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

[H2020 - Grant Agreement No. 815178]

Deliverable D6.4

Multiplatform trial and interworking experimentation

Editor M. Christopoulou (NCSRD)

Contributors National Center of Scientific Research "Demokritos" (NCSRD), University of Málaga (UMA), Nemergent (NEM), Ayuntamiento de Málaga (MoM), Municipality of Egaleo (MoE), Cosmote (COS)

Version 1.0

Date December 23rd, 2021

Distribution PUBLIC (PU)

List of Authors

NCSRD	NATIONAL CENTER FOR SCIENTIFIC RESEARCH "DEMOKRITOS"
M. Christopoulou, G. Xilouris, T. Anagnostopoulos, T. Sarlas, H. Koumaras, A. Gogos	
UMA	UNIVERSITY OF MÁLAGA
B. García, I. González, P. Merino	
NEM	NEMERGENT SOLUTIONS
E. Atxutegi, J. O. Fajardo	
MoM	AYUNTAMIENTO DE MÁLAGA
R. Campos, J. Ternero	
MoE	MUNICIPALITY OF EGALEO
D. Tzempelikos, E. Stamellou, I. Kastrisios, P. Andrianos, G. Antikian	
COS	COSMOTE KINITES TILEPIKOINONIES AE
F. Setaki	

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Version History

Rev. N	Description	Author	Date
1.0	Release of D6.4	M. Christopoulou (NCSRD)	23/12/2021

List of Acronyms

Acronym	Meaning
3GPP	3rd Generation Partnership Project
5GC	5G Core
ADB	Android Debug Bridge
AP	Access Point
AS	Application Server
CA	Carrier Aggregation
CSP	Content Service Provider
DL	Downlink
DNS	Domain Name System
E2E	E2E
ELCM	Experiment Lifecycle Manager
eNB	eNodeB, evolved NodeB, LTE eq. of base station
EU	European Union
EPC	Evolved Packet Core
gNB	gNodeB, 5G NR, next generation NR eq. of base station
ICMP	Internet Control Message protocol
IP	Internet Protocol
KPI	Key Performance Indicator
LTE	Long-Term Evolution
MCS	Mission Critical Services
MCPTT	Mission Critical Push To Talk
MIMO	Multiple Input Multiple Output
MNO	Mobile Network Operator
NAT	Network Address Translation
NS	Network Service
NSA	Non Standalone
NR	New Radio
OAM	Operations, administration and management
PPDR	Public Protection and Disaster Relief systems
QoS	Quality of Service
RAN	Radio Access Network
RTT	Round Trip Time
SA	Standalone
S/D NAT	Source/Dynamic NAT
SLA	Service Level Agreement
TCP	Transmission Control Protocol
UE	User Equipment
UL	Uplink
URLLC	Ultra-Reliable, Low-Latency Communications
VNF	Virtual Network Function
VPN	Virtual Private Network

Executive Summary

This document describes the multi-platform experimentation trials that took place in the last phase of 5GENESIS. During the course of the project, 5GENESIS has produced six experimental platforms across Europe, located in Athens, Berlin, Limassol, Málaga and Surrey, plus a portable version, for validating 5G KPIs. These platforms are instances of a common reference architecture and have evolved to facilities with complete 5G mobile network technologies, cloud and edge computing infrastructure, as well as automated experimentation capabilities.

One of the objectives of 5GENESIS is the interoperability of the platforms through the use of east/west-bound APIs, developed under the umbrella of the Open5GENESIS Suite. This interoperability allows the deployment of distributed experiments, meaning that one can execute experiments that involve several interconnected platforms. In these distributed experiments, the components, services and end-users involved can be located physically in two different platforms/locations. The interconnection of the platforms takes place through GÉANT using a lightweight VPN connection on a best effort basis.

The multi-platform trials included two distributed experiments that were executed over the Athens and Málaga 5GENESIS platforms, to showcase the interworking capabilities of the testbeds.

The two distributed experiments are the following:

1. DE#1: 3GPP MCS over two MNOs: This experiment aims to validate the application of Mission Critical Services (MCS) in a "distributed" scenario, where Public Protection and Disaster Relief (PPDR) Agencies are located physically in Athens and Málaga and should be interconnected in the case of a joint mission. Being based in two different countries means that the agencies use two different MNOs to communicate. The use of two 5GENESIS platforms emulates this scenario, by deploying two 3GPP MCSs supported by two MNOs, which are interconnected via national and international links. The demonstration involved the Málaga and Egaleo Police Departments which successfully communicated over the two platforms via the Nemergent MCS application. The results highlighted the feasibility of the solution on implementation and performance levels, since performance was also very well within the defined 3GPP thresholds, even though increased compared to single platform deployments.
2. DE#2: Remote connection to 5GC: This experiment demonstrated the capability of the 5GENESIS platforms to execute cross-platform experimentation for validation of 5G KPIs. The scenario employed to demonstrate this capability required hardware/software 5G components that are not available in the hosting 5GENESIS platform but are available in another platform. The experimenter is exploiting Open5GENESIS Suite in order to execute a distributed experiment, involving 5G

components distributed across two platforms, a 5G Core (Amarisoft) that is provided by Athens 5GENESIS platform and 5G NR (Nokia AirScale) that is provided by the Málaga 5GENESIS platform. The validated KPIs are Throughput and end-to-end latency (RTT) both available and automated by the Open5GENESIS suite. The results highlighted a significant degradation on the two KPIs compared to single platform deployments, which was expected due to the GÉANT interconnection delays. However, this decrease does not prohibit to deploy services with requirements that fall within the measured limits (e.g., MCS services).

Achieving the highest possible performance was not the main objective of these multi-platform trials. The primary target was to showcase the interworking experimentation capabilities of 5GENESIS and demonstrate the feasibility of the solutions. The results indeed show that it is possible to conduct experiments in more complex “multi-platform” scenarios.

The evolution of the 5GENESIS platforms has added significant value in the 5G experimentation landscape. The testing facilities already serve as testing environments for research and development on Beyond 5G networks. The interworking capabilities will hopefully serve as a meaningful feature for interested stakeholders such as verticals, that wish to deploy their services on top of heterogeneous infrastructures and validate KPIs for more complex scenarios, traversing infrastructures across multiple locations.

Table of Contents

List of Figures

List of Tables

1. INTRODUCTION

1.1. Purpose of the document

This document presents two multi-platform experiments that involve the Málaga and Athens 5GENESIS platforms. These experiments are distributed and demonstrate inter-domain applications and services deployed to more than one 5GENESIS platforms. The deliverable describes the scenarios of the two experiments, their requirements, the results, as well as the necessary configurations on the coordination layers of the two platforms and the networking stack, in order to enable the federation of the two platforms.

The document builds upon other available 5GENESIS deliverables, presented in Table 1.

Table 1 Document interdependencies

id	Document title	Relevance
D2.1 [1]	Requirements of the Facility	The document sets the ground for the first set of requirements regarding supported features of the testbeds, to support the Use Cases.
D2.2 [2]	5GENESIS Overall Facility Design and specifications	It defines the 5GENESIS facility architecture and describes the functional components
D2.3 [3]	Initial planning of tests and experimentation	Testing and experimentation specifications that influence the testbed definition, operation and maintenance are defined.
D2.4 [4]	Final report on facility design and experimentation planning	This deliverable provides a complete view of the final 5GENESIS architecture, covering all the components of the experimentation chain, from the experiment control tools to the infrastructure.
D4.3 [5]	The Athens Platform	This document describes the Athens Platform capabilities and available 5G implementations.

D4.6 [6]	The Málaga Platform	This document describes the Málaga Platform capabilities and available 5G implementations.
D5.2 [7]	System level tests and verification	The document describes the set of integration tests for system level verification.
D6.2 [8]	Trials and experimentation (cycle 2)	The document provides the results of the trials over the five 5GENESIS platforms for various 5G KPIs.

1.2. Structure of the document

Section 2 describes the two distributed experiments of the multiplatform trials and presents their requirements. Section 3 details the configuration regarding the network and the coordination layers on the Málaga and Athens 5GENESIS Platforms. Section 4 presents the demonstration events along with the obtained results and observations. Finally, Section 5 concludes the Deliverable.

1.3. Target Audience

The primary target audience of this Deliverable is industry stakeholders and PPDR end-users, as it provides information for validating 5G KPIs in the context of Mission Critical Services applications and highlights the deployment of third-party applications on top of the 5GENESIS platforms. Other stakeholders that can benefit from this deliverable include: Standardization Organizations, the European Commission, Academic and Research stakeholders, as well as non-experts interested in the capabilities of 5G technology.

2. Distributed Experiments Overview

2.1. Distributed Experiment 1: 3GPP MCS over two MNOs

2.1.1. Overview

Mission Critical Services (MCS) allow smartphone public safety users to access professional communication in groups and in private calls. Voice, video and data services and other multimedia applications are difficult to implement when several Public Protection and Disaster Relief (PPDR) Agencies should be interconnected, especially when these are based in different countries. In this case, the MCS services are provided through different MNOs (one from each country), so this leads to wonder about the feasibility of such a solution, especially when the PPDR Agencies could potentially use different UEs, frequency bands or even 5G configurations (e.g., SA vs NSA).

In this context, the first multiplatform experiment in 5GENESIS is defined as "Distributed Experiment 1: 3GPP MCS over two MNOs" and aims to validate the application of MCS in this "distributed" scenario. The use of two 5GENESIS platforms is a direct way to map this experiment to emulate two 3GPP MCSs supported by two MNOs, which are interconnected via national and international links.

This distributed experiment involves server-to-server connectivity of the MCX[1] side in a virtualized fashion and being deployed by the 5GENESIS suite in both Málaga and Athens. To this end, we have deployed two instances of the MCX VNF in both Málaga and Athens with different realm each of them and interconnected using the connectivity set-up between the two sites. On top of this interconnection, we have established the MCX interconnection using 3GPP's MCX-1 definition [9] (signaling) and [10] (floor control and media), using in this case the untrusted mode.

After a group regrouping operation in MCS, several groups become part of a temporary group. The temporary group is owned by a controlling application server, which manages the floor control of group calls established in the temporary group. These calls reach all the members of all constituent groups, but constituent groups can be managed by different controlling servers, and it can happen that the controlling server of the temporary group is not the same as the controlling server of a constituent group. Controlling servers of constituent groups are called "non-controlling MCX servers", as explained in the 3GPP references [9], [10]. Following this principle, we have patched together a group in Málaga with a group in Athens, being able to call local groups in the standalone MCX mode (designated in Label 1 in Figure 1) or using the cross-connected group (Label 2, Figure 1).

[1] The term MCX is also used, where "x" stands for the deployed service, e.g., voice, video or data.

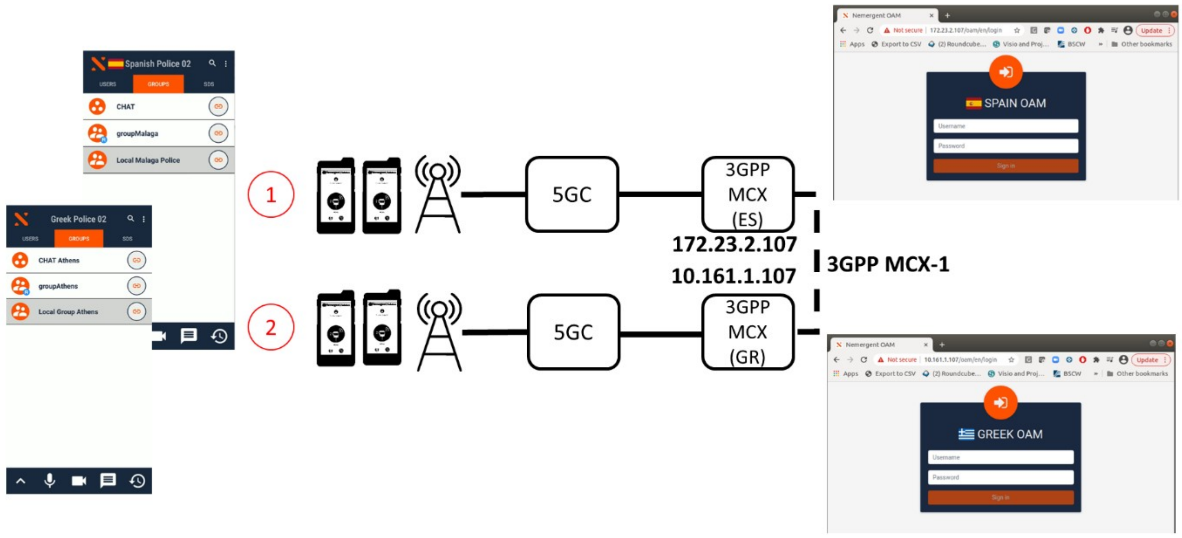


Figure 1 Simplified cross-connected MCX VNFs in Málaga and Athens

In order to better understand the results, we summarize the steps carried out in standalone MCX and cross-connected modes:

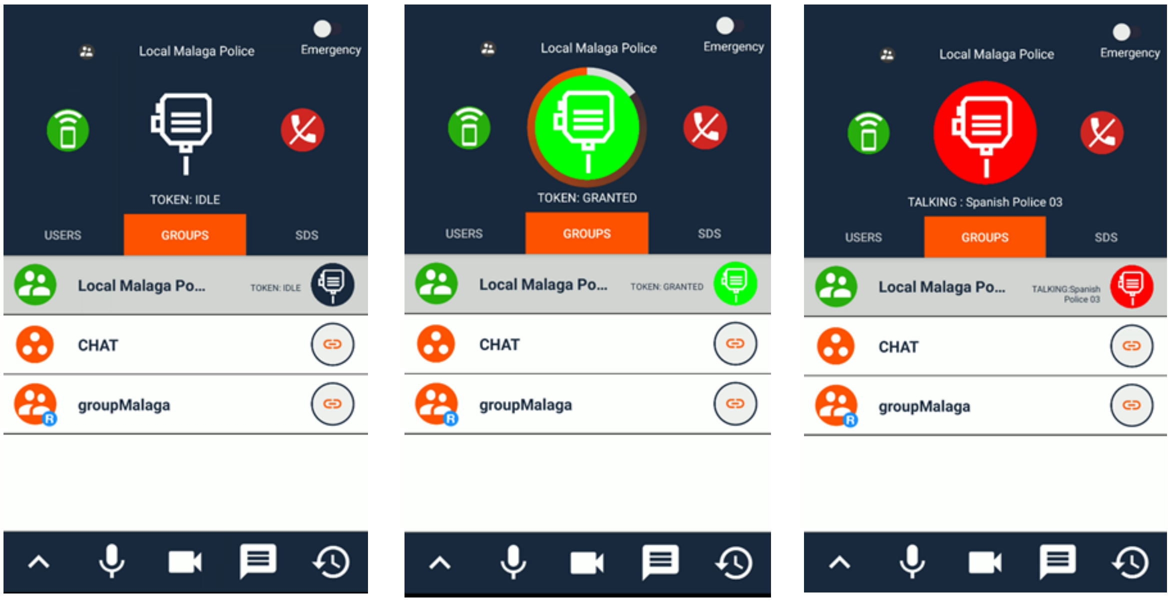
Steps in standalone MCX (Same server and 4 air jumps)

- INVITE from caller to AS
- AS reaches the group locally in the database
- AS distributes one INVITE per client (registered and affiliated to the calling group)
- One client responds 200 OK to AS
- Forward of 200 OK until it reaches the caller

Steps in cross-connected MCX using MCX-1 (Different servers, 4 air jumps and 4 iterations between different site servers.

- INVITE from caller to AS
- AS reaches the group locally in the database and realized that it has two constituent groups involved.
- AS distributes that it will call to other groups to all AS involved and associated with constituent groups
- Each AS responds, positively if there is any user registered and affiliated for that associated group or negatively if not
- AS distributes one INVITE per associated and positively responded group
- AS distributes in each site one INVITE per client (registered and affiliated to the calling group)
- One client responds 200 OK to AS (in both sites)
- Forward of 200 OK until it reaches the caller (the forward could be local or between sites)

After successful authentication and authorization, the MCX client is depicted in Figure 2 with the predefined groups to call (figure shows local groups and regrouped or cross-connected group with small blue “R” on it).



(a) (b) (c)

Figure 2 MCX call established (a) without implicit floor control, (b) GRANTED and (c) TAKEN floor control

2.1.2. Requirements

As specified in [11], in *section 6.15.3.2 - Requirements*, the applicable performance requirement for this experiment states:

"[R-6.15.3.2-014] The MCPTT Service shall provide an End-to-end MCPTT Access time (KPI 2) less than 1000 ms for users under coverage of the same network when the MCPTT Group call has not been established prior to the initiation of the MCPTT Request."

In addition, the requirements (prerequisites) that have to be fulfilled by the 5GENESIS platforms for the experiment to run are summarized in Table 2:

Table 2 5GENESIS platforms requirements for DE#1

DE#1-REQ1	Mobile Access to Network
Priority	Essential
Description	The Mission Critical Services mobile application, installed on smartphones, must be able to access to the 5G network for data transmission
DE#1-REQ2	Server Access to Network
Priority	Essential
Description	The Mission Critical Services servers must be able to access the 5G network core network for data transmission
DE#1-REQ3	Interconnection

Priority	Essential
Description	The Mission Critical Services mobile application, installed on smartphones of agency "A", must be able to communicate with a MCS client of the second agency "B" when each UE is connected locally to their agencies. The interconnection is provided by the MCS servers and it is seamless from the MCS client App or UE perspective.
DE#1-REQ4	Interoperability
Priority	Essential
Description	The Mission Critical Services mobile application of vendor "A", installed on smartphones in an agency "A", in which vendor "B" provides the service at server-side, must be able to interact with the service due to the nature of standardization and adoption of common understanding by both vendors.
DE#1-REQ5	Self-configuring
Priority	Essential
Description	The Mission Critical Services service must be able to receive configuration directives in deployment time and be capable of auto-configuring to allow controllability of orchestrator and service flexibility for multi-instances.
DE#1-REQ6	Routing and discovery
Priority	Essential
Description	Both the Mission Critical Services service and client need to be capable of directly reaching the required service (client to service and service to service) or being able to discover it through network DNS resolution.
DE#1-REQ7	Cross-platform MCS configuration
Priority	Essential
Description	The Mission Critical Service must be able to provide a mechanism to interconnect the platforms at MCS level from server OAM.

2.2. Distributed Experiment 2: Remote connection to 5GC

2.2.1. Overview

The main objective of this use case is to validate and demonstrate the capability of the 5GENESIS platforms to execute cross-platform experimentation for validation of 5G KPIs. The scenario employed to demonstrate this capability is realized over two 5GENESIS platforms interconnected with best effort interconnection over GÉANT using a VPN connection.

The scenario of the distributed experiment is describing the case of a 5G KPI validation experiment that requires hardware/software 5G components that are not available in the hosting 5GENESIS platform, which are available in another platform. The experimenter is exploiting 5GENESIS Portal in order to request/describe the experiment to be executed that provides a semi-automated deployment and execution on both infrastructures, collection of results from all distributed infrastructure elements and access to analytics at the hosting platform.

In detail, for this particular scenario the experiment that is to be executed involves 5G components distributed across two platforms, a 5G Core (Amarisoft) that is provided by Athens 5GENESIS platform and 5GNR (Nokia AirScale) that is provided by the Málaga 5GENESIS platform. The KPIs to be validated are Throughput and end-to-end latency (RTT) both available and automated by the Open5GENESIS suite. In order for this experiment to take place, UE SIM cards have been added to the 5G Core database in Athens. This step is manual; however, it has to only take place once and then the same UEs may be used for other cross-platform experiments. Initially, the experimenter selects/specifies the experiment to be realized and the KPIs that need to be validated via the 5GENESIS portal. Consequentially, the experiment is scheduled by the ELCM and distributed via the dispatcher across the two platforms. When the experiment is finalized, the results from the remote platform are collected and stored in the Measurement database for further analysis. The whole process is automated and the interaction with the experimenter is limited. However, the end-to-end deployment can remain available for further, attended tests to be run by the experimenter.

It is mandatory to be available prior to the setup of any experiment. The quality and accuracy of the results acquired, are proportional to the quality of the interconnection link between the platforms. A dedicated link with specific QoS and low deterministic latency is available, the yielded results have higher level of confidence. However, the influence of the link on the results is also relevant to the actual experiment scenario and component distribution.

2.2.2. Requirements

The requirements (prerequisites) that have to be fulfilled by the 5GENESIS platforms for the experiment to run are summarized in Table 3:

Table 3 5GENESIS platforms requirements for DE#2

DE#2-REQ1	Experimenter Access
Priority	Essential
Description	Experimenter must be able to authenticate only once in hosting platform
DE#2-REQ2	Experiment Descriptor provisions for cross-platform deployment
Priority	Essential
Description	Experiment descriptor must provide sufficient provisions for declaration of local and remote NS deployments required for the experiment
DE#2-REQ3	Synchronisation of experiment lifecycle
Priority	Essential
Description	The hosting platform must be able to perform the synchronized execution of the experiment and the collection, processing and presentation of results
DE#2-REQ4	Interconnection
Priority	Essential
Description	The peering between the interconnected platforms is assumed as already available. Overlay network topology (if required) is assumed as pre-provisioned, subject to agreements between the platforms. In case of no hard-SLA in place, the results obtained are always subject to availability of resources of the best effort path among the platforms. Baseline measurements (without any 5G RAN and Core equipment) may be required in order to gain confidence in the obtained results.
DE#2-REQ5	IP Addressing – Service Discovery
Priority	Essential
Description	In case the deployment of cross-platform NS may use same IP segments, the platform (hosting) should use S/D NAT mechanisms in order to alleviate the issue and introduce DNS in order to allow proper communication.

3. INTER-PLATFORM CONNECTION AND CONFIGURATION DETAILS

3.1. Athens - Málaga interconnection details

Both Athens and Málaga Platforms have set up a gateway for their interconnection, which is running the PfSense software with a WireGuard site-to-site VPN tunnel for the platforms' interconnection. Figure 3 illustrates the interconnection between Athens and Málaga 5GENESIS platforms.

PfSense[2] software is a free network firewall distribution which is based on FreeBSD using a custom kernel and the possibility to add extra functionality by including third party free software. The PfSense software provides all the usual router functionalities and thanks to its additional package system it is able to provide extended functionality which makes it very flexible and expandable. Another point that makes PfSense suitable for our cross-platform interconnection scenario is that it can be installed in a variety of hardware, so each platform can tailor the hardware in which to install it, addressing its specific necessities.

WireGuard is used for the VPN connection and it is available in PfSense as a free third-party package. According to PfSense documentation, WireGuard uses a VPN layer 3 protocol which has been designed to provide speed and simplicity. Just a small number of options need to be configured to setup a tunnel and perform a successful connection and is said to perform nearly as fast as hardware-accelerated IPsec. It has been designed as a general-purpose VPN, although it does not provide the options and conveniences of other more complicated VPN solutions, hence being less suitable for large number of peers or connections. However, for the case of the 5GENESIS Athens and Málaga platforms cross-connection, it is a perfect option that allowed to perform a quick and successful interconnection.

The site-to-site VPN setup for the interconnection has provided connectivity to all the necessary networks and domains to be used by both platforms for the execution of the experiments, as can be seen in Figure 3. The configuration used includes setting up the tunnel endpoint addresses *10.15.210.0* and *10.15.210.1* for Málaga and Athens respectively, the default port 51820, and then generating private and public keys, of which the latest have been shared with the other platform to setup the peer configuration and establish the tunnel.

[2] pfSense open-source security, https://www.pfsense.org/

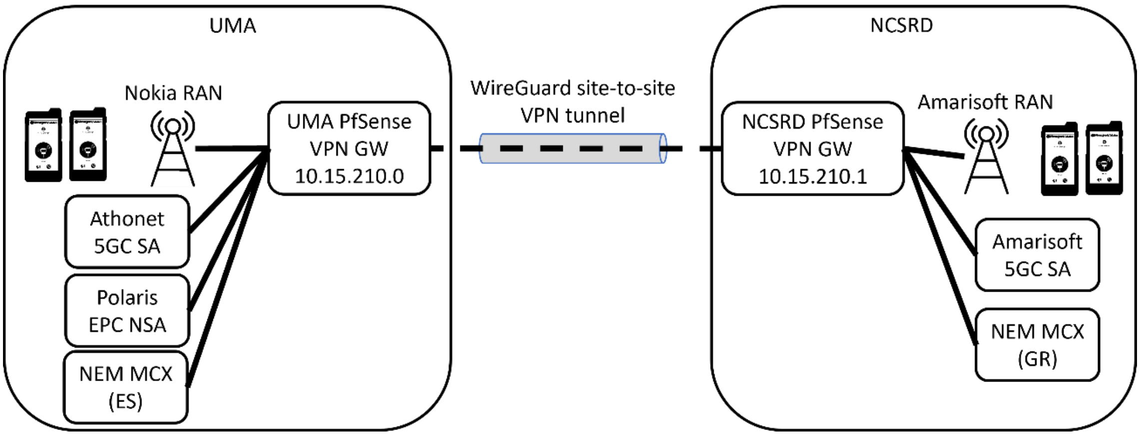


Figure 3. Simplified diagram of Málaga and Athens platforms interconnection

3.2. Open5GENESIS Suite coordination layer configuration

For the realization of the distributed experiments, two instances of the Open5GENESIS coordination layer have been configured in the premises of the Málaga and Athens platforms. The existing Release B deployment has been re-used in the Málaga platform, performing only the additional configuration steps required in order to connect with the Athens platform. In the case of Athens, however, it was decided to deploy a completely new instance of the Open5GENESIS Framework, separate from the existing Coordination Layer and dedicated only for the purposes of these trials.

Figure 4 shows the interconnection of the different elements in both platforms: In each platform, the core elements required for the execution of a distributed experiment (5GENESIS Portal, Dispatcher and ELCM) are deployed and interconnected between them, this being the standard configuration for the deployment of a single coordination layer. On top of these, additional interconnection details are configured for each of the components, so that they are able to communicate bi-directionally with their corresponding peer in the other platform.

At the bottom of the figure the storage of the results and the control of the UEs is described. Both platforms make use of InfluxDb databases, which are not directly connected but share the generated results via the ELCM: at the end of the experiment a copy of the results from the remote platform are sent to the one initiating the experiment. For the management of the UE OpenTAP is used in both platforms: directly connected via USB in the case of Málaga and through the use of a remote ADB (Android Debug Bridge) server in Athens, which is physically connected to the phone.

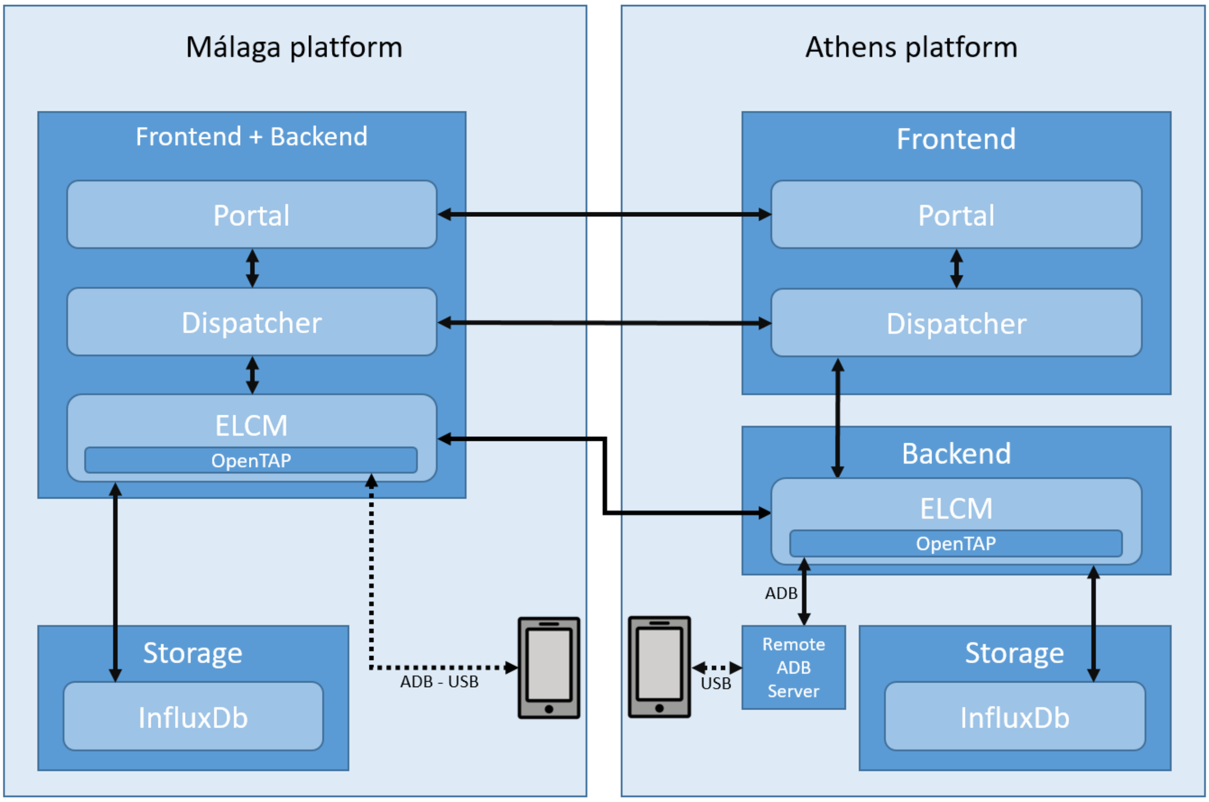


Figure 4 Integration diagram of the separate coordination layers

In order to assess the correct functionality of the deployment in both platforms, as well as validate the interconnection between the elements at both sides, **Test-05-02**, which is an integration test for distributed experiments as described in [7], has been executed. This test finished with a **PASS** verdict; the resulting execution logs can be seen in Figure 5.

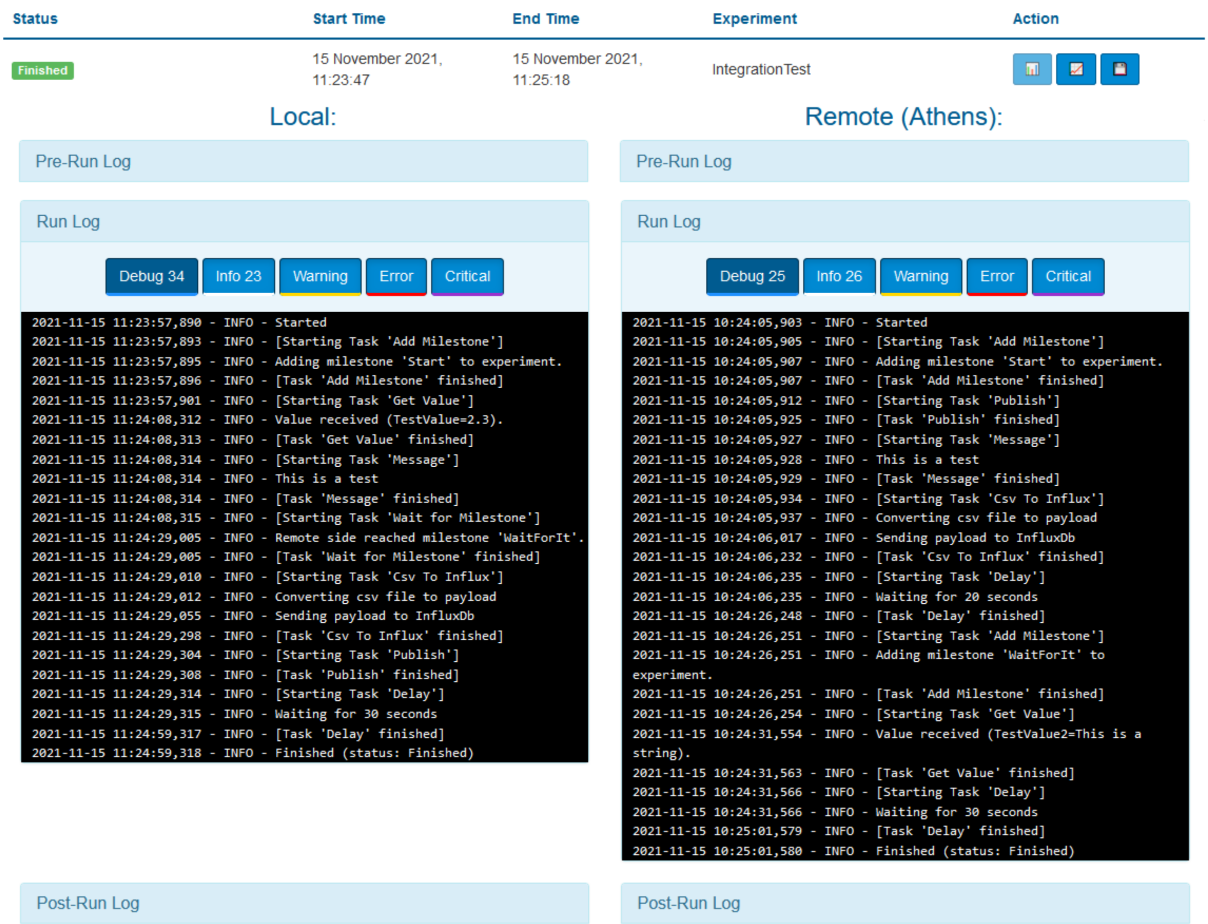


Figure 5 Test-05-02 execution logs

4. Results

4.1. Distributed Experiment 1 Results

The demonstration of this distributed experiment took place the 24th of November at 3 different locations: Málaga platform's Ada Byron Research building, the city center of Málaga City, and the Egaleo Stadium hosting the Athens platform's deployment. The 5GENESIS partners involved in the demonstration were UMA and Municipality of Málaga (Málaga Police) from the Málaga side, NCSRD and Municipality of Egaleo (Egaleo Police) from Athens side, and Nemergent as MCS solution provider, which travelled to Málaga for the showcase.

The equipment used for this event included:

- Málaga Platform's Polaris NSA EPC, the Nokia Airscale eNB and gNB deployment both at the research building and the city center, the Nemergent MCS AS hosted at the UMA infrastructure, and a set of different 5G UEs including Huawei P40 and OnePlus9
- Athens Platform's Amarisoft 5GC and gNB, both deployed at Egaleo stadium edge location, the Nemergent MCS AS hosted at NCSRD cloud infrastructure, and a set of 5G UEs including Huawei P40 Pro and OnePlus 8 Pro.

Interested readers can find more information on the equipment used in both platforms in [5] and [6].

The successful execution of this showcase and the associated distributed experiment verified the 5GENESIS capabilities for performing experiments distributed among different platforms. We also validated the adaptation that took place over the Nemergent MCS service and allowed this interconnection between 2 different AS to make the MCS setup work. During the showcase, multiple calls were executed successfully both between Málaga and Athens participants and also individually at Málaga and Athens. All of them performed properly without any issue. Figure 6, Figure 7 and Figure 8 depict screenshots from the demonstration event.

(a)

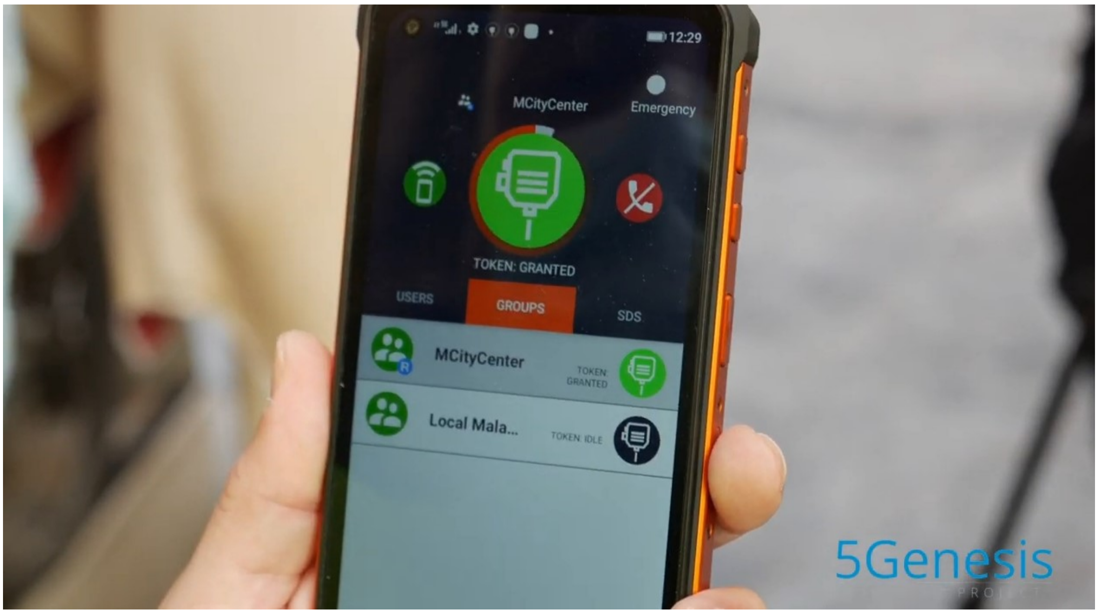
(b)

Figure 6 (a) Málaga and (b) Athens local deployments for the demonstration event of the distributed experiment

(a)

(b)

Figure 7 (a) Málaga Police communicating with (b) Egaleo Police via the Nemergent MCS application running on top of the Málaga-Athens 5GENESIS platforms interconnection



(a)

(b)

Figure 8 Nemergent's MCS application used by (a) Málaga Police and (b) Egaleo Police

In addition to the successful communication between the Málaga and Egaleo Police, we measured the End-to-end Access Time KPI, as an indicator for the quality of the deployed service. The only difference in the setup used for the measurements is that the core solution configured at UMA side was the Athonet Rel. 15 5G SA core instead of the Polaris NSA EPC used during the demonstration. This KPI has also been measured previously with this same setup in local experiments at the Málaga Platform and reported in [8], where also the performance improvement due to 5G compared with 4G was outlined. For reference, in the distributed experiment, the MCPTT E2E Access Time was measured with a mean value of 240.50ms, while in the local-only configuration, the value was approximately at 130ms. The results obtained are included in Table 4. The Test Case ID is derived from *Table 2-1-Test Case and KPI mapping* in *Deliverable 6.2 – Trials and Experimentation (cycle 2)* [8], that contains all the Test Case IDs of the available test cases in 5GENESIS.

Considering the standardized thresholds for the KPI and that the results we obtained are well below the maximum threshold (defined as 1000 ms for E2E Access Time in [11]), we can state that:

- The testing environment does not introduce any additional delays, including the cross-connected path between Málaga and Athens.
- The tested MCX service is efficient even under server-to-server circumstances using 3GPP-compliant MCX-1 interface.
- The involved 5G equipment greatly improves the results in MCX standalone mode and therefore in the cross-connected environment.

Table 4 Distributed Experiment #1 results table – MCPTT E2E Access Time

Test Case ID	*TC_MCPTTAccessTimeIncCallEstablishment_MAL*			
General description of the test	MCPTT end-to-end access time test as distributed experiment involving both Málaga and Athens platforms, this test assesses the time between when an MCPTT User requests to speak and when this user gets a signal to start speaking, including MCPTT call establishment and possibly acknowledgment from first receiving user before voice can be transmitted. The calls for this experiment are group calls involving MCS users at both platforms and such involving the MCS deployments at both platforms.			
Purpose	Measure time from request to speak to permission granted in a MCPTT call, including call establishment. The end-to-end MCPTT access time calibration tests aim at assessing the measurement capabilities of the measurement system employed for further end-to-end MCPTT access time tests. In this particular execution the time measured includes the call establishment between MCS users located at two different 5GENESIS platforms., making this a distributed experiment.			
Executed by	Partner:	UMA	Date:	24.11.2021
Involved Partner(s)	UMA, NCSRD, NEM			
Scenario	Athonet Rel. 15 5G SA Core with Nokia Airscale gNB with 5G NR band 78 at Málaga Platform, Amarisoft 5G SA solution as core and RAN at Athens Platform. The measurements are taken at the application level, in the Nemergent MCS application running in the UE of the Málaga Platform side.			
Slicing configuration	-			
Components involved	NEM MCS applications and MCS server VNF at Málaga Platform, NEM MCS applications and MCS server VNF at Athens Platform, Nokia			

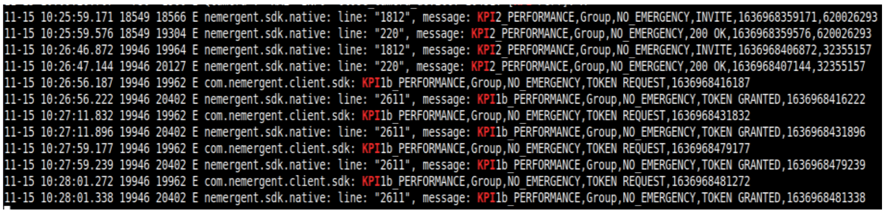
<table>
<tr><td>(e.g. HW components, SW components)</td><td>Airscale gNB, Athonet Rel. 15 5GC, OnePlus9 5G SA UE, Amarisoft 5G SA solution including 5GC and gNB.</td></tr>
<tr><td>Metric(s) under study</td><td>MCPTT</td></tr>
<tr><td>Additional tools involved</td><td>Logcat Android log command-line tool


Figure 9 Examples of KPIs in logcat</td></tr>
<tr><td>Primary measurement results
(those included in the test case definition)</td><td>MCPTT end-to-end access time
<table>
<tr><th colspan="3">End-to-end MCPTT access time [ms]</th></tr>
<tr><th rowspan="2">Mean</th><th colspan="2">95% confidence interval for Mean</th></tr>
<tr><th>Lower bound</th><th>Upper bound</th></tr>
<tr><td>240.50</td><td>218.55</td><td>262.43</td></tr>
</table>
<table>
<tr><th colspan="3">End-to-end MCPTT access time [ms]</th></tr>
<tr><th rowspan="2">95% Percentile</th><th colspan="2">95% confidence interval for 95% pc</th></tr>
<tr><th>Lower bound</th><th>Upper bound</th></tr>
<tr><td>404.00</td><td>357.81</td><td>450.19</td></tr>
</table>
</td></tr>
<tr><td>Complementary measurement results</td><td>n/a</td></tr>
</table>

4.2. Distributed Experiment 2 Results

The second distributed experiment took place on 30th of November 2021 between the Málaga and Athens 5GENESIS Platforms and verified the feasibility of executing cross-platform experimentation for validation of 5G KPIs using Open5GENESIS Suite. Considering that the cross-connection between Málaga and Athens take place on a best effort approach via GÉANT, it is anticipated that additional link delays that have been reported in caused by the interconnection will definitely impact the measured KPIs of RTT and throughput. However, the primary objective of this distributed experiment is not to maximize performance but to verify the proper interconnection between two 5GENESIS platforms and showcase that is possible to execute a variety of scenarios, where 5G components (e.g., RAN or Core) may not be available locally and use a remote deployment. Table 5 presents the RAN configuration of the NOKIA gNB located in Málaga.

Table 5 RAN configuration of NOKIA gNB in Málaga (SA)

Band	n78
Mode	TDD
Bandwidth	100 MHz
Carrier components	1 Carrier
MIMO layers	4 layers
DL MIMO mode	4x4
Max Modulation	256QAM
Beams	Single beam
Subcarrier spacing	30 kHz
Uplink/Downlink slot ratio	1/4

Table 6 provides the detailed results obtained through the distributed experiment on RTT. Similarly to DE#1, the Test Case ID is derived from *Table 2-1-Test Case and KPI mapping* in *Deliverable 6.2 – Trials and Experimentation (cycle 2)* [8]. The mean RTT value was measured at 84.08 +/- 0.31 ms with the 95th percentile at 99.99 +/- 0.51 ms. The standard deviation of the overall measurement was calculated at 9.40 +/- 0.15 ms, a value very close to the reported deviations when experiments are executed on single platforms deployments. While the mean and the 95th percentile are high RTT values, readers should consider that these results include the local delays in each platform and also the RTT of traversing the best effort path through GÉANT. The path delay through GÉANT has been estimated approximately at 60ms during baseline RTT measurements without any 5G equipment in-between. Therefore, the remaining time is due to the local deployments in UMA and NCSRD. While such values are high and not appropriate for URLLC applications, the multi-platform deployment can still support services with latency requirements within these limits (e.g., the MCPTT experiment described in Section 4.1 is an example).

Compared to single platform deployments, where both the RAN and the Core are deployed on the same platform locally, Deliverable D6.2 [8] provides such measurements for comparison. In Málaga, the RTT has been measured at 19.53 +/- 0.30 ms with the same RAN equipment and configuration and a local ATH 5GC. Figure 10 illustrates the RTT statistics between single and multi-platform deployments.

Table 6 Distributed Experiment #2 results table - RTT

Test Case ID	TC-RTT-e2e			
General description of the test	The Round Trip Time test measures the time spent since a probe sends an ICMP echo request to another probe in the network, until the requesting probe receives the corresponding echo response sent by the remote probe. For this test, the gNode-B that gives connectivity to one of the nodes is connected to a core component located in the other platform.			
Purpose	To measure the delay perceived by an application when communicating with a device located in the remote platform, as produced by the network (i.e., not taking into account any possible processing that such requests may require from the remote side).			
Executed by	Partner:	UMA	Date:	30.11.2021
Involved Partner(s)	UMA, NCSRD			
Scenario	A phone (OnePlus 9) connected to a Nokia Airscale gNB with 5G NR band 78, both located in the Málaga Platform. The gNode-B is connected to the Amarisoft 5G SA solution located in the Athens Platform.			
Slicing configuration	-			
Components involved *(e.g. HW components, SW components)*	Nokia Airscale gNB, OnePlus9 5G SA UE, Amarisoft 5G SA solution, Android Ping agents			
Metric(s) under study	*RTT*			
Additional tools involved	N/A			
Primary measurement results	**Round Trip Time [ms]** Mean: 84.08 +/- 0.31 ms Standard deviation: 9.40 +/- 0.15 ms Median: 82.96 +/- 0.44 ms 5% Percentile: 72.49 +/- 0.52 ms 25% Percentile: 75.12 +/- 0.38 ms 75% Percentile: 92.07 +/- 0.48 ms 95% Percentile: 99.99 +/- 0.51 ms Min: 71.36 +/- 0.48 ms Max : 101.50 +/- 0.29 ms			

Complementary measurement results	N/A

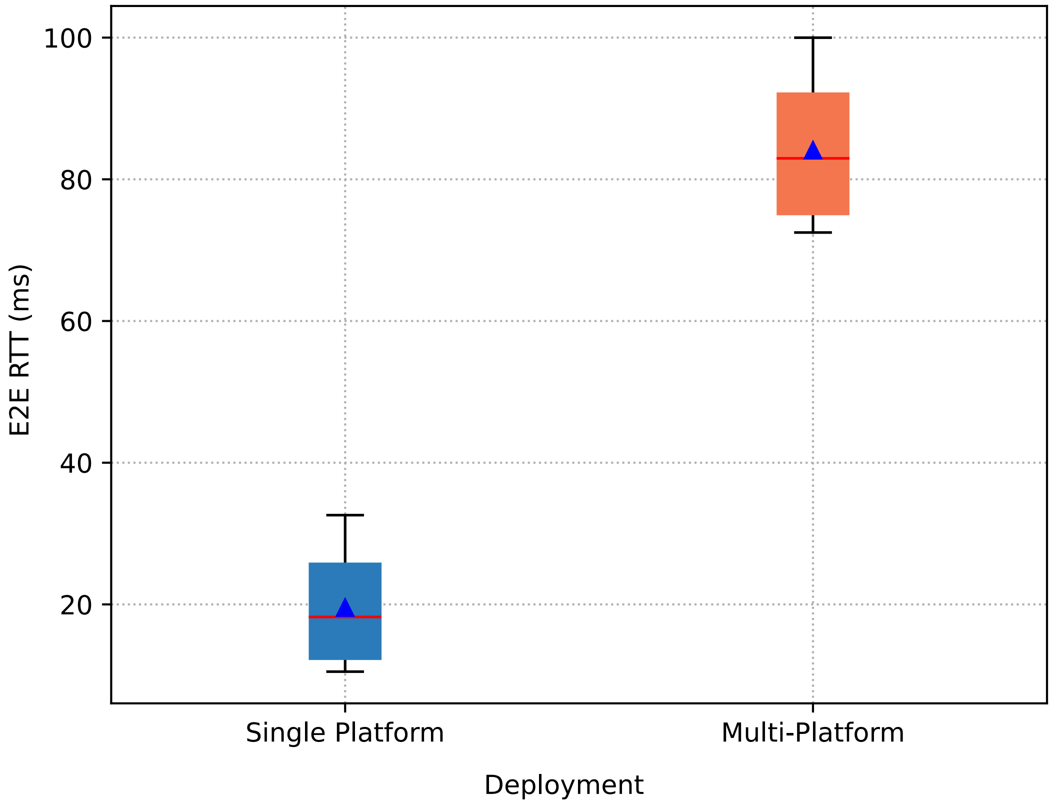


Figure 10 E2E RTT in single and multi-platform deployments

Table 7 includes the throughput measurements with the TCP protocol. Similarly to RTT, the Test Case ID is derived by *Table 2-1* in [8]. In this case, the impact of the intermediary (best effort) GÉANT link is more obvious, leading to a mean DL throughput of 57.01 +/- 3.95Mbps and a mean UL throughput of 19.52 +/- 2.25 Mbps. The TCP flow control adjusts the highest values in order to prevent packet loss due to congestion. It is apparent that applications with extremely high requirements on bandwidth would not perform appropriately. For reference, the TCP DL throughput in the single platform deployment has been reported at 1182.19 +/- 6.01 Mbps. So, multi-platform deployments present shortcomings with regards to throughput, always constrained by the inter-platform link.

Table 7 Distributed Experiment #2 results table - Throughput

Test Case ID	TC-THR-Tcp			
General description of the test	The test assesses the maximum throughput obtained by an application when sending and receiving data from a node located in the remote platform. In this test, the radio interface and the core network are located in separate platforms.			
Purpose	To measure the maximum rate of data that an application can send and receive while using the TCP protocols, when the nodes are located in separate platforms.			
Executed by	Partner:	UMA	Date:	30.11.2021
Involved Partner(s)	UMA, NCSRD			
Scenario	A phone (OnePlus 9) connected to a Nokia Airscale gNB with 5G NR band 78, both located in the Málaga Platform. The gNode-B is connected to the Amarisoft 5G SA solution located in the Athens Platform.			
Slicing configuration	-			
Components involved *(e.g. HW components, SW components)*	Nokia Airscale gNB, OnePlus9 5G SA UE, Amarisoft 5G SA solution, Android Ping agents			
Metric(s) under study	*Throughput*			
Additional tools involved	*N/A*			
Primary measurement results *(those included in the test case definition)*	**Throughput (TCP)** **Downlink** Mean: 57.01 +/- 3.95Mbps Standard Deviation: 17.97+/- 1.61Mbps Median: 57.59+/- 5.25 Mbps 5% Percentile: 29.07 +/- 5.22 Mbps 25% Percentile: 43.05 +/- 5.78 Mbps 75% Percentile: 72.57 +/- 3.78 Mbps 95% Percentile: 81.40 +/- 0.38 Mbps Min: 21.68 +/- 3.76 Mbps Max: 88.16 +/- 1.94 Mbps **Uplink** Mean: 19.52 +/- 2.25 Mbps Standard Deviation: 12.17 +/- 1.20 Mbps			

	Median: 19.52 +/- 2.02 Mbps 5% Percentile: 10.69 +/- 1.46 Mbps 25% Percentile: 15.21 +/- 1.71 Mbps 75% Percentile: 28.52 +/- 3.74 Mbps 95% Percentile: 50.47 +/- 4.58 Mbps Min: 8.77 +/- 1.51 Mbps Max: 57.74 +/- 4.29 Mbps
Complementary measurement results	N/A

5. CONCLUSION

This Deliverable presented the activities that took place in the context of *T6.7 – Multiplatform trial and interworking experimentation*. The activities included two distributed experiments:

- *"DE#1: MCS over two MNOs"*, that validated the use of MCX over two 5GENESIS platforms for communications between two Police Departments located in Málaga (Spain) and Egaleo (Athens)
- *"DE#2: Remote Connection to 5GC"*, that demonstrated the feasibility of validating KPIs using local and remote 5G components.

Both experiments showcased the 5GENESIS capabilities for performing measurements over complex scenarios, that involve different components, parameters, capabilities and end-users. The objective of these experiments is not to achieve the highest possible performance, but rather provide additional features that can be used to emulate real-word use cases on the 5GENESIS experimentation platforms. Performance is an important parameter as well, which was measured alongside the demonstrations. It was shown that while in some cases it is inferior to local-only deployments, it is not a significant barrier to performing experiments.

Finally, the most important result of this activity is that 5GENESIS completed its objective and delivered high-end experimentation platforms with an extensive range of features. These platforms already act as enablers of advanced experimentation, research and development for the upcoming Beyond 5G networks.

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