access Network

6.4.1. UMA indoor 5G Radio Access Network

Some 5G radio equipment can be found as part of the indoor radio deployment of UMA:

- Nokia’s ASiR-pRRH AWHQB 5G n78
  - 5G Access: n78 Band 43 Frequency range
  - Band Frequency:
    - UL: 3600-3800 MHz
    - DL: 3600-3800 MHz
  - RF Output Power: 50mW to 250mW per Tx path
  - RF Bandwidth:
    - OBW: 800 MHz
    - IBW: 1400 MHz
  - Carrier Bandwidth: 50MHz, 100MHz
  - Synchronization: via CPRI timing recovery
  - Antenna:
    - Configuration: 4 Tx/4 Rx (per band)
    - Integrated Omni
    - Nominal Gain: -0dBi

6.4.2. OpenAirInterface 5G

The OAI software is freely distributed by the OpenAirInterface Software Aliance (OSA) and it can be deployed using standard Linux-based computing equipment (Intel x86 PC architecture) and standard RF equipment (e.g., National Instruments/Ettus USRP). In this context, OAI offers a flexible framework for experimentation with prototype 4G/5G implementations of the UE and base station components.

Given the fact that the UE is a simple software program, it can easily be launched and accessed remotely through a *ssh* interface (provided that the laptop is connected to the Internet through an additional connection). In addition, performance measurements with tools like *iperf* or *ping* can be easily carried out locally or remotely.

Since neither commercial gNB nor UE were available for 5G NR at the beginning of the project, two USRP N310 have been used as part of the platform to test new developments and for integration purposes, running the most recent 5G branch of OAI software. OAI also recommends this SDR equipment for 5G NR, and thus it aligns perfectly with the Málaga Platform initially considered scenarios.

Figure 66: USRP N310

This SDR equipment needs an associated computer in order to take care of computation and, additionally, execute the corresponding OAI software for 5G NR initial deployment. This computer needs a capable enough CPU and high-speed network connections at 10 Gbps to exchange data with the USRPs.

The OAI 5G part of the deployment is composed by SDR cards running OAI software from Eurecom to provide a programmable 5G environment, which will also be used for the rest of the project in its evolved form. The SDR cards used are USRP N310, which are based on Xilinx Zynq-7100 System on Chip, and support bandwidth up to 100 MHz, frequency range from 10 MHz to 6 GHz, and 2x2 MIMO. Málaga Platform includes initially 2 USRP N310, one as 5G UE and other as gNB, to deploy its indoor 5G setup. This setup also includes two (one for each USRPs) HP Z6G4 Workstations, configured with Intel Xeon 6154, 3 GHz with 18 cores, and a dual port 10 Gbps Ethernet card for networking. Both USRP N310 are connected to the corresponding PCs with Cat6a Ethernet cable (and needed SFP+ to RJ-45 adaptors, since USRP N310 has SFP+ ports for data communication to the PC) for a proper 10 Gbps connection.

6.4.3. RunEL 5G

RunEL 5G setup includes the different interconnections between the elements that compose it, which are the following: the PC with the basic MAC layer and the video server that connects with the DRAN using IP over a F/O Ethernet link. The DRAN connects with the RRH by a F/O Ethernet ring. The RRH connects with the UE emulator by RF, using either antennas or RF cable. If the latter is used, there is no need to use the internal LNA module of the RRH or UE emulator.

This setup has been demonstrated delivering video and UDP packets from a PC acting as video server to a destination PC in which both the video and the UDP packets were received correctly. The transmitter PC was connected to the DRAN and RRH, while the destination PC was connected to the 5G UE emulator. The radio link between RRH and UE emulator used 3.5 GHz band (3.3 to 4.2 GHz), bandwidth of up to 100MHz, and the throughput achieved for video was of up to 100Mbps.

The software developed allows to optionally add CRC to the packets´ payload, which limits the maximum throughput up to 10 Mbps. The UE emulator includes the functionality to collect some data with performance measurements, e.g. SNR and packet loss.

Configuration of the hardware can be done either using a serial connection through USB or connecting the hardware to a local network through Ethernet to allow the connection to them using ssh. Available configuration for the three hardware components of the setup includes internal IP configuration and some RF parameters, as for example attenuation and gain for reception and transmission or start and stop of LNA module. Firmware update can also be done using either the serial or ssh connection.

6.5. UMA outdoor Radio Access Network

In collaboration with a commercial MNO, the University of Málaga has deployed several outdoor 4G and 5G Nokia base stations to perform mobility tests in real-world scenarios (i.e. outside the laboratory). These cells are connected to the same Athonet and Polaris core networks and Edge to further demonstrate the readiness of the entire setup as it expands its area of operation.

The public procurement to purchase this equipment contained the following main requirements:

- Support of LTE and 5G NR in order to implement the NSA mode.
- Distributed configurations with BBU plus remoted heads (RRH) to move towards a C-RAN deployment.
- Support of several PLMNs with MOCN technologies to implement a first level of slicing at the radio.
- Deployment of 6 cells at UMA campus and more than 10 cells at city center.
- Provisioning of commercial LTE spectrum for LTE (2600 MHz FDD) and 5G (3500 MHz TDD).
- Sharing the cells at the city center with the MNO providing the spectrum in order to include 5GENESIS UEs as MNO users to test 5GENESIS services with two different profiles (MNO and private 5GENESIS network).

The technical specifications of the AirScale system as the outdoor radio system deployed are the following:

- Nokia AirScale System Module Indoor. BaseBand Unit, composed by:
    - AirScale Subrack AMIA 5GC000623 (subrack).
    - AirScale Capacity ABIL 5GC000276 (Capacity Unit).
    - AirScale Common ASIK 5GC000275 (Common Unit).
- Nokia Micro RRH 474147A:
    - Band 7. UL 2500-2570 MHz, DL 2620-2690 MHz.
    - Up to 4x5W per TX.
    - Up to 4 bearers, with 5, 10, 15 and 20 MHz possible bandwidth.
    - MIMO 4x4.
    - 2x CPRI fronthaul CPRI ports (2x 9,8 Gbps).
    - 256 QAM modulation.
- Nokia Micro RRH 5GC001274:
    - Subset of band 78 (LTE band 43). UL 3400-3600 MHz, DL 3600-3800 MHz.
    - Up to 4x10W per TX.

    - Support for bearers with 40, 60, 80 and 100 MHz bandwidth. Upgrade to support 50 MHz bandwidth planned for 2020.
    - 4x4 MIMO.
    - 3x CPRI fronthaul (3x 9,8 Gbps).
    - 256 QAM modulation for DL, 64 QAM for UL.
    - Support for 5G NSA mode, and future upgrade to support SA mode.
- Nokia's AEUB AirScale MMA 8T8R 512AE n257
    - 5G Band/Frequency: n257, n261
    - RF Output Power: BRP 60 dBm 2T2R
    - RF Bandwitdh:
        - OBW: 800 MHz
        - IBW: 1400 MHz
    - Carriers: Up to eight 100 MHz 5G NR carriers
    - Synchronization: via AirScale BBU
    - Antenna:
        - 2Tx/2Rx, 2 simgle polarized 16x16 arrays
        - Horizontal Coverage Angle +/-45º
        - Vertical Coverage Angle +/-45º
        - Horizontal BW: 6º
        - Vertical BW: 6º

A brief diagram of the outdoor deployment at the Ada Byron site can be seen in Figure 67.

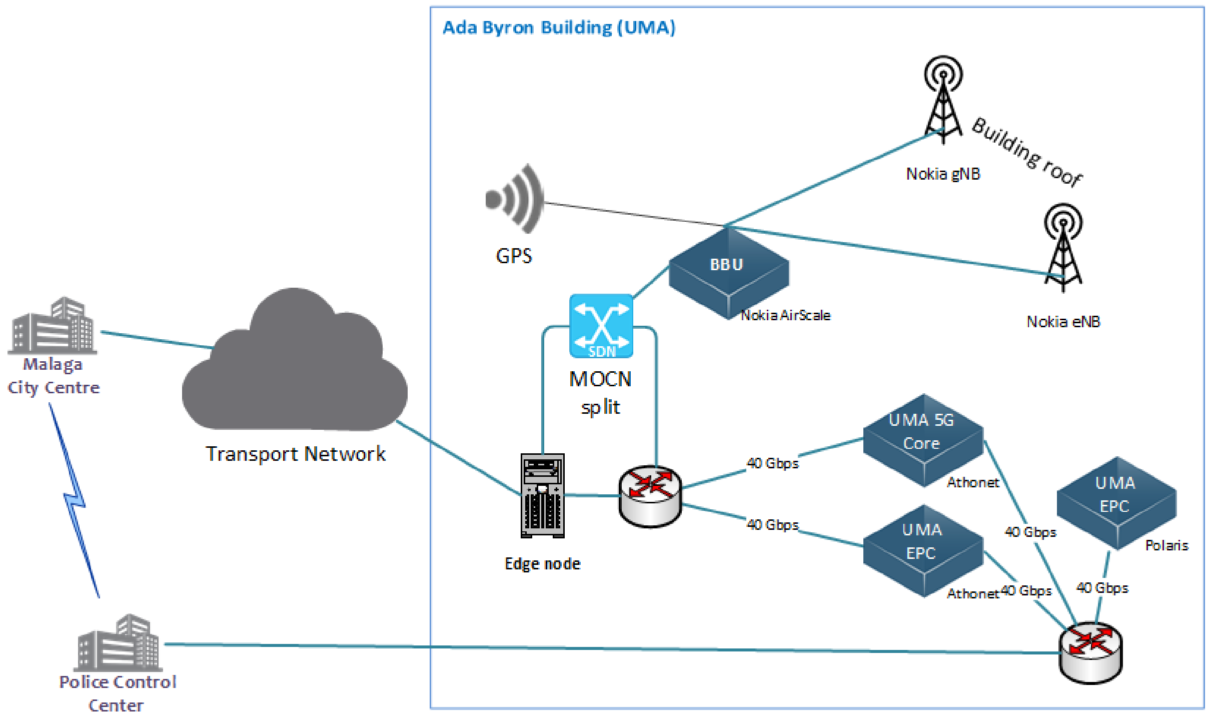

Figure 67: University of Málaga Outdoor Deployment Infrastructure

6.6. MoM outdoor Radio Access Network

Currently, the Police Department of Málaga has several security cameras and 4G base stations deployed in different locations of the city. During the project, those base stations have been upgraded to 5G technology and used in a hybrid approach. With the help of Telefonica and their Edge service, both commercial and experimentation users will be connected to the same cells, discriminating each user's traffic to be processed by the core network of the MNO or the 5GENESIS one. The transport network of the platform will be used to forward the data plane of the end users during the experimentation phase to the Emergency Control Center by using a fixed radio link connected to one of the premises of the Police in the city. A diagram with some details about the city center deployment can be seen in Figure 68.

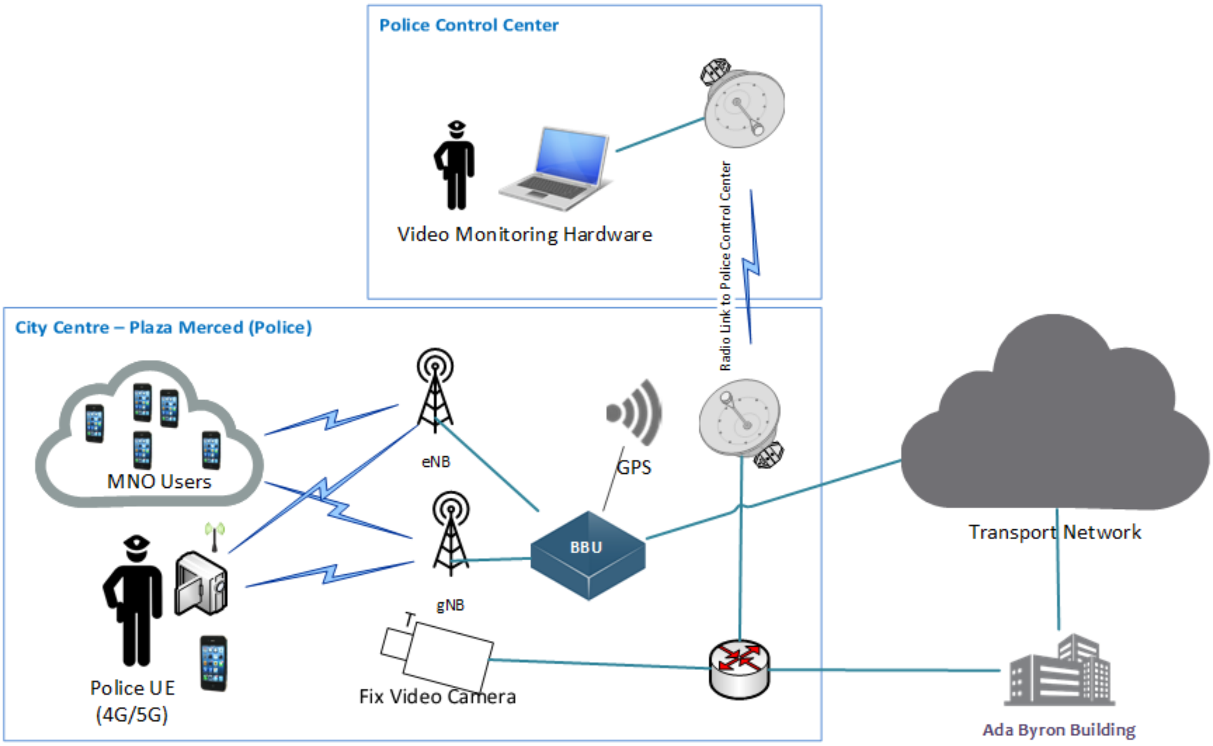

Figure 68: Police of Málaga Outdoor Deployment Infrastructure