5G CITY

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D5.2: Validation and Integration of the Developed Modules and Solutions

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Executive Summary

This deliverable reports on the current status of deployment and validation of the 5GCity Infrastructures and their integration with the released Orchestration Platform in the three target cities of Barcelona (ES), Bristol (UK) and Lucca (IT).

The initial design and plan for delivery of 5GCity infrastructure was released in deliverable D5.1 [1] on June 2018. From that date, the various activities related to procurement, installation on-street, functional testing and performance testing have been progressively executed. In some cases, a number of controlled adjustments to the design occurred due to physical constraints emerged when implementing field works. These design changes applied specifically to the cities of Barcelona and Bristol, often related to the need of the respective infrastructure owners to further extend their infrastructure for 5GCity experiments thanks to the parallel execution of 5G development strategies in the two cities, namely 5GBarcelona and 5G UK Trial in Bristol.

In all the three cities the three major tiers of the 5GCity architecture have been successfully deployed and validated. The detailed information and list of components available in each city for 5GCity RAN, Edge, Metro and Platform layer are presented in this document, with discussion of the design changes and up-to-date information about infrastructure capabilities, location and specifications.

The correct installation and performances of the 5GCity infrastructure and platform components have been verified in two steps. At first, local small system tests have been performed by platform and system integrators to verify basic functionalities offered by the system. Then, a set of common tests and tools for homogeneous validation of the three installations has been elaborated and executed. Four main categories of tests have been profiled and executed:

- Radio Access Network (RAN) tests, to benchmark radio link performances and coverage;
- Connectivity tests, from UE to a compute node at the edge or in metro, or between edge and metro;
- NFV Infrastructure and Virtual Infrastructure Management (NFVI-VIM) tests, to benchmark performances of the installed virtualization platforms;
- 5GCity platform tests, to assess the functionality of the different modules.

The execution of the same test suite in the three city pilots allowed to produce comparable performances indicators and to identify the more effective configurations in preparation of the forthcoming use case trials.

An exhaustive list of test results is presented in this document, which demonstrates the correct operation of the 5GCity infrastructure under the specific working conditions made available in the three pilots (i.e. spectrum bandwidth between 15MHz and 20MHz, duplexing mode TDD in Barcelona and Lucca, WAN uplink to Internet shared, etc.). In all the cases obtained results are in line with the hardware capabilities of the infrastructures, with variations among performances recorded in Barcelona, Bristol or Lucca often related to differences in size and scale of the shared computing environments in use and/or in backhaul connectivity.

It is worth mentioning that even if an optimization process is continuously active to possibly improve performances, the achieved results reported in this document are acceptable for the trials to be executed in each of the three cities.

This deliverable also marks the completion of the 5GCity Milestone MS11 “Prototypes deployed in the city-wide infrastructure”. The activities on the infrastructure and platform will continue with benchmarking of the components involved in service creation and activation (initial results on SDK just included in this report), the completion of the newly approved infrastructure site in Plaza Sant Miquel – Barcelona, the measurement and analysis of KPIs for the six 5GCity use cases. Results of these activities will be reported in future deliverable D5.3 due by the end of the project (March 2020).

1 Introduction

The 5GCity project has designed, deployed and is validating a three-tier infrastructure coupled with an orchestration platform which implements the Neutral Host model (see Figure 1):

- *The 5GCity Tier 1 (RAN)* - a multi-vendor and multi-band radio access network installed in lamppost or in street towers or buildings. Wi-Fi and LTE-A are used in the city pilots as reported in the following of this document and initially designed in deliverable D5.1 [1].
- *The 5GCity Tier 2- Edge/Multi-Access Edge Computing (MEC) Node* – to comprise compute and storage at the edge placed in between the 5GCity/Edge Metro Node and the RAN.
- *The 5GCity Tier 3-Metro/Edge Node* – to comprises computing and storage element used from a metropolitan data centre to run core compute workloads. This tier also hosts the 5GCity Platform components.

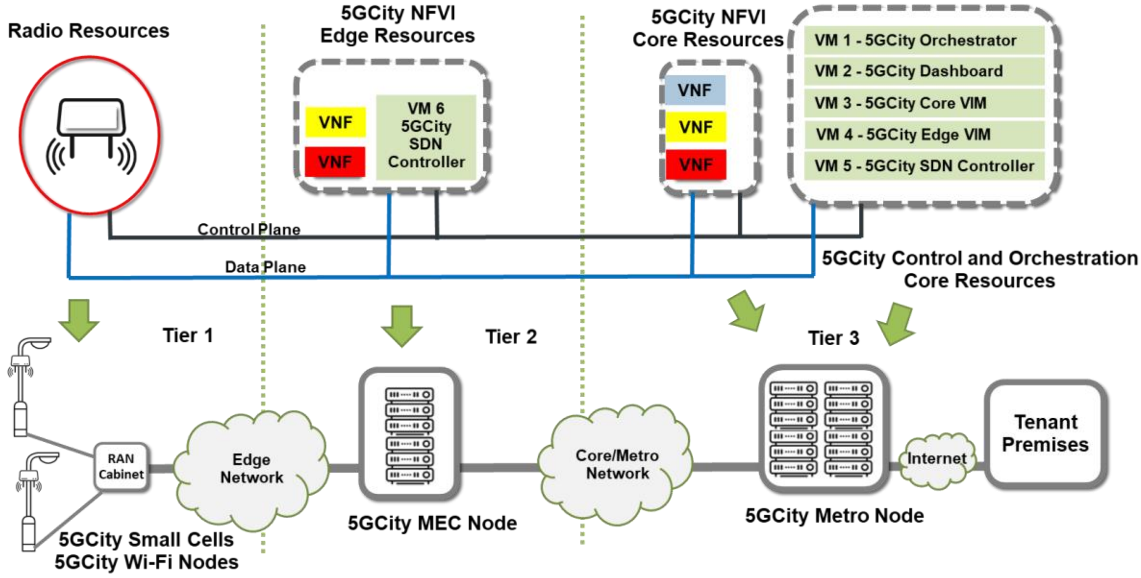


Figure 1: Three-tier 5GCity Infrastructure.

This deliverable marks the completion of the deployment activities of the aforementioned three tiers in the target cities of Barcelona (ES), Bristol (UK) and Lucca (IT), and of the validation activities on the infrastructure and platform components.

A key reference for this deliverable is the “5GCity Infrastructure Design and Definition” released by the consortium through deliverable D5.1 in last Jun. 2018 [1]. The pilot implementation and deployment activities implemented by the Consortium followed the design principles and choices made in D5.1, with controlled variations originated by the need to solve issues emerged in the field once actual planned works have been executed. Details on the actual 5GCity Infrastructure and Orchestration Platform installed and in service are provided in Section 2, with specific details for each of the three target cities.

Another core information provided through this deliverable is the validation process and results for the three 5GCity Infrastructures and for the Orchestration Platform with SDK. Details on validation are provided in section 3, and further divided in tests on RAN performances, on connectivity, on NFV Infrastructure and Virtual Infrastructure Management via OpenStack, on the 5GCity Platform functionalities.
In section 4, a benchmarking methodology for Service Creation & Activation Time is presented, with initial results for 5GCity SDK. Benchmarking on slice creation and service instantiation from 5GCity dashboard through slice-manager and multi-tier orchestrator are postponed to the completion of Use Case 2 – Neutral Host trial activities and will be reported in future deliverable D5.3.

2 5GCity Infrastructures in service

The initial plan for delivery of 5GCity infrastructure components in selected areas of cities of Barcelona (ES), Bristol (UK) and Lucca (IT) was released in deliverable D5.1 [1] on June 2018. During the realization of the deployment activities of this master plan, a number of adjustments occurred due to physical constraints emerged when implementing field works and, specifically for the cities of Barcelona and Bristol, the opportunity to further extend the infrastructure made available for 5GCity experiments thanks to the parallel execution of 5G development strategies in the two cities, namely 5GBarcelona and 5G UK Trial in Bristol.

The rest of this chapter details the final deployment status for the three major tiers of the 5GCity architecture. In each case the specific changes and improvements made eventually available to the project are highlighted and are compared to the original infrastructure design reported in deliverable D5.1.

2.1 Infrastructure Elements in the City of Barcelona

In the original design presented in deliverable D5.1 [1], the 5GCity infrastructure for Barcelona was conceived to be distributed between two major city areas: (i) the metro DC hosted at the OMEGA-DC building of i2CAT/UPC campus; (ii) the on-street radio and edge deployment in the superblock @22 area (*Glòries*). In extension to the original design, a third on-street deployment has been approved in Plaza Sant Miquel, one a building of the City Hall large structure located in the highly touristic *Barrio Gòtico* district. Field activities are in progress at the time of writing this report. The infrastructure extension is part of the contract extensions recently approved by the EC is particularly important to further validate the 5GCity Use Case 5 (mobile backpack transmission) in a more central and lively area of the city of Barcelona, full of local activities and events which can validate more a Live TV streaming through the 5GCity network. The final high-level overview of the 5GCity areas and sites in Barcelona interconnected for 5GCity is presented in Figure 2.

Figure 2: City-wide view of the Barcelona deployment of 5GCity.

The result of deployment activities for Barcelona based on D5.1 plan is reported in the following Table 1.

5GCity Barcelona	Elements planned in D5.1 [1]	Element deployed	Status as of 30Sept '19
5GCity Tier-1 (RAN)			
Mobile Devices	*n/a*	***use in-kind devices***	*>10 (smartphones, 4G Wi-Fi routers)*
Small Cells	5	**3**	**Operational** *(+2 SCs in Plaza Sant Miquel by Q4-2019)*
Wi-Fi APs	5	**3**	**Operational**
Connectivity and Cabinets	2	**2**	**Operational**
Lampposts/Towers	9	**6**	**Deployed** *(+2 indoor locations in Plaza Sant Miquel by Q4-2019)*
5GCity Tier-2 (Edge)			
Compute nodes	1	**3**	**Operational** *(+2 in BeTeVe premises)*
Router/Switch	2	**2**	**Operational**
Street Cabinets/Racks	1	**1**	**Deployed**
Connectivity Cabinet to DC	1	**2**	**Operational** *(+1 to connect BeTeVe)*
5GCity Tier-3(Core)			
Servers	3	**3**	**Operational**
Router/Switch	As per DC infrastructure	**As per DC infrastructure**	**Operational**
Connectivity Cabinet to DC	1	**2**	**Operational** *(+1 to connect BeTeVe)*

Table 1: Inventory of 5GCity infrastructure elements in the City of Barcelona.

It is to be noted that variations on the number of compute and radio devices for RAN in the @22 district were caused by a remodelling of street deployment and issues encountered with the completion of the roadwork authorization processes. However, additional 2 Small Cells will be deployed and will be deployed by Q4-2019 in the new installation ongoing at Plaza Sant Miquel (indoors, city hall), which is part of the 5GCity infrastructure extension approved for Barcelona.

Moreover, the 5GCity edge nodes in Barcelona have been varied from the originally planned street cabinet in Llacuna street (see D5.1) and included two edge servers in the new location at BeTeVe premises used for all the Use Case testing activities in Barcelona (see Figure 3). An additional Odroid platform has been deployed in the Llacuna cabinet to serve Use Case 6.

2.1.1 5GCity RAN at @22 district

While maintaining similar principles with respect to the original plan presented in D5.1, the on-street deployment at @22 district has been slightly altered in the number of lampposts (from potentially 9 to 6 plus a portable one), and in their exact locations. Three of these lamp posts are equipped with 5GCity Small Cells (Accelleran E1010), whereas other 3 lampposts are equipped with 5GCity Wi-Fi Nodes (i2CAT). The 7th lamp post is a portable mixed lamppost (Integration Node), which integrates both Wi-Fi and LTE radio technologies and can be deployed during UC trials if the radio coverage is not enough. Pictures of the 6 deployed lampposts are presented in Figure 4.

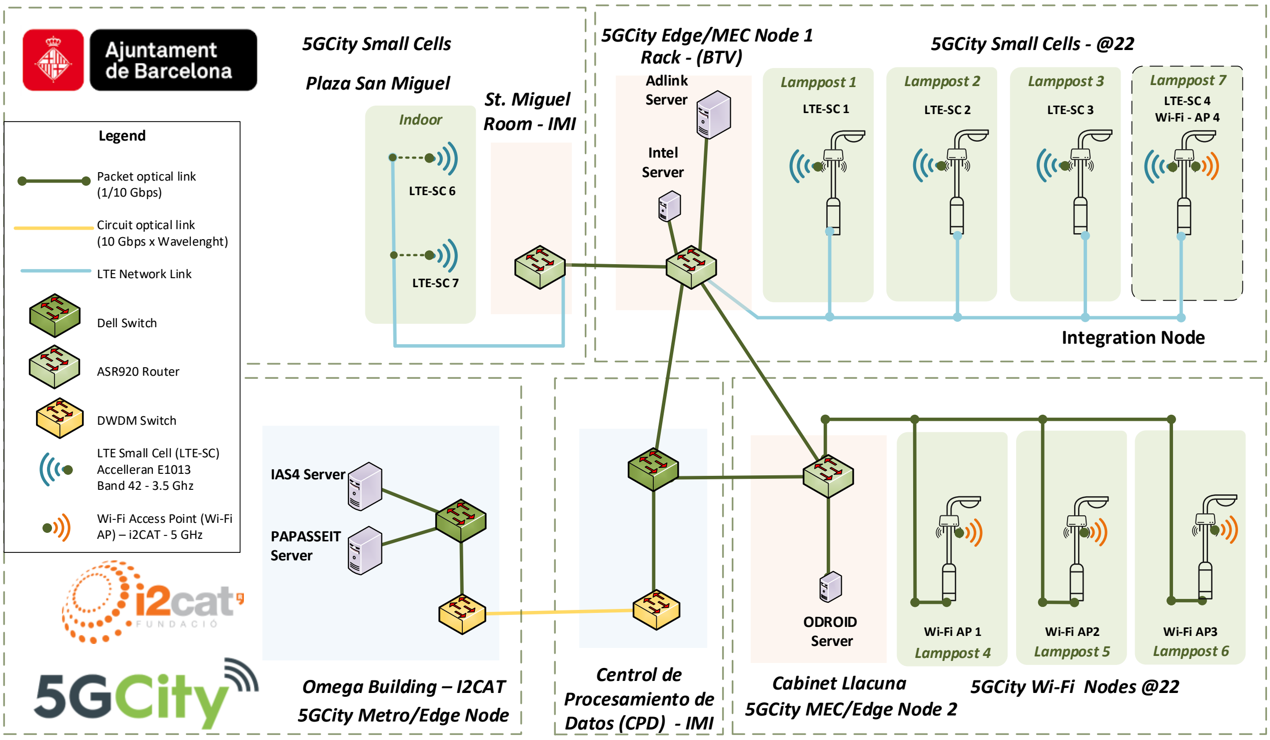


Figure 3: Network Schematic of 5GCity infrastructure in the City of Barcelona.

Figure 4: 5GCity lampposts (LTE or Wi-Fi) in Superblock@22 Barcelona.

2.1.2 5GCity Edge/MEC nodes in BeTeVe premises and Llacuna street

The primary street cabinet for 5GCity was maintained in defined in D5.1 at the crossing of the Llacuna and Pere IV streets (see Figure 5).

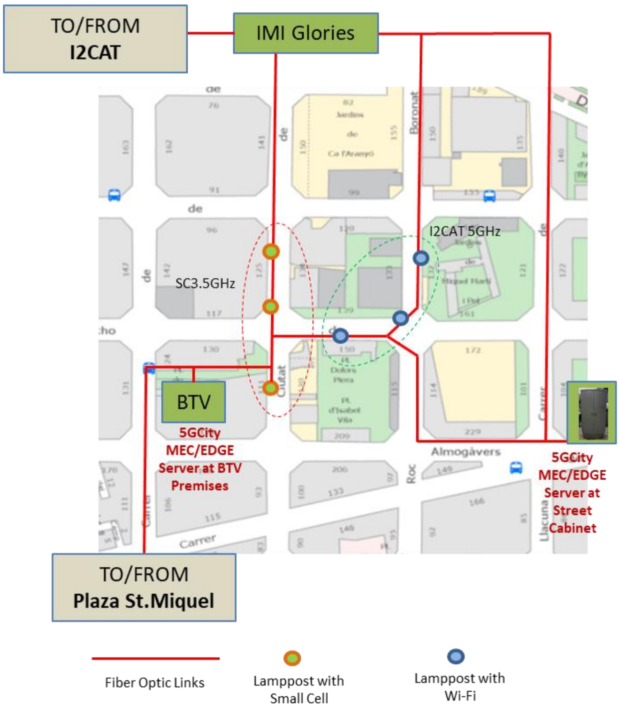


Figure 5: 5GCity street cabinet in Llacuna street, Barcelona.

Figure 6: Fiber path interconnecting IMI to BTV, @22 and Plaza Sant Miquel, Barcelona.

A second edge cabinet location was originally planned in the same district. However, isolation issues emerged at the intended deployment site caused by flooding in case of rain. The second edge cabinet was then deployed at BeTeVe premises, still close to @22 area and in the condition to correctly emulate an edge tier towards 5GCity lampposts and the other cabinet in Llacuna street.

The fiber deployment connecting this edge areas, also extended to cover the new installation in Plaza Sant Miquel is shown in Figure 6.

Following the design approach described in deliverable D5.1, the two edge locations are equipped with an L2/L3 router (Cisco ASR920) which hooks up the local compute, the RAN elements and connects via fiber link to the metro OMEGA-DC located at i2CAT campus. The detailed description of equipment was presented in D5.1 document. In the following figures, we show the actual deployment in operation for this 5GCity Tier-2.

Far-Edge Server - Llacuna Street Cabinet (Figure 7)

Name: ODROID

Hardware: Samsung Exynos5422 Cortex A15 2Ghz and Cortex™-A7 Octa core CPUs, Mali-T628 MP6(OpenGL ES 3.1/2.0/1.1 and OpenCL 1.2 Full profile), 2Gbyte LPDDR3 RAM PoP stacked, eMMC5.0 HS400 Flash Storage, 2 x USB 3.0 Host, 1 x USB 2.0 Host, Gigabit Ethernet port, HDMI 1.4a for display.

Software: Ubuntu 16.04 and FOG05 edge VIM.

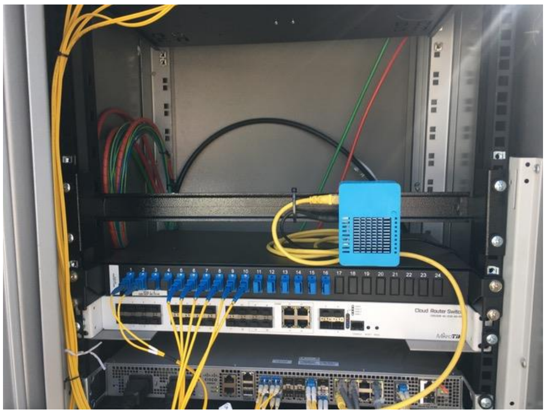


Figure 7: 5GCity Edge/MEC nodes in Llacuna street. *L2/L3 Router Cisco ASR920 (bottom), Far-Edge Server (ODROID, in blue).*

Edge Server 1 – BeTeVe cabinet (Figure 8)

Name: Intel node

Hardware: Intel® Xeon®, 2 PCIE x 4 SSD and SATA SSD, Wi-Fi, 32GB RAM (16GB SODIMM RAM) DDR4 ECC Mini-ITX form, 8xDual PCIe.

Software: Ubuntu 16.04 and OpenStack Queens agents for compute node.

Figure 8: 5GCity Edge/MEC nodes at BeTeVe. *L2/L3 Router Cisco ASR920 (top), Edge Server 1 and Edge Server 2 (at the bottom of the minirack).*

Edge Server 2 – BeTeVe cabinet (Figure 8)

Name: Adlink

Hardware: ADLINK, MXC-6401D/M32G Intel Skylake-H Core i7 CPU+QM170 fanless, 1PCI, 2PCIex8,2DP, 1DVI-I,3xGbE, 6xUSB3.0, 4xCOM,16-CH DIO, 1xCfast socket,4x2.5" SATA port,9-32VDC input,32G DDR4

Software: Ubuntu 16.04 and OpenStack Queens agents for compute node.

2.1.3 5GCity Metro at i2CAT Omega Data Centre

The 5GCity Metro node for Barcelona infrastructure is deployed at the *Omega-DC* building in i2CAT/UPC campus. This data center hosts various compute nodes and networking equipment in use at i2CAT and UPC faculty, part of which are dedicated to 5GCity for the implementation of the Tier-3. The final deployment of the 5GCity Metro DC follows the specification just provided in deliverable D5.1, and consists of three compute nodes, the L2/L3 network devices for interconnection and the fibre infrastructure needed to connect to edge cabinets and the on-street deployments. To add resilience and redundancy to the crucial connection between the Metro DC and the on-street deployment, the team in Barcelona deployed an additional end-to-end fibre connection also supporting 10Gbps line rate between the data centre and the edge cabinets. This backup line allows to maintain end-to-end connectivity also in case of issues caused by interruptions on the primary fibre connection.

Figure 9 shows the racks of the Omega Data Centre hosting IAS4 and PAPASSEIT.

Metro Server 1

Name: IAS4

Hardware: 40 Cores CPU 2.2GHz, 128 GB RAM. 1024 GB SSD. 4 x 1 Gbps Ethernet Ports.

Software: Ubuntu 16.04.5 LTS and OpenStack Queens controller node and agents for compute nodes.

Role: VIM/NFVI Controller and Compute Node

Metro Server 2

Name: PAPASSEIT

Hardware: 16 cores Intel Xeon E5620 2.4 GHz, 48 GB RAM. 1024 GB HDD. 6 x 1 Gbps Ethernet Ports.

Software: Ubuntu 16.04.5 LTS and OpenStack Queens agents for compute nodes.

Role: NFVI Compute Node.

Figure 9: 5GCity Metro DC rack.

2.1.4 5GCity Platform components in Barcelona

Table 2 below shows the 5GCity Platform components that are deployed in the OMEGA-DC for the Barcelona site. These components have been installed and integrated with the underlying infrastructure following the two major releases issued by WP4 in 2019, namely deliverable D4.3 (Interim Release, [4]) and deliverable D4.4 (Final Release, [5]).

In addition to the platform components, also specific connectivity functionalities like EPC (Evolved Packet Core) and split eNodeB have been deployed as part of the integration of releases from WP3 through deliverable D3.2 (Interim release, [2]) and deliverable D3.3 (Final release, [3]).

5GCity Barcelona Platform Module	Status	Version
5GCity Dashboard	**Operational**	*Final release, 5GCity D4.4*
5GCity AAA	**Operational**	*Final release, 5GCity D4.4*
5GCity Slice Manager	**Operational**	*Final release, 5GCity D4.4*
5GCity Multi-tier Orchestrator	**Operational**	*Final release, 5GCity D4.4*
5GCity Resource Placement	**Operational**	*Final release, 5GCity D4.4*
5GCity SDK	**Operational**	*Final release, 5GCity D4.4*
5G App & Service Catalogue	**Operational**	*Release 2.0*
NFVO (ETSI OSM)	**Operational**	*Release 6*
VIM (OpenStack Controller)	**Operational**	*Release Queens*
5GCity Monitoring	**Operational**	*Final release, 5GCity D4.4*
5GCity RAN Controller	**Operational**	*Final release, 5GCity D3.3*

5GCity Infrastructure Abstraction	*Installation not planned*	*Not directly needed by specific use cases in Barcelona*
5GCity Extended Edge Vim (Fog05 VIM)	**Operational**	*Final release, 5GCity D4.4*
5GCity MEAO & MEC Platform	**Operational**	*Final release, 5GCity D4.4*
Virtualized L3 Component	**Operational**	*Final release, 5GCity D3.3*
Virtualized EPC	**Operational**	• *Commercial EPC from Attocore* • *OSS nextEPC aligned to 3GPP R14*

Table 2: 5GCity Platform Components deployed in the City of Barcelona.

Figure 10 shows the location of the different platform modules deployed in the Barcelona pilot.

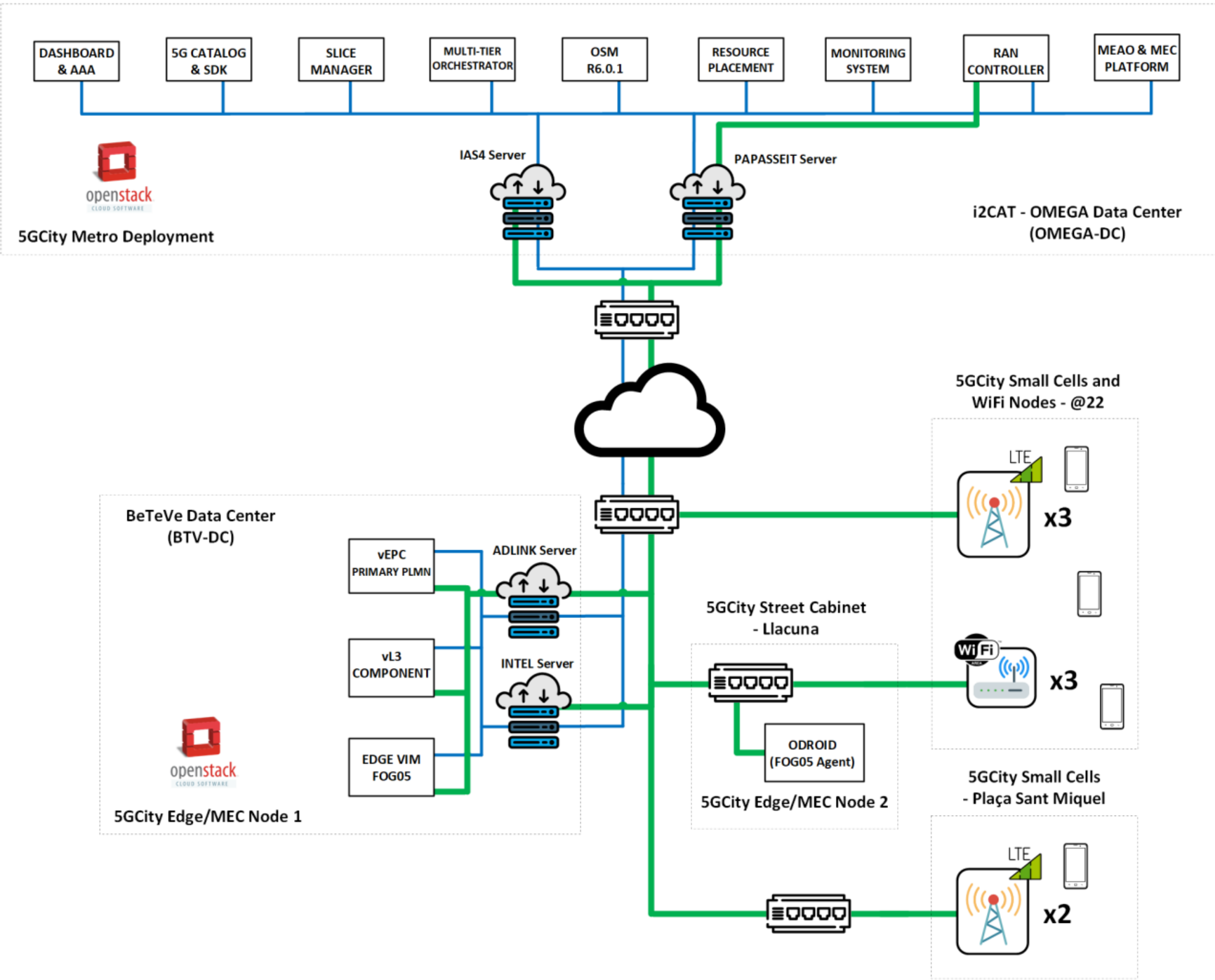


Figure 10: 5GCity Platform components in Barcelona pilot.

2.2 Infrastructure Elements in the City of Bristol

The 5GCity infrastructure deployed in the City of Bristol is part of the 5GUK Test Network. Compared to the design introduced in deliverable D5.1, the currently deployed network implements a larger network coverage and extends the area for trials by including a new site and a new experimentation area at the MShed Museum. The new fibre connectivity and a new edge location deployed at MShed are introduced in Figure 11 (a). They enable a wider experimentation area on the other side of the Avon river by triplicating the radio coverage initially planned for the project through D5.1.

The result of deployment activities for Bristol based on D5.1 plan is reported in the following Table 3.

5GCity Bristol	Elements planned in D5.1 [1]	Element deployed	Status as of 30Sept '19
5GCity Tier-1 (RAN)			
Mobile Devices	*n/a*	**20**	*All smartphones*
Small Cells	2	**2**	**Operational**
Wi-Fi APs	6	**7**	**Operational** *(+1 in MShed)*
Connectivity and Cabinets	2	**3**	**Operational** *(+1 for MShed)*
Lampposts/Towers	6	**9**	**Deployed** *(+2 in MShed)*
5GCity Tier-2 (Edge)			
Compute nodes	2	**4**	**Operational** *(+2 in MShed)*
Router/Switch	2	**3**	**Operational** *(+1 in MShed)*
Street Cabinets/Racks	2	**3**	**Deployed** *(+1 in MShed)*
Connectivity Cabinet to DC	1	**2**	**Operational** *(+1 to connect MShed)*
5GCity Tier-3(Core)			
Servers	3	**3**	**Operational**
Router/Switch	As per DC infrastructure	**As per DC infrastructure**	**Operational**
Connectivity Cabinet to DC	1	**2**	**Operational** *(+1 to connect MShed)*

Table 3: Inventory of 5GCity infrastructure elements in the City of Bristol.

The new optical connectivity and overall locations for Radio Access Network (Millennium Square plus MShed) are depicted in Figure 11 a) and b).

For 5GCity Tier-1 (RAN) in Bristol, we reduced the number of towers from 6 to 4 in Millennium Square and there deployed four 5GCity Wi-Fi Nodes to cover the square and close surrounding areas down to harbour side. The new 5GCity location at MShed Museum has brought in three outdoor 5GCity hotspot locations respectively at East Roof, Middle Roof, and West Roof. There we deployed three Wi-Fi Nodes (Ruckus T710) and two Small Cells (Accelleran E1000 series) as depicted in Figure 11 b).

The 5GCity Tier-2 (Edge) is deployed in the two locations, i.e. the Millennium Square and MShed Museum. Far-edge (ARM Servers 1 and 2), Neighbourhood level MEC nodes (ADLINK) and standard rack servers are installed in We-The-Curious Data Centre (WTC-DC) and in MShed Data Centre (M-DC).

The 5GCity Tier-3 (Metro) is hosted at the University of Bristol High-Performance Network Group Data Centre (HPN-DC) as initially planned in D5.1.

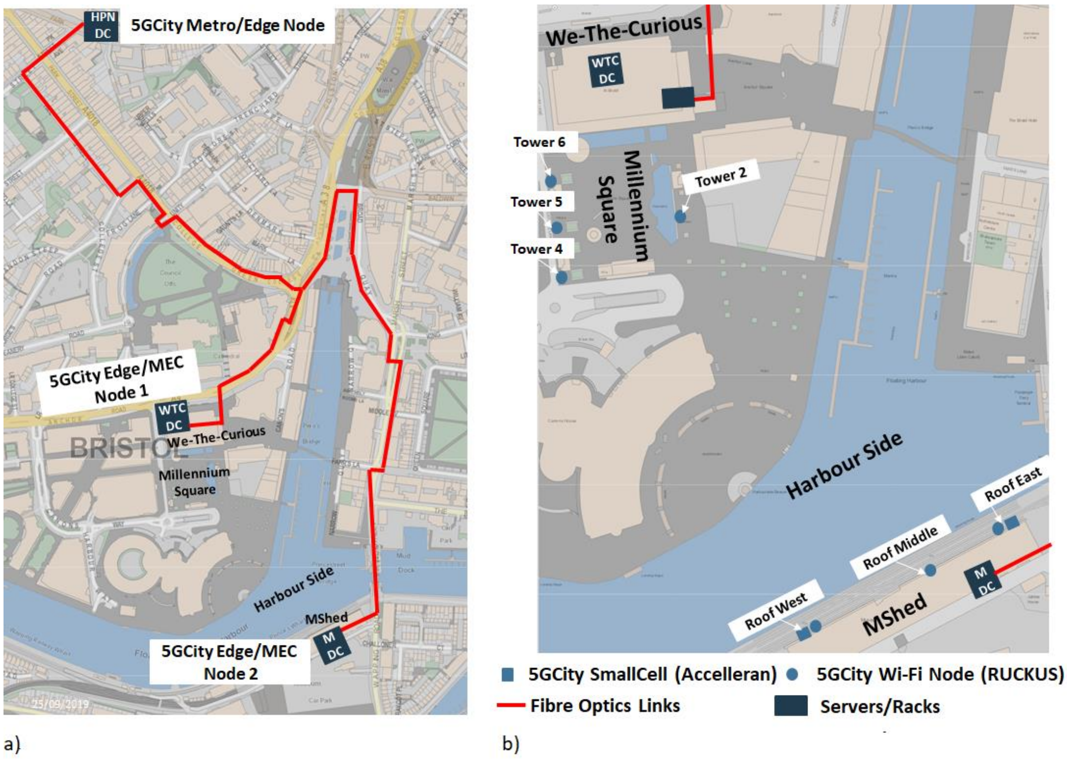


Figure 11: 5GCity infrastructure deployed in 5GUK Test Network in Bristol.

a) Sites for 5GCity Metro/Edge and Edge/MEC nodes in We-The-Curious and MShed connected by a new fibre optic link. b) Main sites and components of the Radio Access Network (RAN) in Millennium Square and MShed.

The network schematic which summarises all these details is provided in Figure 12.

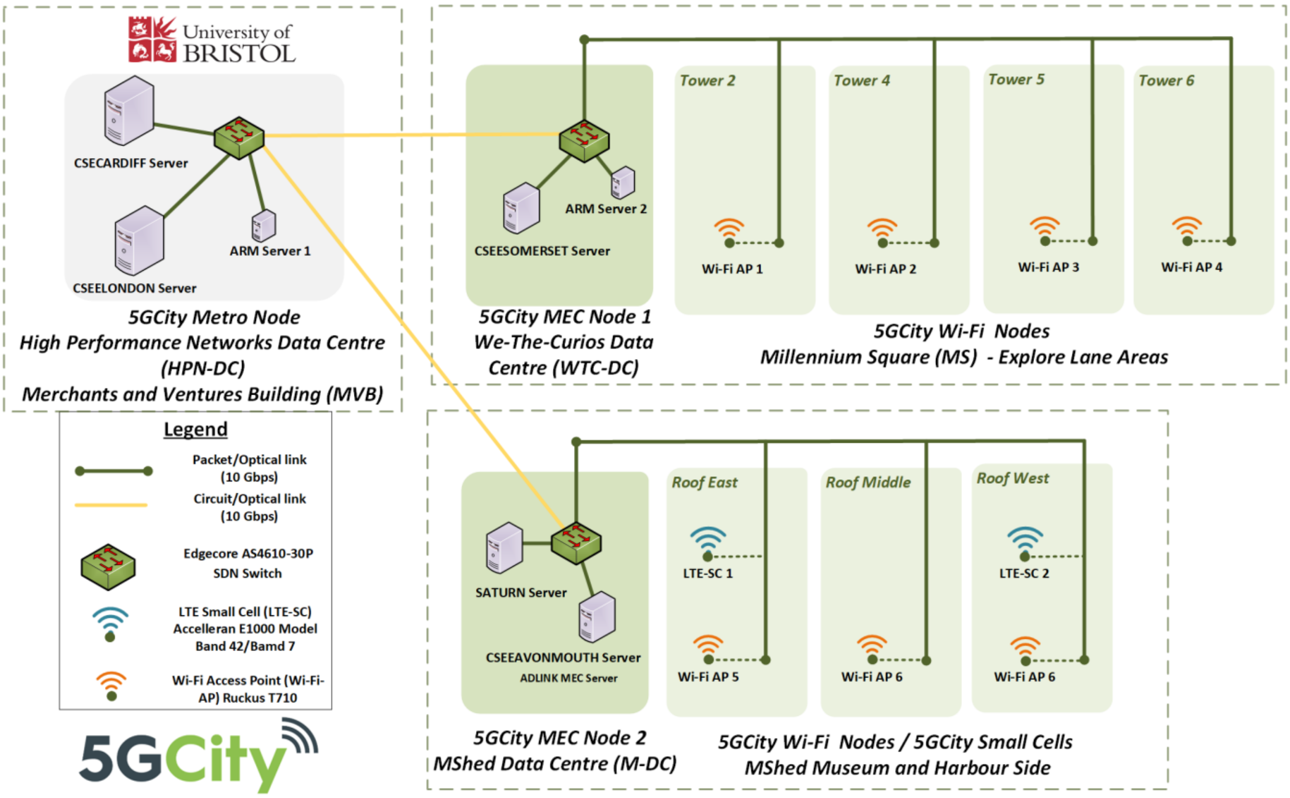


Figure 12: Network Schematic of 5GCity infrastructure in the City of Bristol.

2.2.1 5GCity RAN in Millennium Square and MShed

The design of radio network originally planned in deliverable D5.1 to demonstrate 5GCity project in Bristol was based on a Nokia solution adopted also for 5GUK Test Network. This network could guarantee coverage of Millennium Square and close surrounded areas. Due to the need to extend the experimentation area to the harbour side, University of Bristol deployed three new Wi-Fi Nodes (Ruckus T710) and two Small Cells (Accelleran E1013) in three roof locations a MShed. **Figure** 13 shows photos of the devices installed on the four towers in Millennium Square and on the roof of MShed Museum.

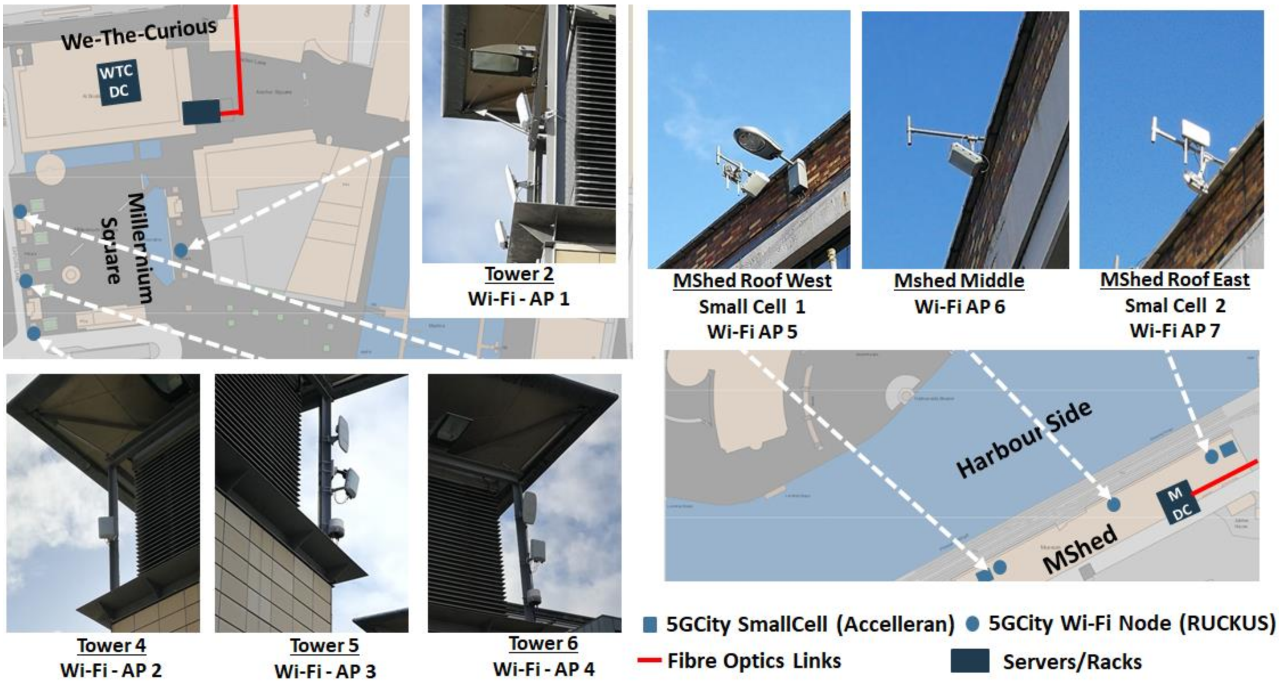


Figure 13: 5GCity RAN Infrastructure in Bristol.

Wi-Fi APs in Millennium Square at the left of the picture. Wi-Fi APs and Small Cells in MShed on the right.

2.2.2 5GCity Edge/MEC nodes deployed in We-The-Curious and MShed

In the following figures, we present the deployed devices in operation for this 5GCity Tier-2 in Bristol.

Edge Server 1 – We-The-Curious (WTC-DC) (Figure 14)

Name: CSEESOMERSET

Hardware: IBM x3455 Node - 4-core AMD CPU 8GB RAM. 80GB HDD.

Software: Ubuntu 16.04 and OpenStack Queens agents for compute node.

Figure 14: 5GCity Edge Servers at WTC-DC.

Ext-Edge Server 2 – We-The-Curious (WTC-DC) (Figure 14)

Name: ARM Server 1

Hardware: Xilinx Zynq UltraScale+ MPSoC ZCU102, quad-core ARM Cortex-A53, 4GB, 512 Mbps RAN

Software: Linux/VOSYS Switch

Edge Server 2 -MShed (M-DC) (Figure 15)

Name: SATURN

Hardware: DELL PowerEdge T630 - 24x 2.4Ghz Intel CPU cores, 64GB RAM. 400GB SSD and 1TB HDD.

Software: Ubuntu 16.04 and OpenStack Queens agents for compute node.

Figure 15: Edge Server 2 - SATURN.

Edge Server 3- MShed (M-DC) (Figure 16)

Name: AVONMOUTH

Hardware: ADLINK, MXC-6401D/M32G Intel Skylake-H Core i7 CPU+QM170 fanless, 1PCI, 2PCI, 32G DDR4

Software: Ubuntu 16.04 and FOG05 VIM

Figure 16: Edge Server 3- AVONMOUTH.

2.2.3 5GCity Metro at University of Bristol HPN Lab datacenter

The 5GCity Metro node for Bristol infrastructure is deployed at the University of Bristol High-Performance Network Group Lab Data Centre (HPN-DC) as initially planned in D5.1. It also includes an additional edge-format server.

Metro Server 1 (Figure 17)

Name: CSEELONDON.

Hardware: DELL PowerEdge T630 – 24x 2.4Ghz Intel CPU cores, 64GB RAM. 400GB SSD and 1TB HDD. 2 x 1 Gbps and 4 x 10 Gbps Ethernet Ports

Software: Linux Ubuntu 16.04 and OpenStack Queens.

Role: Controller and Compute Node – VIM Core.

Figure 17: Metro Server 1 – CSEELONDON.

Metro Server 2 (Figure 18)

Name: CSEECARDIFF

Hardware: IBM x3455 Node – 4-cores AMD CPU 8GB RAM. 80GB HDD.

Software: Linux Ubuntu 16.04 and OpenStack Queens.

Role: Compute Node – Controller.

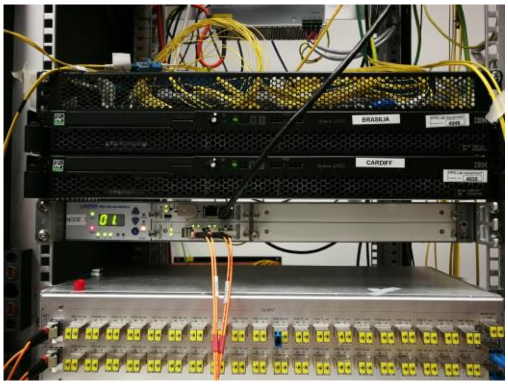


Figure 18: Metro Server 2 – CSEECARDIFF.

Ext-Edge Server 1

Name: ARM Server 1

Hardware: Xilinx Zynq UltraScale+ MPSoC ZCU102 quad-core ARM Cortex-A53, 4GB memory, 512 Mbps RAM.

Software: Linux

2.2.4 5GCity Platform components in Bristol

Table 4 below shows the 5GCity Platform components that are deployed in the HPN Lab datacenter of the University of Bristol. These components are aligned to the latest released from WP3 and WP4, namely deliverable D3.3 (Final release, [3]) and deliverable D4.4 (Final Release, [5]).

5GCity Bristol Platform Module	Status	Version
5GCity Dashboard	**Operational**	*Final release, 5GCity D4.4*
5GCity AAA	**Operational**	*Final release, 5GCity D4.4*
5GCity Slice Manager	**Operational**	*Final release, 5GCity D4.4*
5GCity Multi-tier Orchestrator	**Operational**	*Final release, 5GCity D4.4*
5GCity Resource Placement	**Operational**	*Final release, 5GCity D4.4*
5GCity SDK	**Operational**	*Final release, 5GCity D4.4*
5G App & Service Catalogue	**Operational**	*Release 2.0*
NFVO (ETSI OSM)	**Operational**	*Release 6*

VIM (OpenStack Controller)	**Operational**	*Release Queens*
5GCity Monitoring	**Operational**	*Final release, 5GCity D4.4*
5GCity RAN Controller	**Operational**	*Final release, 5GCity D3.3*
5GCity Infrastructure Abstraction	**Operational**	*Final release, 5GCity D4.4*
5GCity Extended Edge Vim (Fog05 VIM)	*Installation not planned*	*Not directly needed by specific use cases in Bristol*
5GCity MEAO & MEC Platform	*Installation not planned*	*Not directly needed by specific use cases in Bristol*
Virtualized L3 Component	**Operational**	*Final release, 5GCity D3.3*
Virtualized EPC	**Operational**	• *Commercial EPC from Attocore* • *OSS nextEPC aligned to 3GPP R14*

Table 4: 5GCity Platform Components deployed in the City of Bristol.

Figure 19 shows the location of the different platform modules deployed in the Bristol pilot.

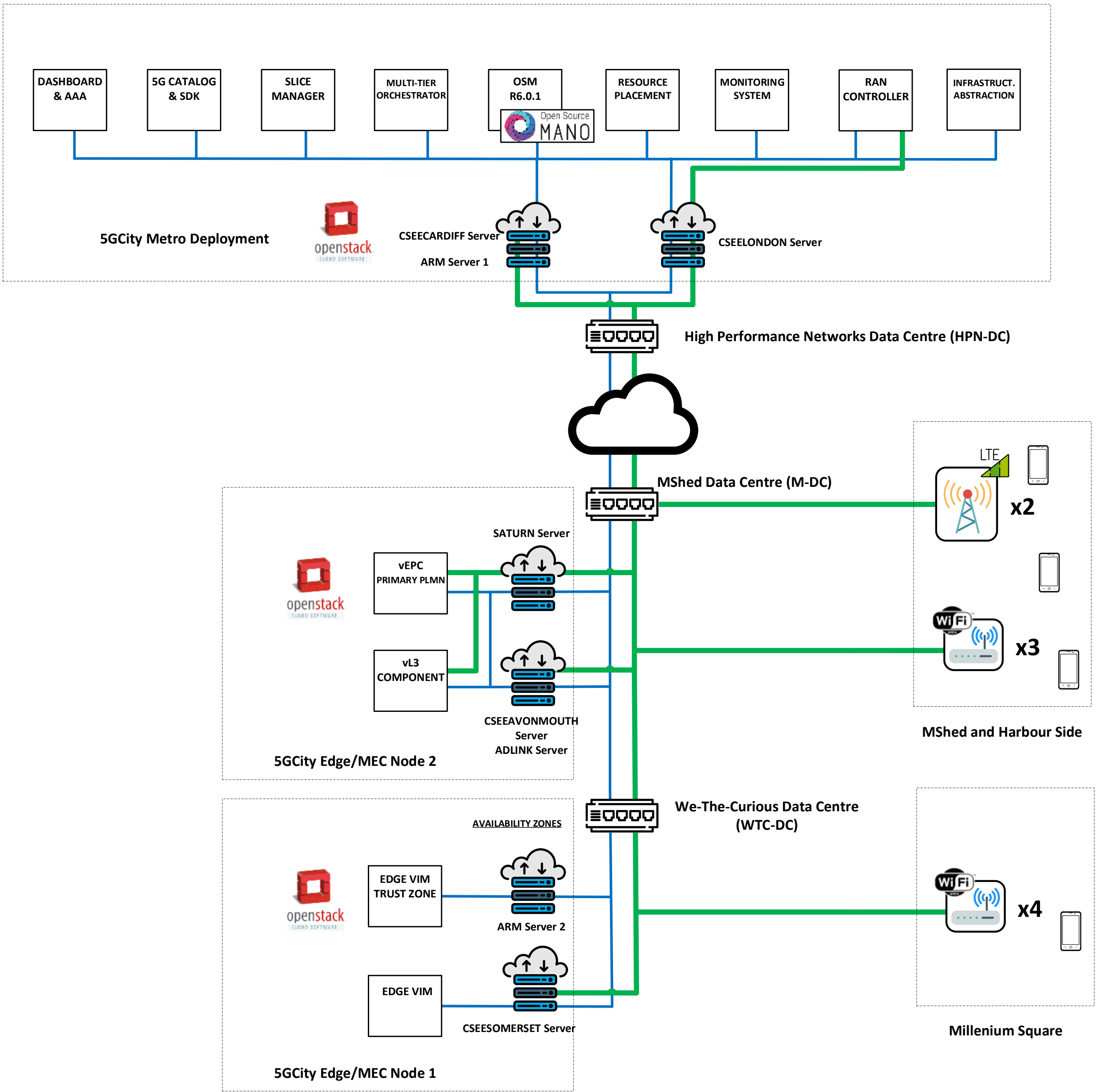


Figure 19: 5GCity Platform components in Bristol pilot.

2.3 Infrastructure Elements in the City of Lucca

The initial design of the 5GCity infrastructure proposed in Deliverable D5.1 for the City of Lucca was conceived to take into account the very specific historical characteristics of the city (historic walls and pathway on top) and the most appropriate target areas for demonstrations and validations of the 5GCity use cases planned for Lucca. For this reason, the 5GCity Infrastructure in Lucca has privileged green areas and squares close to the historical wall with pathway, since – typically – public events occur in there.

The implementation of the initial design resulted substantially appropriate to the needs of experimentation in Lucca with just a minor variation in the number of small cells to be deployed. In fact, the initial number of three Small Cells was decreased of one unit because in the testing area at Porta San Donato was sufficiently covered by the small cell installed at the roof of the San Paolino building. In addition, some temporary re-configurations of the infrastructure where implemented in occasion of major public events, like the Lucca Comics and Games 2018 and the 16th European Digital Forum 2019 hosted at Real Collegio. During these events the tiers of the 5GCity infrastructure were extended and/or moved to implement coverage in specific areas (e.g. ex-Cavallerizza building at Porta San Donato and on the top of the roof of Torre Guinigi). These temporary variations were implemented just for the duration of the events and were needed to support in-situ showcases of Immersive Reality applications by RAI (Use Case 4) at both events and live TV streaming from Torre Guinigi towards Real Collegio during the 16th European Digital Forum.

The result of deployment activities for Lucca is reported in the following Table 5.

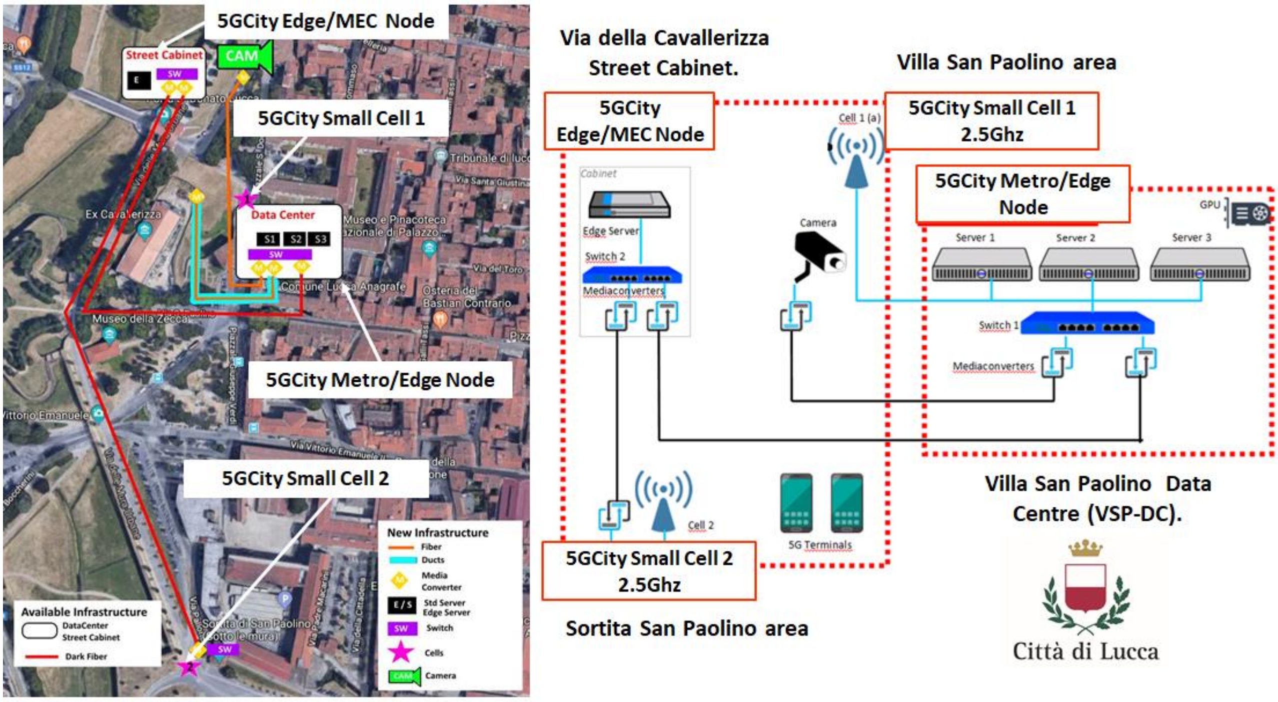
5GCity Lucca	Elements planned in D5.1 [1]	Element deployed	Status as of 30Sept '19
5GCity Tier-1 (RAN)			
Mobile Devices	*n/a*	**8**	*Available:* *5x smartphones,* *2x 4G Wi-Fi routers,* *1x 4G tablet*
Small Cells	3	**2**	**Operational** *(-1 in San Donato Area)*
Wi-Fi APs	0	**0**	**n/a**
Connectivity and Cabinets	1	**1**	**Operational**
Lampposts/Towers	0	**0**	**n/a**
5GCity Tier-2 (Edge)			
Compute nodes	2	**2**	**Operational**
Router/Switch	2	**2**	**Operational**
Street Cabinets/Racks	1	**1**	**Deployed**
Connectivity Cabinet to DC	1	**2**	**Operational** *(+1 for CCTV camera)*
5GCity Tier-3(Core)			
Servers	2	**2**	**Operational**
Router/Switch	As per DC infrastructure	**As per DC infrastructure**	**Operational**
Connectivity Cabinet to DC	1	**2**	**Operational** *(+1 for CCTV camera)*

Table 5: Inventory of 5GCity infrastructure elements in the City of Lucca.

On 5GCity Tier-1 (RAN), two 2x Accelleran Small Cells operating in Band 38 at 2.6 GHz with 10MHz bandwidth (spectrum licensed to Wind Tre, offered to 5GCity for experimentation) are deployed. The small cells have been placed in two locations which offer better radio coverage to the planned use cases: one on the roof of Comune di Lucca IT department building at the crossing between San Paolino street and Baluardo San Donato (SC-San Donato) and one on the roof of Sortita San Paolino on the historical walls (see Figure 20 a).).

The 5GCity Tier-2 (Edge) has been deployed in a street cabinet located in Via della Cavallerizza and hosts an Edge Server, a L2 switch to connect the street cabinet with the metro node. The Video Analytics Server (Server #3 with GPU) for Use Case 1 is deployed at metro data center for racking issues in the cabinet.

The 5GCity Tier-3 (Metro) is deployed in the server room of the Comune di Lucca IT department in Via San Paolino second floor (Villa San Paolino Data Center, VSP-DC), and it is hosting the 5GCity Platform, NFVI and L2 network switches to interconnect the various elements and with the edge/RAN (see Figure 20 b).).



a) b)

Figure 20: 5GCity infrastructure deployed in the City of Lucca.

a) Overview of the final physical deployment (left side). b) Network schematic of the infrastructure.

2.3.1 5GCity RAN in Villa San Paolino and Sortita San Paolino

Based on the D5.1 design, two Small Cells (Accelleran E1013) have been deployed configured to operate in the spectrum (2579-2595 GHz, Band 38) licensed to Wind Tre and offered to the project for experimentation. The user terminals used for basic tests operate in TDD mode (MNC/MCC 99 or 88 – free Access Class or Reject on LA/RA) and connect to the Accelleran small cells. The LTE RAN also implements the RRU component of the 3-Layer based architecture, while the associated vRAN Controller runs in the edge/metro. Figure 21 shows pictures of the Small Cells deployed in villa San Paolino (SC-SDonato) and Sortita San Paolino (SC-SPaolino).

Figure 21 : 5GCity RAN Infrastructure in Lucca.

2.3.2 5GCity MEC/Edge Node in Via della Cavallerizza

The 5GCity MEC/Edge Node deployed at Via Cavalerizza is hosted in a street cabinet which is connected via fiber link to the 5GCity Metro in VSP-DC. One compute node from ADLINK is deployed in the cabinet together with a L2 switching devices which interconnects the server with the Small Cell in Sortita San Paolino and the data center.

Edge Server (Figure 22)

Name: Edge Server

Hardware: ADLINK, MXC-6401D/M32G Intel Skylake-H Core i7 CPU+QM170 fanless, 1PCI, 2PCI, 32G DDR4

Software: Ubuntu 16.04 and OpenStack Queens agents for compute node.

Giga Ethernet Switch

Hardware: D-Link, 24 port DGC-1510-28, 24 RJ-45 autosensing 10/100/1000 ports, 2 10G SFP+ Stacking/Uplink Ports.

Software: Management API.

Figure 22: Street Cabinet in Via della Cavallerizza – Lucca.
Edge Server (bottom) and L2 Switch (top).

CCTV IP camera (Figure 23)

Hardware: WiseNET XNV-6080 2M Network Dome outdoor, 2M Vandal-Resistant Network Dome Camera,

Max. 2megapixel (1920 x 1080) resolution, 4.3x motorized varifocal lens, max 60fps@all resolutions (H.265/H.264), H.265, H.264, MJPEG codec, Multiple streaming, Day & Night (ICR), WDR (150dB), Defog, Loitering, Directional detection, Fog detection, Audio detection, Digital auto tracking, Sound classification, Tampering, Motion detection, Handover, Hallway view, WiseStream II support, IP67/IP66.

Figure 23: 5GCity CCTV camera for UC1.

2.3.3 5GCity Metro in Villa San Paolino Data Centre

The 5GCity Edge/Metro Node deployed in VSP-DC hosts two servers, one (Server #1) for orchestration and interconnection services (VPN concentrator for Lucca), the other (Server #2) acting as NFVI compute node to host workload from the various use cases.
The two servers are interconnected with edge cabinet and the outdoor CCTV IP camera via fiber network and access to the Internet via the corporate network of Comune di Lucca.
The 5GCity rack in VSP-DC also hosts the edge server for video analytics from NEC to be used in Use Case 1 (“Unauthorised Waste Dumping”). This server includes a GPU and was originally designed to be deployed in the edge cabinet; however, the final equipment resulted in an excessive form factor for being mounted at edge and could not fit the current rack sizes at Via della Cavallerizza.

Metro Server 1 (Figure 24)

Name: Server#1

Hardware: DELL PowerEdge R740 - Intel® Xeon® Gold 5120 2.2G - 64 GB RAM, 2 x 600GB HDD.

Software: Linux Ubuntu 16.04 and OpenStack Queen agents for compute and controller nodes.

Role: Controller and Compute Node – VIM Core.

Metro Server 2 (Figure 24)

Name: Server#2

Hardware: DELL PowerEdge R740 - Intel® Xeon® Gold 5120 2.2G - 64 GB RAM, 2 x 600GB HDD.

Software: Linux Ubuntu 16.04 and OpenStack Queen agents for compute node.

Role: Compute Node – VIM Core.

Video Analytics Server (Figure 24)

Name: NEC Server

Hardware: n/a

Software: n/a

Role: run video analytics algorithms by NEC

Giga Ethernet Switch (Figure 24)

Hardware: D-Link, 24 port DGC-1510-28, 24 RJ-45 autosensing 10/100/1000 ports, 2 10G SFP+ Stacking/Uplink Ports.

Figure 24: 5GCity Edge/Metro Node (VSP-DC). *From the bottom of the rack: L2 switch; NFVI Servers (x2); UC1 Video Analytics Server.*

2.3.4 5GCity Platform components in Lucca

Table 6 below shows the 5GCity Platform components that are deployed in the VSP-DC of the Comune di Lucca. These components are aligned to the latest released from WP3 and WP4, namely deliverable D3.3 (Final release, [3]) and deliverable D4.4 (Final Release, [5]).

5GCity Lucca Platform Module	Status	Version
5GCity Dashboard	**Operational**	*Final release, 5GCity D4.4*
5GCity AAA	**Operational**	*Final release, 5GCity D4.4*
5GCity Slice Manager	**Operational**	*Final release, 5GCity D4.4*
5GCity Multi-tier Orchestrator	**Operational**	*Final release, 5GCity D4.4*
5GCity Resource Placement	**Operational**	*Final release, 5GCity D4.4*
5GCity SDK	**Operational**	*Final release, 5GCity D4.4*
5G App & Service Catalogue	**Operational**	*Release 2.0*
NFVO (ETSI OSM)	**Operational**	*Release 6*

VIM (OpenStack Controller)	**Operational**	*Release Queens*
5GCity Monitoring	**Operational**	*Final release, 5GCity D4.4*
5GCity RAN Controller	**Operational**	*Final release, 5GCity D3.3*
5GCity Infrastructure Abstraction	*Installation not planned*	*Not directly needed by specific use cases in Lucca*
5GCity Extended Edge Vim (Fog05 VIM)	*Installation not planned*	*Not directly needed by specific use cases in Lucca*
5GCity MEAO & MEC Platform	*Installation not planned*	*Not directly needed by specific use cases in Lucca*
Virtualized L3 Component	**Operational**	*Final release, 5GCity D3.3*
Virtualized EPC	**Operational**	• *Commercial EPC from Attocore* • *OSS nextEPC aligned to 3GPP R14*

Table 6: 5GCity Platform Components deployed in the City of Lucca.

Figure 25 shows the location of the different platform modules deployed in the Lucca pilot.

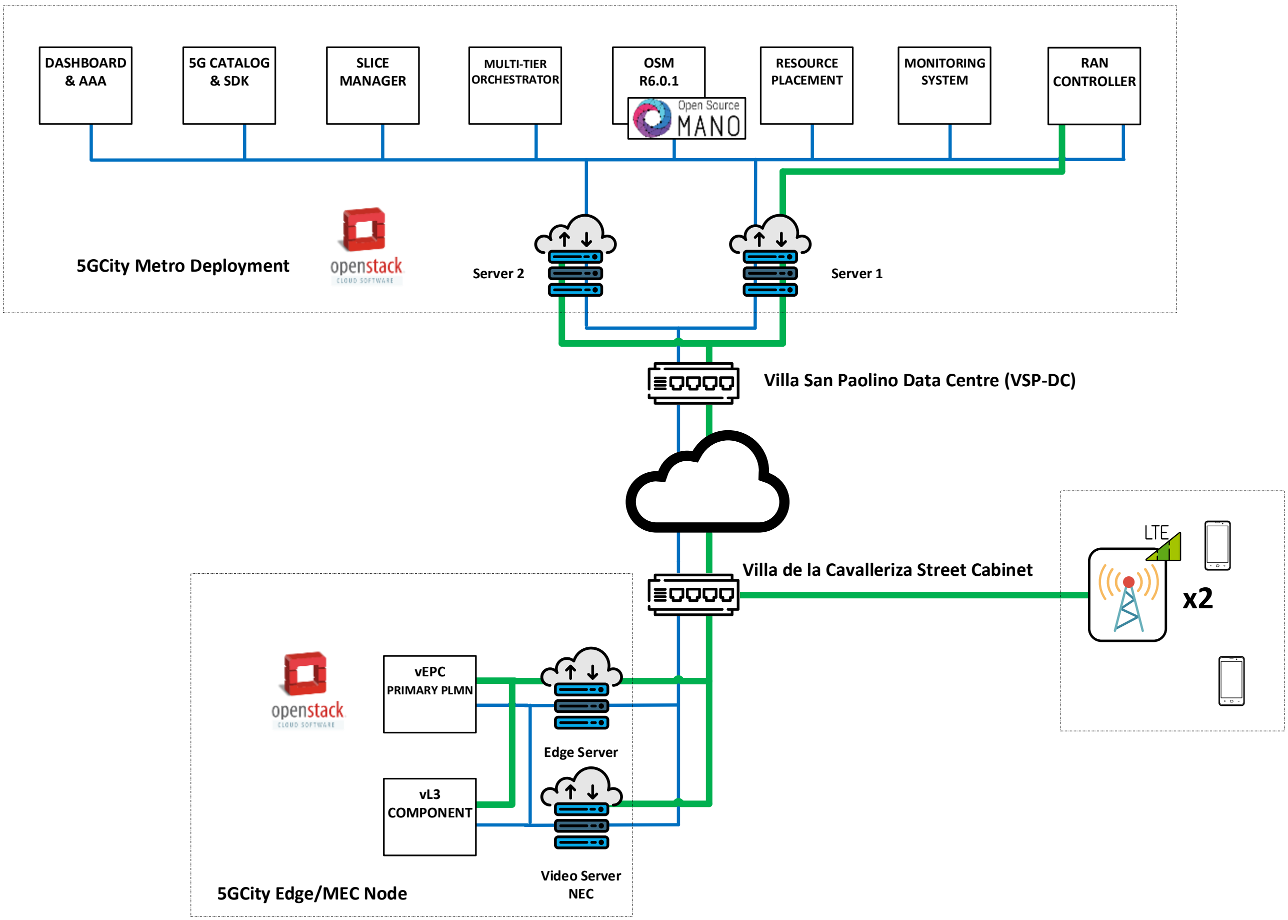


Figure 25: 5GCity Platform components in Lucca pilot.

3 Validation of the 5GCity Infrastructures and Platform

To verify the correct installation and performances of the 5GCity infrastructure and platform components in the three cities, a similar of validation tests have been run in Barcelona, Bristol and Lucca. The main objective of these tests executed by following a similar methodology in the three pilot environments, was to verify performances and better profile configurations in preparation of the forthcoming use case trials.

Four main categories of tests have been profiled, which are discussed in the following:

- Radio Access Network (RAN) tests, to benchmark radio link performances and coverage;
- Connectivity tests, from UE to a compute node at the edge or in metro, or between edge and metro;
- NFV Infrastructure and Virtual Infrastructure Management (NFVI-VIM) tests, to benchmark performances of the installed virtualization platforms;
- 5GCity platform tests, to assess the functionality of the different modules.

3.1 RAN tests

3.1.1 Test methodology

The 5GCity deployments in Barcelona, Bristol and Lucca rely on Accelleran E1000 Series Small Cells in different band variants, which make use of omnidirectional fiberglass antennas. More specifically

City	Available Spectrum	Small Cell type	Bandwidth
Barcelona	B42 (TDD 3400 MHz 3600 MHz)	E1010 Series Small Cells ▪ 2x2 MIMO	20 MHz
Bristol	B42 (TDD 3400 MHz 3600 MHz)	E1010 Series Small Cells ▪ 2x2 MIMO	20 MHz
	(FDD 2500-2570 MHz UL / 2620-2690 MHz DL)	E1020 Series Small Cells ▪ 2x2 MIMO	15 MHz
Lucca	B38 (TDD 2570-2620 MHz)	E1013 Series Small Cells ▪ 2x2 MIMO	15 MHz

Table 7: Overview of 5GCity RAN deployments.

All the small cell band variants support the same MIMO schemes (2x2 MIMO) and the same modulation and coding schemes in downlink (64QAM, 16QAM, QPSK) and in uplink (16QAM, QPSK). However, the three deployments vary for available spectrum, operation more (TDD/FDD) and spectrum bandwidth. Therefore, the three most important radio access factors to consider when evaluating the results are:

- **Spectrum Bandwidth:** The more spectrum bandwidth used the more capacity and throughput that can be achieved on equal channel conditions. As an approximation, the throughput that can be achieved in a 15 MHz channel will be ¾ of the one that can be achieved in a 20 MHz channel. Therefore, it is obvious that in our deployment examples, the throughputs seen in Lucca (15 MHz in TDD B38) should be lower than those seen in Barcelona and Bristol (20 MHz in TDD B42).
- **Duplexing Mode (FDD vs TDD)**: In FDD we have a paired spectrum allocation. For 20MHz bandwidth, it consists of 2 x 20 MHz blocks (40 MHz total), one 20 MHz fully dedicated in the downlink and another 20 MHz block fully dedicated to uplink. In TDD, the spectrum allocation is unpaired and 20

MHz of TDD spectrum correspond to a single 20 MHz block of spectrum which is shared between downlink and uplink slot transmissions according to a particular Downlink to Uplink ratio, most usually TDD DL/UL Configuration 2 (6 downlink slots and 2 uplink slots). The total downlink plus uplink throughput of 20 MHz TDD deployment would therefore be ½ of the 20 MHz FDD one.

- **TDD DL/UL Ratio**: The majority of commercial TDD deployments worldwide use TDD DL/UL Configuration 2 (6 to 2) which maps well to the asymmetric traffic of Mobile Broadband internet service. This is the configuration that will be used for the majority of Use Cases in 5GCity. However, for use cases requiring more throughput in the uplink (for example the BTV Mobile Backpack video transmission) a less downlink asymmetric configuration will be used such as the TDD DL/UL Configuration 0 (2 DL slots and 6 uplink slots). The difference in throughput between the 2 different TDD DL/UL configuration are directly proportional to the ratio difference. For example, if under ideal radio channel conditions, a TDD Small Cell using TDD Configuration 2 can give 10 Mbps throughput, the same TDD Small Cell using TDD Configuration 0 can give 30 Mbps throughput under the same ideal radio conditions.

The different 5GCity deployments will all have different radio conditions experienced by the UEs depending on distance to the small cell, urban clutter (buildings, trees, etc.), elements that can be compared and benchmarked, we need to make the measurements on locations where the Signal to Interference and Noise Ratio (SINR) / Reference Signal Received Power levels (RSRP) conditions are similar for the three cities. We will consider locations at different distances for which radio conditions are considered Excellent, Good, Mid Cell and Cell Edge so that different modulation and coding schemes are used in the LTE radio link leading to specific throughputs. Different measurements can lead to an indication of RF conditions such RSRP, Reference Signal Received Quality (RSRQ) and SIRN. Out of the three, SINR quantifies better the relation between signal quality and throughput. For simplification we will only consider the downlink SINR since we can easily check this value in a Smartphone with some Android applications right before we make the measurement on that location. The added advantage of the deployments using TDD is that since both uplink and downlink are on the same carrier frequency the downlink and uplink channel response is similar.

Downlink Radio conditions definitions	RSRP Range (dBm)	SINR Range (dB)	Value to use for location of measurements
Excellent	>= -80	>= 20	25
Good	-80 to -90	13 to 20	15
Mid Cell	-90 to -100	0 to 13	5
Cell Edge	<= -100	<= 0	0

Table 8: UE radio conditions in various locations.

To measure RSRP and RSRQ we used the CellMapper Android application ([6] and see APPENDIX B for test report from Lucca. Reports from other cities are available but not attached). To track the coverage measures we used the G-NetTrack Android application ([7]). More specifically, the test process consisted of the following steps (in all the three cities):

1. Make sure that the UE is attached to the 5GCity Small Cell that is required for the measurements (You can use information from CellMapper application to make sure that eNB, CellID, MCC, MNC, TAC, EARFCN are the ones from the Small Cell required)
2. Make sure that no other 5GCity Small Cells are active neighbours on the same frequency as the serving cell (this is only applicable in 5GCity Barcelona where several small cells in the same carrier frequency can be close to each other)
3. Move to a location with the smartphone pointing in LOS condition towards the small cell until the Excellent radio condition is achieved

4. Without moving the phone trigger and record the measurement data from the iPerf and Ping tests via associated Android applications
5. Repeat Steps 3 and 4 for Good, Mid Cell and Cell Edge locations

3.1.2 RAN performances in Barcelona

Radio tests were performed over LTE and WiFi network comprising three SCs and three APs active on @22 area (see Figure 26). Tests were executed using an Essential Phone in 3 different locations against CGRA0125 lamppost (the only active Small Cell), using G-NetTracker for SIRN measurement and SpeedTest for throughput measurement. The SC was set to operate in TDD Cfg 2 on 20 MHz (good radio and lab conditions) which should give around 90 Mbps DL / 10 Mbps UL

Figure 26: RAN measurement area in Barcelona @22 district.

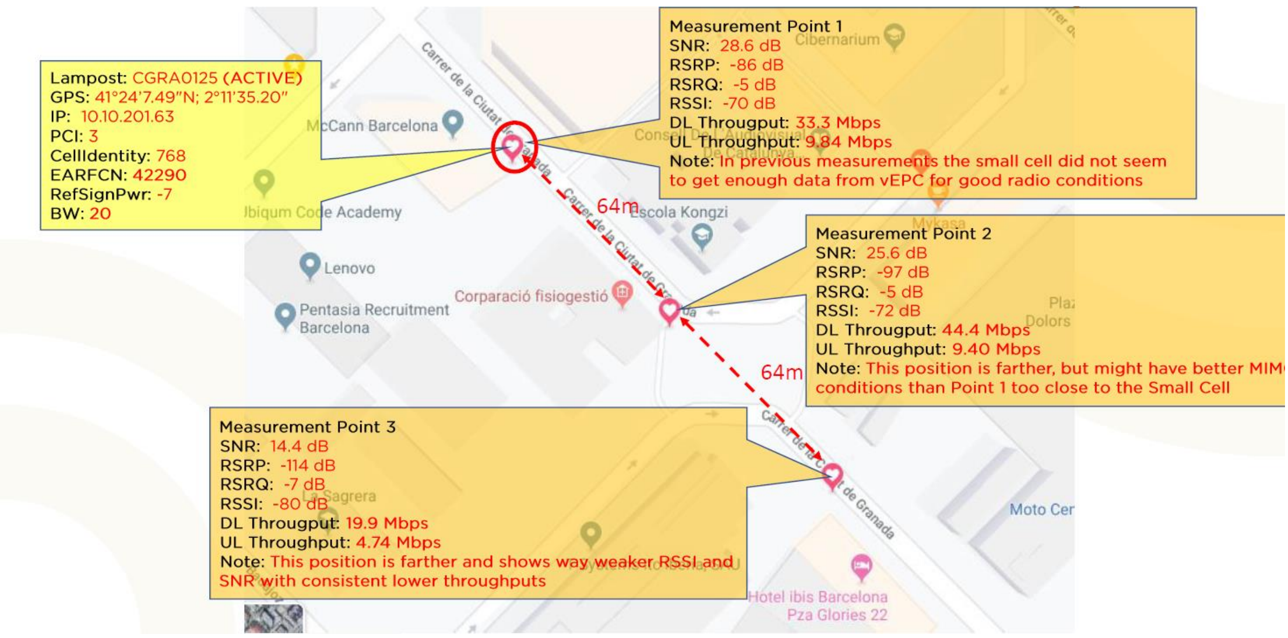


Figure 27: RAN measurement results in Barcelona @22 district.

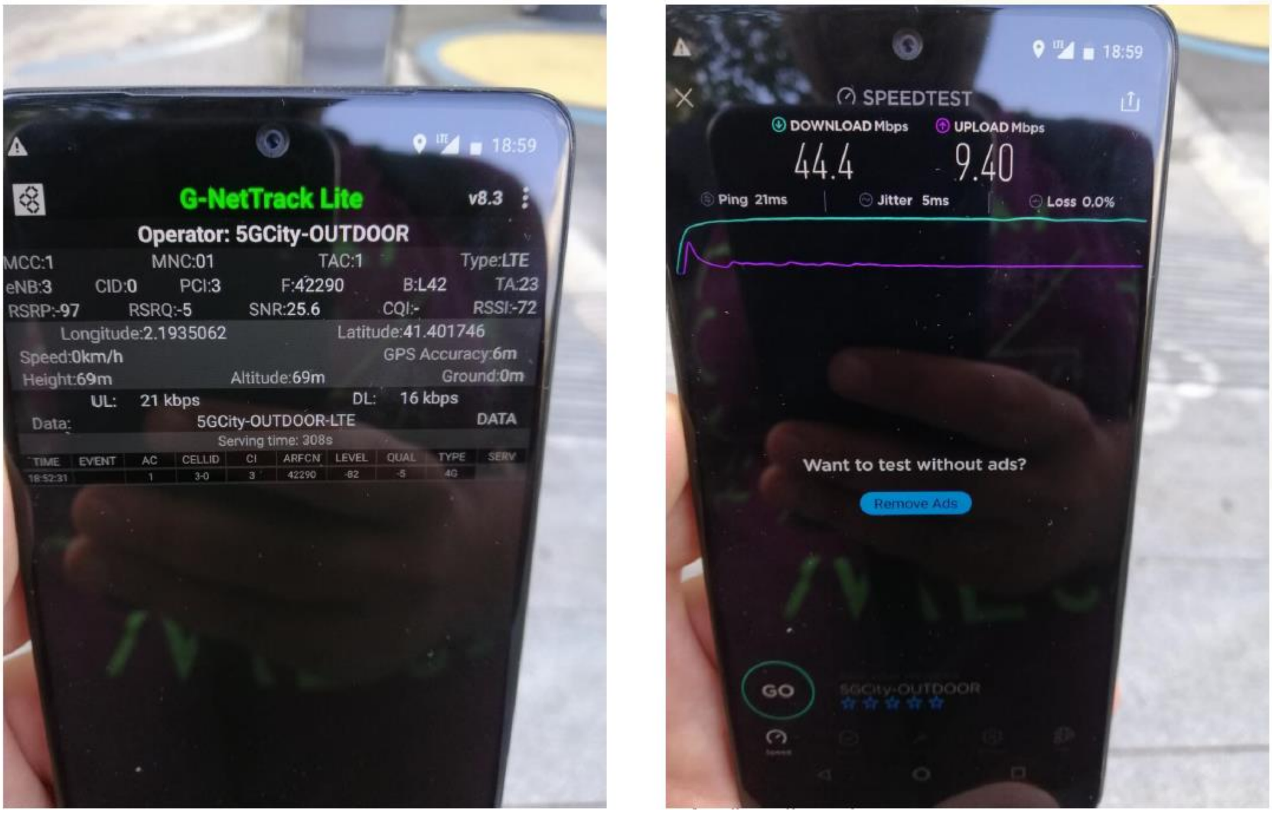
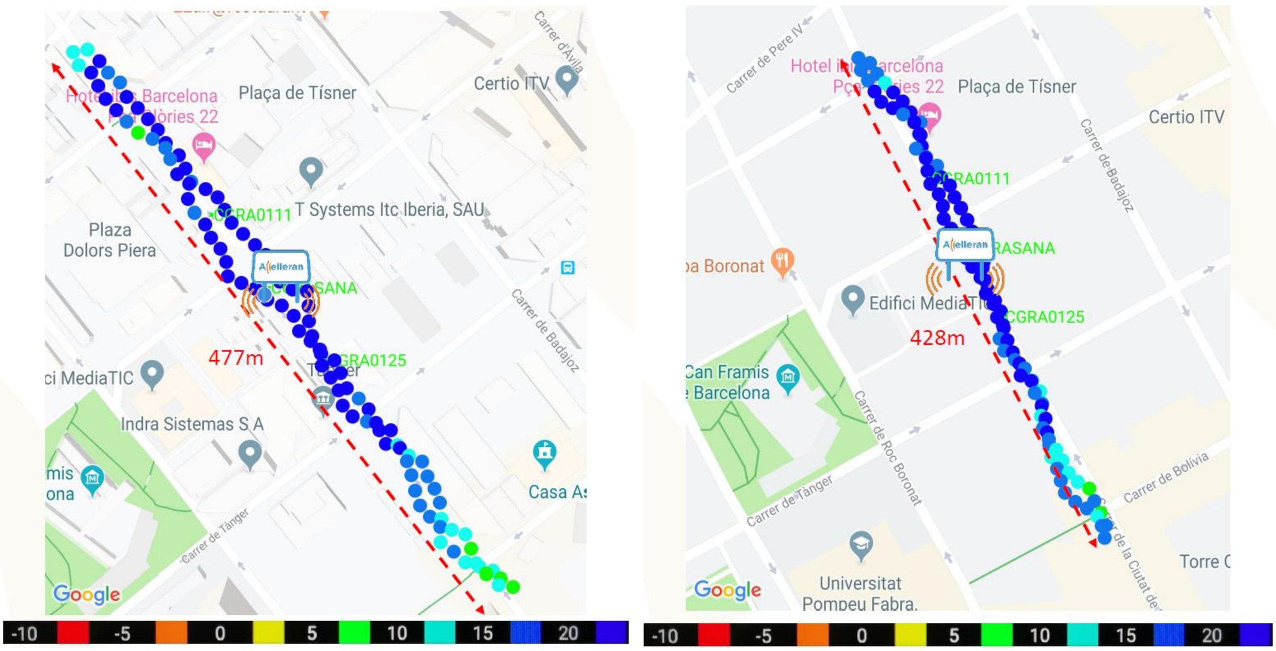


Figure 28: RAN SNR and SpeedTest in Barcelona @22 district (measurement point 2).

The results of the RAN validation tests done in Barcelona are reported in D3.3 as outcome of the RAN virtualization validation.



a) b)

Figure 29: RAN coverage Barcelona: tracked SNR values in CGRASANA at 250mW/port and 125mW/port.

For the specific Barcelona case, Wi-Fi tests have been also executed and reported in deliverable D3.3 [3]. Essential results are provided here for quick reference.

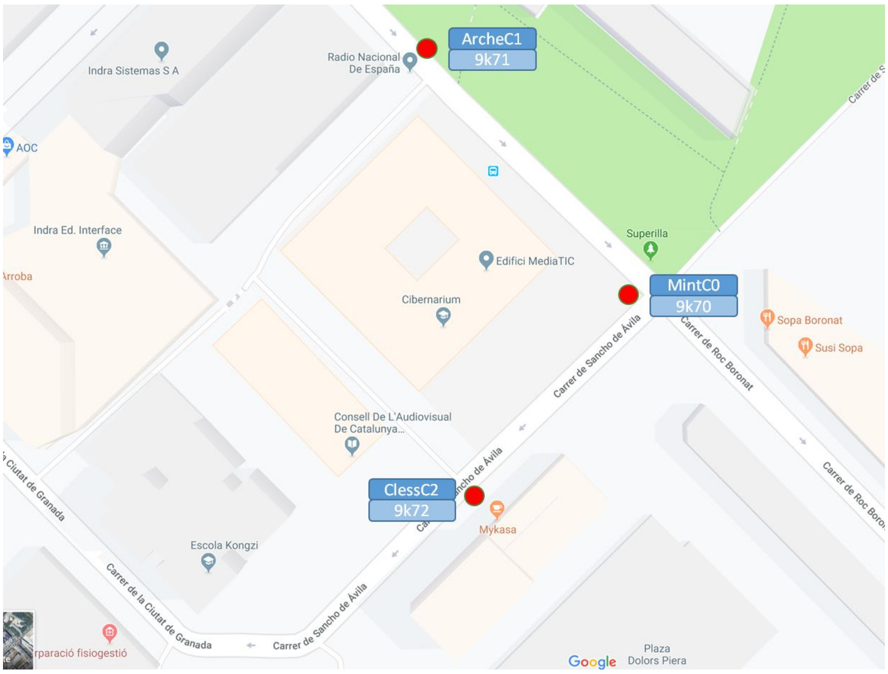
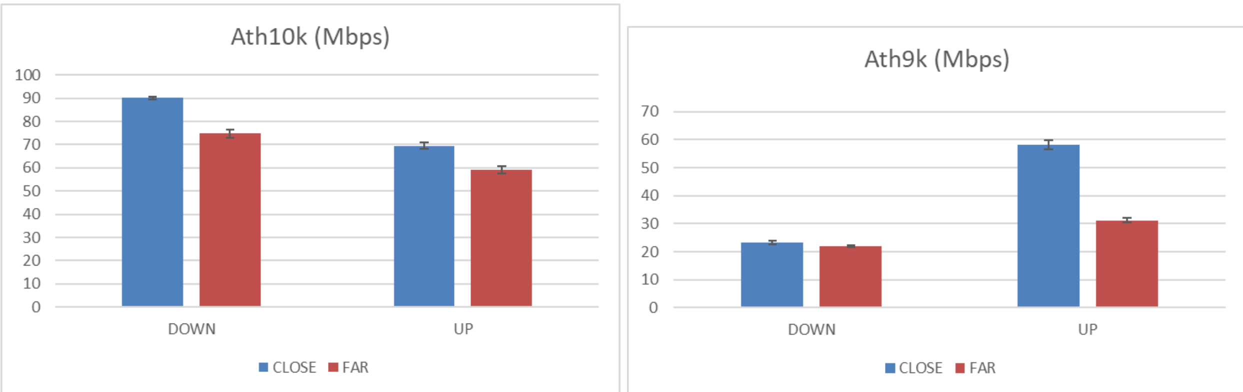


Figure 30: Wi-Fi deployment in 5GCiy Barcelona with names of SSIDs (ath10k / ath9k).



a) b)

Figure 31: Wi-Fi performance over 5GCity-controlled interfaces: a) ath10k, b) ath9k.

These results have been obtained with a Dell laptop used as UE. Results obtained for the ath10k and ath9k (see Figure 31) show that the interfaces are operating correctly. Differences in throughput can be explained by different distances (close/far) and the use of different chipsets (ath9k, ath10k).

3.1.3 RAN performances in Bristol

Radio tests were performed over the LTE and WiFi network deployed in MShed and Millennium Square.

Resources

The resources used for the radio measurement were:

- 1 UE (Essential Smart Phone) with capability to connect WiFi and LTE networks (Band 7/ Band 42).
- 2 SCs Accelleran E1000 – MShed Roof.

- 3 Wi-Fi APs Ruckus T710 – Millennium Square
- G-Net-tracker application for Android OS installed in the UE.

RAN-LTE Measurements

The first LTE test was performed by connecting the UE to the SC Band 7 (MShed Roof West) and walking around key points, in the area to collect levels of SNR (**Figure** 32.a). The second test was performed by connecting the UE to the Small Cell Band 42 (MShed Roof East) and repeating the process with slightly different walking path (**Figure** 32.a). The results identified the area where the signal is better nay demonstration predominantly areas in green, yellow and light blue.

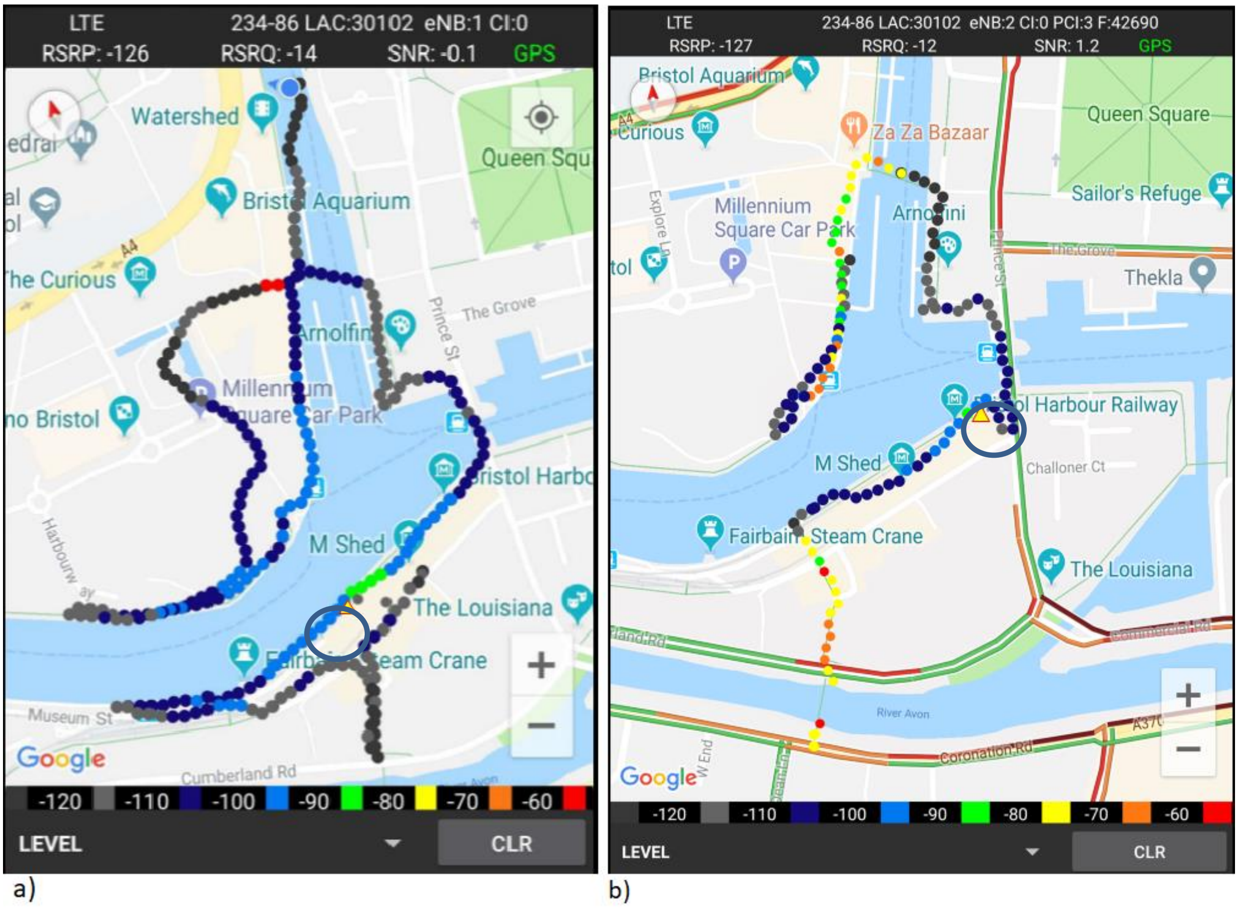


Figure 32: RAN coverage Bristol: tracked SNR values in Bristol's harbour side.

a) Small Cell placed in MShed West Roof. b) Small Cell placed in MShed East Roof.

RAN-Wi-Fi Measurements

The quality of the Wi-Fi signal was measured in Millennium Square to determine the coverage and level of SNR. Figure 33 shows the results of the measurement, with dark green indicating higher levels of signal and SNR.

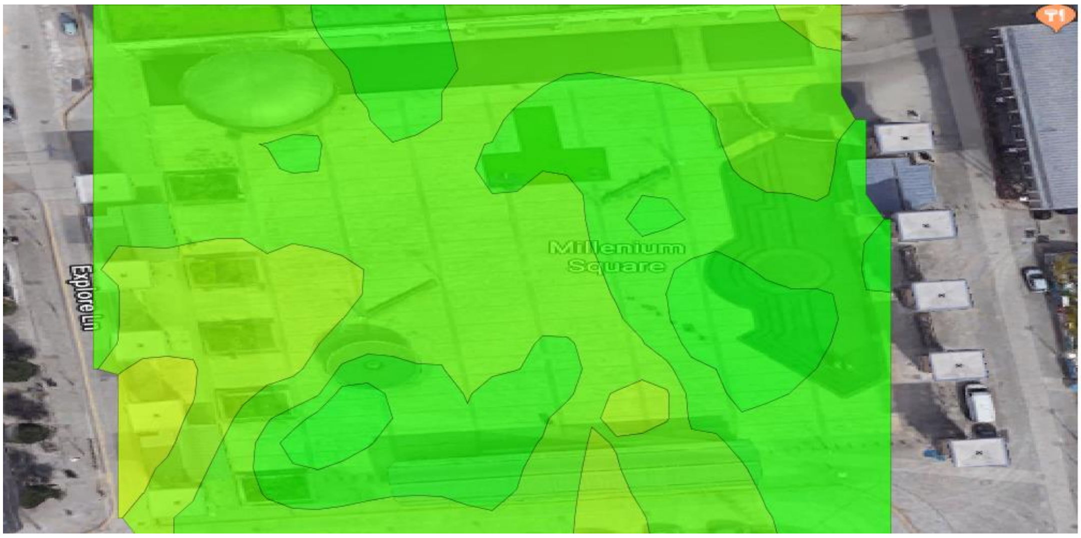


Figure 33: Results Wi-Fi RAN tests in Millennium Square.

3.1.4 RAN performances in Lucca

Radio tests were performed over the LTE network deployed in VSP-DC and Baluardo San Paolino. The following Figure 34 and Figure 35 show the measured results through G-NetTrack netmonitor. Additional results are provided in APPENDIX B, which have been collected with CellMapper application to select the best locations in terms of radio coverage for use case testing in Lucca.

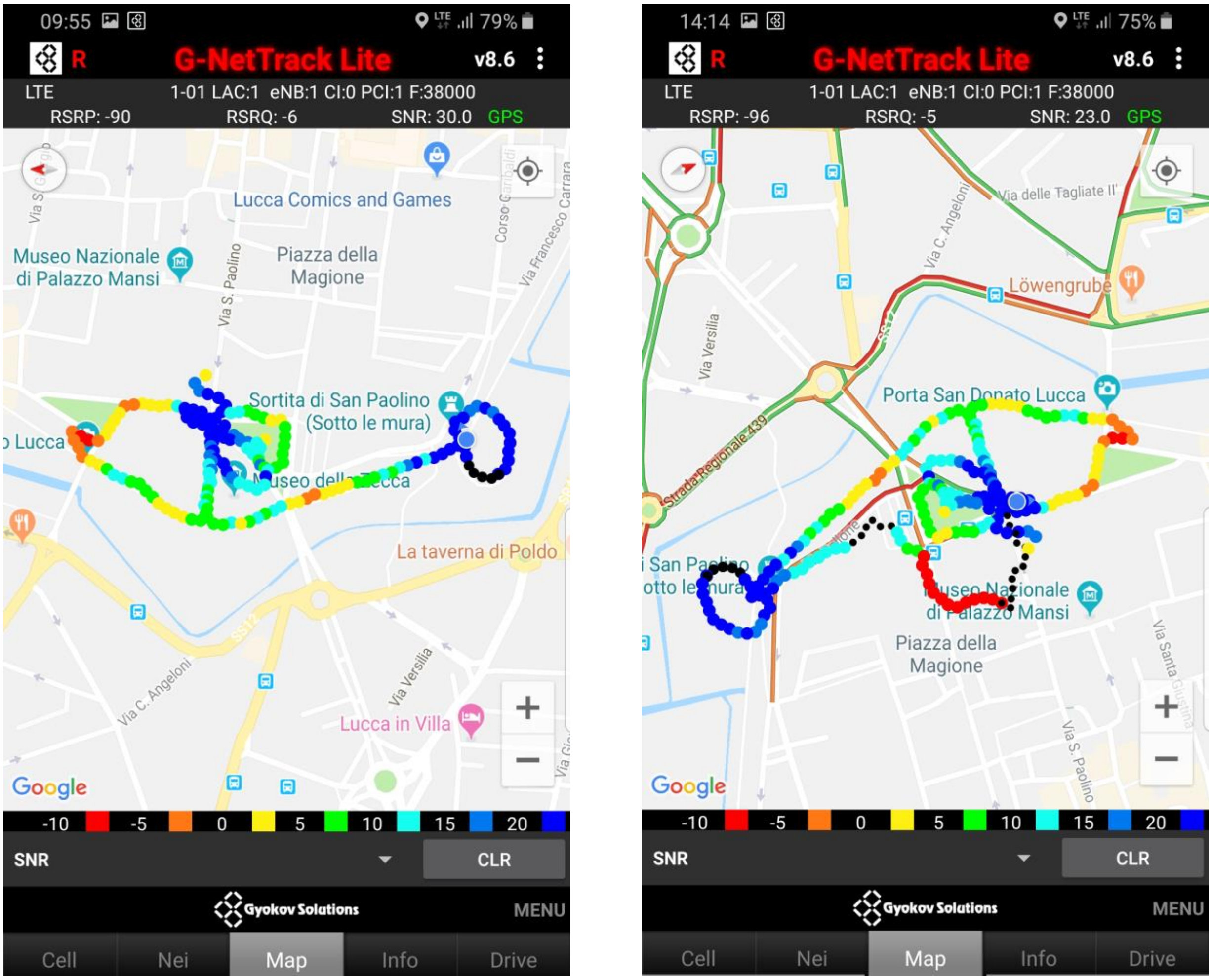
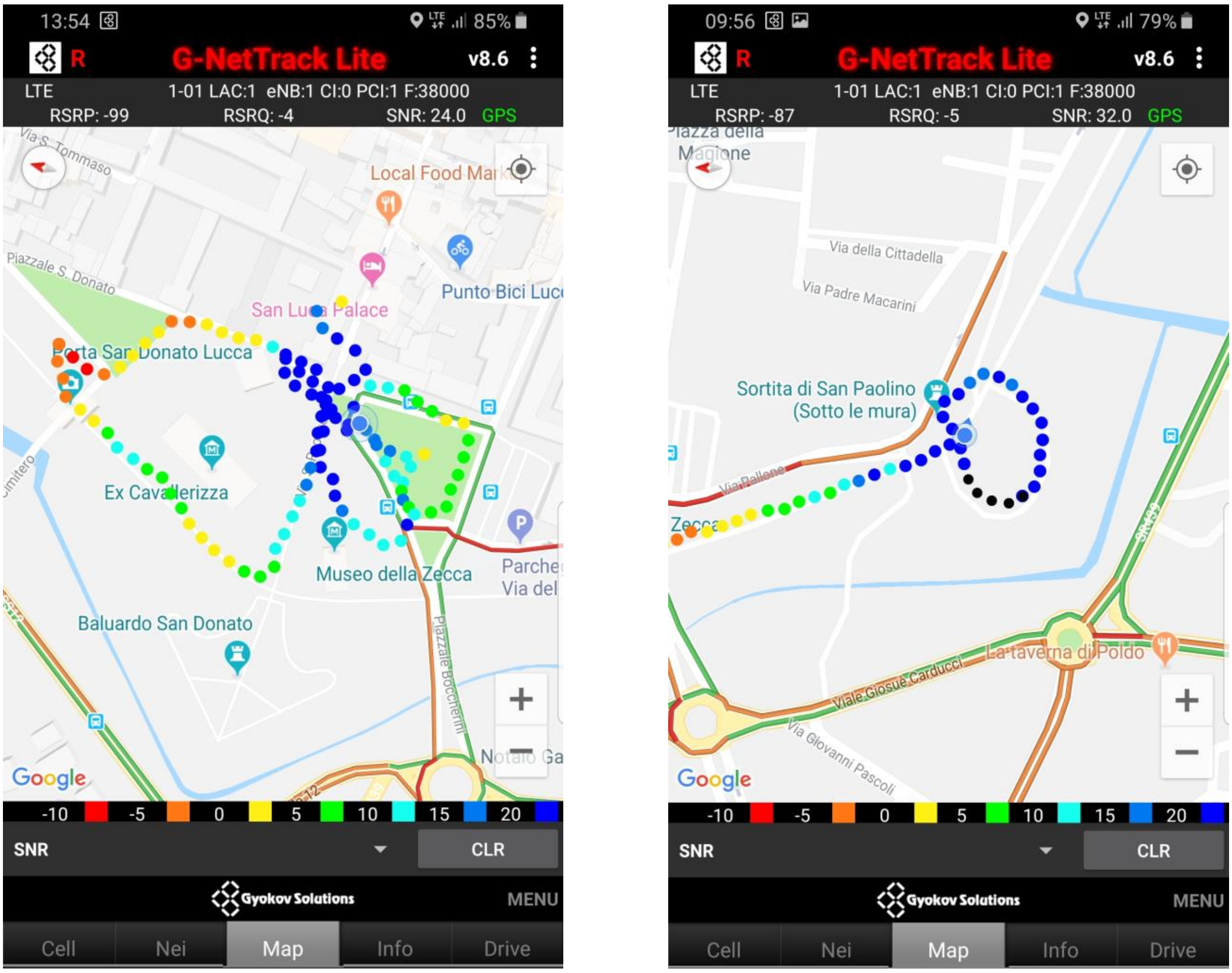


Figure 34: 5GCity LTE coverage in Lucca (High SNR values in blue dots, closer to 5GCity SCs).



a) b)

Figure 35: 5GCity LTE SNR in Lucca around VSP-DC and Baluardo San Paolino.

3.1.5 Discussion of results

Based on results of various configurations of Tx power per port, we found that good performances are achieved when Tx power is between 18 dBm/63 mW and 12 dBm/16 mW per port, i.e. to a Tx power value of 15 dBm / 32 mW per port (RefSignalPwr -16 dBm for 20 MHz channel). This can avoid excessive signal overlapping, particularly in dense deployments (like in Barcelona).

3.2 Connectivity tests

3.2.1 Test methodology

End to end throughput, latency and jitter offered by the LTE network need to be measured in such a way that it includes all the E-UTRA components: EPC, eNB and UE and the transport between them (be it wired interfaces or wireless interfaces such as the UU LTE Radio Interface). None of the components involved externally in the applications and services needed to run the different use cases should be included in the measurements, since they all have different characteristics and impact themselves.

As previously described, the 5GCity architecture is mapped into a three-tier 5GCity infrastructure consisting on radio components, edge/MEC server components and datacenter components. For the implementation of the different use cases, the logical LTE architecture consisting on the usual RAN and Core Network components is mapped into the three-tier architecture as needed according to the services that need to be delivered. The RAN components are split between the Physical Network Functions running on the Small Cells (L2/L1) and the Virtual Network Functions of the Small Cells (L3) running at the Edge. Use cases requiring low latency and local breakout functionality will be implemented with a vEPC component running at the Edge together with the vRAN L3, whereas other use cases will run vEPC component in the traditional datacenters communicating with the vRAN L3 at the Edge (see Figure 36).

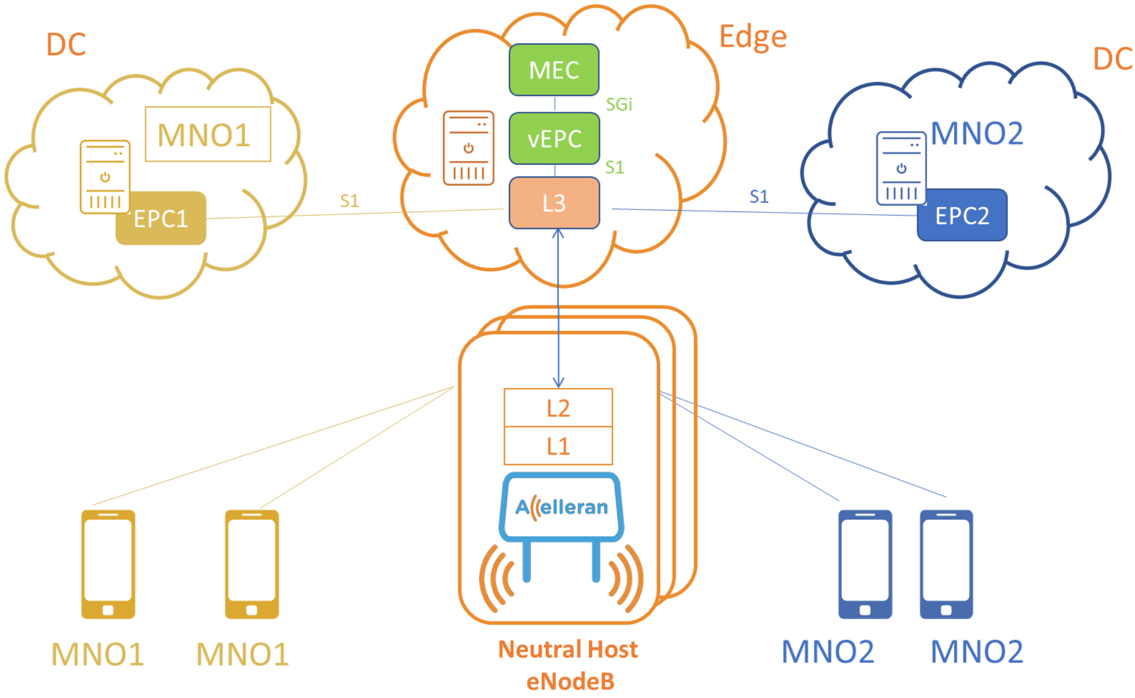


Figure 36: RAN architecture with split eNodeB functionality for Neutral Host scenarios.

The Neutral Host scenario (UC2) is realised according to the schema described in Figure 36. For lower latency and local traffic breakout conditions, the virtual EPC and virtual vL3 function are co-located at edge (scenario of interest for UC6 and UC1 applications). In all the other cases, the virtual EPC can be located at DC servers (scenarios of interest for UC3, UC4, UC5 applications). The probe points in the E-UTRAN logical architecture should be the as below.

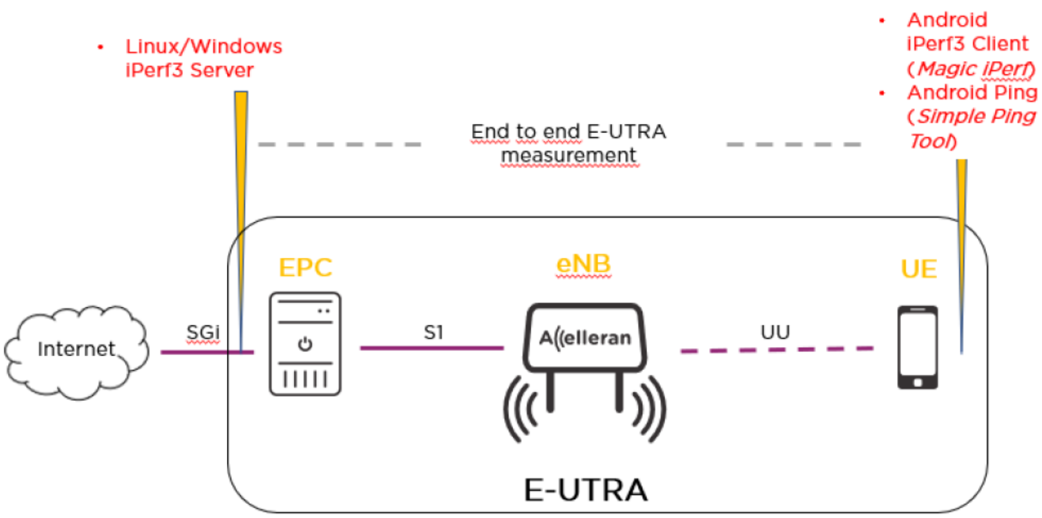


Figure 37: Probe points in the E-UTRAN logical architecture.

The type of deployment required by the different 5GCity use cases will determine which actual Network Side Probe points need to be used depending on where the EPC is deployed.

The best methods for LTE measurements at the proposed probe points would be based on a combination of iPerf3 [8] [9] and Ping tools. There are versions of these tools for Android so that the Smartphones can be used directly to make measurements.

The connectivity tests have been profiled for the three cities to execute, measure and record:

- Bandwidth and Jitter in downlink using UDP:
    - **iPerf3 -c XX.XX.XX.XX -u -b 100000 -R -w 1M -P 3 -t 60**
- Bandwidth and Jitter in uplink using UDP:
    - **iPerf3 -c XX.XX.XX.XX -u -b 100000 -w 32k -P 3 -t 60**
- Bandwidth in downlink using TCP:
    - **iPerf3 -c XX.XX.XX.XX -R -w 1M -P 3 -t 60**
- Bandwidth in uplink using TCP
    - **iPerf3 -c XX.XX.XX.XX -w 32k -P 3 -t 60**

To measure latency, we have configured the Simple Ping Tool [10] on smartphones for a ping count of 20 to the IP address of the iperf3 server. The measure consists of recording RTT min/avg/max/mdev and dividing by 2 (RTT/2).

3.2.2 Connectivity performances in Barcelona

Five connectivity tests were performed between the RAN and computing locations at the edge and in the metro. Each test obtained the average Round Trip Time (RTT), average Jitter, and the average Throughput.

Resources

The resources used in the test are the following:

- 2 UEs with capacity to connect to WiFi and LTE capability (i.e., Band 42).
- 1 Small Cells Accelleran E1000 in Lamppost 2 – @22.
- 1 WiFi APs i2CAT in Lamppost 4 - @22.
- vEPC installed in an VM1 vEPC at the Edge VIM.
- vEPC installed in an VM2 vEPC at the Core VIM.
- VM1 TEST and VM2 TEST with IPERF in the Edge VIM and Core VIM.

Figure 38 presents the tests schematic, the elements involved and the points of measurement. Table 9 describes each test and Table 10 presents the results.

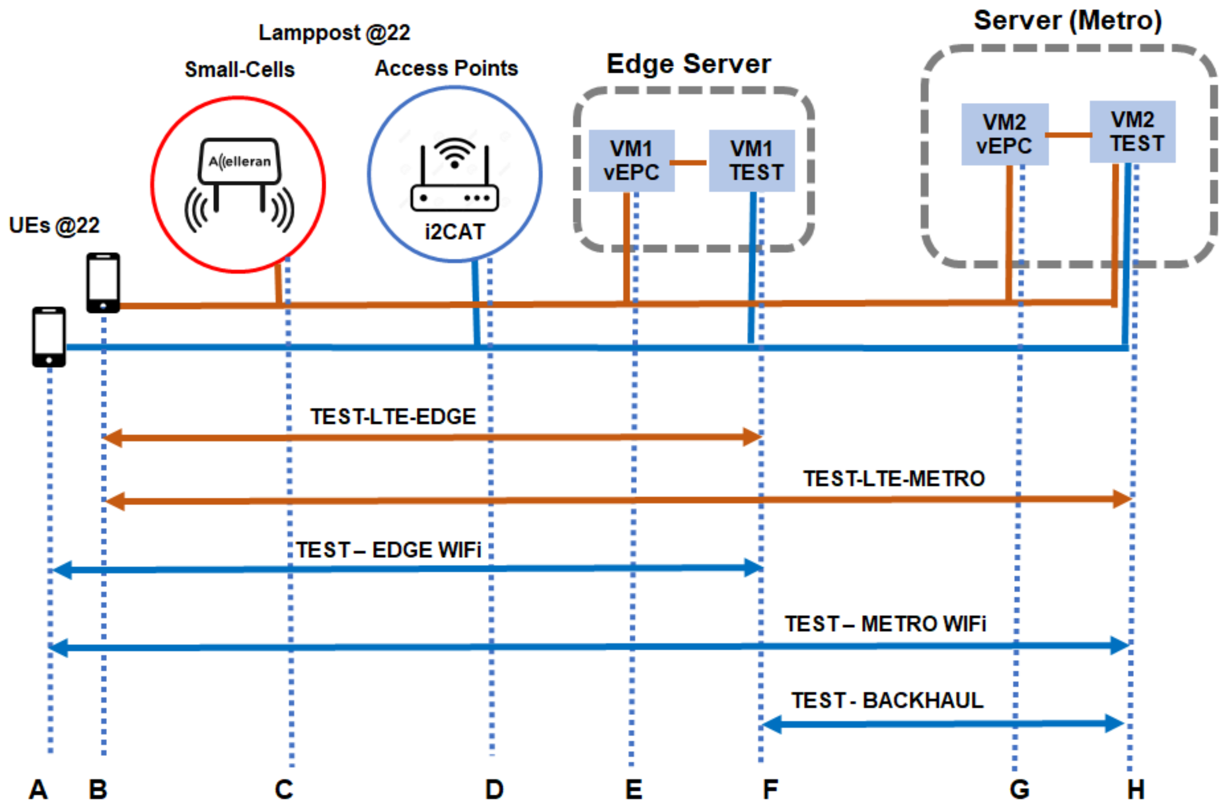


Figure 38: Connectivity Test Schematic for 5GCity Barcelona.

Tests	Setup
LTE-EDGE-42	• UE(B) Dell Laptop with Sierra Wireless Modem connected to a Small Cell(C) Band 42 TDD 2 – 20 MHz (Lamppost 2). • The Small Cell(C) is connected to the Edge Server by a 1GBPS link. • The Edge Server is a Compute Node of OpenStack Queens at the edge hosting the VM1 vEPC(E) and the VM1 TEST(F).
LTE-METRO-42	• UE(B) remains connected to a Small Cell(C) after the finish of TEST-LTE-EDGE. • The Small Cell(C) is connected to the Metro Server at I2CAT-Data Centre by a 1GBPS link. • The Metro Server is a Compute Node of OpenStack Queens part of the Core VIM, hosting the VM2 vEPC(G) and the VM2 TEST(H).
WiFi-EDGE	• UE (A) Toshiba Laptop with integrated Wi-Fi is connected to an Access Point i2CAT (D) (Lamppost 5). • The Access Point (D) is connected to the same Edge Server of TEST-LTE-EDGE by a 1GBPS link.
WiFi-METRO	• UE(A) remains connected to the Access Point (D) after the finish of TEST-WiFi-EDGE. • Access Point i2CAT (D) is connected to the same Metro Server used in TEST-LTE-METRO by a 1GBPS link.
BACKHAUL	• The Edge Server at BTV is connected to a Metro Server at i2CAT by a 10GBPS link.

Table 9:Connectivity tests description in 5GCity Barcelona.

Tests	Average RTT (ms)	Average Jitter (ms)	Average Throughput (Mbps)
LTE-EDGE SNR: 25.0 dB	19.69	3.163	UL: 7.33 DL: 28.4
LTE-METRO SNR:25.0 dB	21.252	4.122	UL: 6.93 DL: 24.1
WiFi-EDGE	11.178	24.657	UL: 52,8 DL: 30.1
WiFi-METRO	12.11	25.706	UL: 49.5 DL: 27.9
BACKHAUL	0.06	0.036	UL/DL: 933

Table 10: Connectivity tests results in 5GCity Barcelona.

3.2.3 Connectivity performances in Bristol

Five connectivity tests were performed between the RAN and computing locations at the edge and in the metro. Each test obtained the average Round Trip Time (RTT), average Jitter, and the average Throughput.

Resources

- 1 UE (Essential Smart Phone) with capacity to connect to the WiFi and LTE networks (Band 7/ Band 42).
- 2 Accelleran Small Cells – MShed Roof.
- 2 Ruckus WiFi APs – MShed Rood.
- vEPC installed in an VM#1 at the Edge VIM – Saturn Server - MShed-Data Centre.
- vEPC installed in an VM#2 at the Core VIM – CSEELONDON – HPN-DC.
- VM1 TEST and VM2 TEST with Video Server and IPERF in the Edge VIM and Core VIM.

Figure 39 presents the tests schematic, the elements involved and the points of measurement. Table 11 describes each test and Table 12 presents the results.

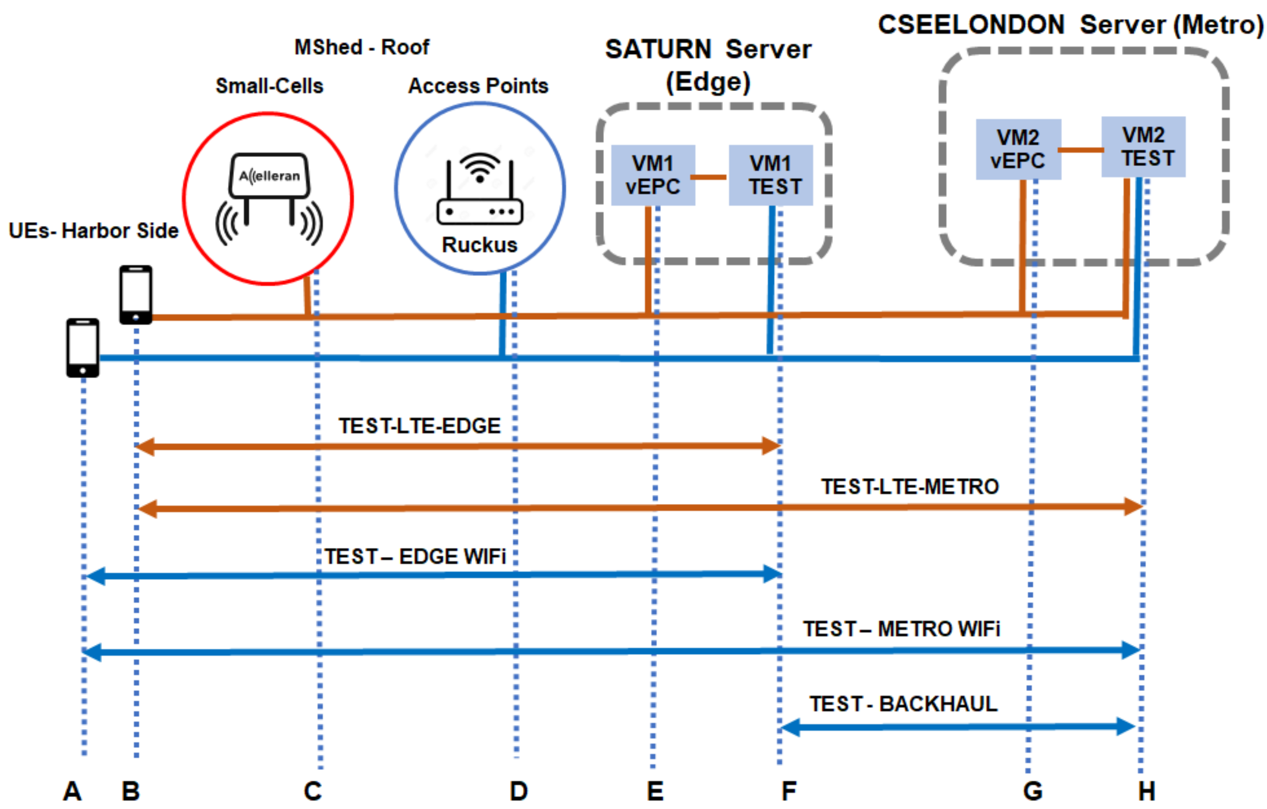


Figure 39: Connectivity Test Schematic for 5GCity Bristol.

Tests	Setup
LTE-EDGE-42	• UE(B) Smartphone Essential connected to a Small Cell(C) Band 42 TDD 2 – 20 MHz (MShed). • The Small Cell(C) is connected to the Edge Server Saturn in MShed by a 1GBPS link. • The Edge Server Saturn is a Compute Node of OpenStack Queens placed in MShed. Two VMs are deployed in the Saturn VM1 vEPC(E) and the VM1 TEST(F).
LTE-METRO-42	• UE(B) remains connected to a Small Cell(C) after the finish of TEST-LTE-EDGE. • The Small Cell(C) is connected to the Metro Server at I2CAT-Data Centre by a 1GBPS link. • The Metro Server is a Compute Node of OpenStack Queens part of the Core VIM, hosting the VM2 vEPC(G) and the VM2 TEST(H).
WiFi-EDGE	• UE (A) connected to an Access Point RUCKUS(D) (East Roof MShed. • The Access Point (D) is connected to the same Edge Server of TEST-LTE-EDGE by a 1GBPS link.
WiFi-METRO	• UE(A) remains connected to the Access Point (D) after the finish of TEST-WiFi-EDGE. • Access Point i2CAT (D) is connected to the same Metro Server used in TEST-LTE-METRO by a 1GBPS link.
BACKHAUL	• Edge Server at MShed is connected to a Metro Server at Smart Internet Lab by a 10GBPS link.

Table 11: Connectivity tests description in 5GCity Bristol.

Tests	Average RTT (ms)	Average Jitter (ms)	Average Throughput (Mbps)
LTE-EDGE SNR: 25.0 dB	17	3.163	UL: 9.76 DL: 44
LTE-METRO SNR:25.0 dB	18	2.2	UL: 9.54 DL: 40
WiFi-EDGE	21	2.3	UL: 46 DL: 93
WiFi-METRO	22	6.2	UL: 39.8 DL: 80
BACKHAUL	0.15	0.023	UP/DL: 994

Table 12: Connectivity tests results in 5GCity Bristol.

3.2.4 Connectivity performances in Lucca

Five connectivity tests were performed between the RAN and computing locations at the edge and in the metro. Each test obtained the average Round Trip Time (RTT), average Jitter, and the average Throughput.

In order to validate the infrastructure three different KPIs are considered:

- Average Round Trip Time (RTT)
- Average Jitter
- Average Throughput

It is worth to mention that such KPIs depend heavily on many factors (e.g. devices model, devices configuration, radio conditions and other external factors) and for that reason it is difficult to compare them with other results obtained under different conditions.

In Lucca's Infrastructure, Small Cells Band 38 with the following configuration parameters are used:

- Bandwidth: 10 MHz
- Reference Signal Power: -5 dBm
- TDD Subframe Assignment: 2

With these parameters and with good channel conditions, the throughput in download and upload should be respectively around 40 Mbps and 5 Mbps.

Resources

- 1 UEs with capacity to connect to the LTE networks (Band 38).
- 1 ACCELLERAN Small Cell Band 38 – C. di Lucca-DC.
- nextEPC installed in an VM#1 at the Edge VIM – Edge Server – San Donato-Edge
- nextEPC installed in an VM#2 at the Core VIM – Metro Sever – VSP-DC
- VM1 TEST and VM2 TEST with Video Server and IPERF in the Edge VIM and Core VIM.

Figure 40 presents the tests schematic, the elements involved and the points of measurement. Table 13 describes each test and Table 14 presents the results.

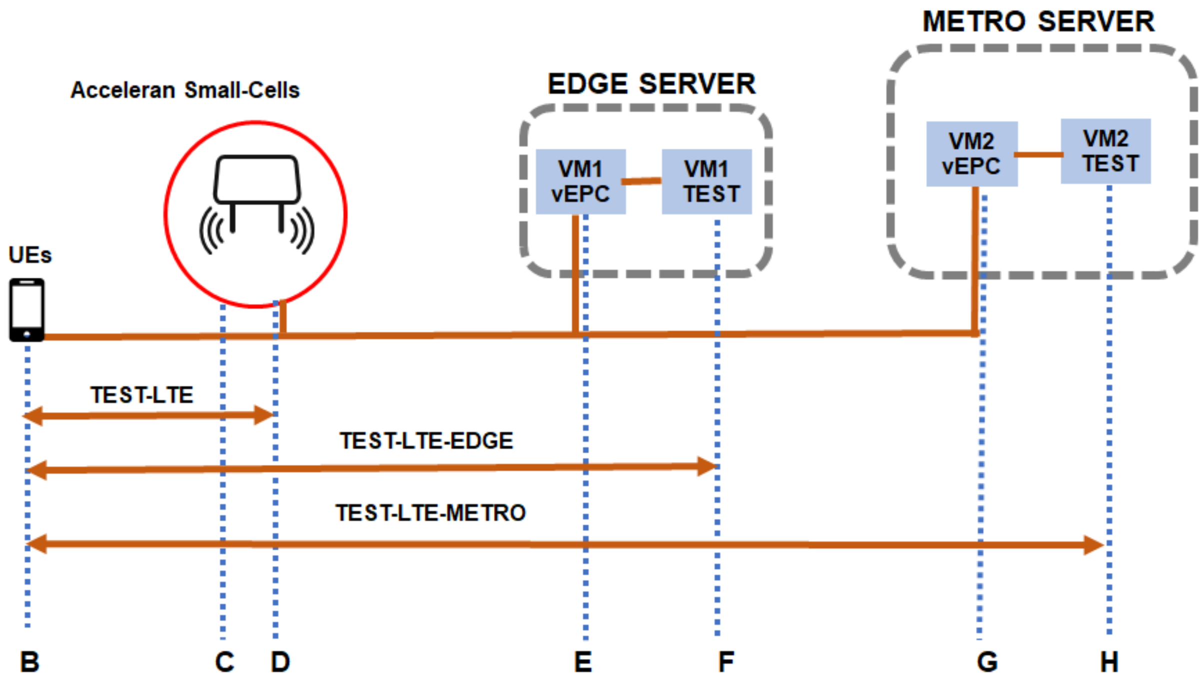


Figure 40: Connectivity Test Schematic for 5GCity Lucca.

Tests	Details
LTE-EDGE-38	• UE(B) connected to a Small Cell (D) Band 38. • The Small Cell (D) is connected to EDGE Server (EDGE) at EDGE DC by a 1GBPS link. • EDGE server uses OpenStack Queens as Edge VIM.
LTE-METRO-38	• UE(B) connected to a Small Cell (D) Band 38. • The Small Cell (D) Band 38 is connected to METRO Server (METRO) at LUCCA DC Lab by a 1GBPS link. • METRO server uses OpenStack Queens as Core VIM.
BACKHAUL	• EDGE Server (EDGE) at Cabinet is connected to METRO Server (METRO) at Smart Internet Lab by a 1GBPS link.

Table 13: Connectivity tests description in 5GCity Lucca.

Test	Average RTT (ms)	Average Jitter (ms)	Average Throughput (Mbps)
LTE-EDGE-38	26.686	1.451	Up: 4.57 Down: 28.5
LTE-METRO-38	25.320	1.278	Up: 4.85 Down: 33,05
BACKHAUL	0.189	0.026	952 (symmetrical)

Table 14: Connectivity tests results in 5GCity Lucca.

In addition to the agreed connectivity tests with other cities, speed tests at the two key Points of Interest (PoI) covered with excellent signal from the two small cells have been executed (see Figure 41 and Figure 42). Results show good performances also towards the Internet, given that Internet connection is provided through Comune di Lucca Internet uplink (30Mbps) and this connection is shared with all the offices (which explains the difference in performances between the two result, captured in different timing of the day).

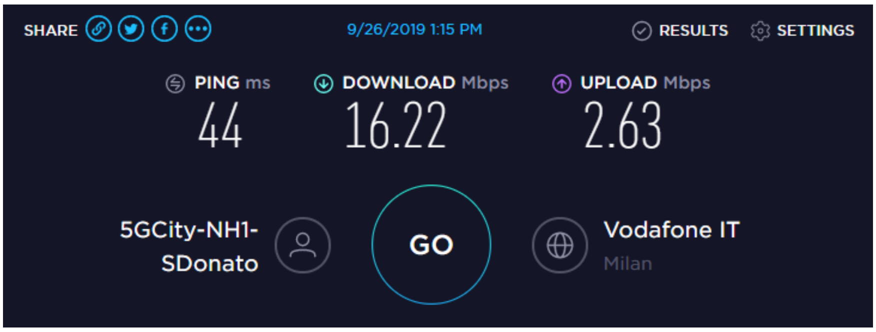


Figure 41: Speedtest through SC-SDonato at PoI: Tourists Office.

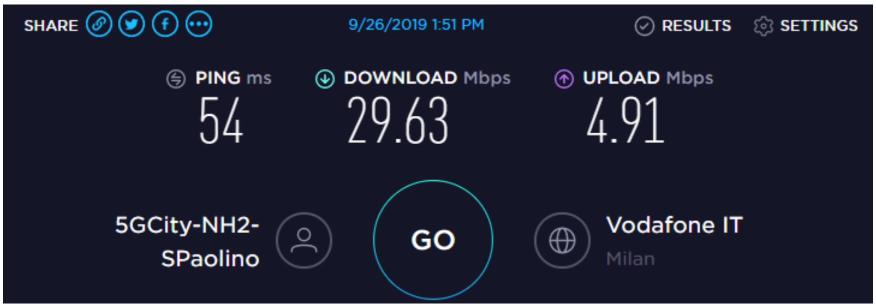


Figure 42: Speedtest through SC-SPaolino at PoI: Baluardo San Paolino.

3.2.5 Discussion of results

It is to be noted for the three cities that:

- Under excellent cell center radio conditions (>20dB SINR) the full nominal DL throughputs are not seen (30% of nominal only) due to Small Cell not getting enough data from the backhaul (vEPC in OpenStack) and possibly because there are no good MIMO effects (too close). In UL we achieve nominal throughputs (SIMO).
- At mid-range from the SC (e.g. 64m) there are still very good channel conditions (good coverage and range) which still achieve close to nominal UL throughputs. Again, DL throughput remains 50% of the nominal, possibly due to the same backhaul bottleneck between RAN and vEPC
- At far-range (i.e. >100m) radio conditions are obviously worse than previous cases, but the UL throughput it still 50% of the nominal with the DL throughput a bit less than 25% of the nominal one. Possibly the root cause in this case is poor radio conditions.
- The backhaul bandwidth is nearly nominal at 1Gbps line rate.

3.3 NFVI-VIM tests

3.3.1 Test methodology

In this section, we introduce the tests executed to validate and profile performances of Virtualization Computing infrastructures deployed in Barcelona, Bristol and Lucca. These tests complement results presented in deliverable D3.3 [3], which have been executed in laboratory environment.

To profile in homogeneous way the three infrastructures we used Rally [11], an automation framework for OpenStack which allows to automate and unify multi-node OpenStack verification, benchmarking & profiling. The concept of validation and benchmarking implemented by Rally is presented in Figure 43.

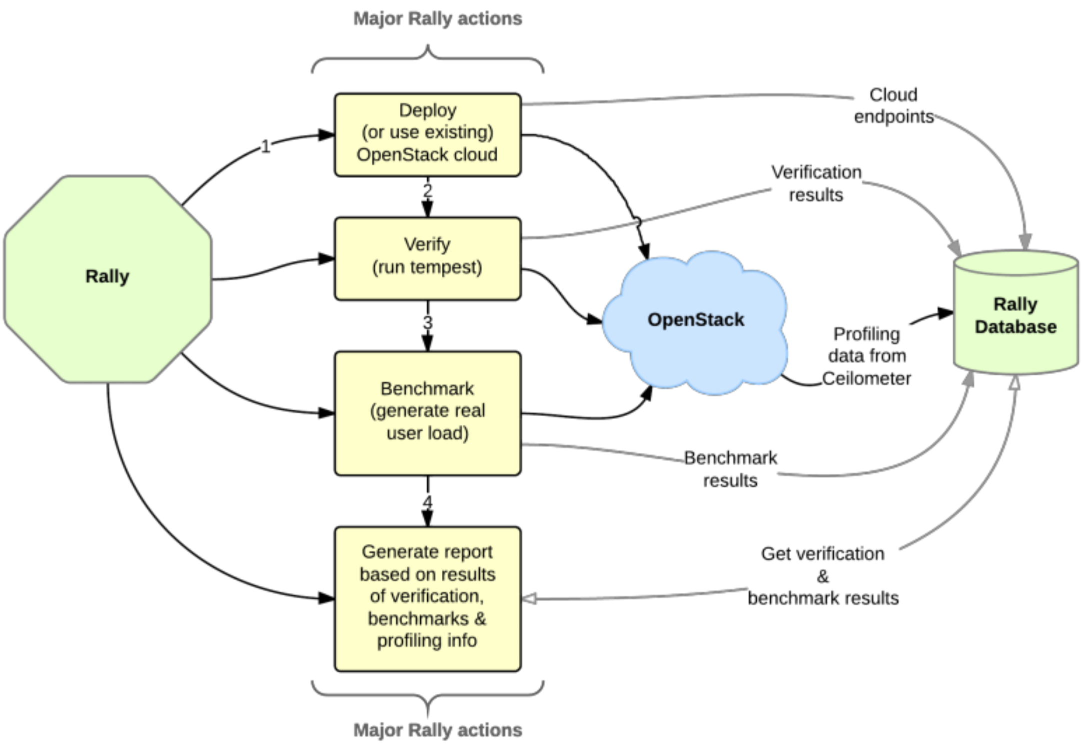


Figure 43: OpenStack benchmarking process with Rally (source https://docs.openstack.org).

To validate the virtualized environment (VIM), we focused on measuring the average Virtual Machine boot and deletion time. To measure this metrics, we used the *NovaServers.boot_and_delete_server* scenario, which automates and repeats 100 times the following action:

- boot a single VM from a user & list all VMs.
- Delete VM

We installed the Rally tool in an external VM connected to the Core VIM (OpenStack controller) in Barcelona, Bristol and Lucca.

3.3.2 NFVI-VIM performances in Barcelona

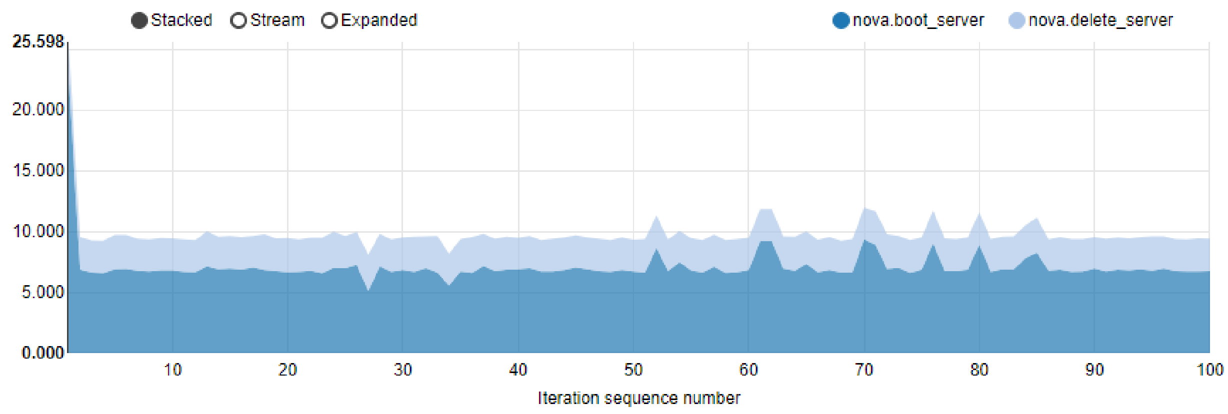
Test and expected results	Results
Description: Execute the boot-and-delete-server scenario with Rally to run the test using the parameters in the provided yaml template **Expected Results:** • HTML report with the time values corresponding to 100 iterations of VM booting and deletion. **Measured Results:** • Average VM booting time • Average VM deletion time	Average Booting Time (s) **7.134** Average Deletion Time (s) **2.684**

Table 15: NFVI-VIM test results in 5GCity Barcelona.

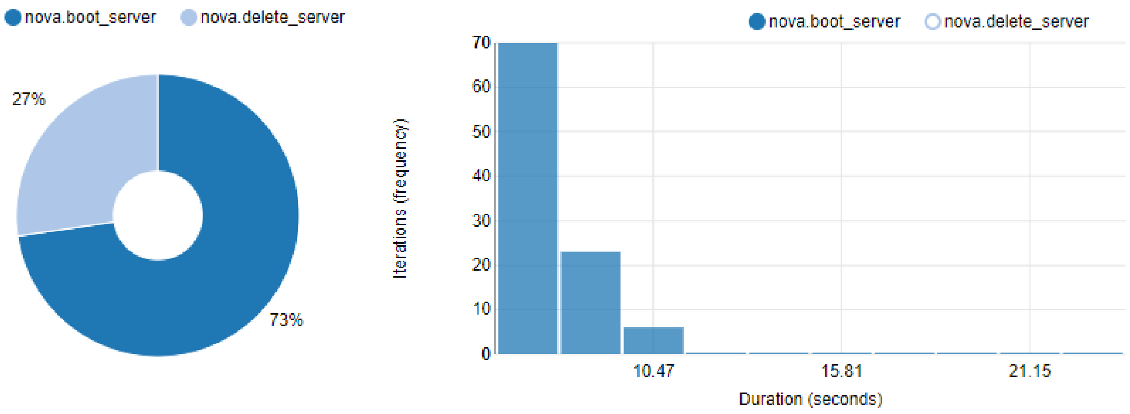
Boot and delete a server.

Overview | Details | Input task

Atomic Action Durations



Distribution



Action	Min (sec)	Median (sec)	90%ile (sec)	95%ile (sec)	Max (sec)	Avg (sec)	Success	Count
nova.boot_server	5.127	6.821	7.498	8.94	22.931	7.134	100.0%	100
nova.delete_server	2.556	2.661	2.827	2.918	2.991	2.684	100.0%	100
total	**8.084**	**9.507**	**10.085**	**11.673**	**25.598**	**9.818**	**100.0%**	**100**
-> duration	*7.084*	*8.507*	*9.085*	*10.673*	*24.598*	*8.818*	*100.0%*	*100*
-> idle_duration	*1*	*1*	*1*	*1*	*1*	*1*	*100.0%*	*100*

Figure 44: Rally report on NFVI-VIM in 5GCity Barcelona.

3.3.3 NFVI-VIM performances in Bristol

Step description and expected results	Results
Description: Execute the boot-and-delete-server scenario with Rally to run the test using the parameters in the provided yaml template **Expected Results:** • HTML report with the time values corresponding to 100 iterations of VM booting and deletion. **Measured Results:** • Average VM booting time • Average VM deletion time	Average Booting Time (s) **6.923** Average Deletion Time (s) **2.432**

Table 16: NFVI-VIM test results in 5GCity Bristol.

3.3.4 NFVI performances in Lucca

Test Summary and Expected Results	Result
Description: Execute the boot-and-delete-server scenario with Rally to run the test using the parameters in the provided yaml template **Expected Results:** • HTML report with the time values corresponding to 100 iterations of VM booting and deletion. **Measured Results:** • Average VM booting time • Average VM deletion time	Average Booting Time (s) **16.539** Average Deletion Time (s) **3.262**

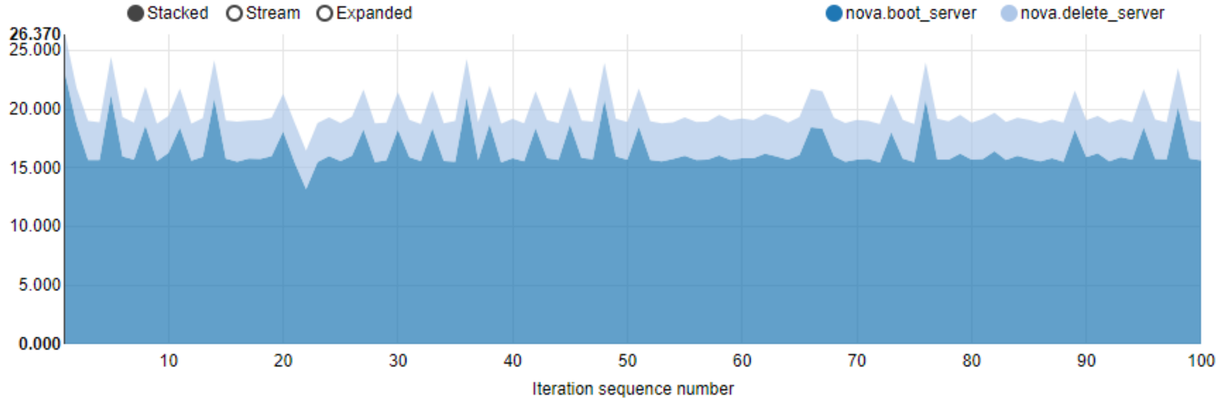
Table 17: NFVI-VIM test results in 5GCity Lucca.

NovaServers.boot_and_delete_server (2,003.552s)

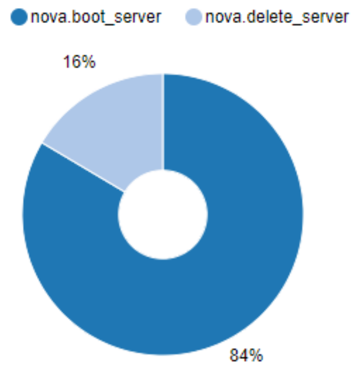
Boot and delete a server.

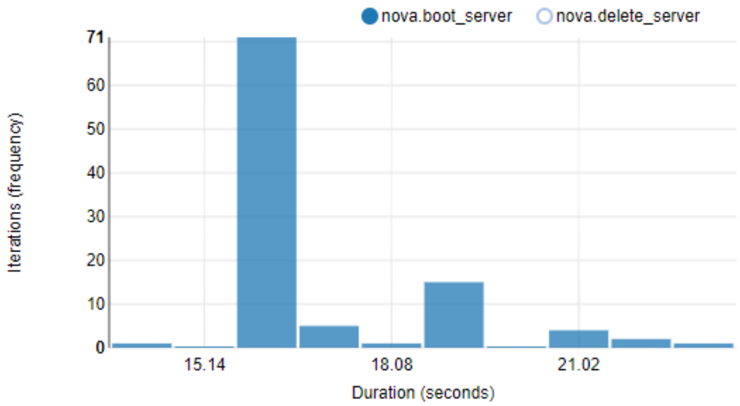
Overview | Details | Input task

Atomic Action Durations



Distribution





Criterion	Detail	Success
failure_rate	Failure rate criteria 0.00% <= 0.00% <= 0.00% - Passed	True

Total durations

Action	Min (sec)	Median (sec)	90%ile (sec)	95%ile (sec)	Max (sec)	Avg (sec)	Success	Count
nova.boot_server	13.175	15.793	18.612	20.782	22.981	16.539	100.0%	100
nova.delete_server	3.078	3.254	3.385	3.406	3.495	3.262	100.0%	100
total	**16.452**	**19.08**	**21.784**	**23.951**	**26.37**	**19.801**	**100.0%**	**100**
-> duration	*15.452*	*18.08*	*20.784*	*22.951*	*25.37*	*18.801*	*100.0%*	*100*
-> idle_duration	*1*	*1*	*1*	*1*	*1*	*1*	*100.0%*	*100*

Figure 45: Rally report on NFVI-VIM in 5GCity Lucca.

3.3.5 Discussion of results

The obtained results are in line with the hardware capabilities of the three cities.

The results obtained in Lucca pilot show higher values compared the ones performed in Barcelona and Bristol, mainly due to the smaller capacity of the servers deployed in that city w.r.t. solutions used from shared computing environments in the other two cities. Nevertheless, the results are acceptable for the trials to be executed in Lucca.

3.4 5GCity platform functional tests

The validation of the 5GCity Platform deployed in the three cities consisted of a set of functional tests aimed at verifying the correct integration of the various orchestration elements and management of the lifecycle management operations for slices and network services.
Details on the 5GCity Platform components respectively deployed in the three cities have just been presented in sections 2.x.4 of this document. In this section we report, in relation to results just presented in deliverable D4.4 [5], a summary of the functional tests repeated on the different platforms, with actions implemented by the Infrastructure owners through the offered GUIs (see Figure 46).

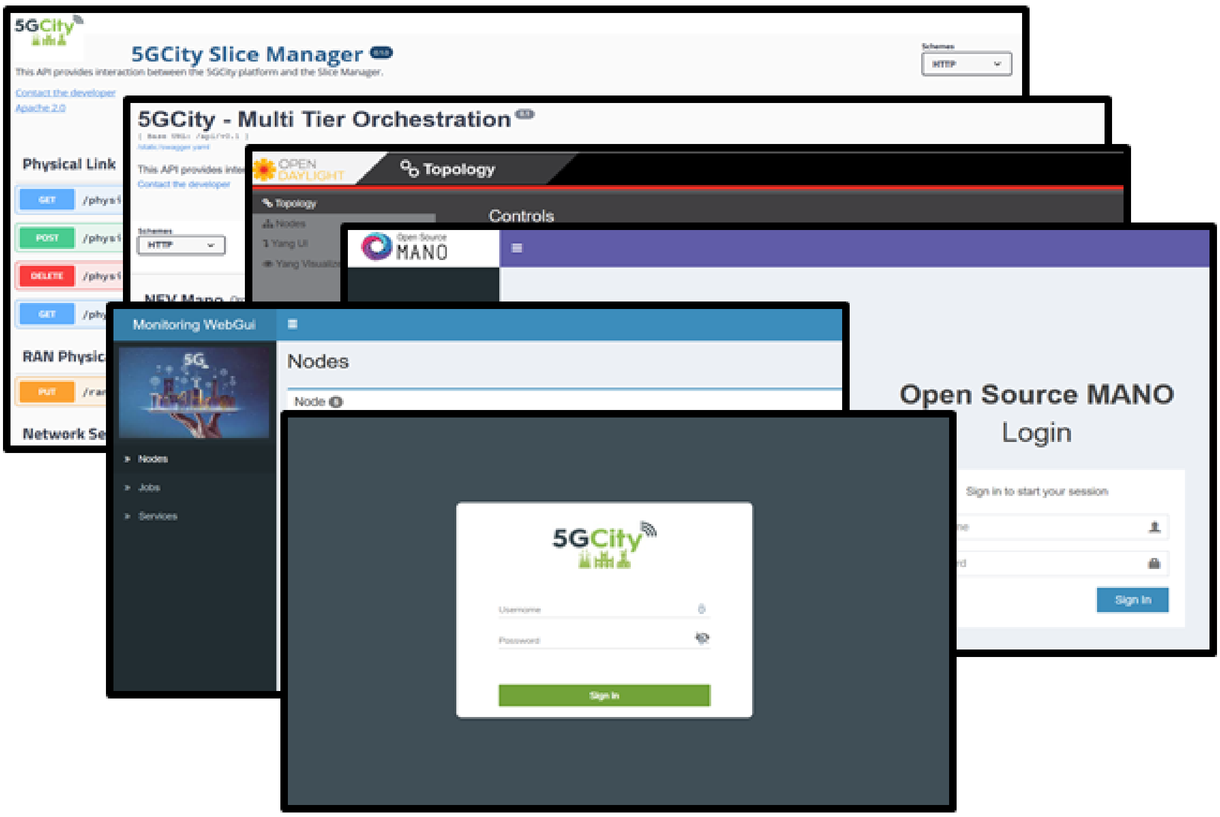


Figure 46: User interfaces of the 5GCity Platform components available at the pilot sites.

As described in sections 2.x.4 above, each module has been deployed on Virtual Machines (VMs) placed in compute nodes in the VIM Core and Edge.

The following Table 18 summarizes the functional validation of the 5GCity platform in the three cities. The platform was deployed on Virtual Machines (VMs) placed in compute nodes in the Core and Edge VIM. In the following subsections, the validation performed is explained in further details.

Functionality	Validation method	Result Barcelona	Result Bristol	Result Lucca	Comments
Platform Components deployment	1. Develop a Terraform (https://www.terraform.io) module to handle the deployment of the platform components automatically. 2. Execute the Terraform scripts for bootstrapping the 5GCity deployment in the private cloud infrastructure. 3. Access to OpenStack to ensure all VMs are successfully bootstrapped and properly interconnected in the cloud infrastructure. 4. Access the GUI of the 5GCity Dashboard and check the endpoints availability of different components via their Swagger APIs.	PASSED	PASSED Only steps 3-4 are applicable (5GCity platform installed manually without Terraform)	PASSED Only steps 3-4 are applicable (5GCity platform installed manually without Terraform)	Results verified: • Deployment of the required 5GCity platform components. • Network topology of the 5GCity Platform in OpenStack. • Available GUIs and Swagger interfaces of the 5GCity platform components.
Infrastructure Registration test	1. Access the 5GCity dashboard with the *infra_owner* user previously created. 2. Select *Infrastructure Management* and click over the desired location on the map. 3. Complete the requested information to register a new compute and save. 4. Repeat previous steps for a physical network and a RAN infrastructure. 5. Check the resources are registered with the provided data (*Infrastructure Management Overview*).	PASSED	PASSED	PASSED	Results verified: • New compute and RAN elements in the 5GCity Dashboard map.

Functionality	Validation method	Result Barcelona	Result Bristol	Result Lucca	Comments
Slice Creation test	1. Access the 5GCity dashboard with the *slice_user* previously created. 2. Select *Create Slice* and choose one compute icon from the displayed map. 3. Complete the requested information and save. 4. Repeat previous step for an openstack vlan and a compute chunk (including WiFi and LTE radio interfaces). 5. Check the creation of each one of these chunks in their corresponding locations and quota assignments.	PASSED	PASSED	PASSED	Results verified: • New project in OpenStack with the provided data. • New VIM account in OSM with the provided data. • New external network in OpenStack with the provided data. • New chunks with the selected interfaces. • New slice in the 5GCity Dashboard.
SDK Function creation and publish	1. Access the 5GCity dashboard with the *slice_user* previously created 2. Select *SDK* tab and then *Functions* 3. Select *Create New Function* and fill in the requested parameters 4. Check on SDK Functions list tab availability of the new function *5. Publish New Function* 6. Check on 5G App & Service and NFVO (OSM) for availability of the news VNFD	PASSED	PASSED	PASSED	Results verified: • New Function in the 5GCity SDK • New VNFD created in 5G App & Service Catalogue • New VNFD created in NFVO

Functionality	Validation method	Result Barcelona	Result Bristol	Result Lucca	Comments
SDK Service Creation and publish	1. Access the 5GCity dashboard with the slice_user previously created 2. Select *SDK* tab and in then *Services* 3. Select *Create New Service, drag in available Functions* and fill in the requested parameters for a service 4. Check on SDK Service list tab availability of the new function *5. Publish New Service* *6.* Check on 5G App & Service and NFVO (OSM) for availability of the news NSD	PASSED	PASSED	PASSED	Results verified: • New Service in the 5GCity SDK • New NSD created in 5G App & Service Catalogue • New NSD created in NFVO
Service Instantiation test	1. Access the 5GCity dashboard with the *slice_user* previously created. 2. Select the previously created NSD and slice and click on instantiate. 3. Complete the requested information and confirm. 4. Check on OSM and OpenStack the deployment status. 5. Check the VMs external connectivity.	PASSED	PASSED	PASSED	Results verified: • New service in the 5GCity Dashboard. • New service instance in. • New VMs instantiated in OpenStack.
Monitoring attachment test	1. Access the Monitoring WebGUI. 2. Check the creation of nodes, job and service associated with the deployed VMs in their corresponding tabs. 3. Check that the monitoring server is receiving the configured metrics	PASSED	PASSED	PASSED	Results verified: • New nodes, job and service created in the Monitoring WebGUI. • Grafana dashboard with monitoring metrics is populated.

Table 18: Results of functional validation of 5GCity Platform in the three cities.

3.4.1 Infrastructure Registration Test

This operation involves two platform components, namely: Dashboard and Slice Manager. It is performed by the infrastructure owner. In order to register the infrastructure provided to multiple tenants through the 5GCity platform, the infrastructure owner will access the Dashboard. Figure 47 shows the information that is requested during the registration of the three considered resources: compute, network and radio.

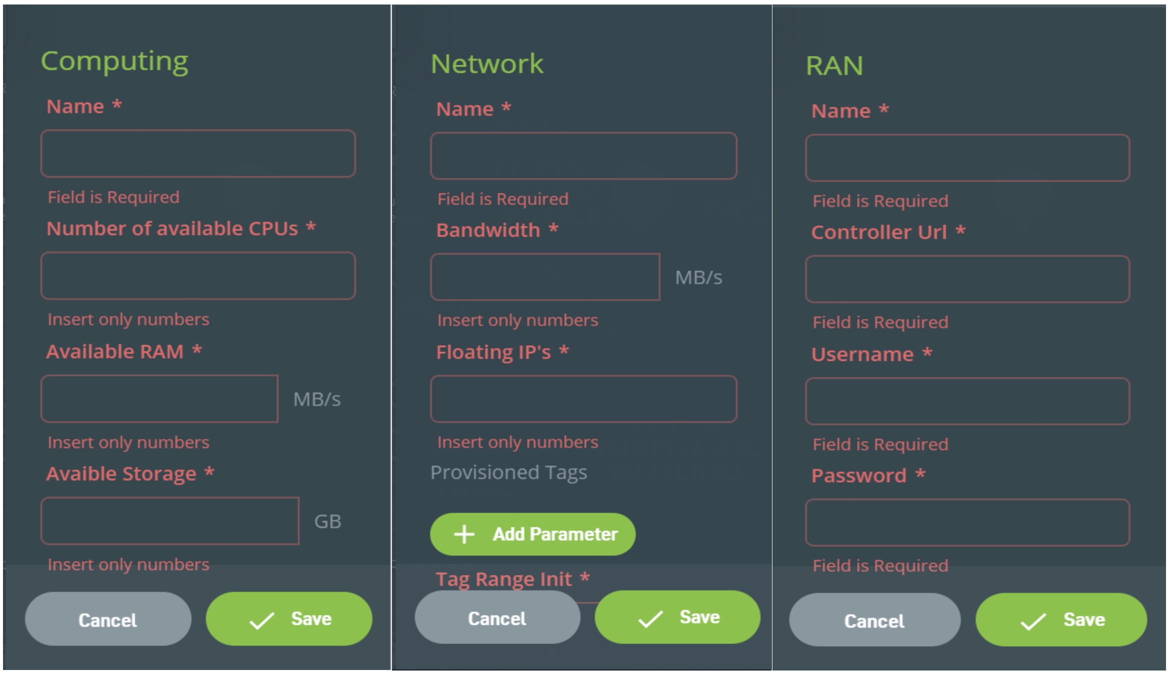


Figure 47: Input parameters for the registration of the infrastructure resources.

After providing this information and confirming the registration request, the resulting map for the city of Barcelona is presented in Figure 48.

Figure 48: Infrastructure resources registered in the Barcelona city pilot.

3.4.2 Slice Creation Tests

Being the slice defined in 5GCity as a collection of chunks, the resources that are registered by the infrastructure owner and their capabilities become available through the Dashboard for their selection and inclusion in the slice. The slice creation, conducted by some tenant or slice user, requires the integration of five platform components, namely: Dashboard, Slice Manager, NFVO, Multi-Tier Orchestrator, VIM and RAN Controller.

For the inclusion of a Compute Chunk, the slice user selects the desired compute, among the ones registered in the platform and provides the amount of resources that are needed in that compute (RAM, CPU and Storage). This request entails the creation of a project in OpenStack with the desired requirements as shown in Figure 49 and the registration of a VIM account in OSM as shown in Figure 50.

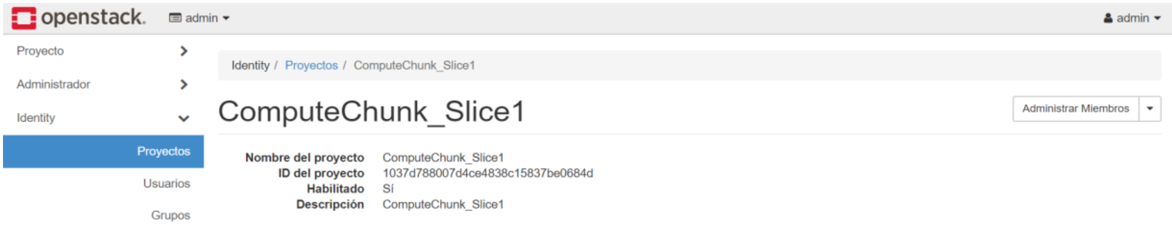


Figure 49: Project generated in OpenStack as part of the slice creation.

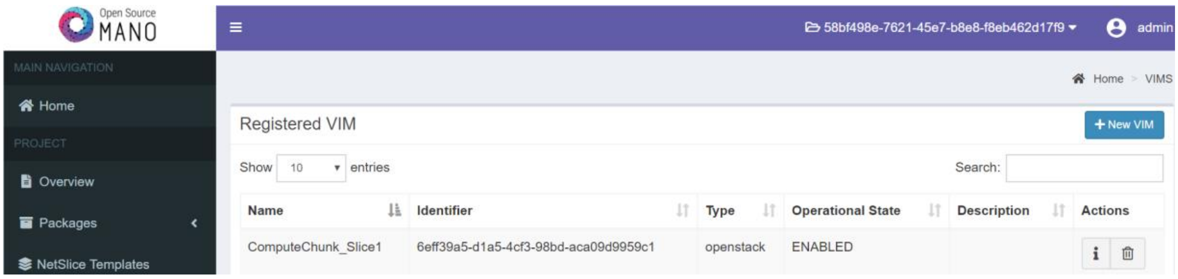


Figure 50: VIM account registered in OSM as part of the slice creation.

Similarly, for the creation of a Networking Chunk, the slice user selects the available physical network and requests the amount of resources needed on that network (bandwidth). Figure 51 shows the external network created in OpenStack, which is VLAN-based in order to ensure the required isolation between slices.

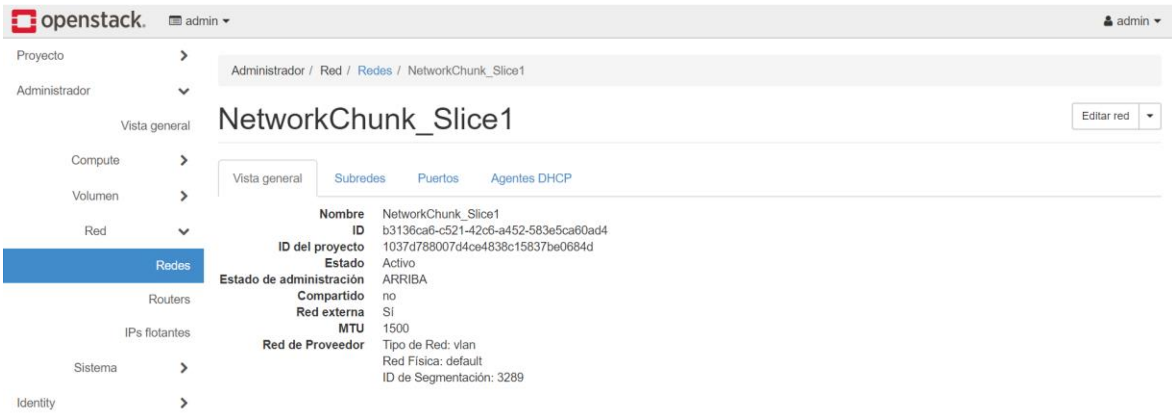


Figure 51: External network generated in OpenStack as part of the slice creation.

3.4.3 5GCity SDK tests

Once logged in 5GCity dashboard, a user can execute actions with SDK based on the specific profile assigned to his/her account (see Table 19), as described in deliverable D2.4 [12].

User/Actor	Role	SDK Service	SDK Function
Admin	Admin	R/W	R/W
Vertical	Composer	R/W	R
Developer	Designer	R/W	R/W

Table 19: Roles and permissions of the 5GCity SDK.

An Admin or a Developer can access the operations related to the creation of new functions (see Figure 52). Once all parameters are specified, the intended function can be published and the corresponding VNF descriptor (VNFD) gets automatically generated by the SDK editor module and pushed in the 5G App & Service Catalogue and in OSM. The published Function results then visible (depending on the visibility level set through its parameters) in the list of functions of the 5GCity dashboard for the given user (see Figure 53).

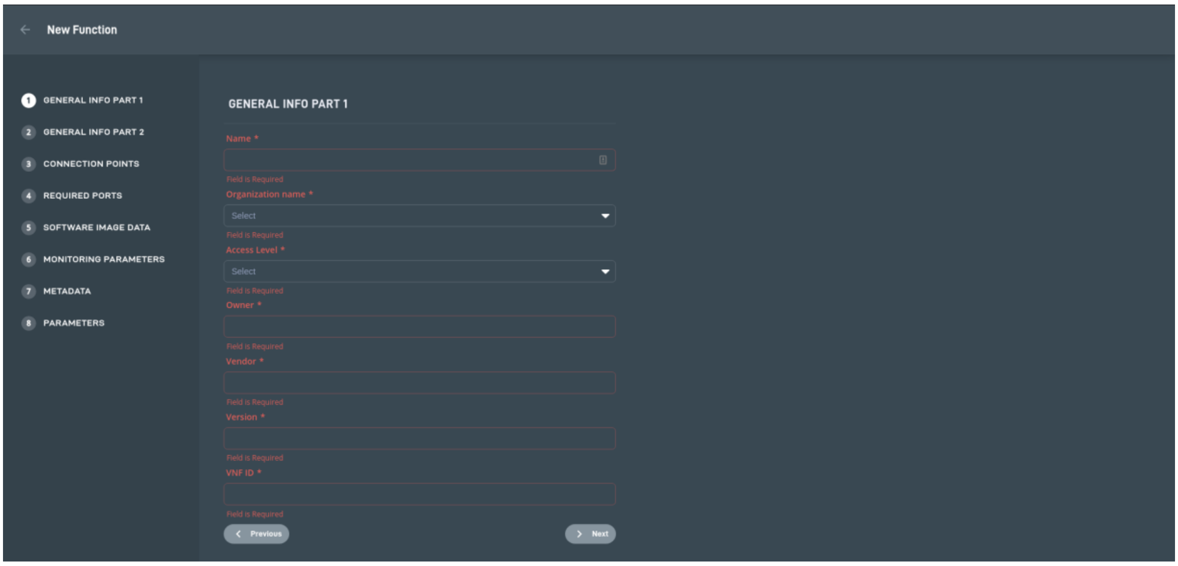


Figure 52: Input parameters for New Function in 5GCity SDK.

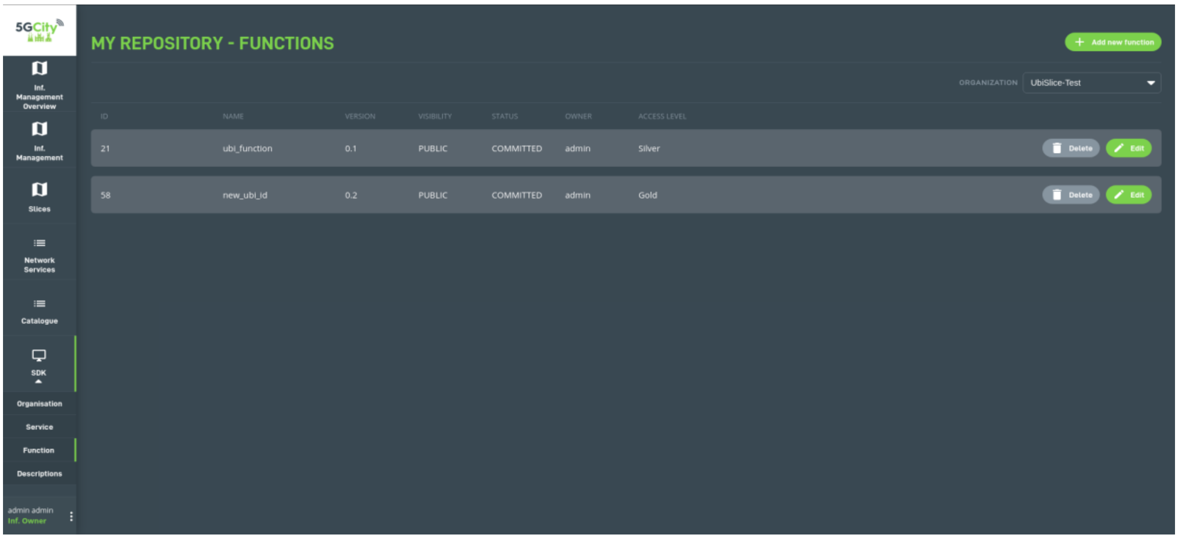


Figure 53: New Function created and published in 5G App & Service Catalogue (State COMMITTED).

Same approach is followed for SDK Services, which are composable by all the type of user's roles defined for SDK. The user can enter the *Composer* tab for editing a new service and start dragging functions from the catalogue on the left panel and wire their interconnections to implement the desired service chain (see Figure 54).

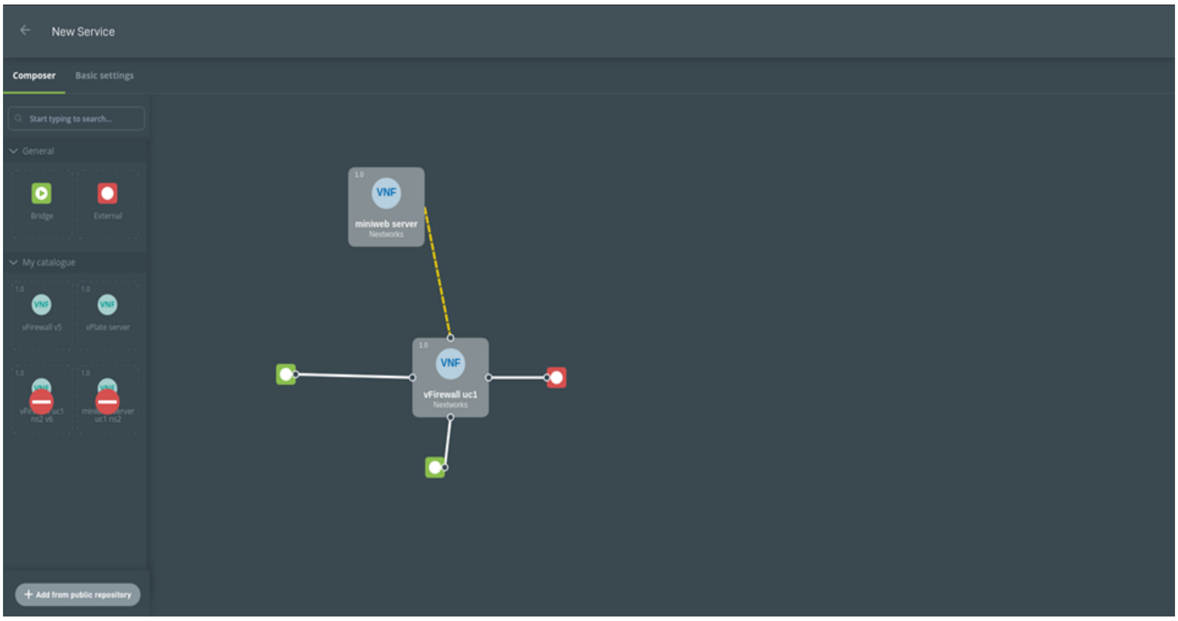


Figure 54: New Service composed in 5GCity SDK.

The additional parameters required for the new Service are then added via specific input forms (see Figure 55); once all the mandatory fields are inserted the service can be published: the SDK composer module automatically translates the simplified SDK service model into a Network Service Descriptor (NSD)and pushes this descriptor into the 5G App & Service Catalogue, which in turns publishes into the underlying NFVO (OSM R6 in 5GCity installations). From that point onwards, the NSD can be used by the slice user for instantiating services in the 5GCity infrastructure.

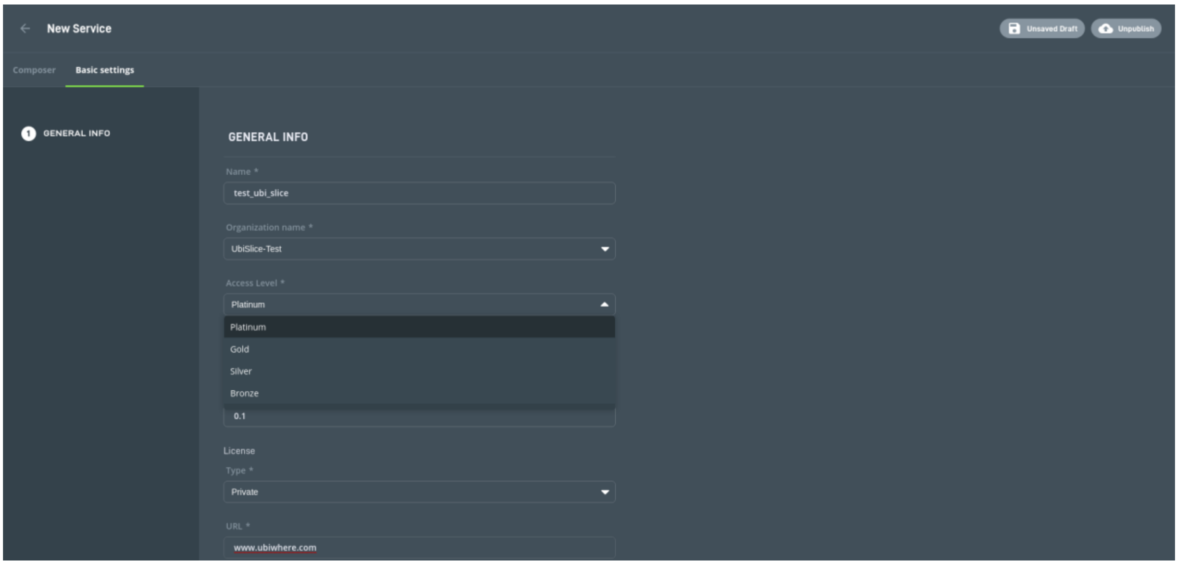


Figure 55: Input parameters for New Service in 5GCity SDK.

3.4.4 Service Instantiation Test

Considering as inputs the previously created network service and slice, the slice user conducts the instantiation of the service. This operation involves several platform components: Dashboard, Slice Manager, Resource Placement, Multi-Tier Orchestrator, NFVO and VIM. The service instantiation can also be validated in the OSM GUI as presented in Figure 56.

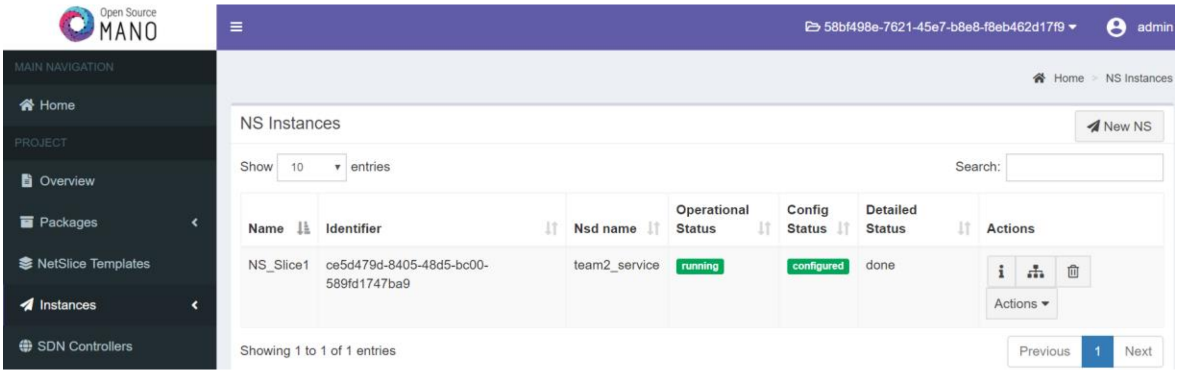


Figure 56: Network service instance registered in OSM.

To check this result at VM granularity level, Figure 57 includes the list of instances deployed in OpenStack as part of the considered service. In this figure, the allocation of the VMs over the computes contained in the slice created over the Barcelona testbed can also be corroborated.

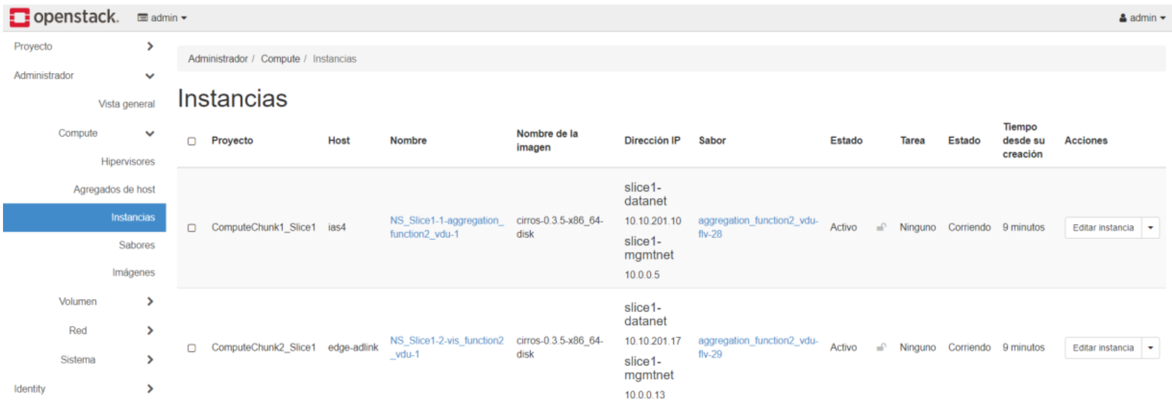


Figure 57: Instances generated in OpenStack.

3.4.5 Monitoring attachment test

Once the service is deployed, the monitoring server, based on Prometheus, is provisioned with the networking data (i.e. IP addresses) of the instantiated VMs. As a result, one node is registered in the Monitoring server per instantiated VM, as well as the associated job and service. This operation involves two platform components: Slice Manager and Monitoring server.

Figure 58, Figure 59 and Figure 60 show the configuration steps in the Monitoring WebGUI.

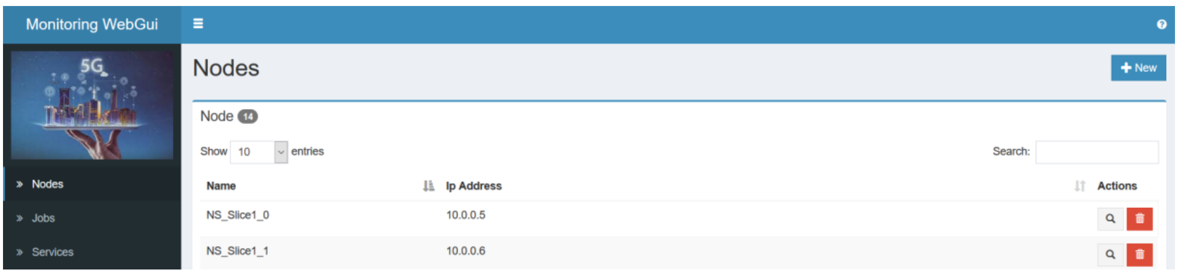


Figure 58: New nodes registered in the Monitoring server.

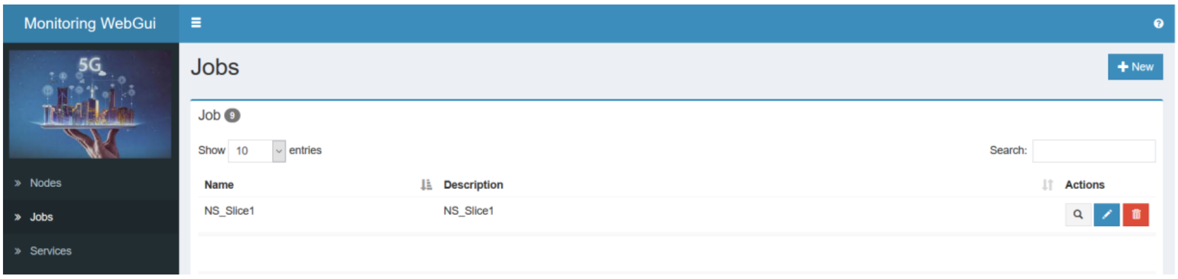


Figure 59: New job registered in the Monitoring server.

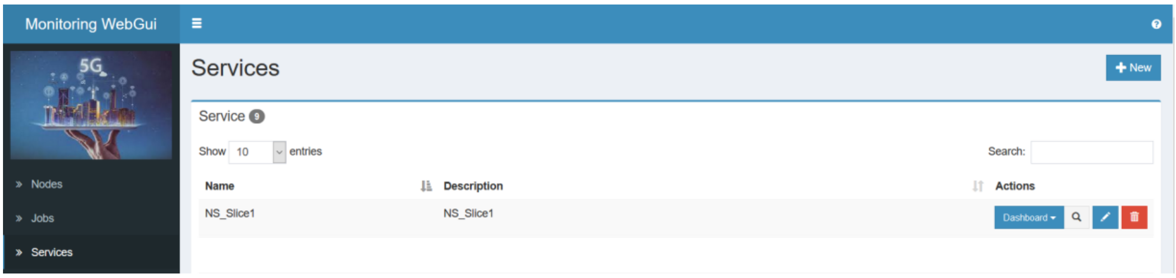


Figure 60: New service registered in the Monitoring server.

Additionally, to validate the operation of retrieving monitoring data from the nodes where Prometheus exporters are configured, Figure 61 shows the Grafana Dashboard obtained for one of the deployed VNFs.

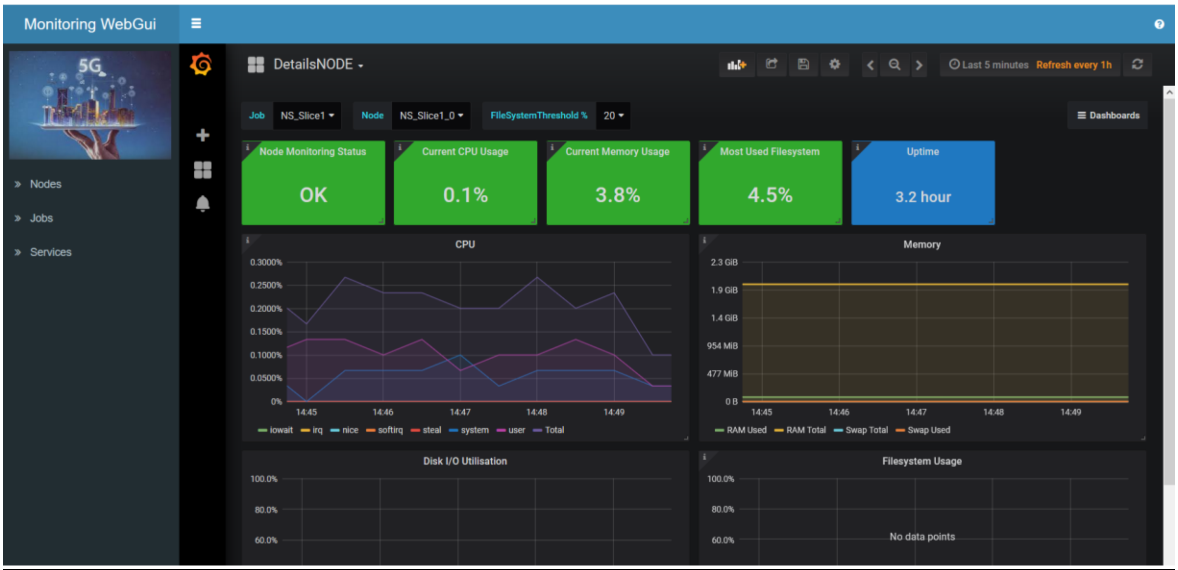


Figure 61: Grafana Dashboard with monitoring metrics.

4 Service Creation & Activation Time benchmarking for SDK

4.1 General methodology towards Creation & Activation Time benchmarking

Service Creation Time is a 5G PPP programmatic KPI which aims to implement solutions which can "*Reduce the average service creation time cycle from 90 hours to 90 minutes*" [15].

A number of 5G PPP projects have worked on this KPI at various levels and a specific coordination activity is undergoing at the time of writing this report among various projects to identify commonalities of approaches and measurement scenarios, potential gaps to be filled and opportunities for convergence towards common definitions and alignment on measurement methodologies.

Key to the correct framing of the KPI assessment on the Creation & Activation Time KPIs is the clear identification how the specific items to measure in the different orchestration workflows, ranging in some cases from the preparations of the virtualized infrastructures, to network slices creation, network services creation and instantiation, VNFs upload, etc.)

A general definition of Service Creation time as reported in ETSI GS NFV-TST 001 V1.1.1, declares that Service Creation Time can be considered as the time needed to activate a Network Service that comprises multiple VNFs in a service chain. In formula:

Service Creation Time = T2-T1

Where,

- **T1** := time when the Service instantiation is requested.
- In the meanwhile, measure the service performance (QoS) metrics periodically (recommended once every 100 ms) until the time when all the QoS metrics meet or exceed the target performance (Ps) of the Network Service.
- **T2** := time when service performance ≥ Ps

However, it is to be noted that various phases of service creation exist, like onboarding, activation, modification and termination and these phases apply to different 5G/NFV constructs like network slices, network services, virtual network functions, MEC applications, service chains, WAN, etc.

For this reason, a number of time components for the computation of the Creation and Activation Time have been identified along with the measurement conditions to be implemented to benchmark results (see Table 20).

Phase 1. Onboarding		
Time components	**What**	**Measurement Conditions**
1.02	Network Service Descriptor (NSD)	Tstart = Request for onboard received in the system Tend = NSD fully onboarded in all the catalogues and available for LCM actions

1.03	VNF package (VNFD)	Tstart = Request for onboard received in the system Tend = VND fully onboarded in all the catalogues and available for LCM actions
1.04	MEC Application Descriptor (MEC AppD)	Tstart = Request for onboard received in the system Tend = AppD fully onboarded in all the catalogues and available for LCM actions
Phase 2. Instantiate, Configure & Activate		
Time components	**What**	**Measurement Conditions**
2.01	Instantiate Network Slice (NSI)	Tstart = Request for slice creation received in the system Tend = NSI fully instantiated, 'alive' and functional and available for monitoring actions (e.g. available for inspection on attached Network Services)
2.02	Instantiate & Activate Network Service (NS)	Tstart = Request for instantiate received in the system Tend = NS fully instantiated, 'alive' and functional and service performance (QoS) metrics meeting or exceeding the target performance (Ps) of the Network Service. Measure the service performance (QoS) metrics periodically (recommended once every 100 ms)
2.03	Instantiate & Configure VNFs in service chain (VNF)	Tstart = Request for instantiate logged in the system Tend = VNF fully instantiated, configuration complete, VNF 'alive' and functional
2.04	Instantiate & Configure MEC Application (MEC App)	Tstart = Request for instantiate logged in the system Tend = MEC App fully instantiated, configuration complete, 'alive' and functional
2.06	Configure other NFVI elements	Tstart = Request for any other NFVI related configuration logged in the system (e.g. HW acceleration, fast-paths, private networks, gateways, etc.) Tend = NFVI configuration complete, 'alive' and functional
2.07	Configure SDN infrastructure	Tstart = Request for any SDN related configuration logged in the system Tend = SDN configuration complete, 'alive' and functional
Phase 3. Modify		
3.x	*Not applicable to 5GCity*	*Modification actions are note possible in 5GCity Platform. Instead, a combination of Terminate (phase 4) and Create (phase 1) is used.*
Phase 4. Terminate		
Time components	**What**	**Measurement Conditions**
4.01	Terminate Network Slice (NSI)	Tstart = Request for termination received in the system Tend = NSI fully terminated

4.02	Terminate Network Service (NS)	Tstart = Request for termination received in the system Tend = NS fully terminated
4.03	Terminate VNFs in service chain (VNF)	Tstart = Request for termination received in the system Tend = VNFs fully terminated
4.04	Terminate MEC Application (MEC App)	Tstart = Request for termination received in the system Tend = MEC App fully terminated
4.07	Remove configuration from SDN infrastructure	Tstart = Request for removing any SDN related configuration logged in the system Tend = SDN configuration complete

Table 20: Phases and measurement methodology for Creation and Activation Times in 5GCity.

In the following sub-section, we present results of the benchmarking activities executed on 5GCity SDK and catalogue, being the benchmarking on Slice creation and Service instantiation postponed to activities related to the completion of Use Case 2 – Neutral Host. Complete results will be presented in future deliverable D5.3.

4.2 SDK and catalogue operations

To benchmark service creation operations in SDK, we have profiled the time spent to implement and complete the actions triggered via REST northbound API.

The measurement chain comprises:

- **REST API client** originating requests towards the 5GCity SDK
- **5GCity SDK**, in which Functions and Services are defined, stored and translated towards the 5G App & Service Catalogue
- **5G App & Service Catalogue**, in which NSDs and VNFDs are stored in ETSI SOL compliant format and published to the underlying NFVO
- **ETSI OSM as NFVO**, in which NSDs and VNFDs are stored in NFVO catalogue in OSM specific format.

Tests on 5GCity SDK Functions have been executed on five core API actions:

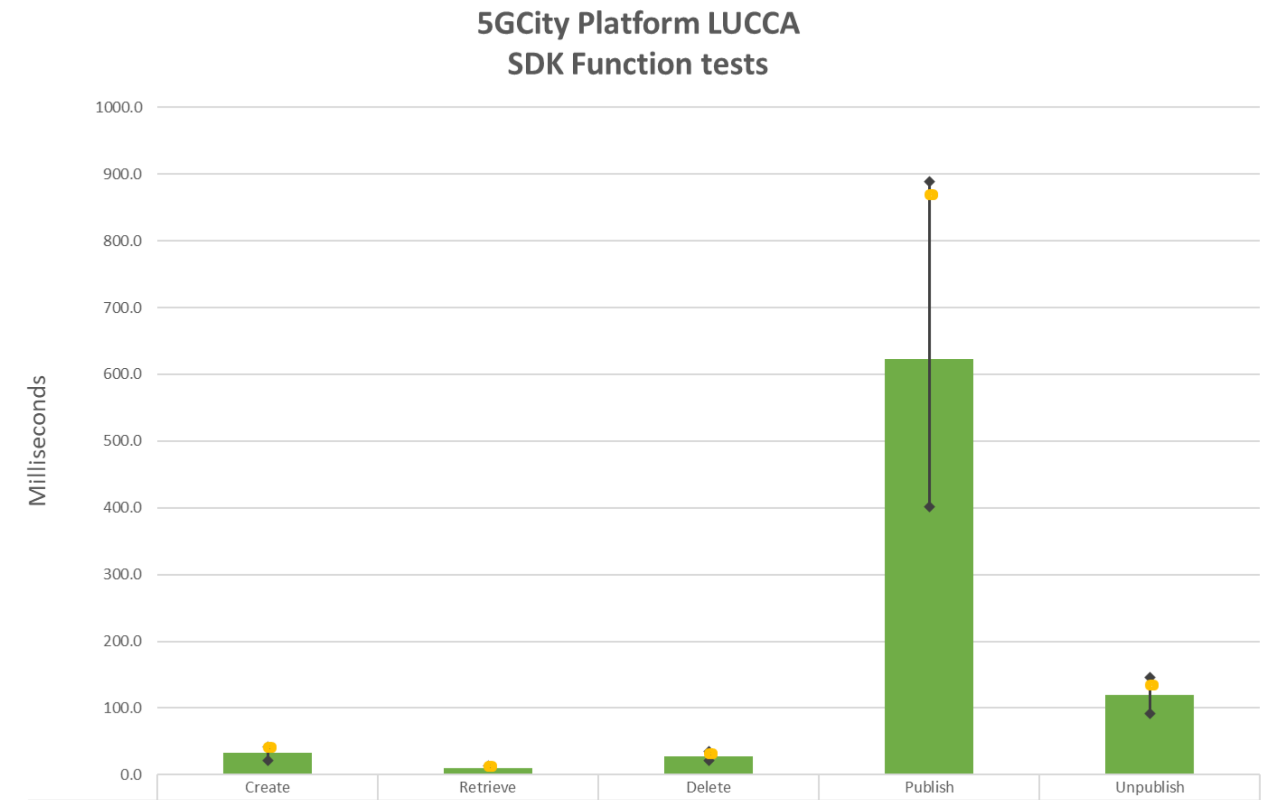
- Create function
- Retrieve function (get)
- Delete function
- Publish function, which also pushes descriptors to the 5G App&Service Catalogue and NFVO
- Un-publish function, which also deletes descriptors from the 5G App&Service Catalogue and NFVO

Results are presented in Figure 62, in terms of avg/min/max and 90-percentile over 100 iterations of the aforementioned methods. It is to be noted that whilst 90% of Function Create completes in less than 41.1 ms (with no interaction with modules external to SDK), and similarly 90% of Function Delete complete in less than 31.4 ms (because of less API contents verification and semantic validation to be executed), the longer lasting actions are Publish and Unpublish which raise up to 869.2 ms for 90-percentile. This is due to the action of 5G App& Service catalogue and NFVO catalogue where VNFDs are to be processed, validated and stored.

Similarly, tests on 5GCity SDK Services have been executed on the same five core API actions as described before, but applied to Service and NSD context.

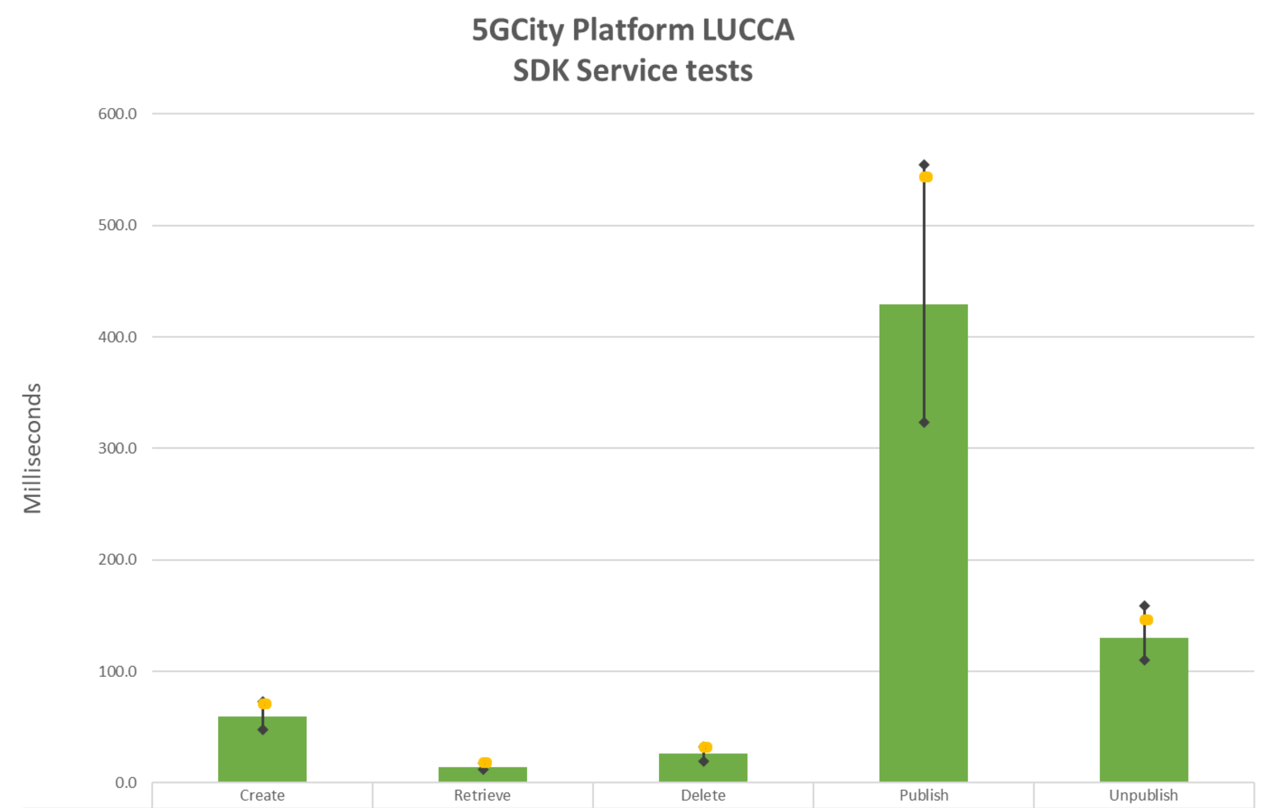
Results are presented in Figure 63, in terms of avg/min/max and 90-percentile over 100 iterations of the aforementioned methods. Also, in this case the actions of Service Create and Delete perform faster than publish and unpublish (respectively 90-percentile at 71.2 ms for Create, 32ms for Delete, 543.2ms for Publish and 145.5 for unpublish). However, whilst Service Create lasts longer than Function Create (due to higher number of consistency checks and verification on the correlation among the composed elements), Service Publish and Unpublish perform faster than the respective counterparts for SDK Function, because of the lower information to be passed in NSD (and thus check) in NSDs.

In all the cases, SDK editing and composing together with the correlated actions of publishing on underlying catalogues remain significantly below the 1s, thus with limited impact on the overall service creation time.



	Create	Retrieve	Delete	Publish	Unpublish
AVG	32.4	10.3	27.3	623.5	119.1
MIN	22.0	7.0	21.0	401.0	92.0
MAX	42.0	13.0	35.0	889.0	146.0
90-PERCENTILE	41.1	13.0	31.4	869.2	134.3

Figure 62. 5GCity SDK Function tests: create, retrieve, delete, publish, unpublish.



	Create	Retrieve	Delete	Publish	Unpublish
AVG	59.1	14.2	25.9	429.4	130.1
MIN	48.0	12.0	19.0	323.0	110.0
MAX	73.0	18.0	32.0	554.0	159.0
90-PERCENTILE	71.2	18.0	32.0	543.2	145.5

Figure 63. 5GCity SDK Service tests: create, retrieve, delete, publish, unpublish.

5 Conclusions

In this document the current status of successful deployment with validation of the 5GCity Infrastructure and Platform in the target cities of Barcelona (ES), Bristol (UK) and Lucca (IT) has been reported.

The activities described in this deliverable are the result of a continuous process of design, procurement, deployment, integration and test which has involved most of the 5GCity partners directly linked to infrastructure roll-out and orchestration software development. In Table 21 the location and validation dates of the various element is reported to show the temporal progress occurred in three cities.

5GCity Infrastructure Components	City of Barcelona	City of Bristol	City of Lucca
RAN	@ 22 Superilla *on September 2019*	Millennium Square *on March 2019*	Villa San Paolino *on November 2018*
	Plaza Sant Miquel (New)* *To be deployed*	MShed-Harbour side *on June 2019*	Sortita San Paolino *on February 2019*
MEC/Edge Node	Llacuna Street Cabinet *on September 2019*	We-The-Curious Data Centre *on January 2019*	Via della Cavallerizza Cabinet *on March 2019*
	BeTeVe Data Centre (*New*) *on September 2019*	MShed Data Centre (*New*) *on July 2019*	n/a
Metro/Edge Node	I2CAT Data Centre *on November 2018*	HPN Data Centre *on November 2018*	Villa San Paolino Data Centre *on December 2018*

Table 21: Location and validation dates of 5GCity Infrastructure components in the three cities.

**Deployments started by Barcelona Municipality in September 2019 after the approval of contract amendment with EC*

The summary of the accomplished validation process is reported in the following Table 22, which provides an overview of tests and dates for the target validation.

5GCity Components	Validation tests	Location/Schedule	Status
Infrastructure	• RAN Measurements • RAN-Edge connectivity • RAN-Metro connectivity • VNF Boot/Deletion	Barcelona and Bristol *May to September 2019* City of Lucca *May and September 2019*	**Accomplished**
Platform	• Infrastructure Registration • Slice Creation • SDK Service and Function Creation/Publish • Service Instantiation • Monitoring Attachment	The three cities *March to September 2019*	**Accomplished**

Table 22: 5GCity Testbed Validation

For preliminary integrations of Use Cases applications into testbeds, validations have also occurred in various occasions, often related to public demonstrations of 5GCity solutions or dissemination actions. In these cases, interim version of 5GCity components have been used and focus has been maintained on use case application. The list if these tests related to public events includes:

- Tests of Use Case 1 (Unauthorized Waste Dumping Prevention) application components and service descriptors in
    - Ljubljana (SL) on June 2018 for EUCNC 2018 demos
    - Wien (AT) on December 2018 for ICT2018 demos
- Test of Use Case 2 (Neutral Host) orchestration components and service descriptors in
    - Ljubljana (SL) on June 2018 for EUCNC 2018 demos
    - Wien (AT) on December 2018 for ICT2018 demos
    - Barcelona (ES) on February 2019 for MWC2019 demos
    - Lucca (IT) on June 2019 for European Digital Forum demos
    - Valencia (ES) on June 2019 for EUCNC 2019 demos
    - Bristol (UK) on July 2019 for 1st 5GCity Hackathon
- Tests of Use Case 3 (Video Acquisition and Production +Community media engagement in live events) application components in
    - Bristol (UK) on August 2018 to collect data for a journal publication
    - Valencia (ES) on June 2019 for EUCNC 2019 demos, jointly with Use Case 5
    - Bristol (UK) on July 2018 for 1st 5GCity Hackathon
- Tests of Use Case 4 (UHD Video Distribution Immersive Services) application components in:
    - Lucca (IT) on November 2018 for Lucca Comics & Games demos
    - Wien (AT) on December 2018 for ICT2018 demo
    - Lucca (IT) on June 2019 for European Digital Forum demos
    - Valencia (ES) on June 2019 for EUCNC 2019 demos
- Tests of Use Case 5 (Mobile Backpack Unit for Real-time Transmission) application components in:
    - Lucca (IT) on June 2019 for European Digital Forum demos
    - Valencia (ES) on June 2019 for EUCNC 2019 demos

The future work in WP5 will continue with the activities like the improvement – where possible – of the achieved performance and platform benchmarking, the completion of the newly approved infrastructure chunks in Barcelona, the measurement and analysis of KPIs for the specific use cases. All this information will be conveyed in future deliverable D5.3 due by the end of the project in March 2020.

6 References

[1] 5GCity Project Deliverable D5.1: "5GCity Infrastructure Design and Definition", Jun. 2018.

[2] 5GCity Project Deliverable D3.2: "5GCity Virtualization Infrastructure Interim Release", May 2019.

[3] 5GCity Project Deliverable D3.3: "5GCity Virtualization Infrastructure Final Release", Sept. 2019.

[4] 5GCity Project Deliverable D4.2: "Scalable Orchestrator Interim Release", May 2019.

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[6] CellMapper Android application, advanced 2G/3G/4G/5G cellular network information, available online at: https://play.google.com/store/apps/details?id=cellmapper.net.cellmapper&hl=en, last visited Sept. 2019.

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[10] Simple Ping Tool Android application, available online at: https://play.google.com/store/apps/details?id=com.kantamori.simpleping&hl=en, last visited Sept. 2019.

[11] Rally tool & framework for OpenStack, Available online at: https://github.com/openstack/rally, last visited Sept. 2019.

[12] 5GCity Project Deliverable D2.4: "5GCity Final Architecture, and Interfaces", July 2019.

[13] C. Colman-Meixner, Pedro Diogo, M. S. Siddiqui, A. Albanese, H. Khalili, A. Mavromatis, Luca Vignaroli, A. Ulisses, J. Colom, R. Nejabati, and D. Simeonidou"5G City: A novel 5G-enabled architecture for ultra-high definition and immersive media on city infrastructure", IEEE International Symposium on Broadband Multimedia Systems and Broadcasting (BMSB), Valencia, Spain, May, 2018.

[14] ETSI, "NFV Management and Orchestration; Network Service Templates Specification", ETSI GS NFV IFA 014, online available at http://www.etsi.org/deliver/etsi_gs/NFV-IFA/001_099/014/02.01.01_60/gs_NFV-IFA014v020101p.pdf

[15] 5G PPP Test, Measurement, and KPIs Validation Working Group, "Validating 5G Technology Performance Assessing 5G architecture and Application Scenarios", version 1.0, June 2019, available online at https://5g-ppp.eu/wp-content/uploads/2019/06/TMV-White-Paper-V1.0-03062019.pdf), , last visited Sept. 2019.

7 Abbreviations and Definitions

7.1 Abbreviations

3GPP	3rd Generation Partnership Project
BW	Bandwidth
DL	DownLink
CPU	Central Processing Unit
EC	European Commission
ETSI	European Telecommunications Standards Institute
E-UTRA	Evolved UMTS Terrestrial Radio Access
E-UTRAN	Evolved UMTS Terrestrial Radio Access Network
FDD	Frequency Division Duplex
GbE	Gigabit Ethernet
HDD	Hard Disk Drive
ICMP	Internet Control Message Protocol
IETF	Internet Engineering Task Force
IP	Internet Protocol
ITU-T	International Telecommunications Union – Telecommunication Standardization Sector
LTE	Long Term Evolution
MCC	Mobile Country Code
MANO	Management and Orchestration
MEC	Multi-access Edge Computing
MIMO	Multiple Input Multiple Output
MNC	Mobile Network Code
MNO	Mobile Network Operator
NFV	Network Function Virtualization
NFVI	NFV Infrastructure
NFVO	NFV Orchestrator
NS	Network Service
NSD	Network Service Descriptor
OS	OpenStack
OSM	Open Source MANO
OSS	Open Source Software
PoI	Point of Interest
QAM	Quadrature Amplitude Modulation
QPSK	Quadrature Phase-Shift Keying
RAM	Random Access Memory
RAN	Radio Access Network
RF	Radio Frequency
RFC	Request for Comments
RSRP	Reference Signal Received Power
RSRQ	Reference Signal Received Quality
RTT	Round Trip Time
SC	Small Cell
SDK	Service Development Kit
SINR	Signal to Interference and Noise Ratio
SNR	Signal to Noise Ratio
TAC	Tracking Area Code

TCP	Transmission Control Protocol
TDD	Time Division Duplex
UDP	User Datagram Protocol
UE	User Equipment
UL	UpLink
VM	Virtual Machine
VNF	Virtual Network Function
VNFD	Virtual Network Function Descriptor
WP	Work Package

APPENDIX A. Macroblocks modelling preliminary results for the City of Barcelona

In the City of Barcelona, the concept of Superblocks/macroblocks well applies to the urbanistic characteristics of the districts and the overall management of the urban areas.

Superblocks are defined theoretically as an "*area of urban organization, from which a series of structured transformation strategies towards a new urban model, where mobility and reorganization of public space represent the first step*".

Macroblocks were initially described in deliverable D5.1 [1]. From an infrastructure owner perspective, the key questions to solve for modelling the process related to these urban areas are:

- Which urbanistic restrictions apply?
- Where can devices be mounted (cabinets, lampposts, etc.)?
- Which distance is technically possible between devices? This can impact:
  - Urban Furniture Configuration
  - Power & Interference Constraints
  - Traffic Constraints

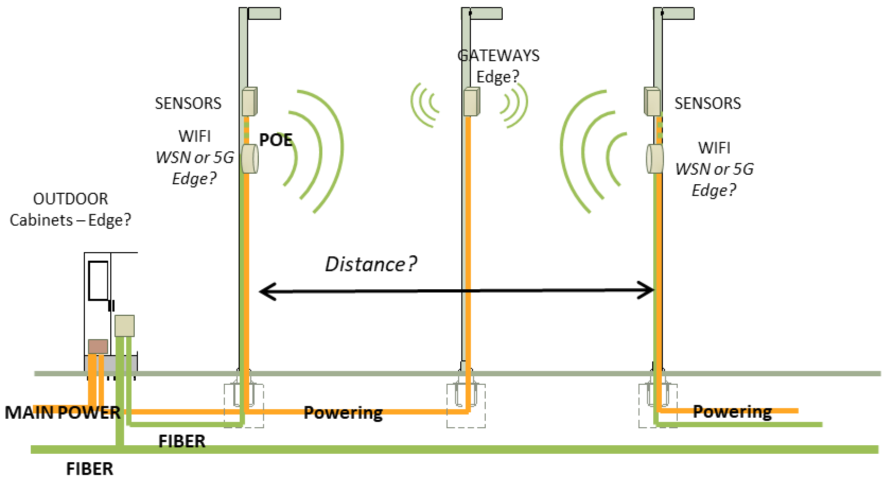


Figure 64: Technical elements and dimensioning questions for macroblocks.

In the study carried out by IMI in Barcelona, the following dimensioning data and constraints were assumed:

- indoor traffic is carried by indoor devices via IOT node (ITU4000 family compliant) and/or macrocells at building roofs
- It is preferred to use urban furniture instead of private walls/building for mounting devices, because of the easier management of authorizations for operations and more efficient installation and operation.
- At the crossing of two streets, maximum 4 poles could be installed (at the 4 corners), with min distance 10 m
- Along a street, typically poles could not be installed with distance between them lower than 11 m
- The max density of population to be assumed is 4 men/square meter

The topologies presented in Figure 65 show four different models that support increasing needs for coverage and throughput. The selected option for 5GCity project is the 14 Small Cell macroblock, with cells positioned as per red dots indicated in the second green square in Figure 65.

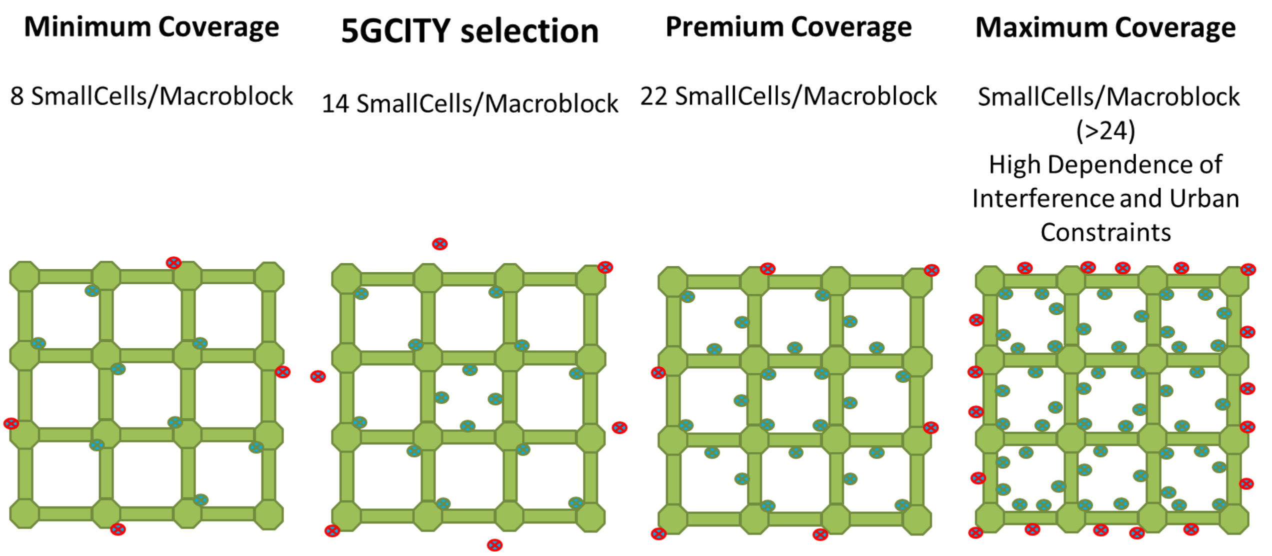


Figure 65: Macroblocks Modelling and 5GCity selection for Barcelona.

The study is under finalization at the time of writing this deliverable. Further expected results will be reported in future deliverable D5.3.

APPENDIX B. Coverage tests in the City of Lucca

In addition to the results presented in section 2.3.1, we report in this appendix additional SNR measurements collected during the on-street field tests in the City of Lucca in locations close to the Small Cells installed for 5GCity. As reported by the images below, specific points of interests were selected to measure LTE RSRP (Reference Signal Received Power Levels), with the objective of validating potential target locations for use case tests in the city areas covered by 5GCity.

The activity was aimed at identifying and selecting the areas with better coverage and higher RSRP values, in order to guarantee better network performances for use cases.

RSRP has been evaluated according to the following scale:

- ***Excellent*** >= -80dBm
- ***Good*** between -80 dBm and -90dBm
- ***Mid Cell*** between -90dBm and -100 dBm
- ***Cell Edge*** <= -100dBm

<u>Small Cell in Villa San Paolino (SC-SDonato)</u>

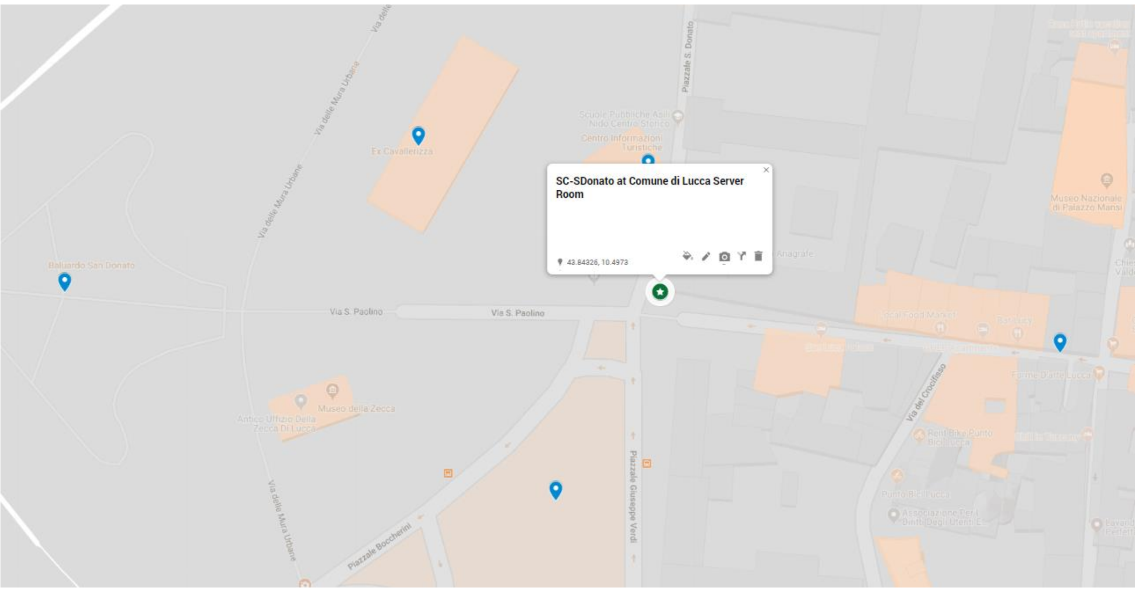


Figure 66: Coverage test area and PoIs for Small Cell in Villa San Paolino (SC-SDonato).

<table>
<tr><th>Location</th><th>Position in Google Maps</th><th>Cell Mapper data</th></tr>
<tr>
<td>

SC-SDonato

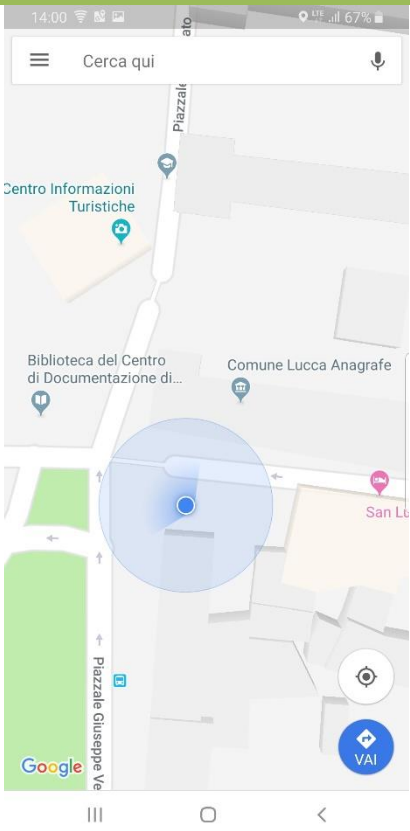
PoI. Villa San Paolino Server Room, 2nd floor

LTE RSRP -57dBm

LTE SINR 30 dB

(Excellent)

</td>
<td>



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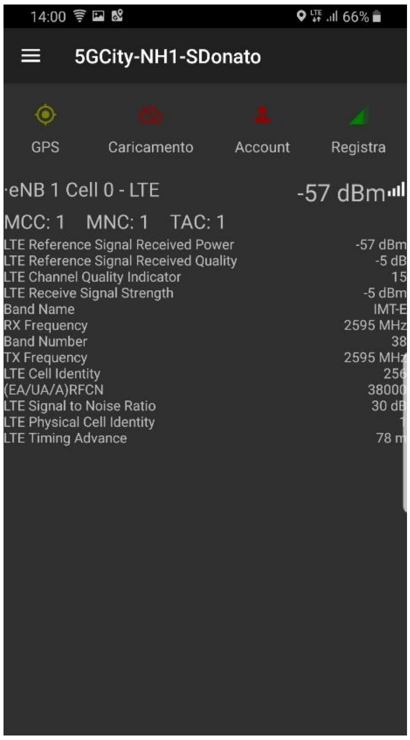


</td>
</tr>
<tr>
<td>

SC-SDonato

PoI: Ex-Cavallerizza building

LTE RSRP -109dBm

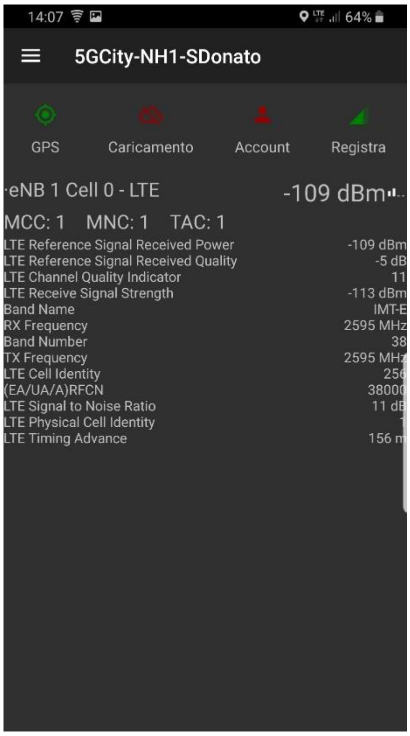
LTE SINR 11 dB

(Mid Cell)

Shadow effect from a Tourist Office building towards the SC

</td>
<td>

</td>
<td>



</td>
</tr>
</table>

<table>
<tr><th>Location</th><th>Position in Google Maps</th><th>Cell Mapper data</th></tr>
<tr>
<td>

SC-SDonato

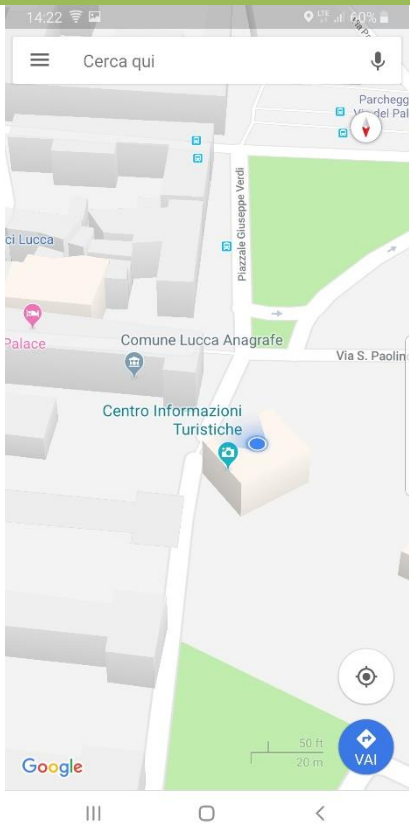
PoI: Tourists Office

LTE RSRP -98dBm

LTE SINR 26 dB

(Excellent)

</td>
<td>



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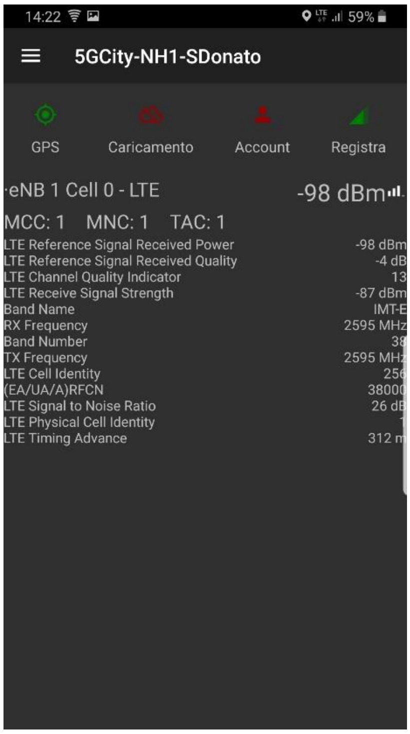

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<tr>
<td>

SC-SDonato

PoI: Piazzale Verdi

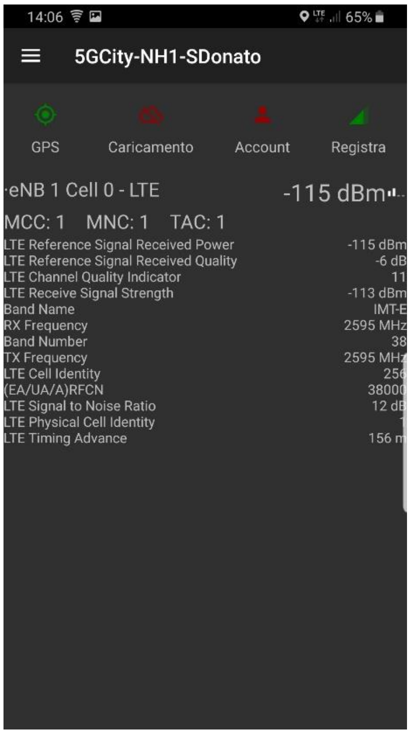
LTE RSRP -115dBm

LTE SINR 12 dB

(Mid Cell / Cell Edge)

</td>
<td>

</td>
<td>



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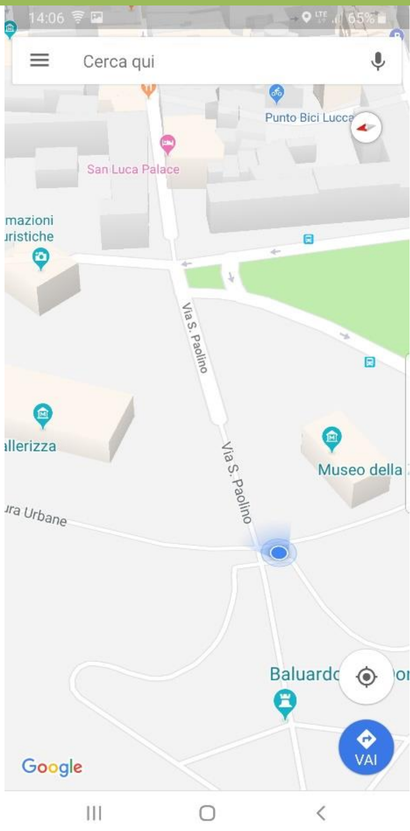
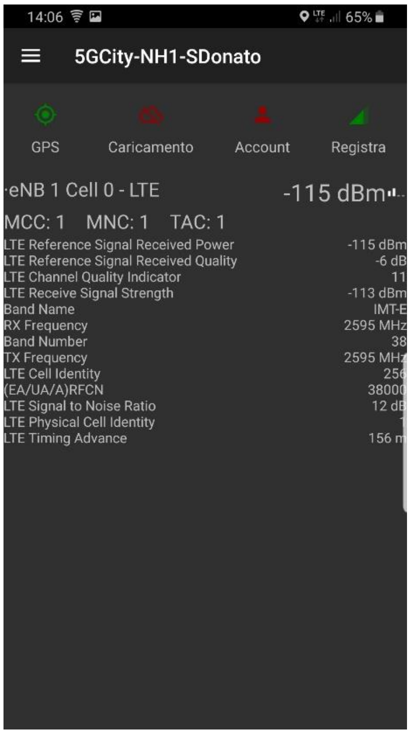
<table>
<tr><th>Location</th><th>Position in Google Maps</th><th>Cell Mapper data</th></tr>
<tr><td>SC-SDonato

PoI. Baluardo San Donato on historic walls pathway

LTE RSRP -115dBm
LTE SINR 12 dB
(Mid Cell / Cell Edge)</td><td>
</td><td>
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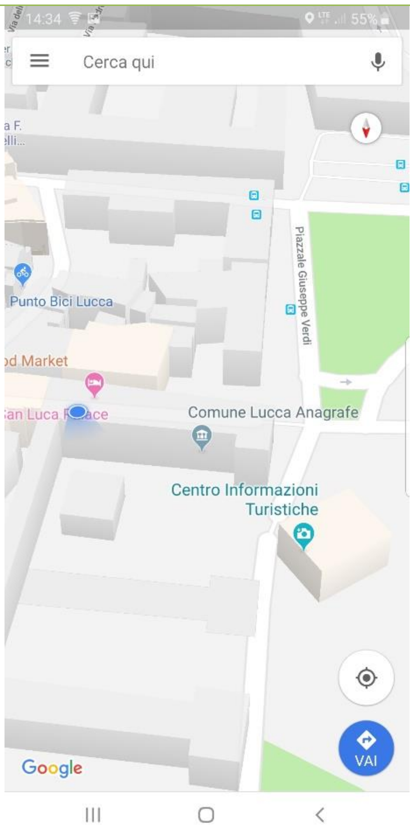
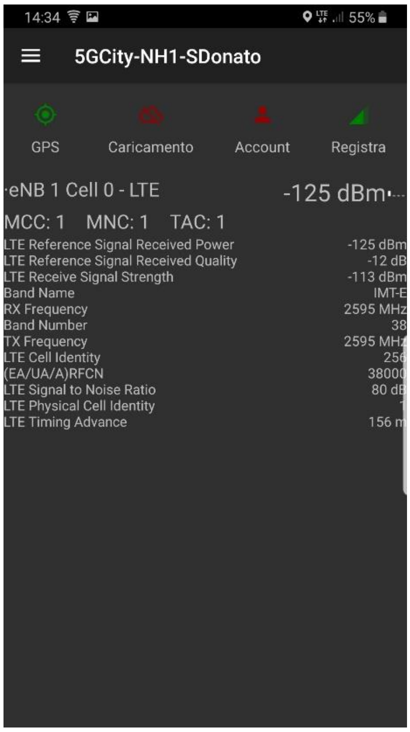
<tr><td>SC-SDonato

PoI: Via San Paolino 136

LTE RSRP -125dBm
LTE SINR no signal
(Cell Edge)</td><td>
</td><td>
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Small Cell in Baluardo San Paolino (SC-SPaolino)

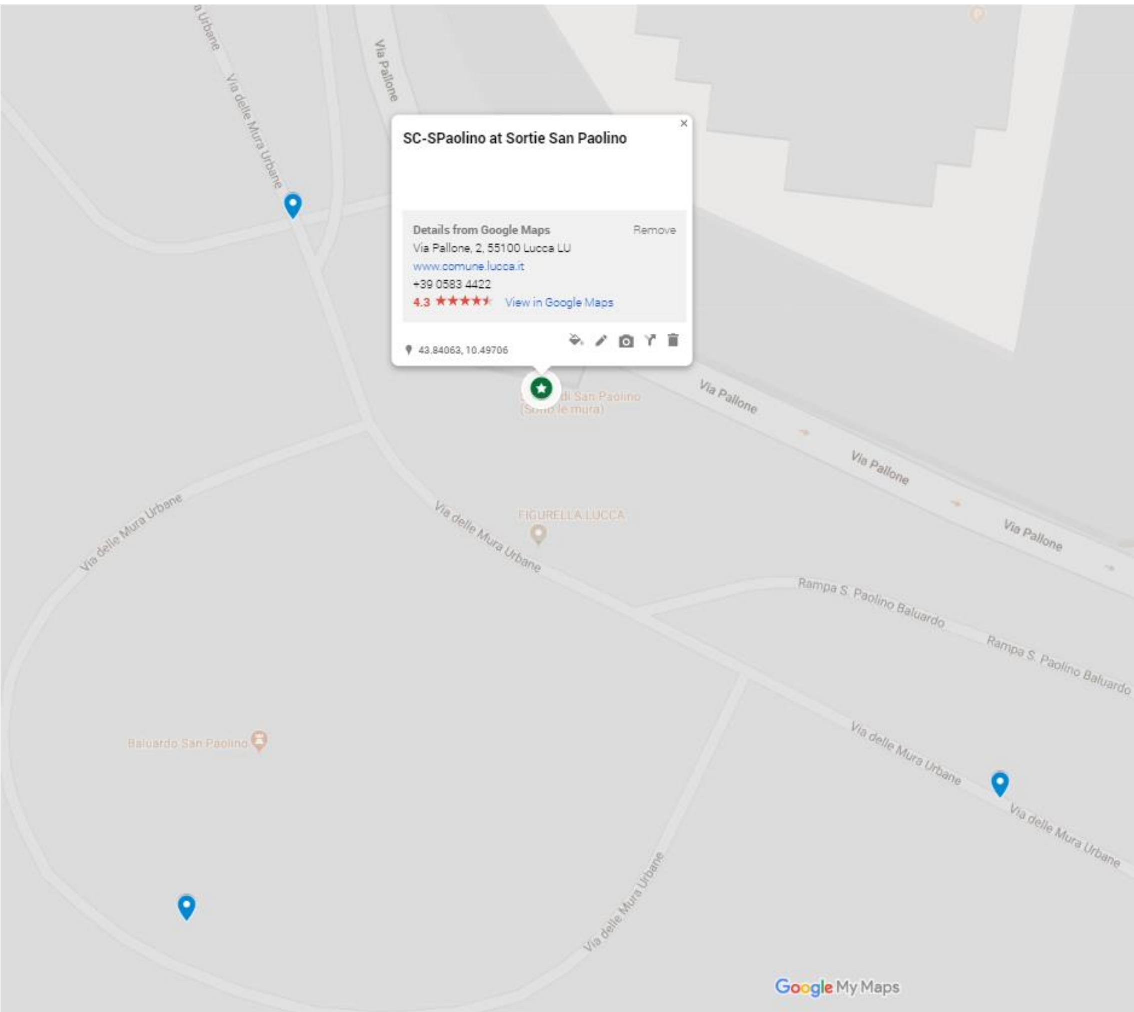


Figure 67: Coverage test area and PoIs for Small Cell in Baluardo San Paolino (SC-SPaolino).

<table>
<tr><th>Location</th><th>Position in Google Maps</th><th>Cell Mapper data</th></tr>
<tr><td>

SC-SPaolino

PoI: Baluardo San Paolino

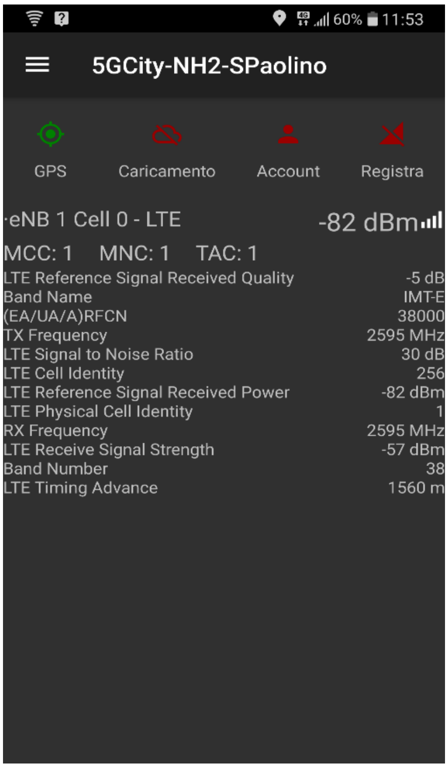
LTE RSRP -82dBm

LTE SINR 30 dB

(Excellent)

</td><td>

</td><td>



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<tr><td>

SC-SPaolino

PoI: Via delle Mura, East side

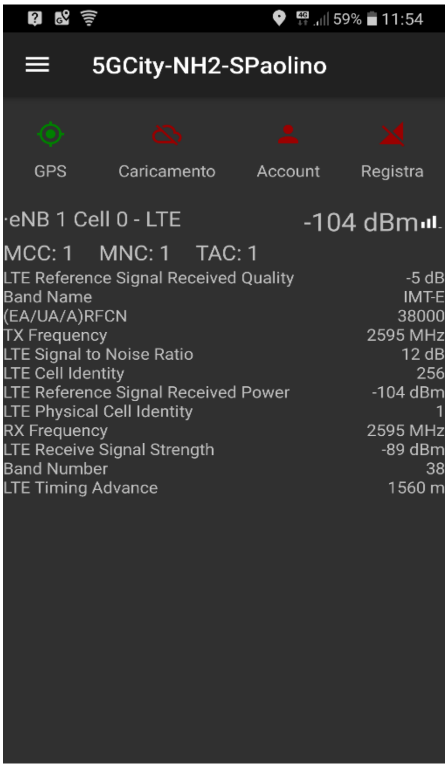
LTE RSRP -104dBm

LTE SINR 12 dB

(Mid Cell / Cell Edge)

</td><td>

</td><td>



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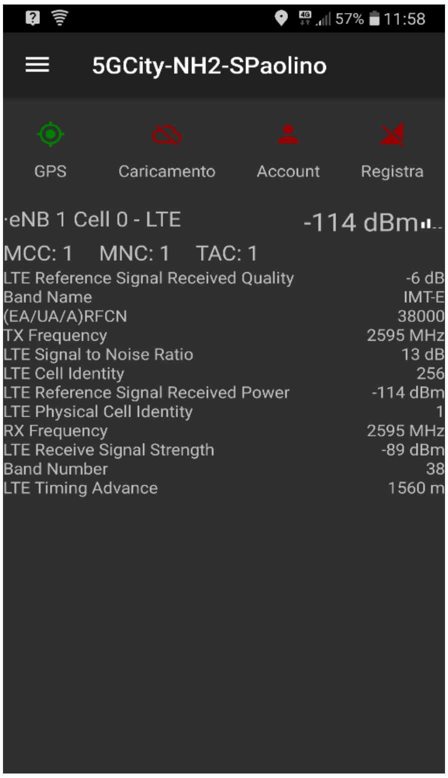
<table>
<tr><th>Location</th><th>Position in Google Maps</th><th>Cell Mapper data</th></tr>
<tr><td>**SC-SPaolino**

PoI: Via delle Mura, West side

LTE RSRP -114dBm

LTE SINR 13 dB

(Mid Cell / Cell)</td><td>
</td><td>
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