5G CITY

Grant Agreement No.761508 5GCity/H2020-ICT-2016-2017/H2020-ICT-2016-2

D5.3: City-wide Pilot Validation City-wide

Dissemination Level		
☒	PU:	Public
☐	PP:	Restricted to other programme participants (including the Commission Services)
☐	RE:	Restricted to a group specified by the consortium (including the Commission
☐	CO:	Confidential, only for members of the consortium (including the Commission Services)

Grant Agreement no: **761508**	Project Acronym: **5G CITY**	Project title: **5G CITY**

Lead Beneficiary: **I2CAT**	Document version: **V1.0**

Work package: **WP5 - 5GCity city-wide pilots' implementation and validation**

Deliverable title: **City-wide Pilot Validation City-wide**

Start date of the project: 01/06/2017 (duration 30 months)	Contractual delivery date: Month 34	Actual delivery date: Date of submission to Coordinator

Editor name: Adriana Fernández-Fernández (i2CAT)

List of Contributors

Participant	Short Name	Contributor
i2CAT Foundation	i2CAT	Adriana Fernández-Fernández, Leonardo Ochoa-Aday, August Betzler, Apostolos Papageorgiou, Shuaib Siddiqui
University of Bristol	UNIVBRIS	Carlos Colman Meixner, Borja Otura
Nextworks	NXW	Leonardo Agueci, Elian Kraja, Gino Carrozzo
NEC Europe ltd.	NEC	Daniel Onoro-Rubio, Felipe Huici
Retevision (Cellnex Telecom)	Cellnex	David Pujals
MOG Technologies	MOG	Cláudia Marinho, Pedro Santos
RAI	RAI	Davide Desirello, Luca Vignaroli
Beteve	BTV	Jordi Colom
Ubiwhere	UBI	Pedro Diogo
Accelleran	XLRN	Antonio Garcia
Instituto Municipal de Informatica	IMI	Laura Vidal, Mariano Lamarca
Comune di Lucca	CDILUCCA	Luca Falsiroli, Pamela Salvatore, Mauro Di Bugno

List of Reviewers

Participant	Short Name	Contributor
University of Bristol	UNIVBRIS	Carlos Colman Meixner
Nextworks	NXW	Gino Carrozzo
i2CAT Foundation	i2CAT	Shuaib Siddiqui

Change History

Version	Date	Partners	Description/Comments
0.0	2019-12-19	i2CAT	Table of Contents
0.1	2020-02-17	i2CAT, BTV, MOG	Integrated version with first round of partner contributions
0.2	2020-03-02	i2CAT, MOG, BTV, RAI, Cellnex, UBI	Integrated version with second round of partner contributions
0.3	2020-03-12	i2CAT, MOG, RAI, NXW	Integrated version with third round of partner contributions
0.4	2020-03-20	i2CAT, XLRN, RAI, Cellnex, UBI, IMI	Integrated version with fourth round of partner contributions
0.5	2020-03-27	i2CAT, UNIVBRIS, NXW	Consolidated version for internal review
1.0	2020-03-31	NXW, i2CAT	QA and Final version ready for submission

DISCLAIMER OF WARRANTIES

This document has been prepared by 5GCity project partners as an account of work carried out within the framework of the contract no 761508.

Neither Project Coordinator, nor any signatory party of 5GCity Project Consortium Agreement, nor any person acting on behalf of any of them:

- makes any warranty or representation whatsoever, express or implied,
  - with respect to the use of any information, apparatus, method, process, or similar item disclosed in this document, including merchantability and fitness for a particular purpose, or
  - that such use does not infringe on or interfere with privately owned rights, including any party's intellectual property, or
- that this document is suitable to any particular user's circumstance; or
- assumes responsibility for any damages or other liability whatsoever (including any consequential damages, even if Project Coordinator or any representative of a signatory party of the 5GCity Project Consortium Agreement, has been advised of the possibility of such damages) resulting from your selection or use of this document or any information, apparatus, method, process, or similar item disclosed in this document.

5GCity has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 761508. The content of this deliverable does not reflect the official opinion of the European Union. Responsibility for the information and views expressed in the deliverable lies entirely with the author(s).

Table of Contents

Figures

Tables

Executive Summary

The main goal of 5GCity is to build and deploy – in live pilot trials – a common, multi-tenant, open platform that extends the centralized cloud model to the extreme edge of the network. The resulting Neutral Host model allows infrastructure operators and Vertical actors to virtualize, orchestrate, and slice the compute, network and radio resources made available in the cities. In the 5GCity project, the Neutral Host model has been tested and trialled with relevant use cases in three different cities: Barcelona (Spain), Bristol (UK) and Lucca (Italy). **Figure 1** illustrates the city scale vision of 5GCity supported by its main technological pillars.

Figure 1 - City scale vision of 5GCity

We reported in previous deliverables on how the 5GCity Neutral Host Platform (Deliverable D4.4) has been designed (Deliverable D5.1) installed, integrated and validated (Deliverable D5.2) with the target field trial infrastructures in the three cities.

This deliverable D5.3 marks the completion of the final phase of the validation process defined by the 5GCity consortium, as it reports on results of validation, in operational conditions, of the six selected use cases at the three city-wide pilots. The six 5GCity use cases target three main areas: Telco, Media and City Security, as depicted in **Figure 2**.

As previously presented in Deliverable 2.1 and D5.1, a great focus exists on Media use cases (3 out of 6) as this category of Vertical applications appear as the most in-demand in 5G-ready city scenarios.

The actual deployment of the six use cases in the three cities is summarised in **Table 1**. Detailed results of all the various runs are reported in the rest of this document.

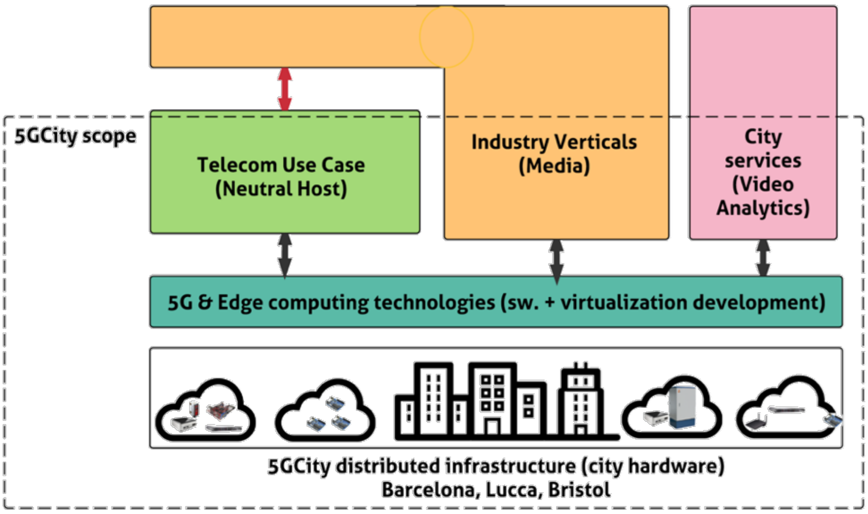


Figure 2 - 5GCity Use cases

Tests for validation have been conducted by executing a number of test cases designed to evaluate the fulfilment of use case requirements and KPIs defined in Deliverable D2.1 while running in the specific actual pilot infrastructures built during the project (see Deliverable D5.2).

Table 1 - 5GCity use cases in the three cities

UC ID	Use Case	City		
		Barcelona	Bristol	Lucca
UC1	Unauthorized Waste Dumping Prevention			✓
UC2	Neutral Host	✓	✓	✓
UC3	Video Acquisition and Production	✓	✓	
UC4	UHD Video Distribution and Immersive Services		✓	✓
UC5	Mobile Backpack Unit for Real-time Transmission	✓		
UC6	Cooperative, Connected and Automated Mobility (CCAM)	✓		

The performed trials have been oriented to:

- Demonstrate the feasibility of the 5GCity Neutral Host platform by validating the correct operation of the technology components designed and developed in the project.
- Measure and monitor a set of pre-defined KPIs, following the conceived methodology and registering the obtained results.
- Assess the pilots' performance when deploying the different use cases by evaluating the obtained measurements against the desired targets.

For each of the executed use case tests the outcomes of the trial are reported, including the explanation of the testing conditions, the technological outcomes, as well as a final assessment of the achievement of the target KPIs. Results show substantial achievements of all the KPIs set for 5GCity platform and infrastructure, e.g. related to service creation and instantiation time, and well as of most of the Use case specific KPIs. Details are provided in the report and summarised in document conclusions.

In addition, this document also presents an analysis of the achieved performance in relation to some core technical objectives of the project.

1. Introduction

The 5GCity project has designed, implemented and deployed a distributed cloud and radio platform for municipalities and infrastructure owners acting as 5G Neutral Hosts. The work to realize this overarching goal has been organized along the following major work-phases:

1. Definition of a reference architecture design for the 5GCity distributed, 3-tier architecture implementing network sharing, slicing and mobile edge computing capabilities (see [1] and [2])
2. Implementation of technical solutions for 5GCity MEC node virtualization platform and guest optimizations (see [3])
3. Implementation of technical solutions for 5GCity radio network virtualization (see again [3])
4. Implementation of scalable virtual infrastructure management & orchestration, and 5GCity service programming models (see [4])
5. Construction and deployment of 5GCity city-wide pilots (see [5][6])

Upon completion of these five phases – results of which have been reported in previous deliverables from WP2, WP3, WP4 and WP5 – the Consortium has progressed towards the final stage of performance validation, in operational conditions, of the six selected use cases (see **Table 1**) against the set of predefined KPIs. This final phase of 5GCity has been oriented to provide a demonstrable scenario and evaluate how the integrated testbeds enable advanced functionalities with great context awareness in a city scale experiments**.** All these Use Cases have been implemented over the corresponding pilots and used as a field of experimentation to evaluate the performance, analyse the results and corroborate the benefits of the 5GCity system. The conducted experiments and trials have allowed to measure relevant KPIs, as related to the service requirements specified in [1] and to assess the level of achievement of project objectives. Through the execution of use case trials, the feasibility of using the Neutral Host model of 5GCity for deploying, provisioning and managing vertical services over a virtualized and shared infrastructure has been also demonstrated.

This deliverable D5.3 is the last technical deliverable of the project and from WP5 and it reports on the main outcomes of the 5GCity use cases' trials. The report contains detailed information on the technical validation activities executed in the three cities, with a particular emphasis on the achievement of KPIs. The document is structured in ten sections and three annexes, each with a specific scope as described in the following:

Section 2 provides an overall description of the 5GCity KPIs that are of relevance for the different use cases; it includes definition of the relevant metrics, targets set per use case and measurement methodology adopted in field trials.

The subsequent *Sections 3 to 8* describe the performed use case trials. In each section, a short overview of the use case workflow is provided, together with the procedure followed to deploy the software components through the 5GCity Orchestration Platform. Additionally, the metrics and KPIs of interest for each use case are introduced and the measurement methodology described. Lastly, a detailed description of trials is provided for each city pilot, including information about the scenario and the obtained results.

Section 9 extends the validation analysis to the area of guest optimizations and specifically reports on tests executed with unikernels to assess the achievement of the technical objectives 2 and 3 of the 5GCity project.

Finally, *Section 10* summarizes the obtained results and includes an overview of lessons learned.

Annexes to this report provide additional results related to a series of field tests, specifically radio measurements, performed in Barcelona to characterize the LTE-based RAN emitted from 5GCity lampposts in the area known as the "Superilla del Poblenou". These tests set the foundations for a sustainable and technically supported urbanistic model for future 5G-based deployments.

2. Overview of 5GCity KPIs

Several KPIs related to 5G networks [7][8] are relevant to 5GCity orchestration and virtualization solutions, as well as to the selected use cases deployed in the trial pilots of Barcelona, Bristol and Lucca. In this section, a baseline for the 5GCity KPIs is set, which includes definitions, related metrics and target values per use case. For each KPI, the adopted measurement methodology for metrics is introduced, which has been used during field trials to profile all the performances. It is worth nothing that KPIs targets defined in this section highly depend on the characteristics of the radio infrastructure adopted in 5GCity. In fact, 5GCity deployed LTE radio (as opposed to 5G New Radio) and Wi-Fi radio IEEE 802.11ac (as opposed to IEEE 802.11ax). As known, this type of radio infrastructure can support data plane performances very different from those expected by 5G networks, above in terms of throughout and latency. However, it is worth noting that:

1. The KPI targets set in the 5GCity project were aligned to the fulfilment of selected use case, their requirements and expected performances.
2. 5G New Radio devices (both base stations and UEs) were not available in the 5GCity trial infrastructure neither commercially nor in prototype versions made available from vendors to the project.
3. The alignment of 5GCity radios to the performances of 5G New Radio has never been an objective of the project, which contrarily was conceived to have main focus on developing seamless orchestration and slicing of virtualized radio and edge/core technologies with service creation times in the order of minutes.

It is acknowledged that use of novel radio technologies in the 5GCity infrastructures might improve in future the working KPIs of the 5GCity systems. In order to quantify such potential improvements, a study is presented in this section together with working KPIs used in the trial, with the aim to serve as baseline for future developments and upgrades of the 5GCity infrastructures in the three cities after the end of the project.

2.1 5GCity Gen-KPI#1: User Experienced Data Rate

Definition. As defined in 3GPP [9], the user experienced data rate is the minimum data rate required to achieve a sufficient quality experience in the user plane (without considering the scenario of broadcast services). This definition is adapted in the scope of 5GCity to extend the concept of user plane in 3GPP radio to the data plane in general where the traffic from devices to virtual application servers in edge/cloud are deployed.

Targets. The KPI target highly depends on the radio technology adopted and the bandwidth of the interconnection links among the infrastructure components. Values set for 5GCity consider the physical characteristics of the three city pilots and the minimum acceptable requirements of the use cases. **Table 2** outlines the specific targets that have been set for this KPI across the different use cases, reflecting the data rate requirements to be met by a single user equipment.

5GCity KPI	Targets per Use Case					
	UC1	UC2	UC3	UC4	UC5	UC6
Gen-KPI#1: User Experienced Data Rate	4 Mbps per camera	30 Mbps cumulative across slices	2 Mbps per mobile device	15 Mbps per HD, UHD, 4K and Video-360	8 Mbps per camera for a HD transmission	*Not applicable*

Table 2 - User Experienced Data Rate targets specified per use case

Measurement methodology. For all the use cases listed in **Table 2**, the measurement of this KPI is done at the application server by monitoring the throughput achieved by a single UE that generates traffic towards the server. The specific methodology (i.e. tool, sample periods, etc.) to be used to measure the data rate may differ from one use case to another according to the capabilities provided by the application server. For UC2 tests are executed with iperf client on UE device against an iperf server positioned in different parts of the 5GCity network (edge server, core server).

It is to be noted that the user experienced data rate depends not only on the available system bandwidth but it is also influenced by the user equipment capabilities (CPU, RAM, internal TCP stack configurations). Therefore, the attainment of the targets strongly depends on the infrastructure components and devices used for the use case trials. The higher performance metric has been set for the UC2 trials (see Section 4), where multiple slices have been deployed and traffic isolation conditions have been measured.

2.2 5GCity Gen-KPI#2: Service Latency

Definition. As stated in 3GPP [9], service latency is the time elapsed between the event that triggers the service execution and the availability of the service response at the system interface. In 5GCity, the overall service latency depends on the delay on the access radio link, the transmission within the 5G slice towards the server (which may be also outside the 5G system) and the request processing at the server. While some of the aforementioned factors are directly related to the capabilities of the deployed 5G system itself, the impact of others can be reduced. In particular, in the scope of 5GCity this metric performance has been improved by enabling a more suitable allocation of the server closer to the end user, i.e. at the edge, in order to reduce network latencies. Likewise, the functional split of the application functions during the service design and the optimization of the application response time (i.e. the amount of time it takes an application to return the results of a submitted request to an end user) are two criteria exploited in 5GCity.

Targets. **Table 3** outlines the specific targets that have been set for this KPI across the different use cases, reflecting the service latency requirements to be achieved.

5GCity KPI	Targets per Use Case					
	UC1	UC2	UC3	UC4	UC5	UC6
Gen-KPI#2: Service Latency	*Not applicable*	<= 15 ms	<= 2.5 s	<= 500 ms	<= 500 ms	<= 30 ms

Table 3 - Service Latency targets specified per use case

Measurement methodology. Given that this KPI is heavily dependent on the infrastructure and use case application performance, different approaches are used between the various UCs to measure it: these follow the peculiarities of the considered scenarios and applications. Nonetheless, all the measurements conducted in the validation trials follow the generic metric definition provided here. In general, latency can be measured in active mode by using ICMP over IP packets between an application server running at core data center, or the edge or either at far edge computing. This measurement produces an indication of round-trip time which is twice the intended definition of latency. It is worth noting that:

- Latency between UE and Edge computing instance (20 ms ca RTT in 5GCity LTE/Wi-Fi), may depend on traffic load, UE distance from small cell, propagation conditions, and does not include processing time at network functions.
- Latency between edge and core data center is instead more constant as interconnection is typically over a fiber network (5 ms ca RTT in 5GCity)

- End-to-end latency between the UE and the application server (30 ms ca RTT in 5GCity) includes also the processing delay introduced by network functions and applications traversed, in addition to network delay.

2.3 5GCity Gen-KPI#3: Slice Deployment Time

Definition. The Slice Deployment Time (SDT) reflects the overall time required to deliver an active slice over the Neutral Host infrastructure. In essence, SDT refers to the time required for the provisioning, creation and activation of an end-to-end network slice, including the creation and configuration of all the virtual components that are entailed in the slice. This metrics takes into account the execution of two main steps in the 5GCity platform workflow, namely: the slice creation and the slice activation.

a) *Slice Creation Time (SCT)*: refers to the amount of time it takes the 5GCity Slice Manager to return the results of a submitted slice creation request to an end user. This operation includes the sequential creation of all the chunks belonging to the slice and the grouping of those chunks into the resulting slice. This time is measured from the moment when the creation request of a slice is sent to the 5GCity Slice Manager, until receiving the confirmation that the slice has been created.
b) *Slice Activation Time (SAT)*: refers to the amount of time it takes the 5GCity Slice Manager to return the results of a submitted slice activation request to an end user. This operation includes the instantiation of the vEPC and the configuration of the corresponding PLMNIDs in the SCs included in the slice. This time is measured from the moment when the activation request is sent to the 5GCity Slice Manager, until receiving the confirmation that the slice is ready to be used. Such confirmation is provided after receiving the acknowledgment from OpenStack about the vEPC instantiation and from the RAN Controller regarding the SCs configuration. Note that still some more seconds might be required to complete both operations as well as to finalize the *cloud-init* configurations on the vEPC VM.

Henceforth, in the scope of this project, the Slice Deployment Time can be computed according to the following equation:

$$SDT = SCT + SAT$$

It is worth noting that although slices are delivered to all the use cases deployed using the 5GCity platform, this feature is of particular relevance to use case 2 (Neutral Host) as the other use cases inherit the same performances as they are instantiated in slices.

Targets. The targets set for this KPI are listed in **Table 4**.

5GCity KPI	Targets per Use Case					
	UC1	UC2	UC3	UC4	UC5	UC6
Gen-KPI#3: Slice Deployment Time (SDT)	*See UC2*	<= 30 s	*See UC2*	*See UC2*	*See UC2*	*See UC2*

Table 4 - Slice Deployment Time targets specified per use case

Measurement methodology. To compute this metric, a custom Python script has been used to automate the slice deployment, time measurement and slice removal by sending the required REST API calls to the 5GCity Slice Manager. The script measures and stores in a database the times involved in each operation, simulating user requests (like the ones done via the 5GCity Dashboard).

The script automatically computes based on timestamped logs:

$$SCT = T2(create) – T1(create)$$

Where

- T1(create) is the time when the Slice creation is launched from the 5GCity dashboard at the Slice Manager
- T2(create) is the time when the Slice is created in the 5GCity Slice Manager, ready for being activated.

Similarly

$$SAT = T2(activate) – T1(activate)$$

Where

- T1(activate) is the time when the Slice creation is completed in Slice Manager and its activation in VIM is launched by the Slice Manager
- T2(activate) is the time when the Slice is available in the 5GCity platform ready for instantiating network services

2.4 5GCity Gen-KPI#4: Service Instantiation Time

Definition. The Service Instantiation Time (SIT) is the time required for the provision and deployment of a network service (NS) over a given slice. This operation includes three main actions, namely:

a) Creation of a network in VIM/OpenStack intended to connect each VNF included in the NS with the 5GCity Monitoring server;
b) Computation of the VNFs allocation (i.e. VNF/compute resource mapping) according to the 5GCity Resource Placement algorithm;
c) Deployment and configuration of the network service instance through NFVO/OSM.

SIT is measured from the instant when the instantiation request of a network service is sent to the 5GCity Slice Manager, until the moment when the service instantiation is completed, i.e. when all the virtual components that are entailed in the service descriptor are active and running. Since in 5GCity the NFVO used is ETSI OSM, the indication of a successful deployment is triggered when the service instance in OSM appears as running (operational status) and configured (configuration status).

Targets. In 5GCity, SIT KPI is measured for all the use cases where application-layer NSs are to be deployed (i.e. UC1, UC3, UC4 and UC6). In UC2 and UC5 just the connectivity service from radio to EPC is instantiated, thus no extra VNFs are deployed but vEPC. The targets set for this KPI are listed in **Table 5**.

5GCity KPI	Targets per Use Case					
	UC1	UC2	UC3	UC4	UC5	UC6
Gen-KPI#4: Service Instantiation Time (SIT)	<= 120 s	*Not applicable*	<= 120 s	<= 120 s	*Not applicable*	<= 120 s

Table 5 - Service Instantiation Time targets specified per use case

Measurement methodology. As with the SDT, to compute this KPI, a custom Python script has been used to automate the service instantiation over a given slice by sending the required REST API calls to the 5GCity Slice Manager. The script measures and stores in a database the times involved in this operation, simulating user requests (like the ones done via the 5GCity Dashboard). Likewise, the script also performs the service removal in order to leave the system in the original state before repeating this sequence. For this test, all the required descriptors are available in the 5GCity Catalogue and onboarded to ETSI OSM. Likewise, all the required

images are already available in OpenStack, therefore only the instantiation time is considered, not including the descriptors creation and onboarding process.
The script automatically computes based on timestamped logs:

SIT = T2(instantiate) – T1(instantiate)

Where

- T1(instantiate) is the time when the service instantiation is launched towards ETSI OSM
- T2(instantiate) is the time when ETSI OSM declared the service instance as running (operational status) and configured (configuration status).

2.5 Impact of 5GCity radio infrastructure on the KPIs

The 5GCity project focused on the design and validation of a Neutral Host platform in a city-wide environment by orchestrating jointly core, edge, and distributed radio technologies. Study of innovative radio access technologies for cellular and Wi-Fi networks was not in scope. Hence, LTE radio has been deployed as opposed to 5GNR, and Wi-Fi radio IEEE 802.11ac has been used instead of newer IEEE 802.11ax. Various motivations are behind this choice, notably the commercial unavailability and lack of maturity of 5GNR (3GPP Rel.15) and IEEE 802.11ax solutions during their design, development, planning, and deployment stages.

We expect for a near future, new releases of Neutral Host platforms originating from 5GCity research which will integrate newer radio technologies. Since some of the validated KPIs are dependent on the radio capabilities, it is fair to highlight the differences between the radio technologies used by the project for validation and what the new radio technologies can achieve in future deployments. In order to give a hint of performances achievable with 5GNR and IEEE 802.11ax technologies, we compared these with 5GCity radio technologies and tried to extrapolate major improvement trends.

2.5.1 LTE Radio deployed in 5GCity testbed vs 5GNR

In terms of mobile radio capabilities, 5GCity used mainly LTE TDD mode single carrier small cells with different frequencies and bandwidths depending on each of the three cities. B42 (3.5 GHz) making use of 20 MHz BW channel with a mix of TDD DL/UL ratio 2 and TDD DL/UL ratio 1 (Barcelona, Bristol), and B38 (2.6 GHz TDD) small cells making use of 15 MHz channel and TDD DL/UL ratio 1 (Lucca). The general modulation capability was 64 QAM DL and 16 QAM UL and MIMO 2x2. With regards to latencies, the LTE radio interface with a 10 ms frame structure and 1 ms TTI can lead to round trip times of the order of 50 ms.

5GNR capabilities used to pinpoint the throughputs achievable with this technology can benefit from bigger spectrum blocks (100 MHz), higher order modulations (256 QAM) and massive MIMO schemes leading to a higher spectrum efficiency (3-4 times higher efficiency than LTE). With regards to radio access latency, the shortest transmission time is 0.125 ms which can lead to round trip times of 1 ms.

A straightforward extrapolation from used LTE radio configuration to usual 5GNR radio configurations would lead to a DL/ datarate 15-20x higher and radio latency 50x lower. Throughput and latency differences in the radio access segment of the end-to-end solution should be kept in mind when looking at the actual KPIs achieved in 5GCity. Already back in MWC 2018, Qualcomm's network simulation platform showed how different configurations and simulated deployment cases in cities could lead to significant gains in user experience with the use of 5G radio technology (see [10]) and showed some KPI comparisons between LTE Cat 4 (used in 5GCity) and 5GNR capabilities (see **Figure 3**).

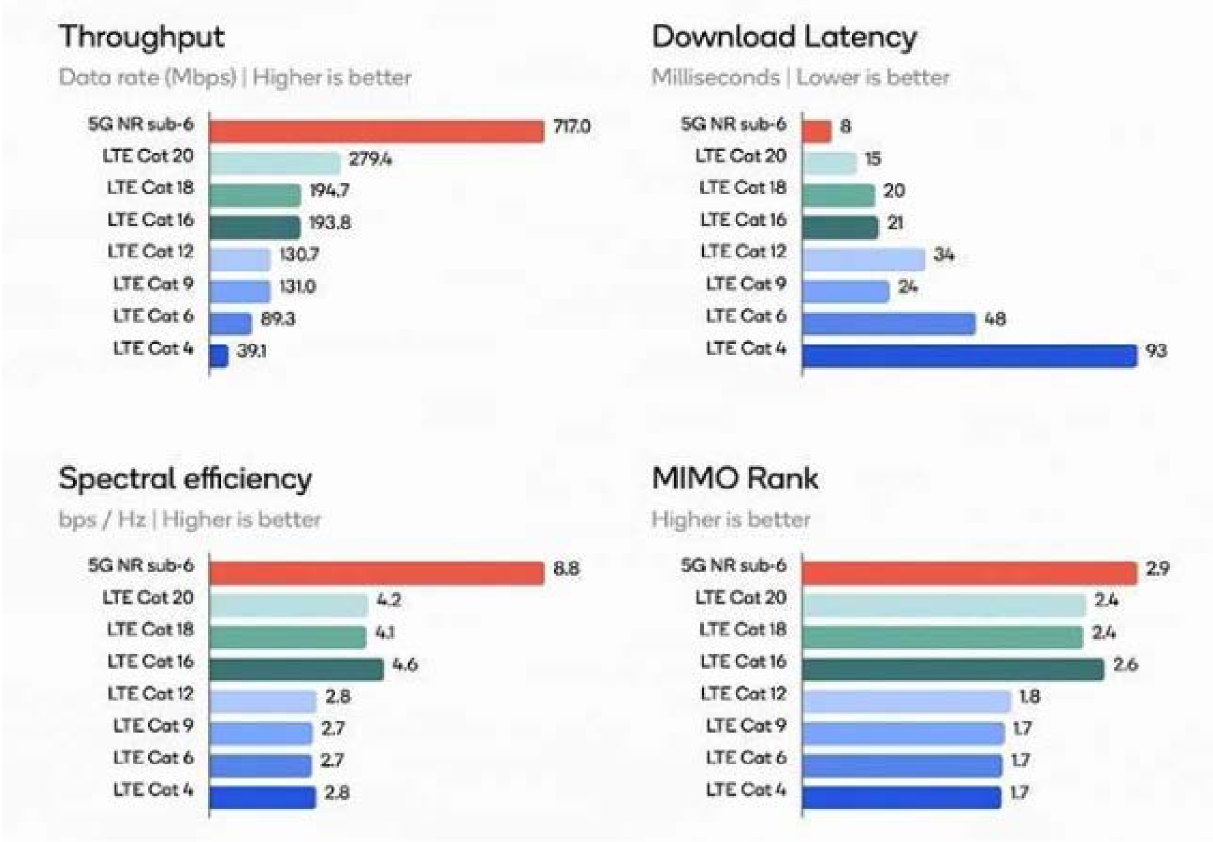


Figure 3 - LTE vs 5GNR KPI comparison from Qualcomm simulation (bursty traffic type, 90th percentile device ranking)

2.5.2 Wi-Fi Radio Deployed in 5GCity vs Wi-Fi 802.11ax

Similar to the difference between the performance of LTE technology and 5GNR, there are notable improvements as well in throughput and delays when comparing the Wi-Fi technologies used in Bristol and Barcelona with Wi-Fi 6 (IEEE 802.11ax). With IEEE 802.11ac (Barcelona) between 100 and 200 Mbps of real transmission speed was observed. The ping would vary between a few milliseconds and tens of milliseconds, depending on the number of UEs connected and the ongoing background traffic from other APs operating in the same 5 GHz band.

In Wi-Fi 6, additional modulation coding schemes using OFDMA and supporting up to 1024 QAM promise rates in the Gbps per second range when using multiple spatial streams and 80/160 MHz configurations. In 802.11ac the performance drops noticeably as the number of UEs attached to an AP increases. The new approach followed with OFDMA in Wi-Fi 6 enables Multi-User MIMO to simultaneously receive data from and transmit data towards several users, key to some of the media UCs validated in 5GCity. This feature also reduces the latency at the radio level, as the typical contention seen in IEEE 802.11ac is mitigated. As such, time critical services deployed on top of the Neutral Host infrastructure would run even better.

3. Unauthorized Waste Dumping Prevention Use Case Trial (UC1)

The Unauthorized Waste Dumping Prevention use case (UC1) is a smart automatic system of the real-time survey of violations related to the illegal ways of waste dumping in the collection areas, the transmission of the alarm to the nearest 5G terminals and support to the immediate individualization of the transgressor. UC1 consists of two network services, one related to the video acquisition and processing, and one related to the violation visualization. The first network service has only one virtual network function (Central Infringement Notification Service), which works in conjunction with a physical network function (ML-based Infringement Recognition Server), while the second network service has two virtual network functions (Infringement Visualization Service and Virtual Firewall).

The video stream, acquired from an IP camera placed in the area, is processed by the ML-based Infringement Recognition Server. When a potential violation is detected, a notification is sent to the Central Infringement Notification Service. Each notification contains the video frames of the detected violation, the timestamp when it was detected and the identification code of the area. At this stage, an Operator in the City Control Centre checks the notification and, displaying the frames, determines whether it is a true violation or not. In the first case, the Operator forwards the notification to the Infringement Visualization Service and sends a message to the Police Officers, whereas in the second case he/she just discards the potential violation warning. When the Police Officers receive the message, they visualize the violation accessing the web server through a dedicated network and can react immediately to the transgression.

The high-level architecture of UC1 can be seen in **Figure 4**.

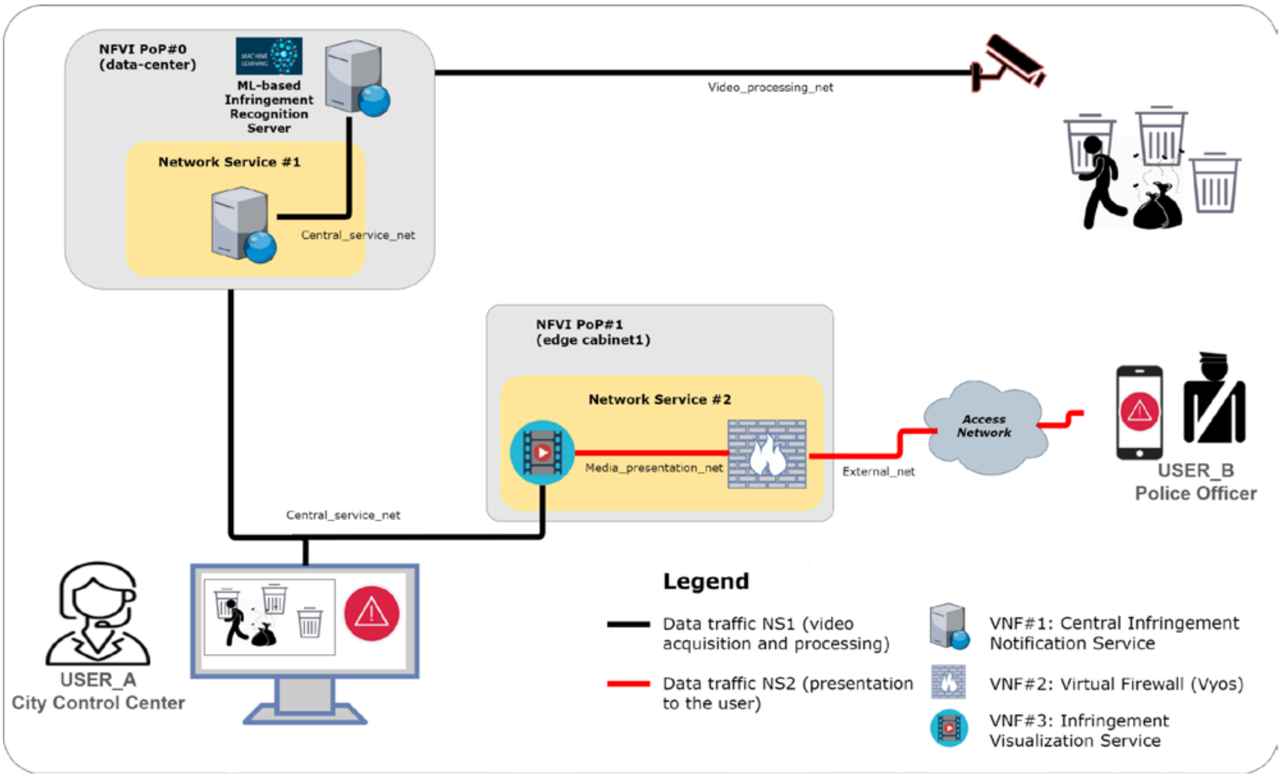


Figure 4 - UC1 High Level Architecture

The specific components of the use case are described in the following:

- **ML-based Infringement Recognition Server (PNF)** – cutting edge artificial intelligence technology that analyses video sequences to detect illegal dumping actions. The server can analyse video files or it can directly connect with the video feed of a camera. If the software detects that a person is leaving trash when she leaves the scene, it will send an alarm that will contain a few image shots of the infringement, the time, and other metadata. The software is a multithread program written in Python, which runs in real-time. It requires a GPU to speed up the processing time. As an additional remark, the algorithm runs at 6.5 Fps real time on a single GPU.
- **Central Infringement Notification Service (VNF)** – built on top of a GNU/Linux-based operating system, its main purpose is storing the notifications containing the possible violations that are sent by the ML-based Infringement Recognition Server. The service is written in Python and it offers a REST API that can be used to upload the possible violations.

The features of the Central Infringement Notification Service are the following:

  - Store violation data: it receives two requests from the ML-based Infringement Recognition Server
    - POST violation: a list of metadata is received to identify the violation, the location and date on which it occurred.
    - PUT violation data: a zipped file containing the images of the violation is received. File is unzipped and stored in the filesystem for presentation through the GUI.
  - Validation of the violation: an Operator checks the list of possible violations and validates them manually.
  - Notification to the Police Officers: these will receive via email the violation details and an URL to the infringement images on their smartphones.

- **Infringement Visualization Service (VNF)** – based on Nginx[1], a free, open source, high-performance HTTP server and reverse proxy. Nginx is well known for its high performance, stability, rich feature set, simple configuration, and low resource consumption. As web server, it allows the Police Officers to display the list of validated violations.
- **Virtual Firewall (VNF)** – based on VyOS[2] an open source GNU/Linux-based operating system extended with network routing and firewall software suitable for being deployed in VNFs in the form of Virtual Machines (VMs). The Virtual Firewall provides several network functionalities such as monitoring and control on incoming and outgoing network traffic based on predetermined security rules, routing and Network Address Translation (NAT).

While the PNF runs in a dedicated bare-metal server, an image for each VNFs was built and made available in the OpenStack VIM. In **Table 6**, the requirements in terms of vCPU, vRAM and storage for each VNF are listed.

VNF	Requirements
Central Infringement Notification Service	• 1 vCPU • 2 GB vRAM • 10 GB HDD
Infringement Visualization Service	• 1 vCPU • 1 GB vRAM • 5 GB HDD

[1] https://www.nginx.com/
[2] https://www.vyos.io/

Virtual Firewall	• 1 vCPU • 1 GB vRAM • 3 GB HDD

Table 6 - UC1 VNFs requirements

3.1 Use case deployment using the 5GCity platform

To deploy UC1 using the 5GCity platform, a dedicated repository (uc1_repo) and user (uc1_user) were created by the platform administrator. Uc1_user has been granted the role of Designer, one of the three roles available in the 5GCity platform. This role allows uc1_user to design his own functions as well as compose them in services.

Based on the design and requirements of UC1, firstly, three VNFDs (see **Figure 5**) and two NSDs (see **Figure 6**) were created using the 5GCity platform and in particular the SDK component. Secondly, the descriptors were published to the 5G Apps & Services Catalogue (see **Figure 7**) and consequently to the OSM Catalogue.

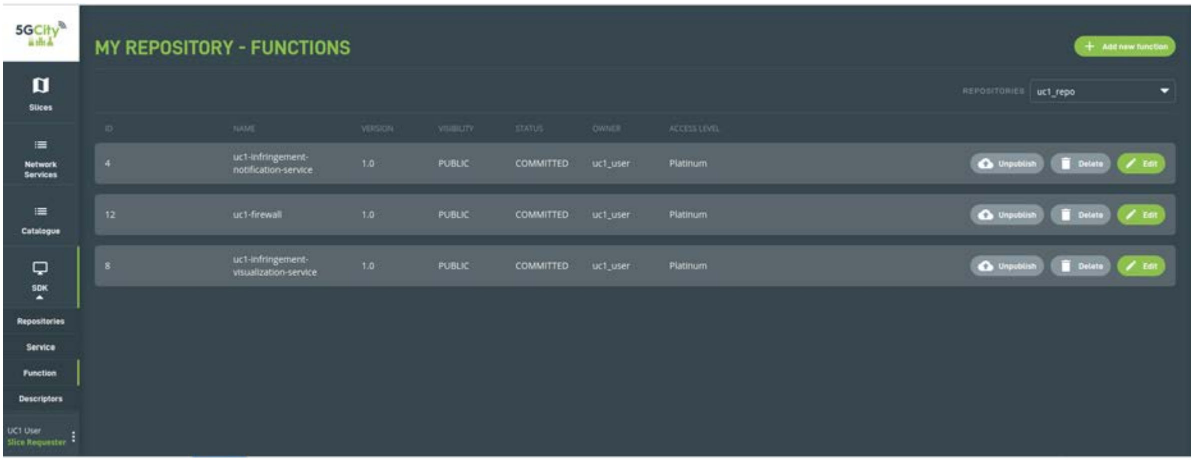


Figure 5 - UC1 functions created using 5GCity platform

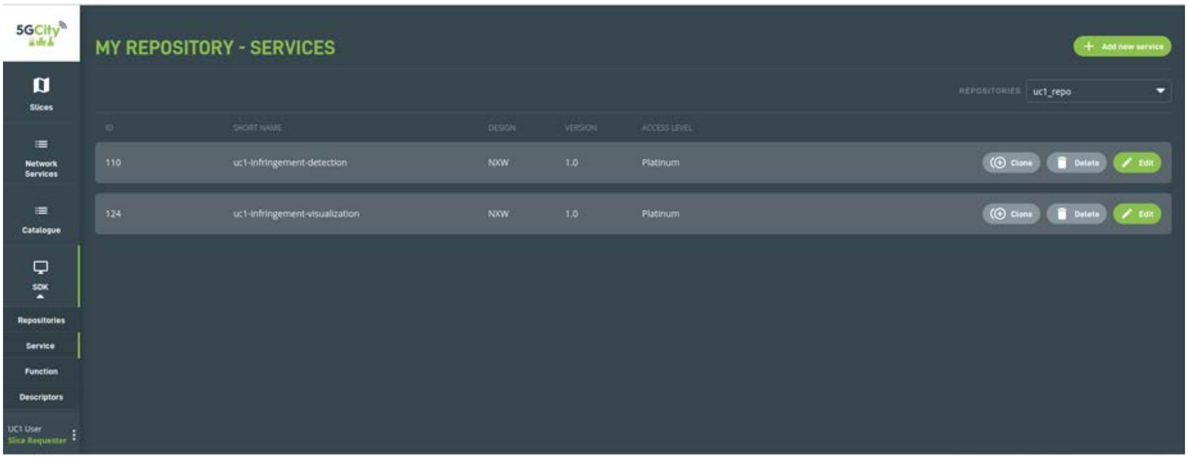


Figure 6 - UC1 network services created using the 5GCity platform

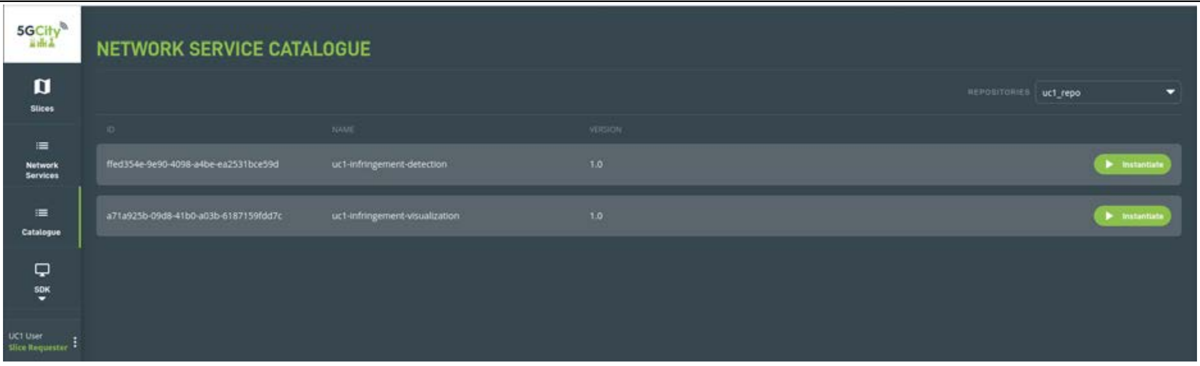


Figure 7 - UC1 network services on-boarded in the 5G Apps and Services Catalogue

Once functions and services were built, the slice where to deploy the services was created. According to the use case requirements, two compute chunks were created over both compute nodes. The chunk created over the core compute node at Villa San Paolino Data Center hosted the network service for video acquisition and processing, whereas the chunk created over the edge compute node at Via Cavallerizza hosted the network service for the violation presentation. Moreover, both small cells at Villa San Paolino and Sortita San Paolino were chosen as part of the slice to maximize the coverage area and provide access to the Police Officers. The resulting slice is illustrated in **Figure 8**.

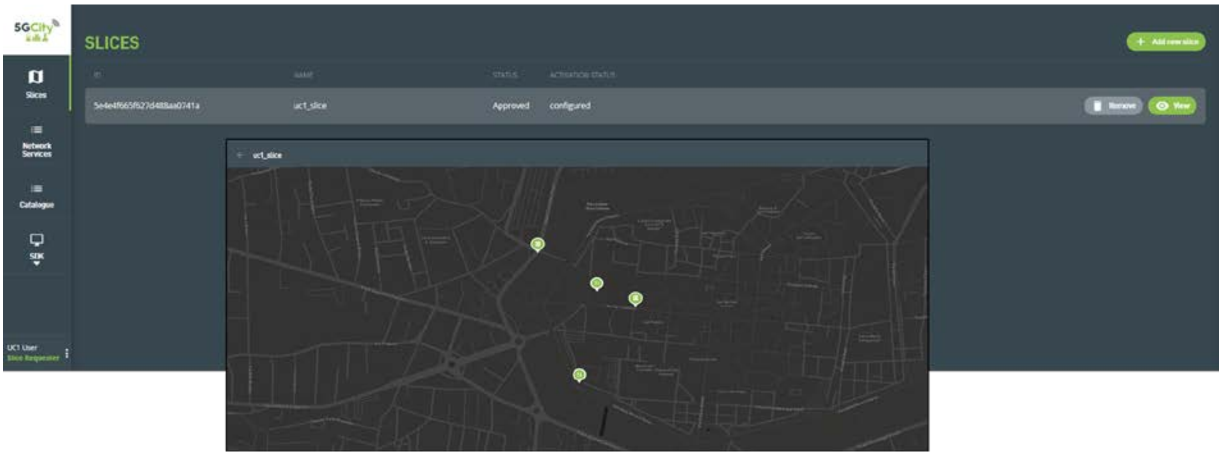


Figure 8 - Slice created for UC1 with location of nodes over the map

Finally, the last step was the instantiation of the network service. **Figure 9** shows the running services deployed across the 5GCity platform.

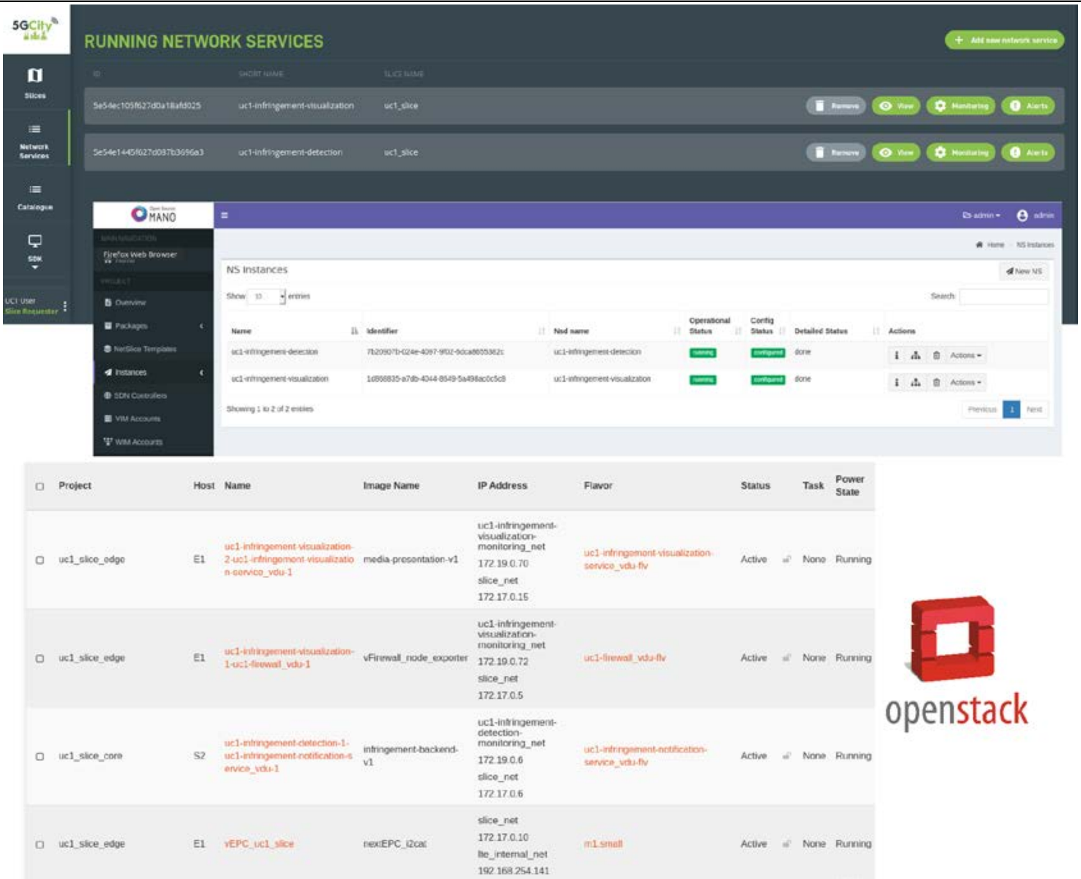


Figure 9 - View of the deployed UC1 in the 5GCity Dashboard, OSM and OpenStack

In **Figure 9,** we can corroborate the instantiation in OpenStack of the three VNFs contained in the two NSs of UC1. In addition, the vEPC deployed after the activation of that slice can also be observed in the referred figure.

3.2 Considered Metrics and KPI

As with the other use cases, the considered metrics can be classified into two main categories: **generic metrics** and **application-specific metrics**.

The generic metrics for the UC1 are summarized in **Table 7**.

Generic Metric	Description
User Experienced Data Rate	Throughput at ML-based Infringement Recognition Server (from camera to server).
Service Instantiation Time (SIT)	Time when the service is ready to start the use case.

Table 7 - UC1 generic metrics

The chosen UC1's application-specific metrics consider some of the typical and most relevant performance parameters of a machine learning recognition and classification system as well as metrics for calculating the time to detect the infringements. These are outlined in **Table 8**.

Application-specific Metric	Description
True Positives (TP)	Infringements correctly detected.

False Positive (FP)	Non-infringements wrongly detected.
True Negatives (TN)	Non-infringement correctly not detected.
False Negatives (FN)	Infringement wrongly not detected.
Infringement Detection Time (IDT)	Time when the infringement is detected.
Infringement Notification Time (INT)	Time when the infringement is notified.

Table 8 - UC1 application-specific metrics.

Finally, **Table 9** describes the KPIs for the UC1.

KPI ID	Definition	Description	Target	Priority [H/M/L]
UC1_KPI#1	**User Experienced Data Rate**	Throughput over time at ML-based Infringement Recognition Server (from camera to server).	**4-10 Mbps per camera**	H
UC1_KPI#2	**Service Instantiation Time**	Amount of time (seconds) needed to have the entire use case up and running.	**<= 120 s**	M
UC1_KPI#3	**Accuracy (ACC)** **ACC = (TP + TN) / Quantity of test data**	Ratio of the correctly classified subjects to the whole pool of subjects.	**> 80%**	M
UC1_KPI#4	**F1Score** **Precision (PPV) = TP / (TP + FP)** **Recall (TPR) = TP / (TP + FN)** **F1Score = 2 * (TPR * PPV) / (TPR + PPV)**	Precision is the ratio of correctly predicted positive observations to the total predicted positive observations. Recall is the ratio of correctly predicted positive observations to the all observations in that class Harmonic mean of the precision and recall.	**> 90%**	H
UC1_KPI#5	**Time to detect infringement (TTDI)** **TTDI = INT - IDT**	Total amount of time to detect the infringement and notify it	**< 2 mins**	H

Table 9 - KPIs considered for UC1

3.3 Measurement Methodology

To get all the necessary metrics, as described later in the trial description section, participants of the UC1 have acted as Citizens performing several discharges of waste to simulate the different scenarios for approximately 40 minutes. Although the ML-based Infringement Detection Server analysed the video stream in real-time acquiring it directly from the IP camera, the video was recorded in order to allow the computation of all the necessary metrics.

The generic metrics have been collected with the support of the 5GCity platform or external tools.

- **User Experienced Data Rate**, considered as the throughput from the camera to the server, was measured over the time using the vnStat[3] Linux tool (see **Figure 10**).

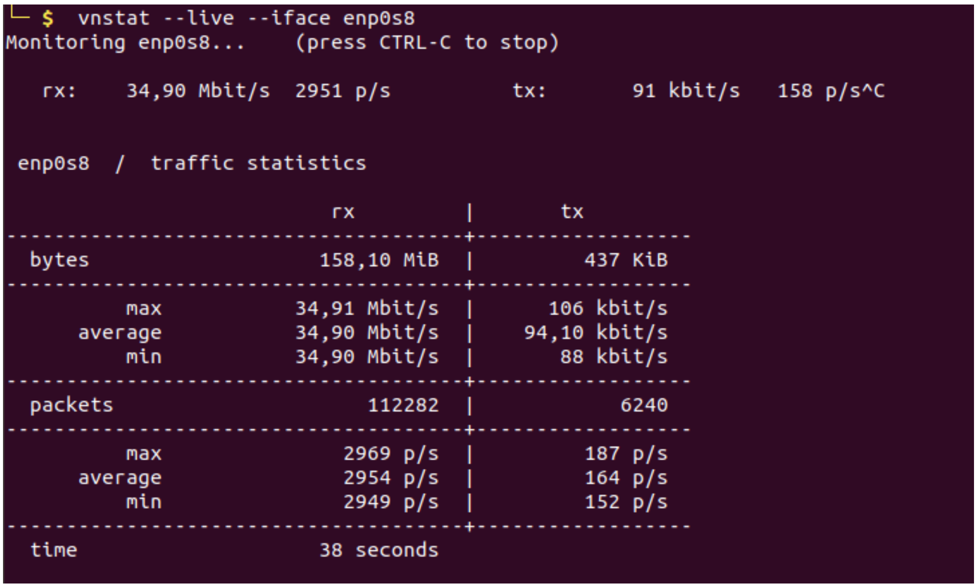


Figure 10 - vnStat Example

- **Service Instantiation Time** was taken from the 5GCity Slice Manager component with the support of a script that executed the creation and activation of the slice and the instantiation of the service several times, as described in Section 2.4.

The application-specific metrics, instead, required more effort to be extracted. Initially, there was a preparation phase where the acquired video was labelled distinguishing between infringements and non-infringements (see **Figure 11**). Given this, which is normally called Ground Truth in Machine Learning, it has been possible to identify the related metrics.

- **True Positives** and **False Positives** were counted checking the list of infringements sent by the ML-based Infringement Recognition Server to the Central Notification Service against the previous created Ground Truth. True Positives are those present in that list and labelled as infringements in the Ground Truth, while False Positives are those present in that list but labelled as non-infringements.

- **True Negatives** were counted considering the non-infringements labelled in the Ground Truth that did not generate a notification from the ML-based Recognition Server to the Central Notification Service.

- **False Negatives**, as well, were counting considering the infringements labelled in the Ground Truth but that did not generate a notification from the ML-based Recognition Server to the Central Notification Service.

- **Infringement Detection Time** and **Infringement Notification Time** were taken from the Central Infringement Notification Service and the email that arrives to the Police Officer respectively (see **Figure 12**). It is worthy to point out that the Infringement Notification Time strongly depends on the time taken by the Operator to identify the real infringements and to send the notifications to the Police Officer. For this reason, it might be influenced by several factors and therefore it is difficult to get a significant measurement.

[3] https://linux.die.net/man/1/vnstat

Figure 11 - (a) Infringement Example (b) Non-infringement Example

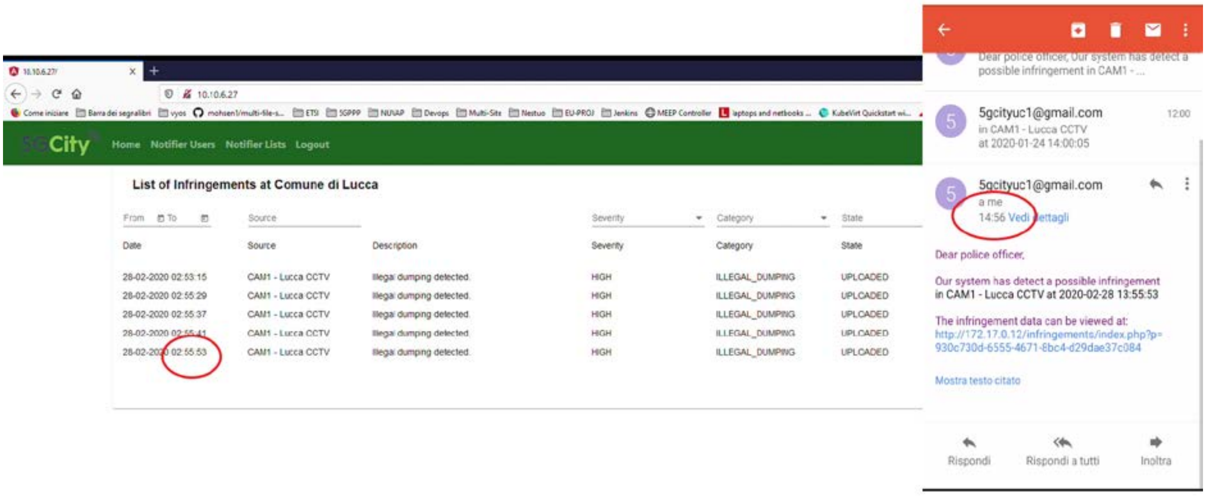


Figure 12 - Infringement Detection Time and Infringement Notification Example

3.4 Lucca Pilot Validation

3.4.1 Scenario and Trials Description

The chosen area for the trials in the City of Lucca is in a quarter characterized by interesting aspects essential to evaluate the potentialities of the 5GCity platform: for example, the area is traffic restricted and specifically designed for the mobility of the people. As mentioned before, this area is covered by two small cells and by an IP camera installed near some trash bins.

The global area of the city involved in the trials is illustrated in **Figure 13**.

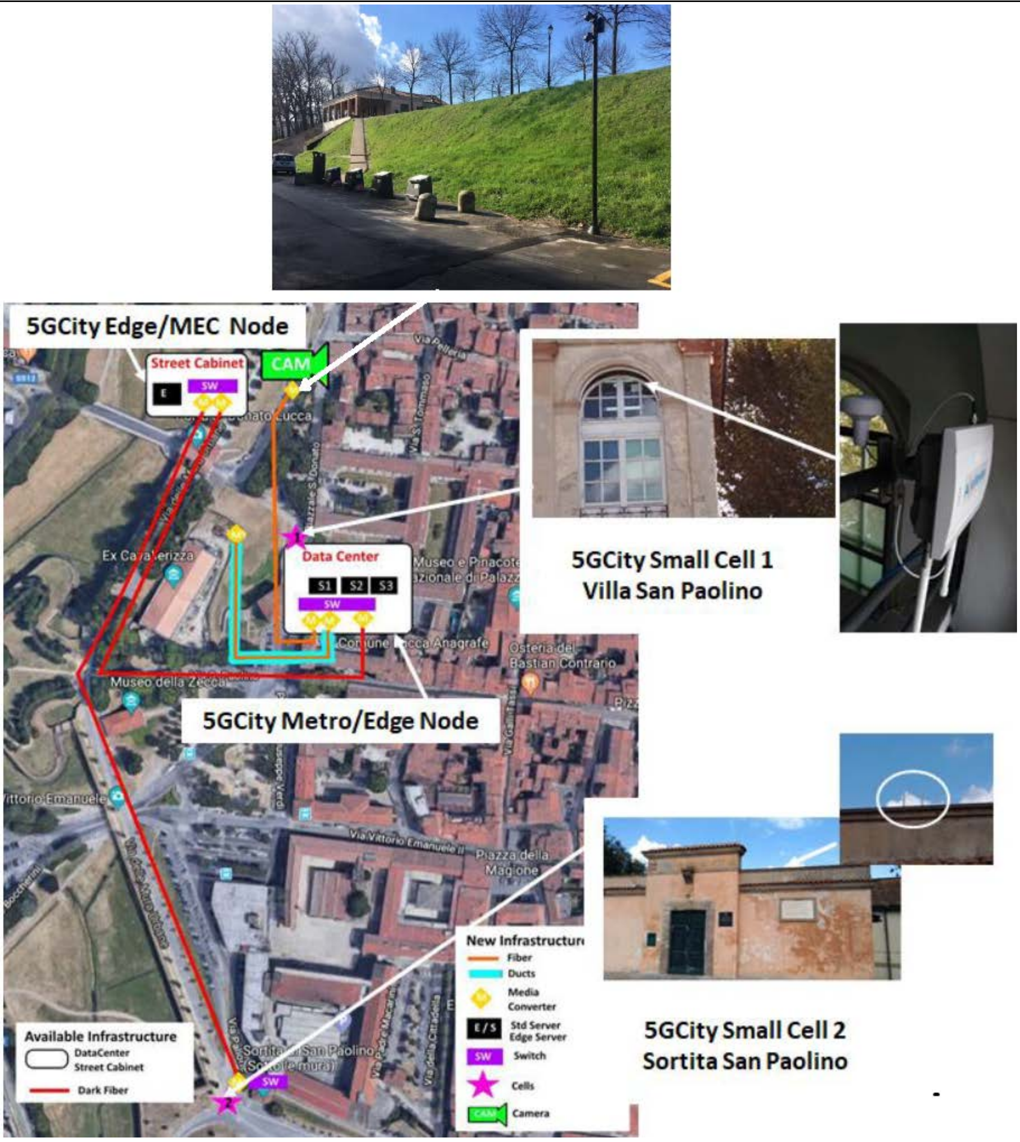


Figure 13 - UC1 trials area overview in the City of Lucca

The trials took place in Lucca between 26th and 28st of February 2020. It is appropriate to specify that during the trials the area near the trash bins was under maintenance and therefore the scenario was slightly different form the original one on which the artificial intelligence technology of the ML-based Infringement Recognition Server was trained (see **Figure 14**). This affected the final performance of the system as underlined in the next section.

Figure 14 - Trash bins area before (a) and during (b) the trials

The trials consisted of testing the entire use case workflow, from video acquisition and processing up to infringements detection, and sending notifications to the Police Officer. For this purpose, two participants of the UC1 have performed several discharges of waste to simulate the different scenarios for approximately 40 minutes (see **Figure 15**). In the meanwhile, another participant was acting as Operator, verifying the potential violations sent by the ML-based Infringement Recognition Server.

Figure 15 - Simulating discharges of waste

When a real violation was detected, the Operator sent, through the Central Infringement Notification Service a notification to the Police Officer (see **Figure 16**). This, in service into the area of coverage of the UC1, receives an email notification with the link to the violation data stored into the Infringement Visualization Service (see **Figure 17**). To access this service, the police officer has been equipped with a smartphone and a SIM card configured to access the server.

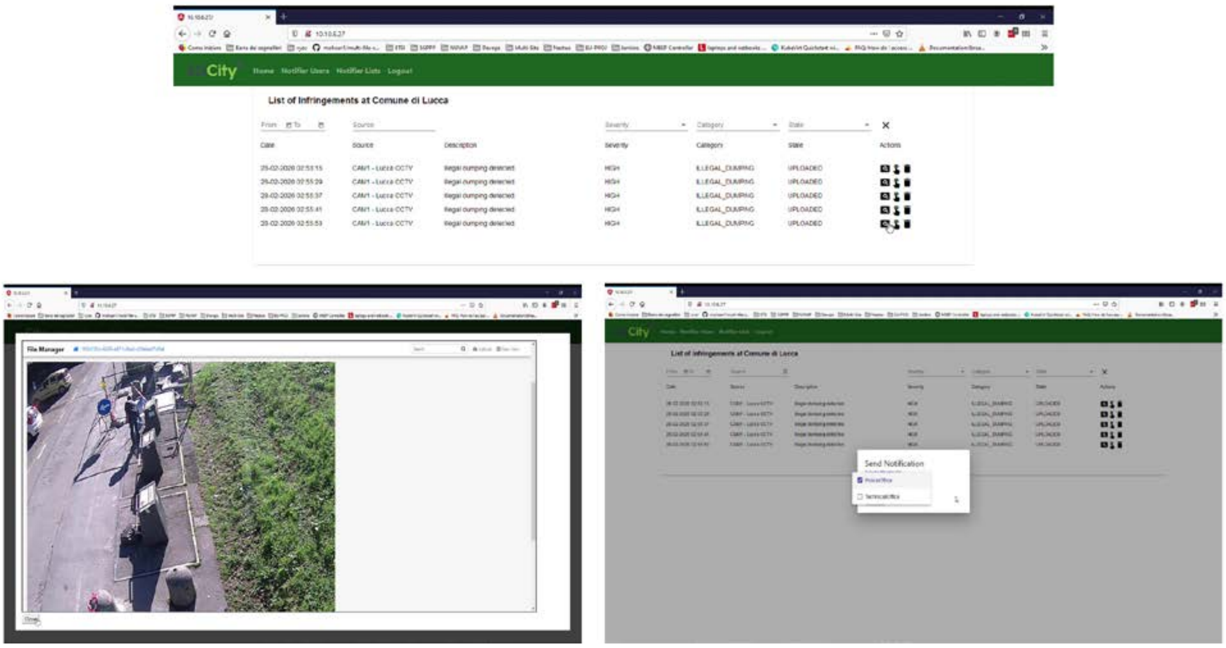


Figure 16 - Infringement Notification Service Overview

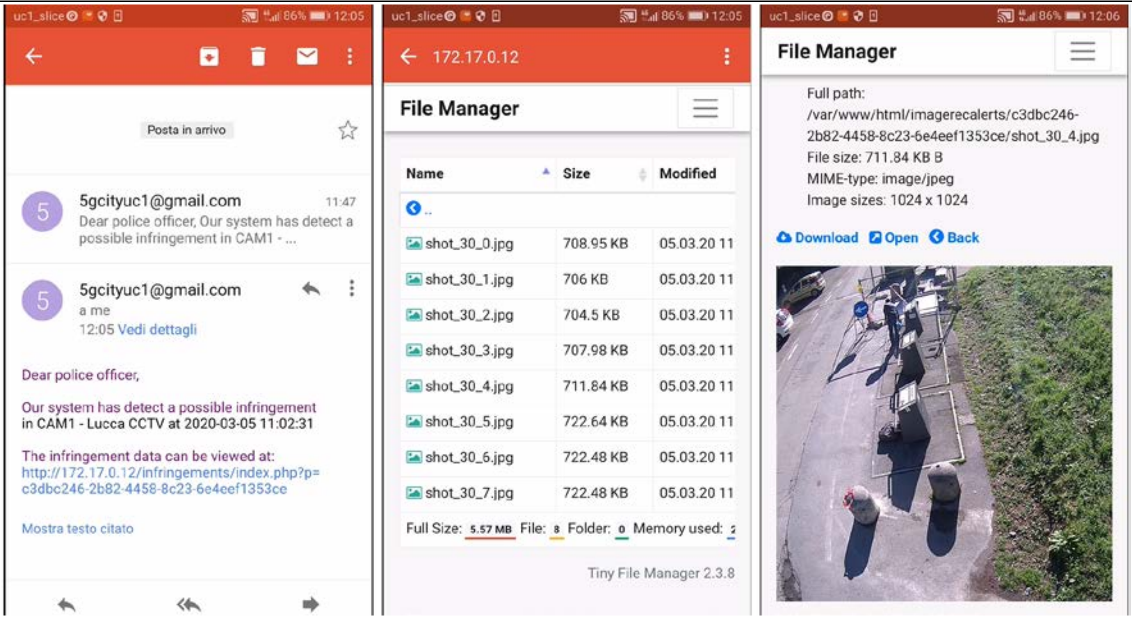


Figure 17 - Notification sent to the Police Officer

3.4.2 Results Analysis

The collected metrics and the related KPIs are presented and analysed in this section.

- **User Experienced Data Rate**

The User Experienced Data Rate, i.e. the throughput at ML-based Infringement Recognition Server (from camera to server), has been collected in real-time during the video stream acquisition. It was used an external Linux tool called vnStat. The throughput has been sampled every minute and the result is graphed in **Figure 18**.

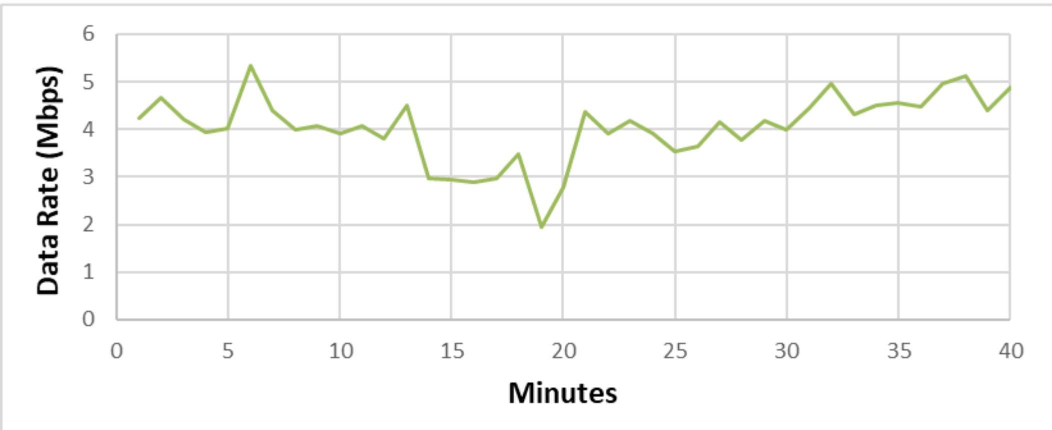


Figure 18 - UC1 User Experienced Data Rate KPI

As summarized in **Table 10**, the resulting average value is 4.04 Mbps and therefore the target KPI, i.e. 4-10 Mbps, can be considered achieved.

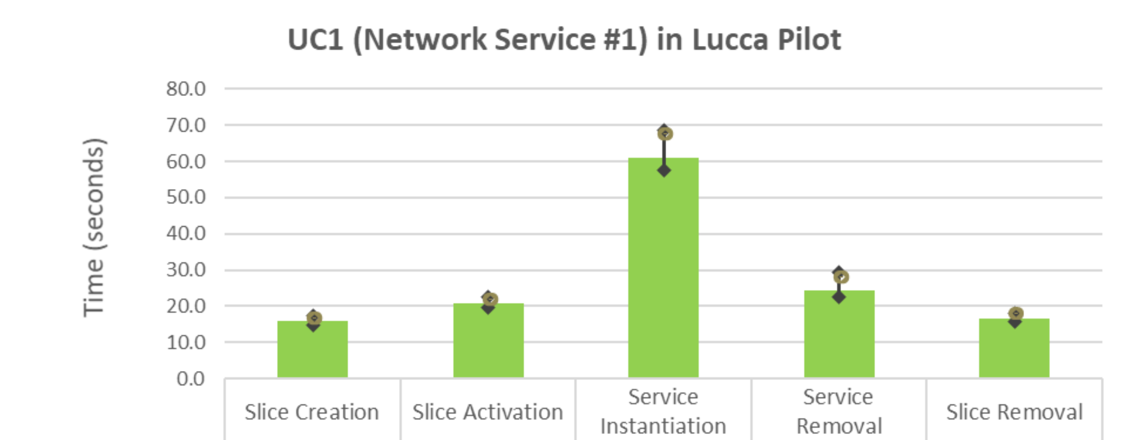
Average	Min	Max	Standard Deviation
4.04 Mbps	1.95 Mbps	5.33 Mbps	0.69 Mbps

Table 10 - UC1 User Experienced Data Rate KPI Statistics

- **Service Instantiation Time (SIT)**

As described at the beginning of this section, UC1 is composed of two network services. Therefore, the measurements for the Service Instantiation Time KPI were collected independently for each one of the two network services.

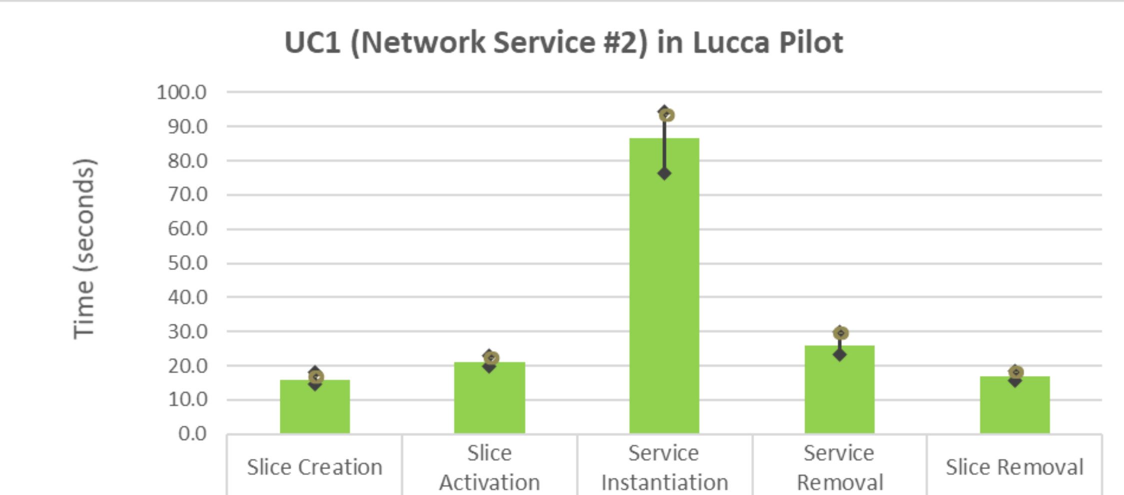
In **Figure 19**, the instantiation times obtained for the first network service of UC1, after running the automated script at the 5GCity Slice Manager 30 times, are plotted.



	Slice Creation	Slice Activation	Service Instantiation	Service Removal	Slice Removal
AVG	15.82	20.86	60.93	24.50	16.73
MIN	14.80	19.69	57.71	22.51	15.62
MAX	17.30	22.46	68.60	29.31	18.18
90-PERCENTILE	16.46	21.74	67.46	28.04	17.65

Figure 19 - Service Instantiation Time KPI of UC1 Network Service #1

Similarly, **Figure 20** shows the same measurements for the case of the second network services.



	Slice Creation	Slice Activation	Service Instantiation	Service Removal	Slice Removal
AVG	15.71	21.03	86.45	26.08	16.90
MIN	14.79	19.78	76.49	23.27	15.72
MAX	18.00	22.82	94.41	30.03	18.41
90-PERCENTILE	16.53	22.20	93.25	29.23	17.86

Figure 20 - Service Instantiation Time KPI of UC1 Network Service #2

In addition to the Service Instantiation Time, for the sake of completeness **Figure 19** and **Figure 20** also contains other time measurements (i.e. Slice Creation, Slice Activation, Service Removal and Slice Removal times) that are collected during the execution of the aforementioned script.

A comparison between both figures reveals that deploying the network service #2 requires more time than the network service #1. This result is expected since the second network service is a bit more complex (with two VNFs) than the first one (with just one VNF). Meanwhile, the other time measurements are very similar for both experiments since they depend on the slice composition, which is the same for every network service deployed as part of UC1. In general, the average time values required to instantiate both network services are below 120 seconds, hence the KPI target has been achieved.

- **Accuracy** and **F1Score**

During the test, the software analysed the camera feed. The test lasted for 40 minutes. During that time, volunteers who were not involved in the development of the algorithm, simulate illegal dumping actions. At the end of the test, 120 samples were collected.

After the test was completed, the data was manually inspected, and the Ground Truth was created by a human operator. Then, the performance of the system was computed based on the following metrics:

- True positives (TP): number of detections over actions that were illegal and were predicted as illegal.
- True negatives (TN): number of detections that were not illegal, and were predicted as not illegal.
- False positives (FP): number of detections that were negative, but were predicted as positive.
- False negative (FN): number of detections that were positive, but were predicted as negative.
- Accuracy: ratio of hits (including positive and negative).
- Precision: TP/(TP + FP)
- Recall: TP/(TP + FN)
- F1Score: 2 * P*R/(P + R)

Table 11 summarizes the obtained results:

TP	TN	FP	FN	Accuracy	Precision	Recall	F1Score
14	79	1	34	0.73	0.93	0.29	0.44

Table 11 - UC1 Infringement detection results

The results show a high number of false negatives. The main reason was that more than half of the FN occurred in blind spots of the camera such as behind the containers. In fact, 18 out of 34 occurred in that way. Additionally, the scenario for this test substantially changed due to some constructions. This issue moved the position of the camera, and introduced additional elements to the scene such as rocks or traffic signs that were confused as trash. These unexpected factors affected the final performance of the system.

It is worth noting that preliminary tests of the image recognition virtual function, before the live trials with users in street and before the roadworks, showed positive performance metrics. In fact, we obtained:

- **Accuracy: 83.3%**
- **F1 score: 90.9%**

The detector did not show any false negatives thus obtaining a Sensitivity: 1.0.

In conclusion, the system during the trials did not produce the expected performance due to changed scene conditions; however, the trends and results from previous tests show that re-training of the ML model on the new changes scene captured by the camera would definitely lead to full achievement of KPIs set for Accuracy and F1 score. Furthermore, additional cameras capable to cover the blind spots and increasing the number of scenarios for training the model could lead to a high-performance system.

- **Time to Detect Infringement**

The last KPI taken into consideration is the Time to Detect Infringement. Since the metrics are calculated for each notification sent by the Operator to the Police Officers, the number of samples in this case depend on the number of infringements correctly identified by the ML-based Infringement Recognition Server and therefore is equal to 14 (i.e. the number of true positives).

The obtained results are presented in **Table 12**.

Infringement	Infringement Detection Time	Infringement Notification Time	Time to Detect Infringement
1	5:53:53 PM	5:54:39 PM	46 s
2	5:55:07 PM	5:56:38 PM	91 s
3	5:59:36 PM	6:00:11 PM	35 s
4	6:00:59 PM	6:02:39 PM	100 s
5	6:03:49 PM	6:04:53 PM	64 s
6	6:05:39 PM	6:06:43 PM	64 s
7	6:11:33 PM	6:13:28 PM	115 s
8	6:15:27 PM	6:16:22 PM	55 s
9	6:16:48 PM	6:17:41 PM	53 s
10	6:19:38 PM	6:20:22 PM	44 s
11	6:21:35 PM	6:22:17 PM	42 s
12	6:25:55 PM	6:26:38 PM	43 s
13	6:30:14 PM	6:31:19 PM	65 s
14	6:32:36 PM	6:33:28 PM	52 s

Table 12 - UC1 Time to Detect Infringement KPI

As it is possible to see in **Table 13**, the maximum obtained value is 115 s, i.e. less than the target of 2 minutes stated in Section 3.2 of this document. Moreover, these results demonstrate that is possible to detect an infringement and react to it in just over a minute on average (62.07 s).

Average	Min	Max	Standard Deviation
62.07 s	35 s	115 s	23.88 s

Table 13 - UC1 Time to Detect Infringement KPI Statistics

Table 14 summarizes the obtained results comparing them with their respective target values.

KPI	Target Value	Obtained Value
User Experienced Data Rate	4-10 Mbps per camera	4.04 Mbps per camera
Service Instantiation Time	<= 120 s	60.93 s and 86.45 s
Accuracy	> 80%	83.3% before field trial in Feb-2020 73% in Feb-2020
F1Score	> 90%	90.9% before field trial in Feb-2020 44% in Feb-2020
Time to detect infringement	< 2 mins	62.07 s

Table 14 - UC1 KPI results

In overall, almost all the KPI targets set for UC1 were met, with exception of the Accuracy and the F1Score, the achievement of which was affected by external factors during the validation period.

4. Neutral Host Use Case Trials (UC2)

UC2 analyses the capacity of a platform making use of a single infrastructure to serve different telecommunications operators (MNO) and even vertical operators. The entity providing this infrastructure is called the Neutral Host operator. This role will become a key point in the 5G roll out, especially in urban scenarios where very dense Cell deployments are expected to be required. This will lead to a higher number of cells being deployed in order to achieve the required parameter performances (latency, throughput, reliability and scale). Some analysis and studies are talking about such 5G deployments providing up to 10 times more performance than current 4G networks [10]. Currently telecom networks are deployed separately by each MNO, a practice that leads towards having a multitude of radio nodes covering the same area. This model is not sustainable or cost efficient at all. The 5G network rollout intends to minimize this situation and the Neutral Host will be a key point to achieve this, enabling common infrastructure (small cells, fibre, etc.) to be used by multiple MNOs.

Figure 21 depicts a case where three active slices give LTE connectivity to users on street. Each slice, represented in the figure by the yellow, blue and brown colours, is composed of the physical RAN access over a dedicated PLMNID, and the necessary L2 connectivity to the compute infrastructure, which contains the vEPCs for each slice. As expected, slices are isolated from each other and UEs can only attach to the slices for which the users have been registered in the vEPC.

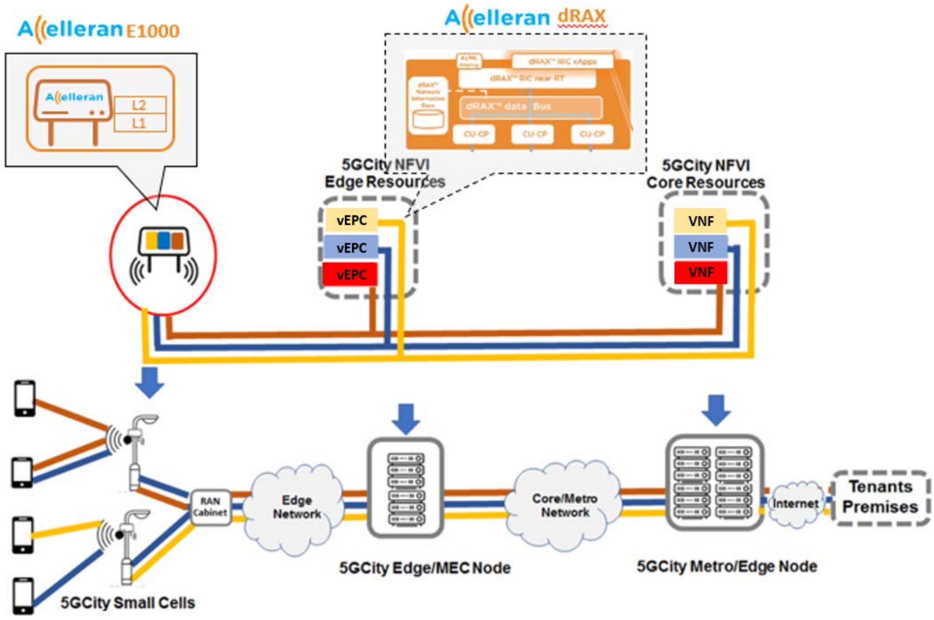


Figure 21 - Neutral Host deployment over the 5GCity infrastructure

The end-to-end environment to be validated in UC2 ranges from the UE (e.g. smartphone) to any specific server on the Internet or other IP networks behind the core (vEPC). This end-to-end connectivity is established over a series of physical paths. First, the radio link from the UE to the Accelleran Small Cell acting as Radio Units on a lamppost, then over fibre to the Edge/MEC Node where the Accelleran Small Cell's vL3 (vRAN dRAX™ product implementing amongst others, vL3/CU CP Small Cell functionality) element sits as part of the platform and after that over copper/fibre arriving to the vEPC (Attocore, NextEPC or Open5GS). The vEPC can either be co-located with Accelleran dRAX™ (vRAN) at the Edge/MEC Node or alternatively at the Data Centre. From there a gateway permits going out to the Internet or another network (including local at Edge Server for localised VNFs) to reach the destination server (or service). This is a common 5G/4G network scheme. Note that the Accelleran dRAX™ (vRAN), being a Cloud Native solution, could also be deployed at the Data Center.

4.1 Use case deployment using the 5GCity platform

The deployment of the Neutral Host use case consisted in the creation and activation of several network slices over the shared infrastructure. In particular, each slice is composed of a compute chunk, a network chunk and a radio chunk with LTE as radio access technology. The creation of the required slices was performed via the 5GCity Dashboard where the registered infrastructure is provided to slice users as presented in **Figure 22,** using as example the Barcelona pilot.

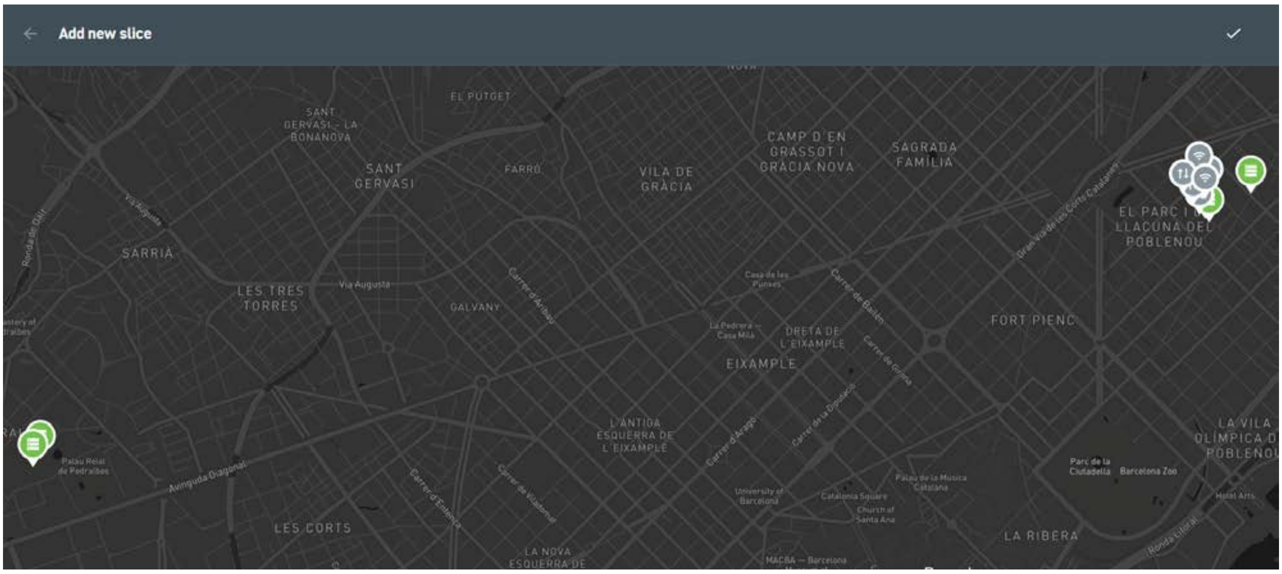


Figure 22 - Infrastructure elements registered in the 5GCity platform for the Barcelona pilot

In **Figure 22**, we can see the two locations, geographically split, where the 5GCity infrastructure is deployed in the Barcelona testbed. In particular, in the left part of the figure two compute nodes are illustrated, representing the compute resources of the main datacentre. Meanwhile, in the right part of the figure, we can see the 22@ area, where the edge compute nodes are placed (green icons), and very closed to them we find the on-street devices providing Wi-Fi and LTE radio access (grey icons).

After selecting the desired compute, network and radio resources, the slice creation request is processed by the 5GCity Slice Manager, which interacts with other platform components (i.e. OpenStack, as VIM, OSM, as NFVO, and the 5GCity RAN Controller) to create the required chunks at each domain. In **Figure 23**, the three resulting slices are shown as presented in the 5GCity Dashboard.

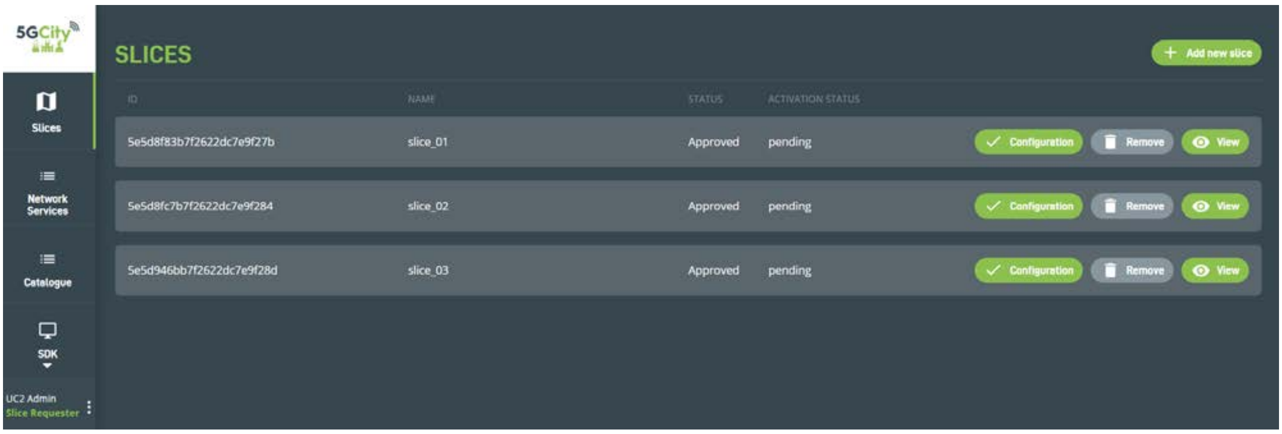


Figure 23 - List of slices created for UC2 in the 5GCity Dashboard

The next step for the UC2 deployment, using the 5GCity Dashboard, is the activation of the previously created slices. The slice activation consists in the instantiation of a vEPC as the virtualized core of the mobile network slice, together with the required configuration of the radio access node included in the slice.

In **Figure 24**, the three slices, after being activated, are shown as presented in the 5GCity Dashboard. Note that the activation status of each slice has changed from *pending* (as depicted in **Figure 23**) to *configured* to indicate the completion of the slice deployment process. For the sake of illustration, in **Figure 24**, we can also appreciate one example per city of the created slices, showing the slice components that were selected in each case and the locations of such components over the map.

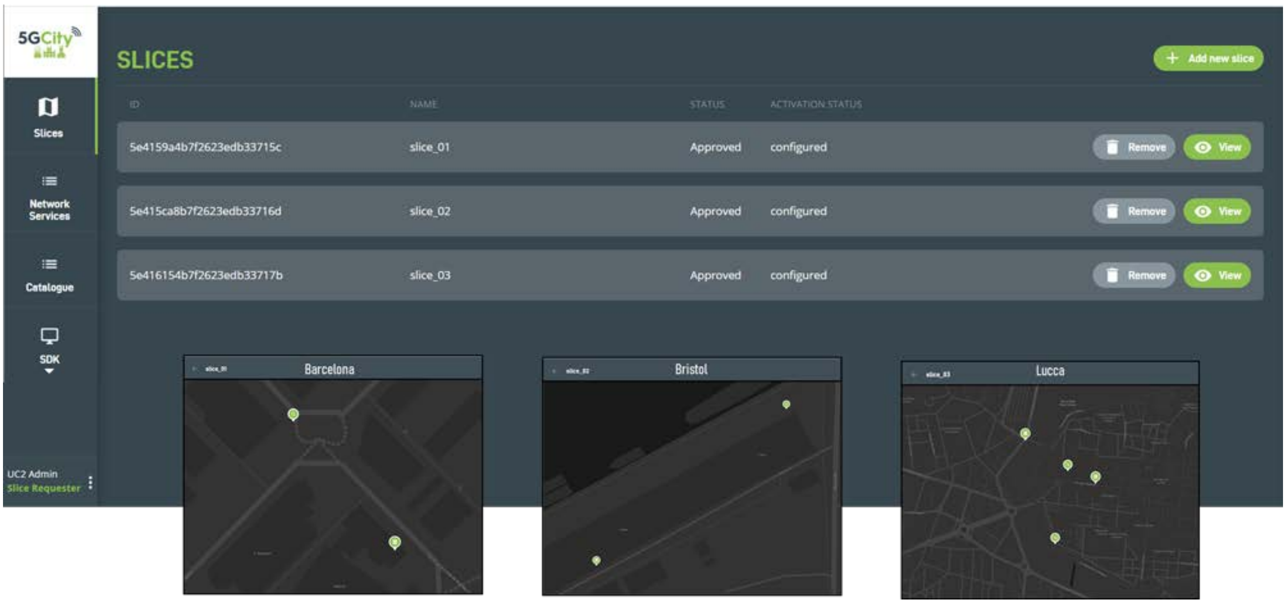


Figure 24 - List of slices activated for UC2 in the 5GCity Dashboard

To corroborate the creation of a vEPC per active slice, the resulting VMs, using as example the Bristol testbed, are shown in **Figure 25**.

☐	Project	Host	Name	Image Name	IP Address	Flavour
☐	slice3	saturn	vEPC_slice3	nextepc	slice3 192.168.194.3 5GCity Mgmt 10.68.34.143	nextepc.flavor
☐	slice2	saturn	vEPC_slice2	nextepc	slice2 192.168.193.29 5GCity Mgmt 10.68.34.142	nextepc.flavor
☐	slice1	saturn	vEPC_slice1	nextepc	slice1 192.168.192.25 5GCity Mgmt 10.68.34.141	nextepc.flavor

Figure 25 - vEPCs instantiated in OpenStack for three active slices deployed in Bristol testbed

In summary, the UC2 deployment performed over the 5GCity infrastructure is set up with three independent slices, each one configured with a different PLMNID as they are connected with different vEPCs. These vEPCs take the role of three different Mobile Network Operators (MNOs) acting as virtual network operators by making use of only one physical network infrastructure (representing here the infrastructure provided by a Neutral Host).

4.2 Considered Metrics and KPI

According to the list of 5GCity KPIs presented in Section 2, for the Neutral Host use case we focus our attention on the following generic metrics presented in **Table 15**.

Generic Metric	Description
User Experienced Data Rate	Downlink throughput achieved by the UE connected to a given slice in a multi-tenant scenario with 3 active slices
Slice Deployment Time	Time after which the active slice is delivered to the user

Table 15 - Generic metrics relevant for the UC2

This use case has a set of main objectives:

- To create multiple end-to-end slices to demonstrate the multi-tenancy capabilities of the Neutral Host infrastructure.
- To maintain each operator's data privacy by completely isolating slices from each other.
- To manage the ability of SLA monitoring for each slice separately from the entire Neutral Host infrastructure.

According to the previous UC objectives, **Table 16** gathers the application-specific metrics that are specifically relevant to the operation of a Neutral Host use case.

Application-specific Metric	Description
Data Plane Delay	Half of typical average Round Trip Time (RTT). Time for an IP packet to reach Internet or some VM (located both at the edge and core data centers) and return.
Multi-tenancy	Number of entities that can make a separate use of the infrastructure
Isolation guarantees	Capability of avoiding data from each tenant to be reached by the others

Table 16 - Application-specific metrics considered for the UC2

Finally, **Table 17** describes the KPIs for UC2.

KPI ID	Definition	Description	Target	Priority [H/M/L]
UC2_KPI#1	**Multi-tenancy**	Number of slices established over the common Neutral Host infrastructure.	**≥ 3 slices**	H
UC2_KPI#2	**Slice Deployment Time (SDT)**	Time required to delivering an active slice to the users.	**<= 30 s**	H
UC2_KPI#3	**Isolation guarantees**	To avoid crossing data from one slice to another.	**Ensured**	H
UC2_KPI#4	**User Experienced Data Rate**	Downlink throughput achieved by the UE connected to a given slice in a multi-tenant scenario with 3 active slices	**30 Mbps cumulative across slices**	M
UC2_KPI#5	**Data Plane Delay**	Half of Round Trip Time (RTT) for IP packets to reach	**<= 15ms**	M

		Internet or some VM (located both at the edge and core data centers) and return.		

Table 17 - KPIs considered for UC2

4.3 Measurement Methodology

By making use of the 5GCity platform the trial consisted in setting up three isolated slices, each one connected to a different vEPC (core network) simulating three different MNO providing their own services to the end users. Each Accelleran dRAX™ (vRAN/vL3), together with the Radio Unit it controls, supports Neutral Host MOCN enabling the broadcast of the different PLMNIDs associated to each slice/vEPC and providing Network Node Selection Function (NNSF) towards the vEPCs. We setup the available infrastructure in each of the three cities and three mobile phones acting as UEs. Each of these mobile phones should have to be connected to one of the available slices. For the validation of UC2 deployment performed with three active and isolated slices, the required elements are listed below:

- Three vEPCs instances. In the project both Attocore and NextEPC solutions are used (it could also be Open5GS which is based on NextEPC)
- 1 active Accelleran Small Cell (Radio Unit with L1+L2 on the lamppost, L3 virtualized in the MEC/Edge Node as part of Accelleran dRAX™)
- Three UEs (UE1, UE2 and UE3)
- Three testing SIM cards as the one shown below in **Figure 26,** which should be registered in the vEPC HSS (Home Subscriber system) database in order to become active in the system and be able to connect to each of the vEPCs.

Figure 26 - SIM Card used for 5GCity tests

In addition, the WebUI of the DRAX component provided by Accelleran is used to corroborate that the selected Accelleran Small Cell Radio Unit is radiating. In **Figure 27**, we can observe the RAN connectivity scheme presented in this interface, taking as example the experiments conducted in the Barcelona pilot, where one Accelleran Small Cell Radio Unit was used to transmit all the three active slices in the same frequency carrier. The specific channel to be used (in this case 20 MHz in the Band 42 at 3.5 GHz) was initially configured by the Neutral Host as infrastructure owner.

Then, in the UE setup menu select the corresponding mobile network name (which is set by the 5GCity platform as the slice name) and configure the APN (Access Point Name). Each APN configured in the UEs should correspond with the same APN configured in the vEPC settings (such as internet1, internet2 or internet3). After all these configuration actions, the UEs are able to connect to the network, accessing to the correspondent vEPC and finally reaching Internet.

To measure the 5GCity network behaviour, UEs were setup with some mobile apps such as Magic Iperf[4] (Android application based on iperf3) and IPTools[5] in order to be able to perform the desired network tests.

[4] https://play.google.com/store/apps/details?id=com.nextdoordeveloper.miperf.miperf
[5] https://play.google.com/store/apps/details?id=com.ddm.iptools

In particular, the Magic Iperf application was used to get throughput measurements from each UE towards a server located behind the vEPC within each slice.

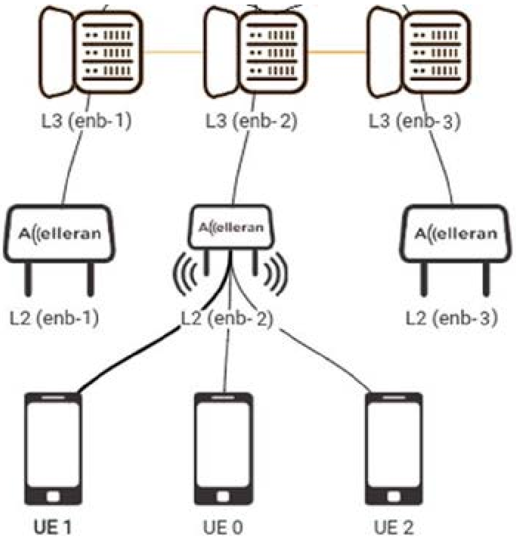


Figure 27 - RAN connectivity scheme in Accelleran dRAX™ Dashboard for the Barcelona pilot

4.4 Barcelona Pilot Validation

This section describes the trials that have been conducted in the scope of the 5GCity project in the Barcelona pilot to deploy and validate the Neutral Hosting Use Case (UC2).

4.4.1 Scenario and Trials Description

The validation trial of UC2 in Barcelona testbed was conducted in the 22@ area, where the access nodes of the 5GCity infrastructure are deployed. **Figure 28** shows the location of the 5GCity lampposts at 22@ District with Accelleran Small Cells. In this particular use case, the small cell denoted in the figure as CGRASANA was used for the measurements.

Figure 28 - 5GCity lampposts at 22@ district with Accelleran Small Cells

As part of the work carried out during the project to elaborate a 5G integration and rollout model from an urbanistic and business point of view for Barcelona based on the 5GCity deployment in the 22@ area, a series of RF measurements have been performed to characterize the power consumption and coverage of the small cells. The main goal of these evaluations was to determine an adequate power level for each radio node, while looking for a compromise between coverage and overlapping of neighbouring nodes, all the while taking into account the requirements of radio coverage for the different UCs. The outcomes of these evaluations, captured in detail in the Annexes A and B, have revealed the right physical locations to be used for the radio devices in the UC validations. Further, the experiments have delivered several important insights:

- Taking as reference Spain RF Regulations for 4G LTE Stations (RD 1066/2001) and our SC deployment proposal for each Superblock Unit (see Annex C), the electrical field measurement revealed that our radiation exposure level is 38 times lower than the one specified in RD1066/2001 in a scenario of maximum density.
- Also, the flat RAN coverage that is achieved with the physical settings determined during the RF evaluations increases service stability (due to a stabilized SNR).
- Finally, another important aspect for the UCs is the requirement of a smaller latency. With 5GCity applying the edge computing paradigm and in combination with the optimised radio settings, the networking level needs of the UCs can be satisfied and excellent results can be achieved as detailed in the evaluations below.

The UEs used in Barcelona were three Android-based *Google Pixel 3* smartphones that support band 42. In the setup process of the trial, three SIM cards were provisioned, one in each of the vEPCs representing the three different MNOs. Each UE was then equipped with one of these testing SIM cards to access one of the different slices (i.e. *slice_01*, *slice_02* and *slice_03*) deployed within the 5GCity platform. In this way, we can assure each terminal is connected to one different core network (vEPC) acting as mobile phone core network. Each vEPC has an independent control plane, this is a different Serving Gateway, MME (Mobility Management Entity), HSS (Home Subscriber Server) and PDN Gateway.

To conduct the user experienced data rate measurements, we executed the Magic Iperf tool (in each user terminal at the same time) during 60 seconds, in order to receive data from the remote server, giving us the throughput when crossing the network from the remote server to the user terminal through the Accelleran Small Cell.

A single Magic Iperf instance running on the public IP 84.88.34.20 serves as endpoint for the throughput measurement. Each end-to-end connection from a UE from a specific slice is multiplexed using a dedicated port on the same public IP. As such, the first UE (UE1) was connected to remote server 84.88.34.20 port 8008, the second UE (UE2) was connected to remote server 84.88.34.20 port 8181 and the third UE (UE3) was connected to remote server 84.88.34.20 port 8000.

4.4.2 Results Analysis

The collected metrics and the related KPIs for the Barcelona pilot are presented and analysed in this section.

- **Multi-tenancy**

After equipping each UE with a testing SIM card, the first test performed was intended to ensure that each UE was able to connect to its corresponding slice. **Figure 29** shows the three mobile devices attached to the slices (i.e. slice_01, slice_02 and slice_03) deployed within the 5GCity platform. In this way, the multi-tenancy capability of UC2 in the Barcelona pilot was corroborated.

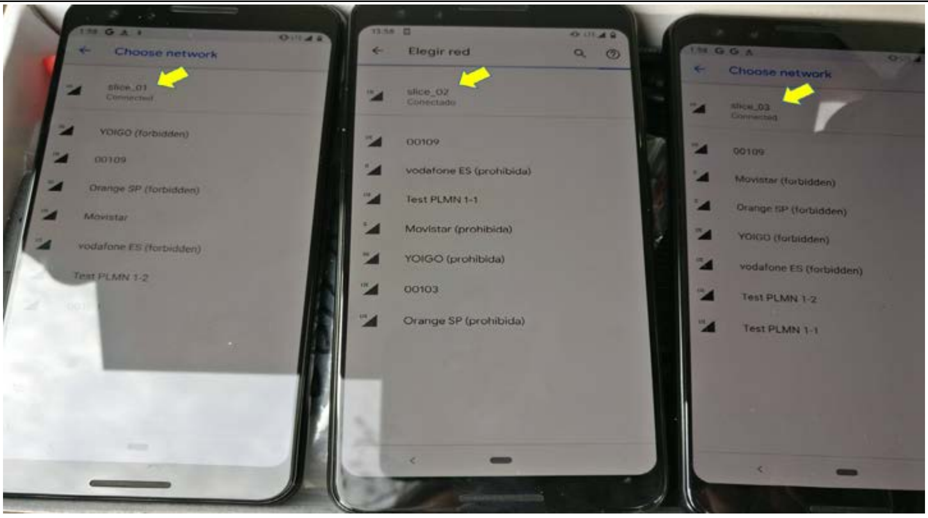
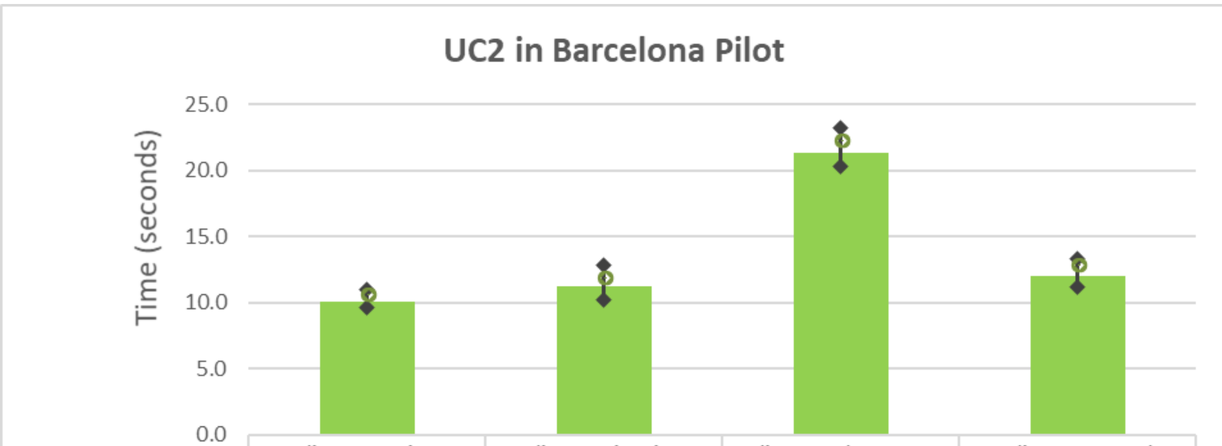


Figure 29 - Three UEs connected to the different slices

- **Slice Deployment Time**

The measurements for the Slice Deployment Time (SDT) KPI were computed as indicated in Section 2.2, being $SDT = SCT + SAT$. In **Figure 30**, we can see the deployment times obtained for the Barcelona pilot by running the automated script at the 5GCity Slice Manager 30 times. Additionally, the times required for removing the slice are also plotted in **Figure 30**.



	Slice Creation	Slice Activation	Slice Deployment	Slice Removal
AVG	10.08	11.27	21.35	12.06
MIN	9.61	10.17	20.28	11.15
MAX	11.04	12.80	23.19	13.28
90-PERCENTILE	10.64	11.93	22.26	12.94

Figure 30 - Slice Deployment Time KPI of UC2 in Barcelona Pilot

As can be observed in **Figure 30**, the resulting average SDT value is 21.35 secs, which complies with the considered KPI target (i.e. less than 30 secs).

- **Isolation guarantees**

The Accelleran dRAX implements control plane Network Node Selection function to enable via MOCN the support of Neutral Host (PMNIDs) in the 5GCity deployment. Regarding the user plane, the isolation of user plane data traffic is implemented via standardized per-UE GTP-u tunnels, which are directed to different S-GWs/P-GWs based on NNSF and vEPC/slice associations. The WAN IP addresses associated to the different

UEs are separated from each other since they are associated to the IP address pool of the different P-GW components associated with the different slices.

We demonstrated the isolation guarantees by performing the following test:

a) Firstly, we made a ping from each UE to a server located on its own network, and corroborated that IP packets reached those servers.
b) Secondly, we made the same action but trying to reach a server from another slice. That time we realized that no IP packet reached the target neither returned.

- **User Experienced Data Rate**

The User Experienced Data Rate, i.e. the downlink throughput achieved by an UE connected to a given slice in the deployed multi-tenant scenario with three active slices, has been collected using the Magic Iperf tool. The throughput has been sampled every second during a period of 60 seconds and the result is graphed in **Figure 31** for the UE connected to slice_01.

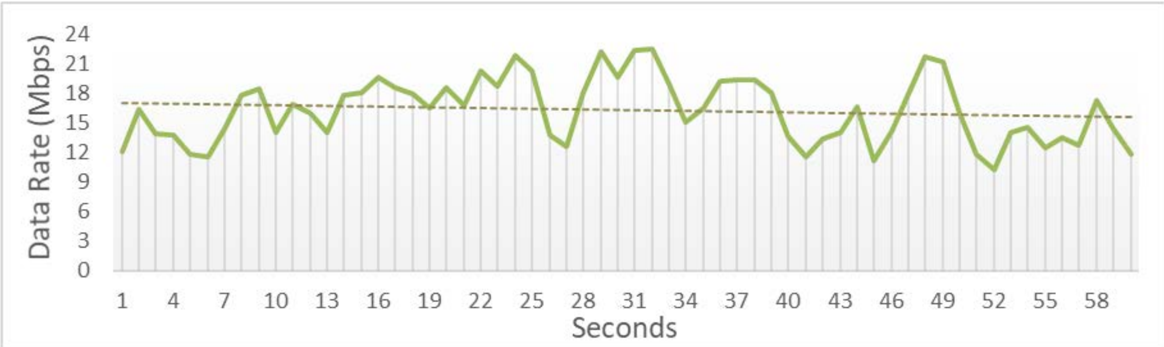


Figure 31 - UC2 User Experienced Data Rate KPI in the first slice of Barcelona Pilot

Similarly, **Figure 32** shows the data rate obtained for the UE connected to slice_02.

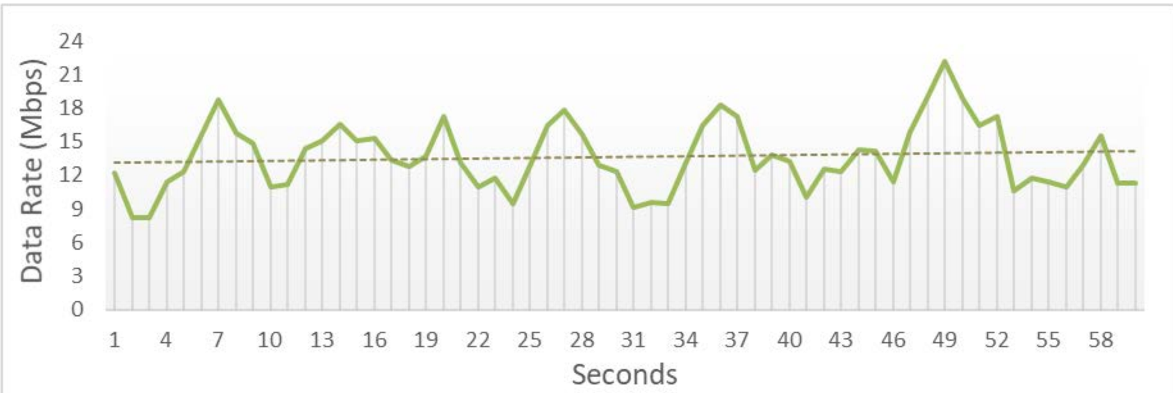


Figure 32 - UC2 User Experienced Data Rate KPI in the second slice of Barcelona Pilot

Similarly, **Figure 33** shows the data rate obtained for the UE connected to slice_03.

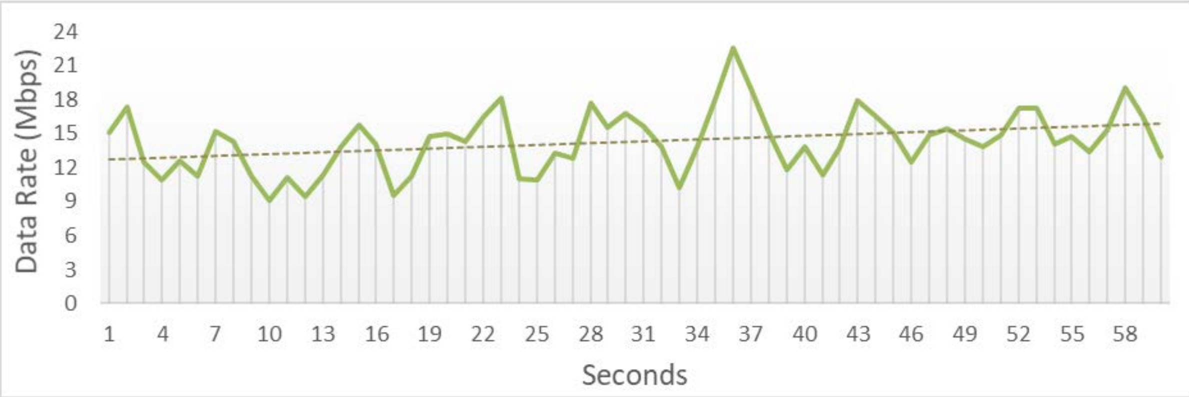


Figure 33 - UC2 User Experienced Data Rate KPI in the third slice of Barcelona Pilot

Table 18 summarizes the resulting average data rate value obtained by the UEs connected to each slice.

Total	Interval (sec)	Average Data Rate (Mbps)		
		slice_01	slice_02	slice_03
Receiver	0.00-60.00	16.3	13.7	14.3
Sender	0.00-60.00	16.3	13.7	14.4

Table 18 - UC2 User Experienced Data Rate KPI Statistics of Barcelona Pilot

With the Accelleran Small Cell configured in TDD Uplink/Downlink ratio mode 2, around 90 Mbps is the nominal bandwidth available for downstream traffic and 10 Mbps for upstream traffic under ideal cell center RF conditions. Therefore, the maximum overall downloading data rate possible in this scenario in optimal radio conditions is limited by this capacity threshold. The Magic Iperf test results showed an average of transfer rate for each user equipment between 10 Mbps to 20 Mbps, which is lower than the maximum available capacity per UE but expected given that tests were performed in open field conditions. The data rate plots shown above clearly demonstrate the effect of fluctuations of the channel quality and how it impacts the measured data rate. It is also important to take into account that a TCP-based streams, as used for the tests, which implies flow control mechanisms. In combination with the fluctuations of the radio channel quality, this leads to increments and reductions of the data rate over time, which explains why the data rate is not linear in the plots shown above.

In addition to the iperf-based tests, we also performed a 60 seconds duration speed test making use of the Fast[6] speed test web page. The results, shown in **Figure 34,** were slightly different from the Magic Iperf test as the fast speed test shows the peak ratio of each downloading test while Magic Iperf is focused on the average results. In summary, around 25 Mbps (between 20 Mbps and 30 Mbps) of peak downloading were achieved in this test.

[6] https://www.fast.com/

Figure 34 - Screenshot showing the results obtained in the fast.com speed test

The difference between the ideal throughput (overall 90 Mbps) and the expected results (less than 30 Mbps per UE) can be explained mainly because the maximum connectivity performance can be achieved in perfect transmitting conditions, which is not the case in a real environment on the streets. Further, each type of physical UE behaves differently and achieves a different degree of performance. Previous testing in the lab shows that for example MiFis used in UC5 can reach up to 40 Mbps per UE. In addition, the Iperf tests performed were based on TCP, which achieves a lower throughput than UDP (tested in the preparation of D5.2).

In general, we observe that transmitting and receiving conditions are not ideal when performing measurements in the streets where there are some interferences and loss of energy if the receiver is not well aligned with the energy lobe (see **Figure 35**). All these factors were influencing the results that made it impossible to reach the maximum expected performance. It is also known that the small cell MCS is changed upon the radio conditions (SINR) and this MCS value affects the available data rate the small cell is offering.

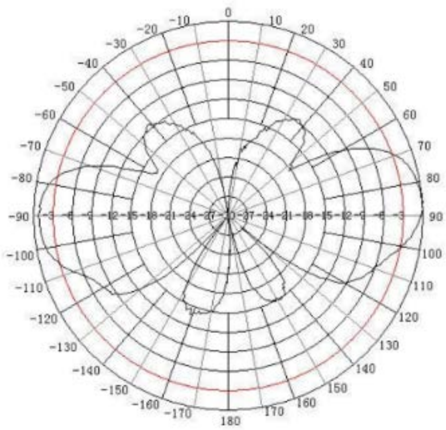


Figure 35 - E1000 series small cell energy diagram

- **Data Plane Delay**

As part of the tests, we also performed a series of ping measurements to evaluate the RTT between UEs and a server that was running behind each of the vEPCs. Making use of the IPTools application installed inside the user equipment, the ping execution showed no packet losses and network latency values of just above 10 ms for a single trip, which can be extracted from the results seen in **Table 19**.

Metric	Value	Average RTT	Min RTT	Max RTT
Data Plane Delay	11.3	22.60	16.27	31.10

Table 19 - Data plane delay (ms) in Barcelona pilot

Table 20 summarizes the obtained results comparing them with their respective target values. In overall, all the KPI targets set for UC2 were met during the validation in the Barcelona pilot.

KPI	Target Value	Obtained Value
Multi-tenancy	≥ 3 slices	3 slices
Slice Deployment Time	<= 30 s	21.35 s
Isolation guarantees	Ensured	Ensured
User Experienced Data Rate	30 Mbps cumulative across slices	44.7 Mbps
Data Plane Delay	<= 15ms	11.3 ms

Table 20 - UC2 KPI results in Barcelona Pilot

4.5 Bristol Pilot Validation

This section describes the trials that have been conducted in the scope of the 5GCity project in the Bristol pilot to deploy and validate the Neutral Hosting Use Case (UC2).

4.5.1 Scenario and Trials Description

The validation trial of UC2 in Bristol testbed was conducted in two different locations, where access nodes of the 5GCity infrastructure are deployed. The first location was near the M Shed located in the port area of Bristol, and the second one was in the High Performance Networks (HPN) Lab of the University of Bristol. In particular, **Figure 36** identifies the location of the two Accelleran Small Cells that were used during the trials.

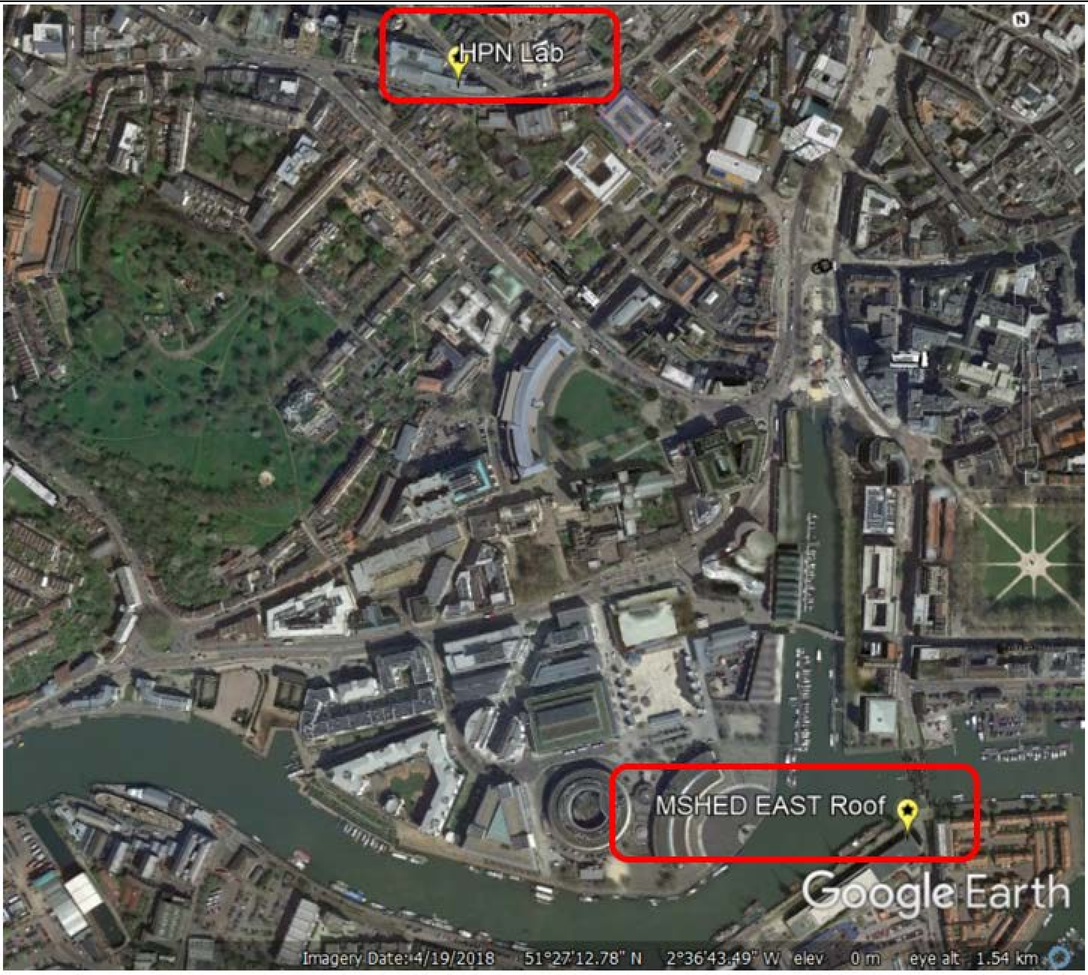


Figure 36 - UC2 trials location in the Bristol pilot

The UEs used to conduct the validation trial of UC2 in Bristol testbed were 2 Google Pixel Smartphones, which support band 42, and 1 Accelleran CPE connected by Ethernet to a laptop. Specifically, the latter device is the Accelleran 3.5GHz Cat-6 Outdoor CPE manufactured by Gemtek. The mapping between slices, configured PLMNID and devices is listed below:

- Slice1: Using PLMNID 00101 and UE corresponding to a smartphone type **Google Pixel 3**
- Slice2: Using PLMNID 00102 and UE corresponding to a smartphone type **Google Pixel 3**
- Slice3: Using PLMNID 00103 and UE corresponding to an **Accelleran CPE**

After registering the corresponding testing SIM cards in each of the deployed vEPCs (representing the three different MNOs), these SIM cards were inserted into the smartphones in order to access one of the different slices (i.e. slice1, slice2, slice3) deployed within the 5GCity platform. In **Figure 37**, the attachment of the three UEs with the Accelleran Small Cell supporting the three slices can be corroborated.

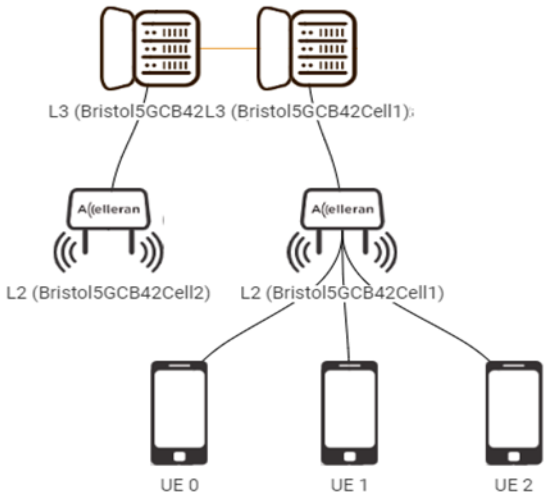


Figure 37 - RAN connectivity scheme in Accelleran dRAX™ Dashboard for the Bristol pilot

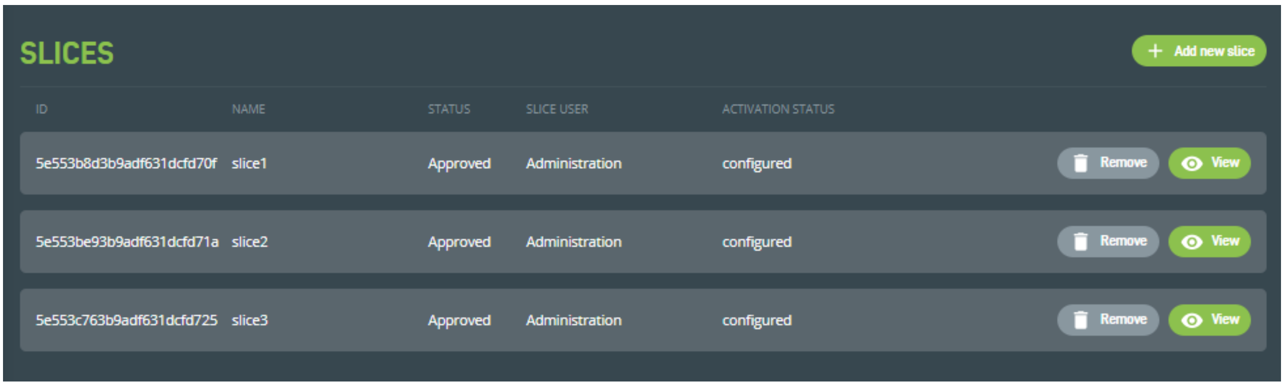
For the data rate tests, three Magic Iperf instances were setup (in each one of the deployed vEPCs) as endpoints for the throughput measurements. As such, the first UE (UE1) was connected to vEPC (slice1) 192.168.192.25 port 5201, the second UE (UE2) was connected to vEPC (slice2) 192.168.193.29 port 5201 and the third UE (UE3) was connected to vEPC (slice3) 192.168.194.3 port 5201.

4.5.2 Results Analysis

The collected metrics and the related KPIs for the Bristol pilot are presented and analysed in this section.

- **Multi-tenancy**

Once the setup of the considered scenario was completed, we tested the connectivity of each UE to its corresponding slice among the ones (i.e. slice1, slice2 and slice3) deployed within the 5GCity platform (see **Figure 38**).


SLICES

+ Add new slice

ID	NAME	STATUS	SLICE USER	ACTIVATION STATUS	
5e553b8d3b9adf631dcfd70f	slice1	Approved	Administration	configured	Remove View
5e553be93b9adf631dcfd71a	slice2	Approved	Administration	configured	Remove View
5e553c763b9adf631dcfd725	slice3	Approved	Administration	configured	Remove View

Figure 38 - Slices deployed in Bristol Pilot

Figure 39 shows that the three UEs were successfully attached to its slice, simultaneously. In this way, the multi-tenancy capability of UC2 in the Bristol pilot was also corroborated. The third UE (CPE) connected to slice3 corresponds to the laptop screen behind. The CPE does not provide the engaged network name. However, you can see the IMSI number from the SIM card, which 5 first numbers correspond to the PLMNID 00103 of slice3.

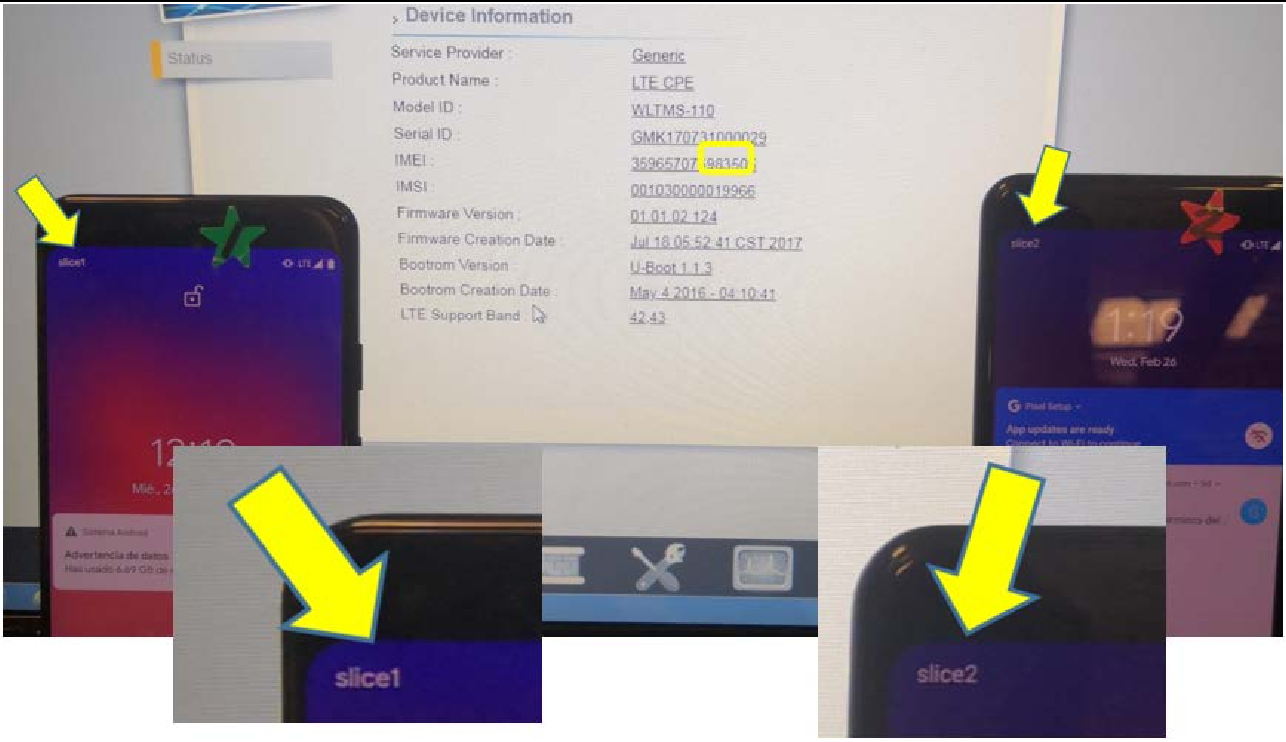
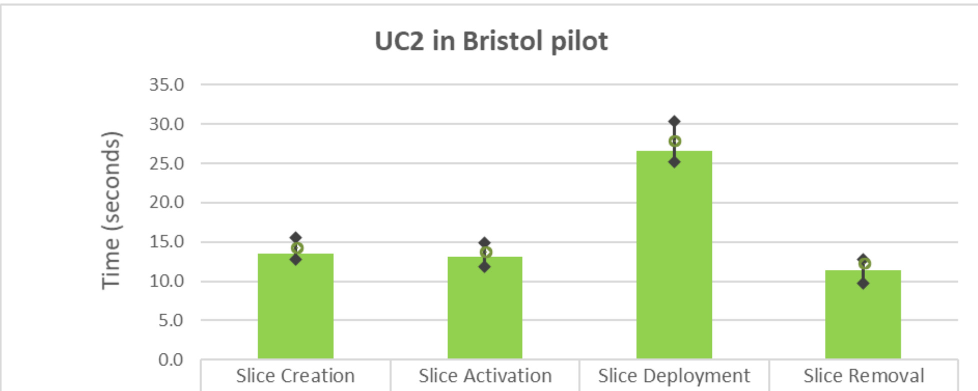


Figure 39 - UEs connected to different slices

- **Slice Deployment Time**

Regarding the Slice Deployment Time (SDT) KPI, the same procedure described in Section 2.2 was followed. In **Figure 40**, we can see the deployment times obtained for the Bristol pilot after completing 30 iterations of the automated script at the 5GCity Slice Manager. In this figure, the times required for removing the slice are also included. The resulting average SDT value depicted in **Figure 40** is 26.53 secs, which complies with the considered KPI target (i.e. less than 30 secs).



	Slice Creation	Slice Activation	Slice Deployment	Slice Removal
AVG	13.48	13.04	26.53	11.34
MIN	12.76	11.89	25.25	9.69
MAX	15.50	14.87	30.38	12.80
90-PERCENTILE	14.36	13.82	27.92	12.33

Figure 40 - Slice Deployment Time KPI of UC2 in Bristol Pilot

- **Isolation guarantees**

To validate the isolation guarantees KPI, several ping attempts were performed, as listed below. In summary, we validated that each UE had Internet connectivity and ping to the vEPC allocated in its own slice (either to the interface connected to the radio devices (S1) and to the interface connected to the mobile core), but not to the other vEPCs.

- UE1
    - Slice1 VLAN: 192.168.192.25 OK
    - Slice2 VLAN: 192.168.193.29 NOT ALLOWED
    - Slice3 VLAN: 192.168.194.14 NOT ALLOWED
    - Slice1 EPC S1: 10.68.34.141 OK
    - Slice2 EPC S1: 10.68.34.142 NOT ALLOWED
    - Slice3 EPC S1: 10.68.34.143 NOT ALLOWED
    - Internet: 8.8.8.8 OK
- UE2
    - Slice1 VLAN: 192.168.192.25 NOT ALLOWED
    - Slice2 VLAN: 192.168.193.29 OK
    - Slice3 VLAN: 192.168.194.14 NOT ALLOWED
    - Slice1 EPC S1: 10.68.34.141 NOT ALLOWED
    - Slice2 EPC S1: 10.68.34.142 OK
    - Slice3 EPC S1: 10.68.34.143 NOT ALLOWED
    - Internet: 8.8.8.8 OK
- UE3
    - Slice1 VLAN: 192.168.192.25 NOT ALLOWED
    - Slice2 VLAN: 192.168.193.29 NOT ALLOWED
    - Slice3 VLAN: 192.168.194.3 OK
    - Slice1 EPC S1: 10.68.34.141 NOT ALLOWED
    - Slice2 EPC S1: 10.68.34.142 NOT ALLOWED
    - Slice3 EPC S1: 10.68.34.143 OK
    - Internet: 8.8.8.8 OK

- **User Experienced Data Rate**

The User Experienced Data Rate, i.e. the downlink throughput achieved by an UE connected to a given slice in the deployed multi-tenant scenario with three active slices, has been collected running three reverse TCP-based iperf3 instances (one on each UE) in parallel against the corresponding iperf3 server provisioned in each vEPC. The obtained throughput, sampled every second during a period of 60 seconds, is plotted in **Figure 41** for the UE connected to slice1.

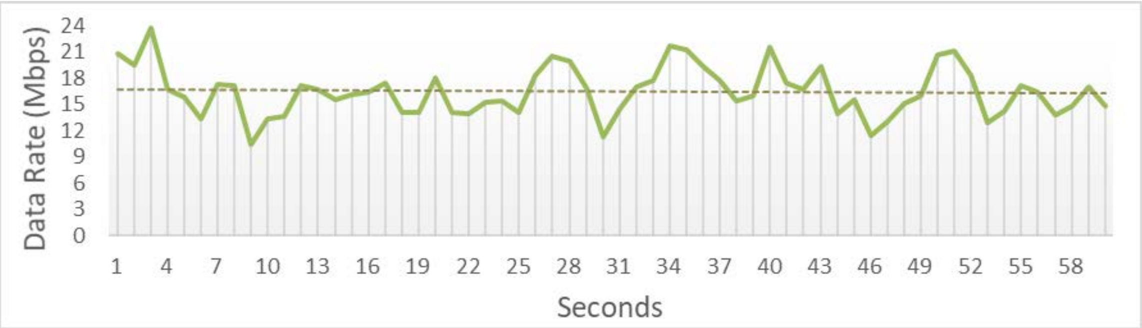


Figure 41 - UC2 User Experienced Data Rate KPI in the first slice of Bristol Pilot

Similarly, **Figure 42** shows the data rate obtained for the UE connected to slice2.

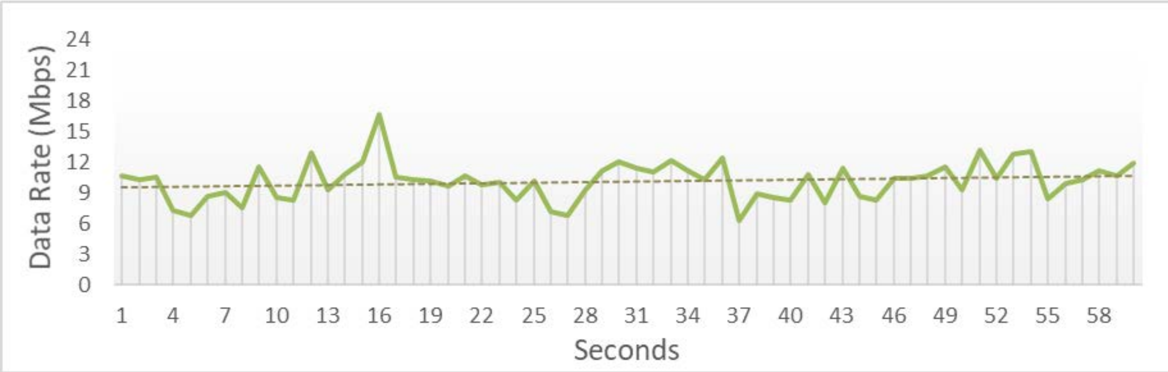


Figure 42 - UC2 User Experienced Data Rate KPI in the second slice of Bristol Pilot

Similarly, **Figure 43** shows the data rate obtained for the UE connected to slice3.

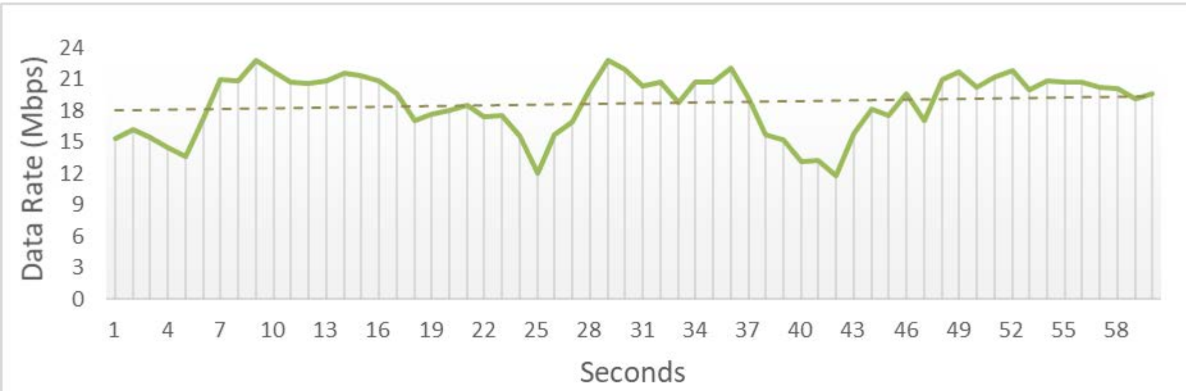


Figure 43 - UC2 User Experienced Data Rate KPI in the third slice of Bristol Pilot

Table 21 summarizes the resulting average data rate value obtained by the UEs connected to each slice.

Total	Interval (sec)	Average Data Rate (Mbps)		
		slice1	slice2	slice3
Receiver	0.00-60.00	16.5	10.2	18.8
Sender	0.00-60.00	16.5	10.2	18.7

Table 21 - UC2 User Experienced Data Rate KPI Statistics of Bristol Pilot

In addition, using the internet speed-testing tool Fast.com, we performed another speed test from the three UEs concurrently. The results, captured in **Figure 44**, show that the three devices almost reach the maximum allowable bandwidth configured in the SC (i.e. 90 Mbps).

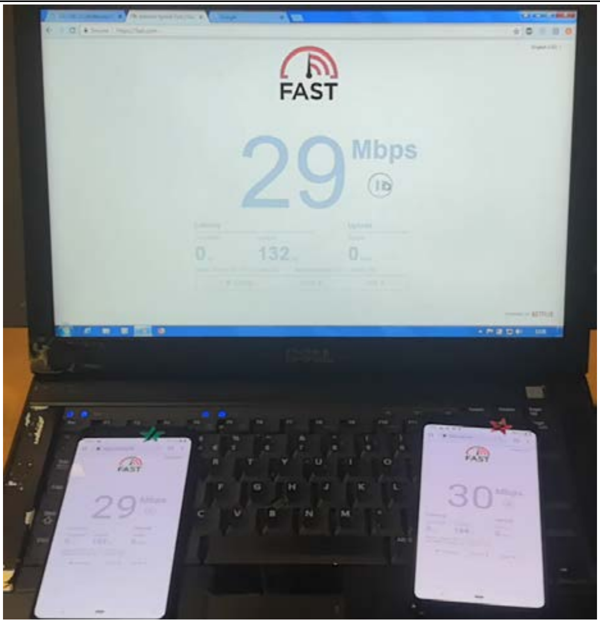


Figure 44 - Results from Fast.com tests in University of Bristol

The difference in these outcomes from Bristol and Barcelona measurements is due that in Barcelona the tests were performed in an outdoor environment. On the contrary, the tests realized in Bristol were made in a laboratory with much better conditions (i.e. no noisy environment, no interferences and UEs placed much nearer the SC).

- **Data Plane Delay**

This metric was evaluated by performing a ping test from one of the UEs. This test consisted in sending IP (ICMP) packets in sequential mode from the UE to the core network (EPC) and waiting for their return to the origin. As they go and return, half the time spent on the round trip is the expected to be the network delay, and in consequence the Data Plane Delay. **Table 22** summarizes the results obtained with 100 packets transmitted and 0 packet lost.

Metric	Value	Average RTT	Min RTT	Max RTT
Data Plane Delay	11.5	23	15	43

Table 22 - Data plane delay (ms) in Bristol pilot

We can conclude that in average about 11.5 ms is the network delay. It is not so far from the desired value for a 5G network where it is expected to be under 10 ms (ideally 1ms), but we have to take into account that this network is not a complete 5G one. Some network elements will be improved in the next coming months or years.

Table 23 summarizes the obtained results comparing them with their respective target values. In overall, all the KPI targets set for UC2 were met during the validation in the Bristol pilot.

KPI	Target Value	Obtained Value
Multi-tenancy	≥ 3 slices	3 slices
Slice Deployment Time	<= 30 s	26.53 s
Isolation guarantees	Ensured	Ensured
User Experienced Data Rate	30 Mbps cumulative across slices	45.5 Mbps

Data Plane Delay	<= 15ms	11.5 ms

Table 23 - UC2 KPI results in Bristol Pilot

4.6 Lucca Pilot Validation

This section describes the trials that have been conducted in the scope of the 5GCity project in the Lucca pilot to deploy and validate the Neutral Hosting Use Case (UC2).

4.6.1 Scenario and Trials Description

The validation trial of UC2 in Lucca testbed was conducted in the scenario depicted in **Figure 45**, where the two Accelleran Small Cells (operating in Win3 B38 spectrum) that were used during the trial are highlighted.

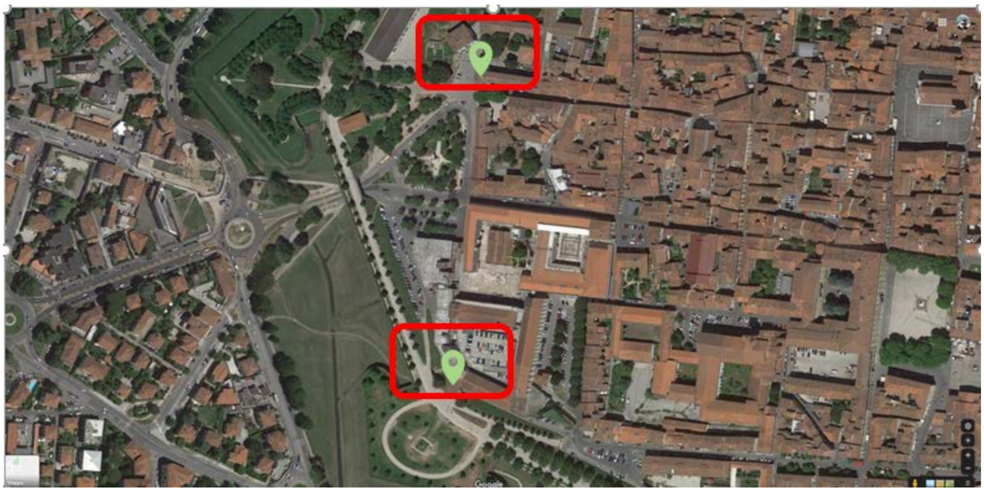


Figure 45 - UC2 trial location in the Lucca pilot

In the considered scenario, three slices have been created via the 5GCity dashboard. Each of the vEPC has been assigned with one slice, consecutively named uc1_slice, uc2_slice and uc4_slice. These slices act as three independent network operators. In that sense, these elements are working in a MOCN (Multi Operator Core Network) RAN sharing mode (Network Node Selection Function implemented in Accelleran dRAX™ vL3/vRAN), which allows using a shared infrastructure among different operators. This leads to make the deployment and maintenance of the new 5G technology more cost effective and sustainable.

The UEs used to conduct the validation trial of UC2 in Lucca testbed were three smartphones of different fabricants, namely an Apple iPhone11, a LG V90 and a Huawei P10 Plus. After registering the corresponding testing SIM card in each of the deployed vEPCs (representing the three different MNOs), these SIM cards are inserted into the smartphones in order to access one of the different slices deployed within the 5GCity platform. The mapping between slices, configured PLMNID and devices is listed below:

- Slice1: uc1_slice, using PLMNID 00102. UE corresponding to a smartphone type **LG V90**
- Slice2: uc2_slice, using PLMNID 00103. UE corresponding to a smartphone type **iPhone11 Pro**
- Slice3: uc4_slice, using PLMNID 00101. UE corresponding to a smartphone type **Huawei P10 Plus**

The data rate tests were performed using Magic Iperf on Android devices and Iperf 3 Wi-Fi Speed Test[7] on iOS device. These tests were using two different configurations, were run in standalone from all slices and also simultaneous run from 2 slices. Here we had an unexpected issue with one of the devices in Lucca and

[7] https://apps.apple.com/us/app/iperf-3-wifi-speed-test/id1462260546

as a third UE was used a personal smartphone (iPhone). However, the app used on this device was not very configurable and to avoid misleading results and since from a technical point of view nothing should change on the usage of 2, 3 or more UEs we decided to make the simultaneous runs (both iperf and speed tests) with the only 2 android UEs.

4.6.2 Results Analysis

The collected metrics and the related KPIs for the Lucca pilot are presented and analysed in this section.

- **Multi-tenancy**

Ready to start testing, the three UE devices were connected to one of the three deployed slices (see **Figure 46**) representing that each UE was making use of a different mobile network operator.

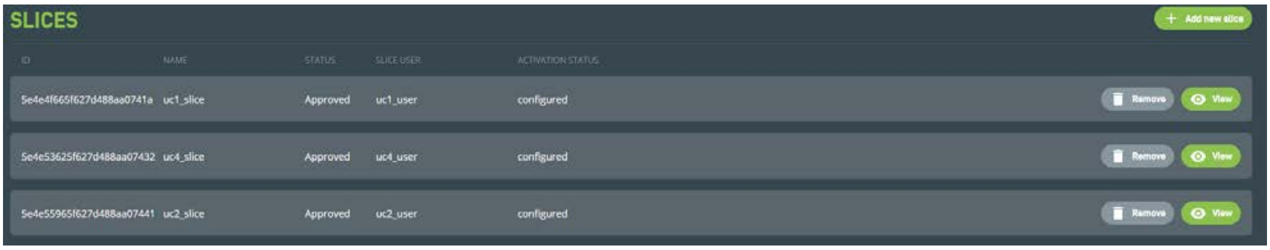


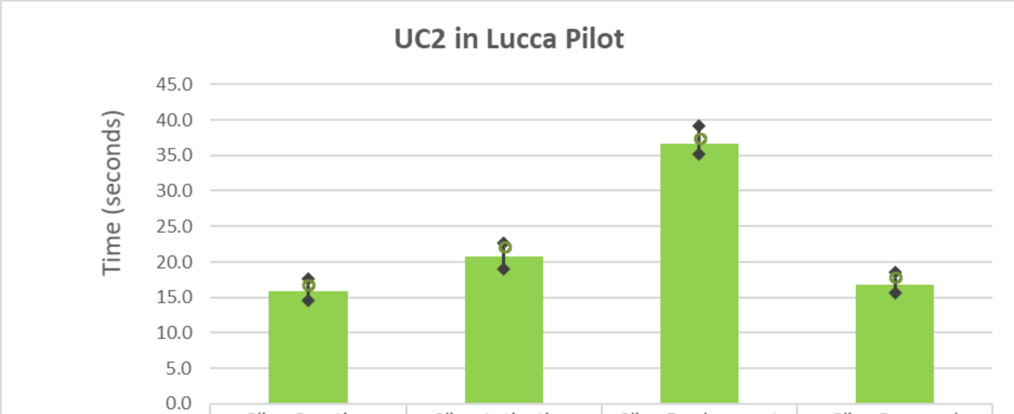
Figure 46 - Defined slices in the 5GCity platform Dashboard

In **Figure 47**, we can appreciate the users connected, validating also the multi-tenancy capability in the Lucca pilot.

Figure 47 - Three UEs engaged with each one of the deployed slices (red arrow)

- **Slice Deployment Time**

In Figure 48, we can see the deployment times obtained for the Lucca pilot by running the automated script at the 5GCity Slice Manager 30 times. In the referred image, the times required for removing the slice are also included. The resulting average SDT value depicted in **Figure 48** is 36.72 secs, which is a bit higher than the considered KPI target (i.e. less than 30 secs). We consider this deviation due to temporary reduction of the resources assigned to the 5GCity Platform component in terms of vRAM and vCPU. Tests executed with higher resources assigned to slice manager and OpenStack controller led to subsequent reduction of the slice deployment times below 30 secs.



	Slice Creation	Slice Activation	Slice Deployment	Slice Removal
AVG	15.93	20.78	36.72	16.84
MIN	14.59	18.96	35.22	15.61
MAX	17.56	22.72	39.18	18.51
90-PERCENTILE	16.72	22.16	37.34	17.90

Figure 48 - Slice Deployment Time KPI of UC2 in Lucca pilot

- **Isolation guarantees**

Regarding the isolation, to demonstrate this KPI we chose a UE connected to one of the deployed slices and tried to reach the core server (vEPC) from this slice and then tried to reach the servers from the other slices. Specifically, the tests have been done using UC2 Slice on the iOS device with the iNetTool for iOS. The conclusion of each step performed for this test are listed below and illustrated in **Figure 49**.

- Step 1. Making ping (ICMP protocol) from the UE to the server in the same network slice (IP address 172.17.2.8) we could see how the UE was able to reach the server and also receive ICMP packets from there.
- Step 2. Making ping (ICMP protocol) from the UE to another server in a different network slice (IP address 172.17.1.7) we could see the UE was not able to reach that server.
- Step 3. The same as step 2 using the other slice. Making ping (ICMP protocol) from the UE to the last server and its network slice (IP address 172.17.0.5) we could see the UE was not able to reach that server too.

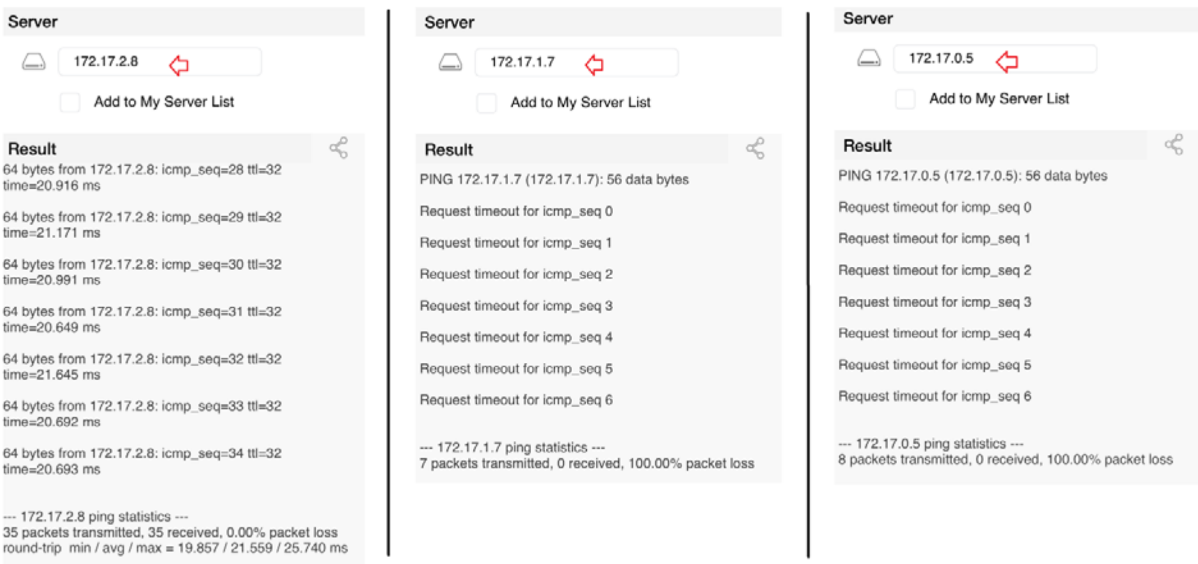


Figure 49 - Results by pinging from the same UE to different slices

We can state that three different UE connected to three separate networks (slices) are making use of the same network and radio resources to work as if they were independent network operators. The three UEs are using one only infrastructure which is sharing its network and radio capacity among the three operators.

- **User Experienced Data Rate**

The User Experienced Data Rate, i.e. the downlink throughput achieved by an UE connected to a given slice in the deployed multi-tenant scenario with three active slices, has been collected running two reverse TCP-based iperf3 instances (one on each UE) in parallel against the corresponding iperf3 server provisioned in each vEPC. The obtained throughput, sampled every second during a period of 60 seconds, is plotted in **Figure 50** for the UE connected to uc1_slice.

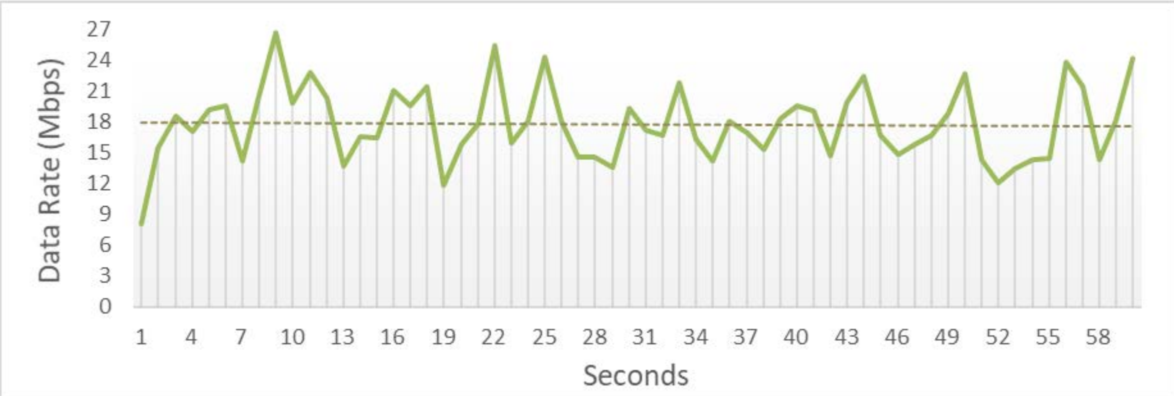


Figure 50 - UC2 User Experienced Data Rate KPI in the first slice of Lucca Pilot

Similarly, **Figure 51** shows the data rate obtained for the UE connected to uc2_slice.

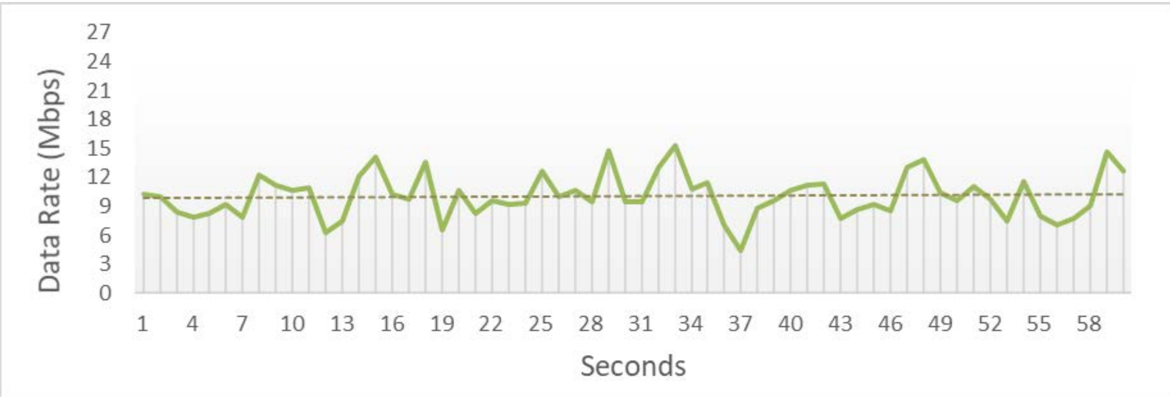


Figure 51 - UC2 User Experienced Data Rate KPI in the second slice of Lucca Pilot

Similarly, **Figure 52** shows the data rate obtained for the UE connected to uc4_slice.

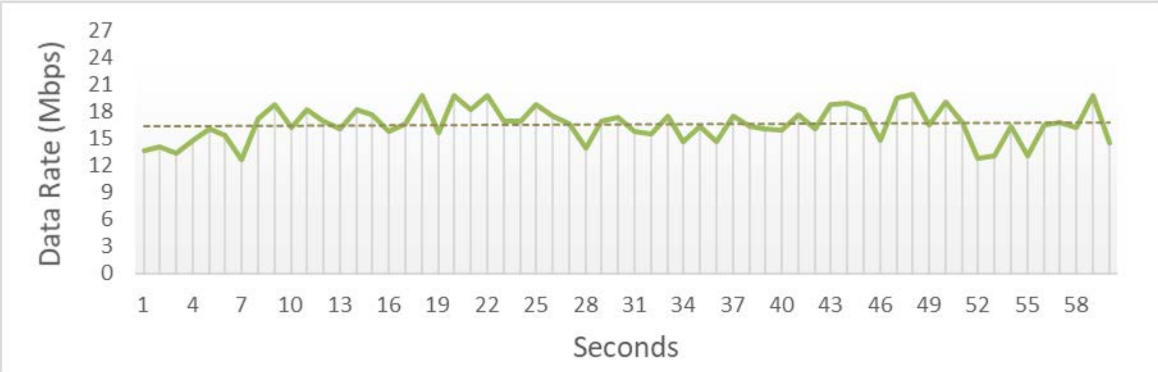


Figure 52 - UC2 User Experienced Data Rate KPI in the third slice of Lucca Pilot

Table 24 summarizes the resulting average data rate value obtained by the UEs connected to each slice.

Total	Interval (sec)	Average Data Rate (Mbps)		
		uc1_slice	uc2_slice	uc4_slice
Receiver	0.00-60.00	18.8	10.2	16.6
Sender	0.00-60.00	18.7	10.2	16.5

Table 24 - UC2 User Experienced Data Rate KPI Statistics of Lucca Pilot

Additionally, by making use of the speed-test[8] analysis web tool we were able to assess the capacity for each slice to get data from outer networks. **Figure 53** shows the obtained throughput results of two UEs using this tool in the field environment. These results are closer to the data obtained in Barcelona trial, as they were also performed outdoors.

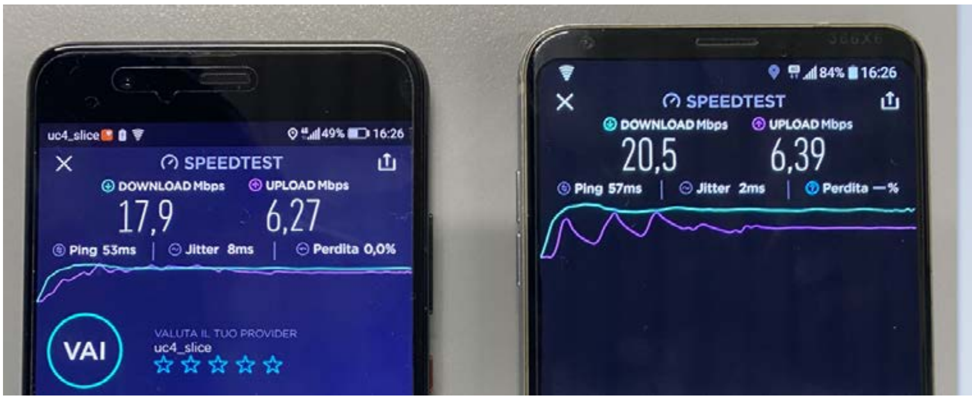


Figure 53 - Results from Speedtest.net tests in the city of Lucca

As stated above, we had an unexpected issue with one of the devices and as a third UE was used a personal smartphone (iOS). The app used on this device could not be configured as in the other devices. Then, to avoid misleading results we preferred to make the simultaneous runs (both iperf and speed tests) with the only 2 android UEs.

- **Data Plane Delay**

This KPI was evaluated by performing ping tests (sending IP packets (ICMP) in sequential mode) from two of the UEs to several remote servers. We made three tests, two of them towards internal servers and another to an Internet server. Regarding the internal servers, we connect to a core server and to another server on

[8] http://www.speedtest.net/

the edge and. For the Internet server, we use the Google DNS server. Then waiting for the packets to return at the origin to measure the spent time. As they go and return, half the time spent on the round trip is the expected time to be the network delay, and thus the Data Plane Delay. Results obtained from each test summarized in **Table 25**.

Metric	Value	Average RTT	Min RTT	Max RTT
Data Plane Delay (edge server)	8	16	13	32
Data Plane Delay (core server)	10	20	15	32
Data Plane Delay (Google server)	19	38	33	64

Table 25 - Data plane delay (ms) in Lucca pilot

The average values of 8, 10 and 19 milliseconds to reach the local and remote servers are not that far from what is expected from a 5G network (below 10 ms). The edge server is nearer the UE as it is on the edge of the network and is one of the first devices behind the radio part of the network. The core server could be far away but it is in the same network while the Internet server is in another network.

Before extracting conclusions we have to think in two important premises, in the field there are no ideal conditions and the 5GCity network does not use 5GNR radio interface (see Section 2.5.1), as it was designed at the beginning of the project when 5G was under study and development.

Having taken this into account we can say from the outcomes, that the RTT from Internet test is almost double than the local test due to the outside transmission through Internet to reach the Google server. In addition, the difference between the trip to an edge server and the trip to a core server is only 2 ms in average of difference, which is in line whit what we could expect from this kind of network.

Table 26 summarizes the obtained results comparing them with their respective target values. In overall, almost all the KPI targets set for UC2 were met during the validation in the Lucca pilot, with the exception of the SDT KPI, for which the obtained value was less than 7 seconds larger than the considered target.

KPI	Target Value	Obtained Value
Multi-tenancy	≥ 3 slices	3 slices
Slice Deployment Time	<= 30 s	36,72 s
Isolation guarantees	Ensured	Ensured
User Experienced Data Rate	30 Mbps cumulative across slices	44.7 Mbps
Data Plane Delay	<= 15ms	8 ms (edge), 10 ms (core)

Table 26 - UC2 KPI results in Lucca Pilot

5. Video Acquisition and Production Use Case Trials (UC3)

MOG's use case is a platform that allows real-time editing of multiple video streams captured in an event by the audience using their smartphones. In this way, the MOG platform enables collaborative content production in the coverage of large events. After establishing a connection to the 5GCity Wi-Fi, the platform's users in the event location have access to the UC's web page on their smartphone that enables them to create live feeds as is represented in the left side of **Figure 54**.

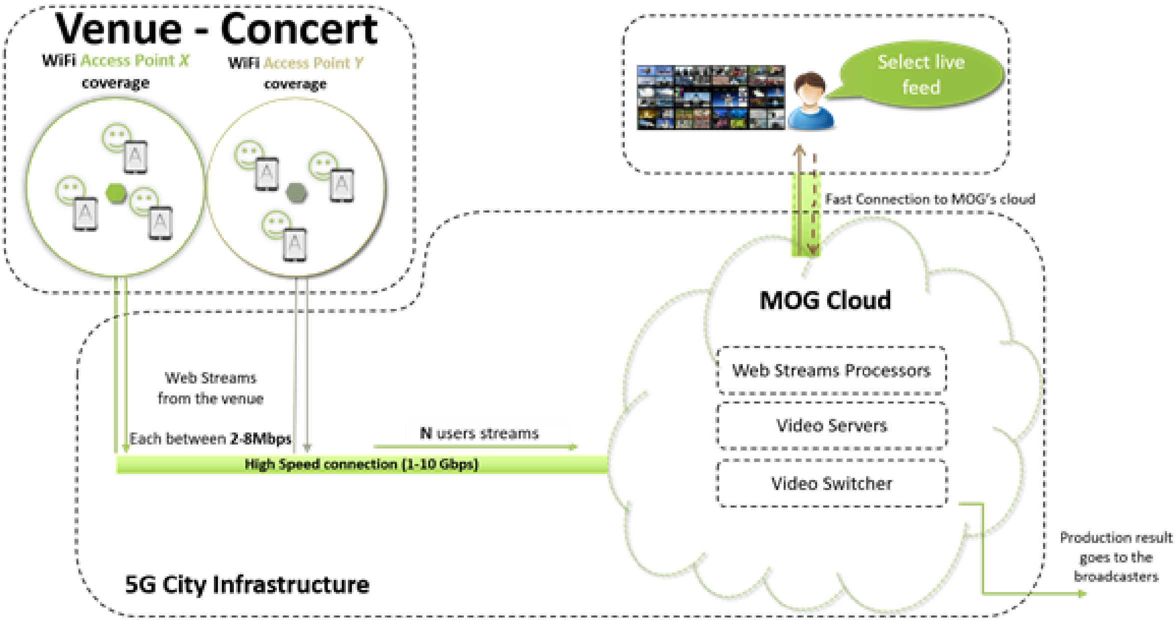


Figure 54 - Use case 3 overview

The live feeds created in the event venue are relayed to MOG's cloud server infrastructure that processes the web streams collected from the event venue. On the production side, the video director in charge of covering the event can preview the captured feeds using a multi-viewer panel. Using this interface, the producers in charge of the event can examine, browse, filter and select the most relevant streams out of the ones displayed to them. The selected feeds can then be relayed to external broadcast channels such as *YouTube*. All of this is illustrated on the right side of **Figure 54**.

The high-level architecture of the different components of MOG's use case can be seen in **Figure 55,** where the referred web page is represented by the recorder and the multi-viewer panel by the switcher page.

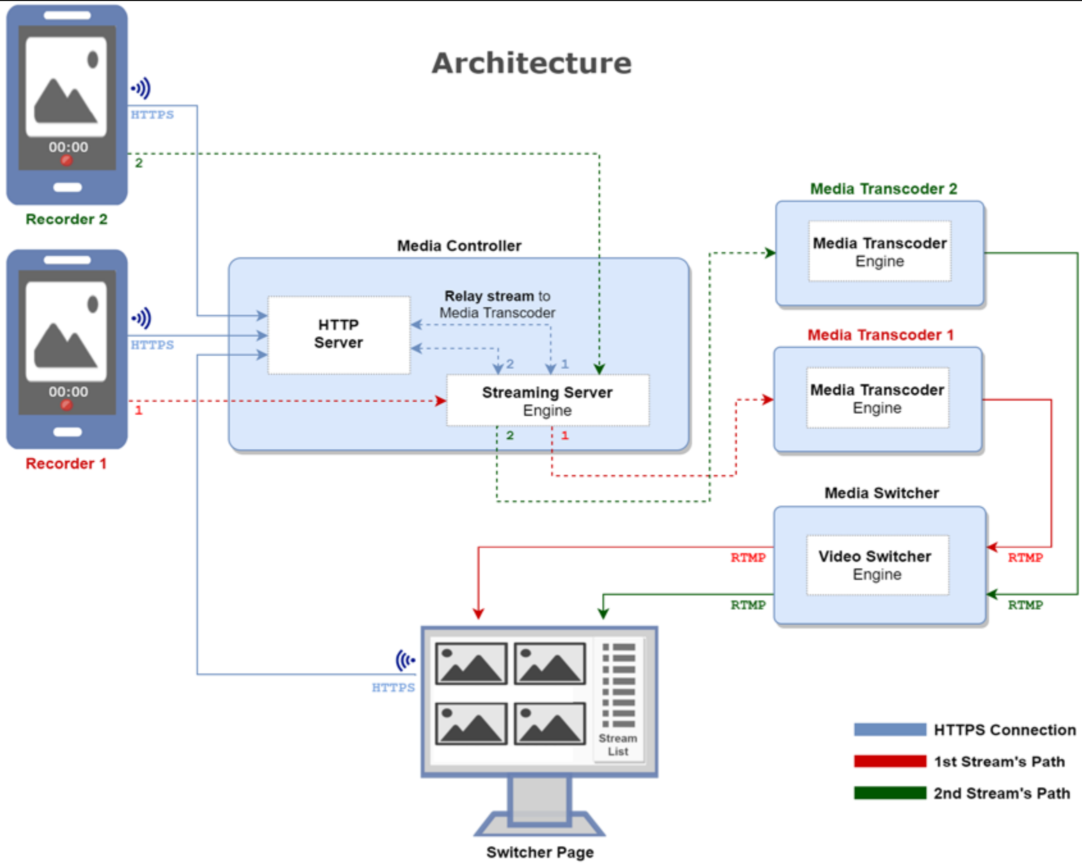


Figure 55 - Use case architecture

As depicted in **Figure 55**, the use case is divided in three different components in order to fully support the use case's features. These three different components translate into three different VNFs, namely: controller, switcher and transcoder. Below, we describe the function and purpose of each one of these VNFs.

- **Media controller** - responsible for all the business logic of the platform and for serving the web pages to the mobile application users and to the video director. This component, responsible for orchestrating all the media flows, is also the entry point for the live feeds created in the mobile devices. After receiving them, the media controller relays the streams to the media transcoders for further media processing. In addition to all of this, the media controller contains the logic for scaling the UC3 solution as will be later described in this document.
- **Media transcoder** - media engine used for transcoding live streams captured by the mobile phones to RTMP streams with a video resolution of 720p and with H.264 video codec and AAC audio coding. The transcoding process for each stream consumes a large amount of resources. The output of the transcoding process of each live feed is sent to the media switcher.
- **Media switcher** - media engine capable of simultaneously receiving multiple RTMP streams and choose one to be selected as output. The referred output can be provided by this component to feed broadcast channels such as *YouTube*. Also, can provide four monitoring streams to be used for control purposes and to feed the switcher GUI.

5.1 Use case deployment using the 5GCity platform

In order to validate the use case operation, the first step was to deploy the developed service in the two considered city testbeds (i.e. Barcelona and Bristol) using the 5GCity platform. To do so, the three different

VNFs and the resulting network service were created using the SDK component and published to the 5GCity Catalogue into the repository created for this particular use case. The VNFs and network service created in the 5GCity Dashboard can be observed in **Figure 56** and **Figure 57**, respectively.

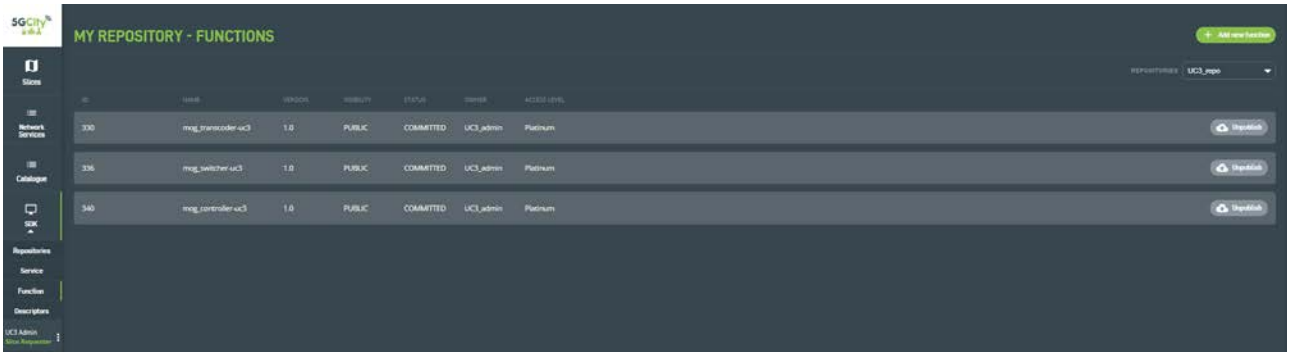


Figure 56 - UC3 functions created using the 5GCity platform

Figure 57 - UC3 network service created using the 5GCity platform

According to the use case requirements in terms of compute resources and radio access nodes, a customized slice was created for MOG's use case in each one of the two involved cities. In particular, a compute chunk with enough resources was created over one of the compute hosts located in the Omega building (Barcelona testbed) and in the Saturn cluster (Bristol testbed). As for the radio chunks, Wi-Fi nodes at each location were selected and allocated as part of the referred slice. These Wi-Fi nodes allowed users to access MOG's use case after connecting to the access points in their devices. The resulting slice, together with the position of the aforementioned nodes over the map at each city, are depicted in **Figure 58**.

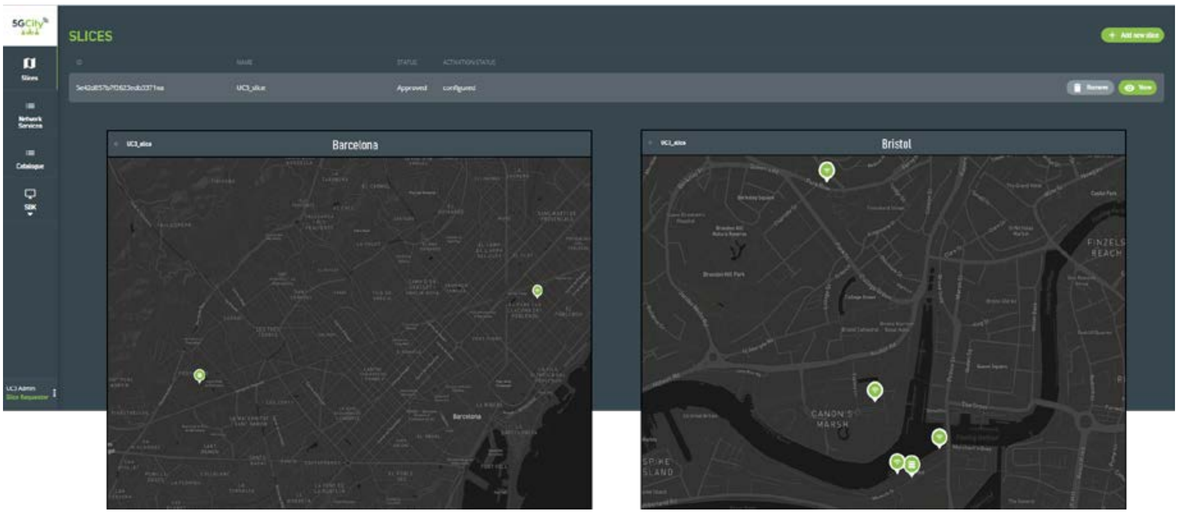


Figure 58 - Slice created for UC3 with location of nodes over the map in both cities.

Once the service and the slice were available, we proceeded with the instantiation of the service over the corresponding slice. The successful instantiation of the UC3 service can be in **Figure 59**, in which we can see the service running in the 5GCity Dashboard and in OSM, as well as the different VMs created in OpenStack. In the referred figure, we can also corroborate that in addition to the four VNFs composing the network service, a DHCP server and a DNS server were automatically deployed by the platform as well, in order to support the service operation.

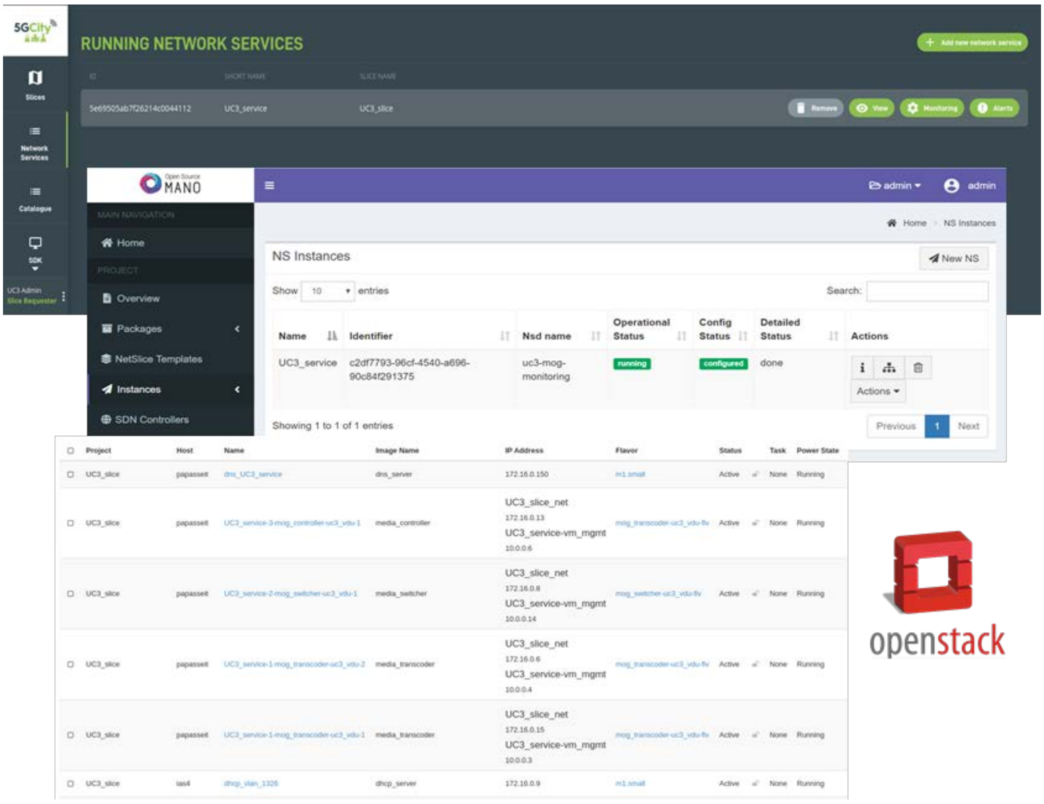


Figure 59 - View of the deployed UC3 in the 5GCity Dashboard, OSM and OpenStack

5.2 Considered Metrics and KPI

The metrics collected during the preformed trials can be divided in two major categories: **generic metrics** and **application-specific metrics**.

The generic metrics mainly comprise fundamental capacity indicators, such as CPU usage, memory consumption and data throughput, providing a good indication of the amount of resources our use case consumes over time. The considered generic metrics and their relevance to our use case are listed below in **Table 27**.

Generic Metric	Description
User Experienced Data Rate	Inbound throughput at the controller VNF (from users to server) averaged per mobile device.
Service latency	Stream latency between the camera capturing the event using the UC's recorder page and the switcher output feed. The switcher output feed contains the feed selected on the switcher GUI and can be published on broadcast channels, such as *YouTube*, that add some delay to the stream due to transcoding on their side. The lower the service latency, the better the performance of our use case.

Service Instantiation Time (SIT)	How many seconds it takes to rise each of the use case's VNFs to be ready to start the use case.

Table 27 - Generic metrics considered for the UC3

Regarding the application-specific metrics, several parameters were defined to monitor the usage and performance of our application. The measurement of such metrics is crucial to understand whether the use case objectives are being met or not. The application-specific metrics considered for our use case that were collected during the trials are listed below in **Table 28**.

Application-specific Metric	Description
CPU usage per VNF	The number of cores running changes when users enter and leave the platform. It is important to understand how many cores are used and what is the workload on them, so that no VNF is overloaded with work.
RAM usage per VNF	The amount of RAM used changes during the time, because users enter and leave the platform. It is important to analyse RAM usage so that no VNF is overloaded with work.
Network throughput of each VNF	If the VNF is receiving more load than the virtual network support, we will see some delay processing the video and the video image will stutter when playing it. The throughput refers to the inbound and outbound traffic.
Use case uptime	How many seconds/minutes/hours the UC was up and running.
Number of VNFs running	With the scaling mechanism in place, we need to know how many VNFs are running, so that it is possible to distribute the application workload among them.
Number of users	Number of users simultaneously creating live streams using the use case's recorder page. As the number of users increases, the resource's consumption increases as well.
Free transcoding slots per transcoder VNF	Number of free transcoding slots in each transcoder VNF. This number depicts how much live feeds a transcoder can process.
Total number of free transcoding slots	Total number of free transcoding slots among all available transcoders. Fewer resources will be available the lower this number is. As such, this number depicts how much resources are available for our use case at a specific time.
Video resolution of live feeds	The video resolution of the live feeds acquired from the mobile devices that are used to feed the switcher GUI.
Video codecs of the live streams	It is important to identify what video codec the smartphone is using to stream. Different devices use different video codecs, and this has an impact in the media graph developed for the UC.
Audio codecs of the live streams	It is important to identify what audio codec the smartphone is using to stream. Different devices use different audio codecs, and this has an impact in the media graph developed for the UC.
Transcoder Scaling Time	Time required to instantiate one Transcoder VNF after the scaling strategy.

Table 28 - Application-specific metrics considered for the UC3

It is also important to define the KPIs for our platform to gauge whether the use case objectives were met or not. Taking into account the aforementioned metrics, the KPIs we set to measure the performance of our application are listed below in **Table 29**.

KPI ID	Definition	Description	Target	Priority [H/M/L]
UC3_KPI#1	**Video resolution**	The uniformed streams at the video switcher engine should have HD resolution.	**HD resolution (1280x720)**	H
UC3_KPI#2	**User Experienced Data Rate**	Average network throughput used per mobile device. As each mobile device sends data at different levels, this value is an average between all of them.	**2-8 Mbps per mobile device**	L
UC3_KPI#3	**Service latency**	Delay between the camera filming the event and the switcher output feed used to feed *YouTube*.	**<= 2.5 s**	H
UC3_KPI#4	**Service Instantiation Time**	Amount of time (seconds) needed to have the entire use case up and running.	**<= 120 s**	M
UC3_KPI#5	**Transcoder Scaling Time**	Time required to instantiate one Transcoder VNF after the scaling strategy.	**<= 60 s**	M

Table 29 - KPIs considered for UC3

5.3 Measurement Methodology

The generic metrics are collected using the *Prometheus* exporter for default system-wide metrics. The *Prometheus* exporter collects all the data needed to analyse the generic metrics over time, such as CPU, memory, disk, I/O bandwidth, among others. In the controller and transcoders VNFs, the node exporter was installed with a collector facility that allowed MOG to expose custom metrics to the node exporter page.

The collector facility in the node exporter allowed MOG to define and expose application-specific metrics in the node exporter endpoint. The custom metrics that were exposed at the controller VNF in its node exporter were:

- Number of users, i.e., the number of active live streams at a time;
- Total number of free transcoding slots;
- Number of devices using different video codecs (like H264 and VP8);
- Number of devices using different audio codecs (like OPUS);
- Video resolution of acquired images and the corresponding number of devices with that video resolution at a time.

The only custom metric that was defined in the transcoder VNFs was the number of free transcoding slots. This number allowed to gauge whether a transcoder VNF was out of resources at a specific time.

After the deployment of the use case, the node exporter page for each VNF is exposed to the 5GCity's Monitoring system. With this, the metrics collected over time can be used to create graphics using *Grafana* dashboards as seen in **Figure 60** for the case of generic metrics.

Figure 60 - *Grafana* dashboard for generic metrics

Likewise, it is also possible to create customized graphics and *Grafana* dashboards using the 5GCity's Monitoring system for the application-specific metrics as seen in **Figure 61**.

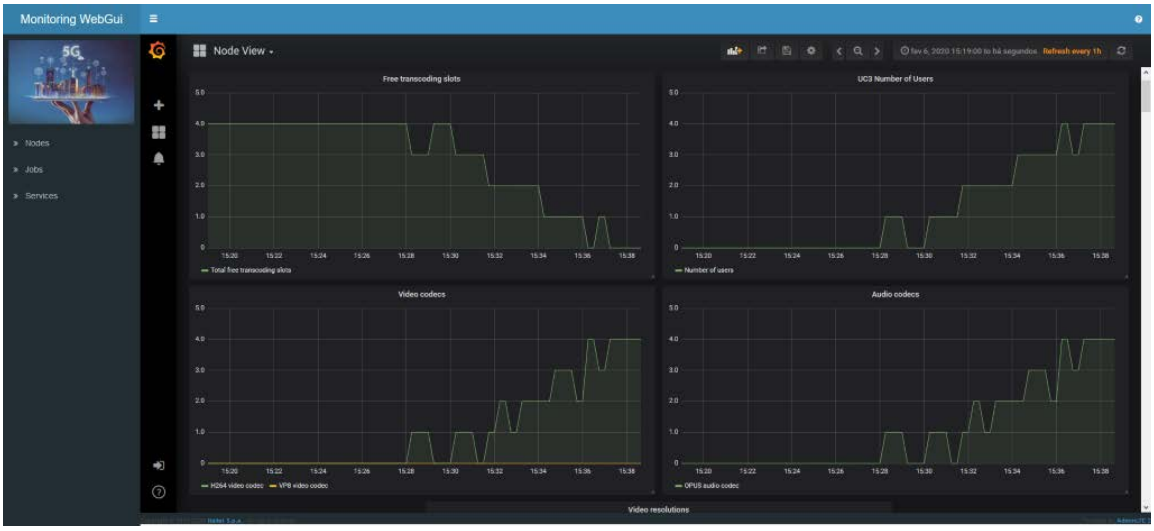


Figure 61 - Graphics of application-specific metrics created using the 5GCity's Monitoring system

Some of the information for the metrics is also available in the Resource Manager of our use case, such as:

- Number of active users;
- Number of free transcoding slots per transcoder;
- Video resolution of the acquired images from the mobile devices;
- Number of transcoders VNFs running.

The page in which this information can be seen is the Resource Manager GUI depicted in **Figure 62**.

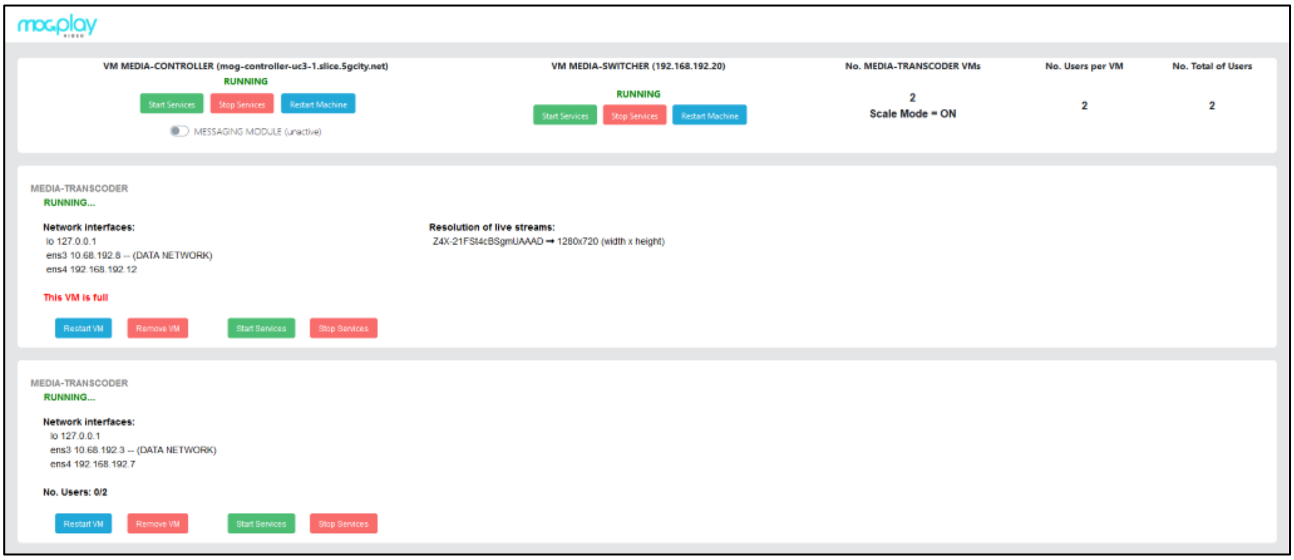


Figure 62 - UC3 Resource Manager

However, some metrics cannot be collected with the 5GCity's Monitoring system such as the service latency, the instantiation time of the VNFs and the transcoder scaling time.

To measure the service latency, a clock needs to be used following the steps below:

1. Film the clock using the use case 3's recorder page;
2. Select the stream filming the clock on the switcher GUI;
3. Publish the stream filming the clock to *YouTube*;
4. Play the switcher output feed using FFmpeg[9];
5. Take a picture of the output feed and the clock;
6. Take a picture of the *YouTube* feed and the clock.

As for the measurements of the instantiation and scaling times, it was necessary to look at 5GCity platform's logs and compute how much time it took to perform these operations during the trial. Moreover, after the trial was conducted the performance of the platform (in terms of times consumed by the different operations required to deploy and scale the use case) was further investigated. In particular, an automated script was used to perform, in a consecutive order, the different requests to the platform and store the times involved in each step. Then, after completing several runs of the experiment, the average value for each operation (including the average instantiation time and average scaling time) is also provided.

5.4 Barcelona Pilot Validation

The use case trials were held in Barcelona between 29th and 31st of October 2019. Below, the use case's test scenario will be presented in detail, describing the features that were validated during the trials held at Barcelona. During the trial, we were not able to take advantage of the scaling mechanism, as this component was not mature enough for a street trial. Nevertheless, this component obtained valuable feedback during the trials that helped us reach the final stage of development of this mechanism.

As such, the remote tests that were later performed using the scaling mechanism will also be presented. These tests were held in the Barcelona infrastructure after the street trials, between 11th of and 20th of

[9] https://www.ffmpeg.org/

December 2019. We will also describe how the scaling mechanism works and describe the main objectives of the remote tests that were held in the Barcelona infrastructure.

5.4.1 Scenario and Trials Description

The scenario used for the pilot validation consisted in deploying the MOG's use case (UC3) at the intersection between *Carrer de Sancho de Ávila* and *Carrer de Roc Boronat*. This intersection is covered by three Wi-Fi access points and connected to the computing resources in Betevé and Omega datacentres. In **Figure 63**, we can see the infrastructure deployed in Barcelona in which the trial took place. The red circles in the figure point where the Wi-Fi access points are mounted. For the trial, the Wi-Fi access point in front of the MediaTIC building was used (red circle in the center).

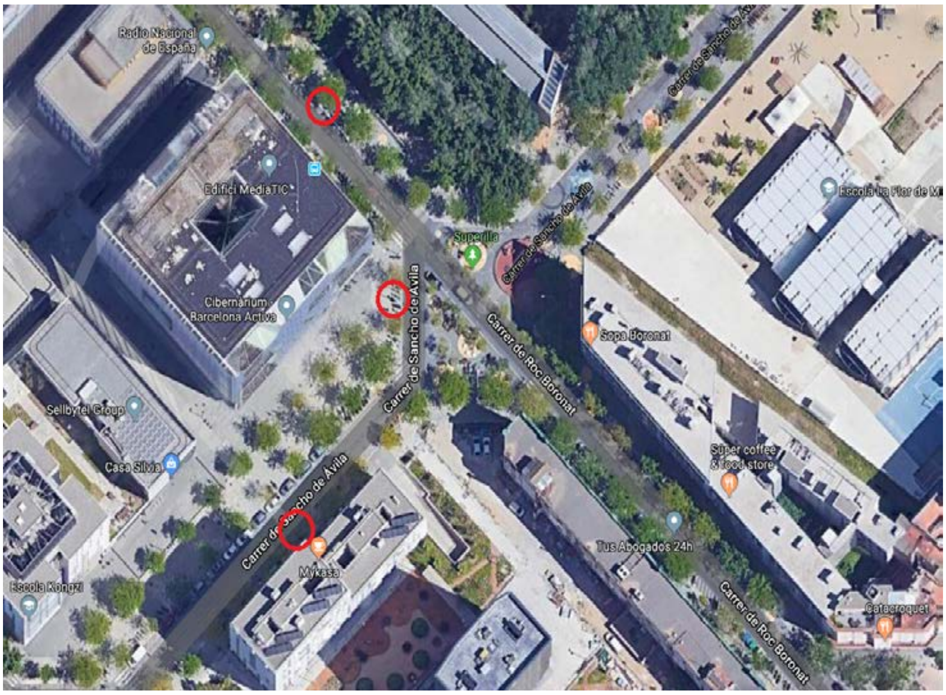


Figure 63 - Aerial vision over the intersection where the trial was deployed

The trial consisted in deploying the UC3 application with the help of the 5GCity platform, testing all the features the use case has to offer. The deployment of this use case brought the possibility of feeding live content with the participant's smartphones. The smartphones did not need any special pre-configuration, they just need connect to the 5GCity Wi-Fi, open the browser and press the start button after loading the use case's web page.

5.4.1.1 Barcelona Trial - Test Scenario

The use case developed by MOG Technologies empowers users of the web application to capture live video and/or audio through their smartphones and transmit it to the cloud in near real-time. The users of the UC application are also able to switch the camera that captures the video and mute (or unmute) the audio to be sent in the transmission. The recorder page in which these features are made available to its users can be seen in **Figure 64**.

Figure 64 - UC3 recorder page

All the live feeds received in the cloud are then relayed to the switcher page, being displayed to the video directors. The interface of the UC3 solution that enables the real-time management of live streams can be seen at **Figure 65**.

Figure 65 - UC3 switcher page, running on the laptop connected to the 5GCity platform via Wi-Fi

With the list of stream thumbnails being displayed on the right side of the interface, the producer is able to select one of those streams and to drag and drop it into one of the four video players that are present on the left side of the main panel of the switcher page, as depicted in **Figure 65**. The platform also allows the publishing of a stream in real-time to external broadcast channels, such as *YouTube Live*, after selecting a video source in the producer's GUI.

In the trial held at Barcelona, one of the main objectives was to validate the use case features described above with three users creating live streams simultaneously using their mobile phones. These live streams would be previewed by the director in charge of the switcher page. The video director would then choose the video output to publish on *YouTube Live*.

The scenario described previously is depicted in **Figure 66** in which we see three users of the use case using their mobile phones to record live streams and a video director in front of the laptop. In this scenario, the video director will use the switcher page to preview the live feeds and select the video output to relay to *YouTube Live*.

Figure 66 - Barcelona trial test scenario

Another validation made in Barcelona was to conduct a series of experiments regarding the interoperability of the UC with professional video cameras. A synergy between MOG and betevé allowed to use the UC3 as an agent to stream professional footage directly to *YouTube* without any other equipment, just a camera connected to 5GCity platform and the UC3 running, as pictured in **Figure 67**. This synergy started before the Barcelona's trial and it was successfully used as a media solution for the series of interviews promoted by 5GCity project during the EuCNC 2019 in Valencia, Spain.

To sum up, the objectives of the street trials in Barcelona were to:

- Deploy use case 3 in the 5GCity's infrastructure;
- Create three live streams simultaneously;
- Send the selected feed to YouTube;
- Validate other UC features;
- Integrate with the 5GCity's Monitoring system;
- Collect metrics during the trials;
- Validate the interoperability of the UC with professional video cameras.

Figure 67 - Professional camera connected to 5GCity platform and UC3, during the Barcelona's trial

5.4.1.2 Barcelona Remote Tests – Solution Scaling

Through laboratory tests, we have concluded that the media controller and media switcher VMs are able to handle 50 users simultaneously, without scaling these components. This can be seen in **Figure 68**, in which four live feeds are being previewed in the main panel and more 46 live streams are available for playing in the list of *Live stream previews*. In these tests, both the media controller and media switcher VMs were using 4 CPU cores and 4 GB of RAM each.

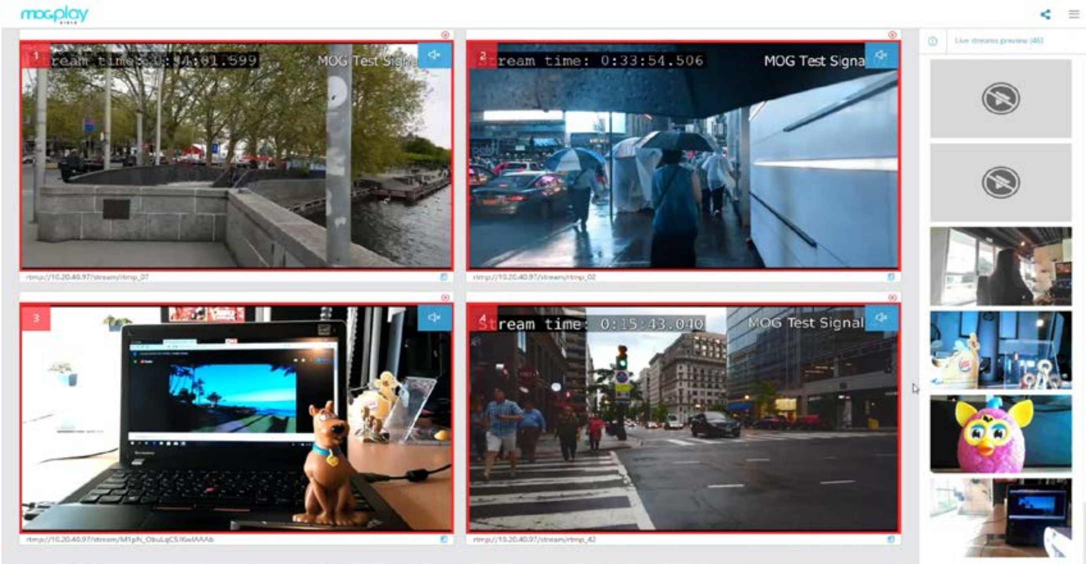


Figure 68 - Switcher page with fifty live streams

However, the same did not apply for the media transcoder. That was because the video transcoding process for each live feed consumes a huge amount of resources; each live stream uses up at least 1 CPU core and 100 MB of RAM. As such, for a single transcoder VNF to be able to transcode 50 live streams simultaneously, the VNF would have to have at least 50 CPU cores! As that number of CPU cores is too much for a single machine, a scaling mechanism was developed in order to distribute the usage of resources among the available transcoders.

For the scaling solution to work, the transcoder VNFs need to register their IP information in the Resource Manager, a service running in the controller VNF. For that registration to work, the transcoders need to know either the IP or the domain name of the controller. Considering that the IPs of the use case VNFs change per deployment, a DNS service was deployed along with UC3's VNFs in order to prevent post-deployment configurations in the transcoder VNFs. That is, the transcoders used the controller's domain name to register their IP information in the Resource Manager.

With the transcoders registered in the Resource Manager, this service will select a transcoder with enough resources available when a user starts a new live stream using the UC3. In the configuration file for the Resource Manager, we also define the number of live streams (or users) each transcoder can process so that no VNF is overloaded with work. The Resource Manager GUI for the UC3 can be seen in **Figure 69**.

Figure 69 - Resource Manager GUI

However, there was a limitation to this scaling mechanism: the transcoders could not be scaled after the initial deployment. For example, if there were only two transcoders deployed and each of them could only transcode one live stream, the solution would only be able to support two users simultaneously. Considering the feedback MOG received from i2CAT regarding this issue, a work around to this limitation was implemented that would allow new transcoders to be deployed when transcoding resources were almost or completely depleted. This work around was implemented by MOG along with i2CAT.

The logic to the horizontal scaling process was implemented in the Resource Manager in which we define the pool size of the transcoder VNFs, i.e., we define the number of transcoders' VNFs that should always be free. If one of the buffer transcoders is occupied by at least one live stream, then the trigger to deploy a new transcoder should be fired. This process, called scale out mechanism, is illustrated in **Figure 70**, in which the transcoders' pool size is set to 1. The example illustrated in the referred figure is the same scenario that was used in the remote tests to validate the scale out process.

The 5GCity's Monitoring system was used to integrate the scale out mechanism in the 5GCity platform. Therefore, when the transcoding resources are almost or completely depleted, the Resource Manager will set the custom metric **collector_ADD_MORE_TRANSCODERS** to 1 in the controller VNF's metrics exporter. This will generate a new alert called *IncreaseTranscoders* in 5GCity's Monitoring server. This alert will be the trigger to manually deploy a new transcoder VNF. When the new transcoder VNF is registered in the Resource Manager, the metric **collector_ADD_MORE_TRANSCODERS** will be set to 0, turning off the *IncreaseTranscoders* alert, which will allow this process to be repeated when transcoding resources are depleted again.

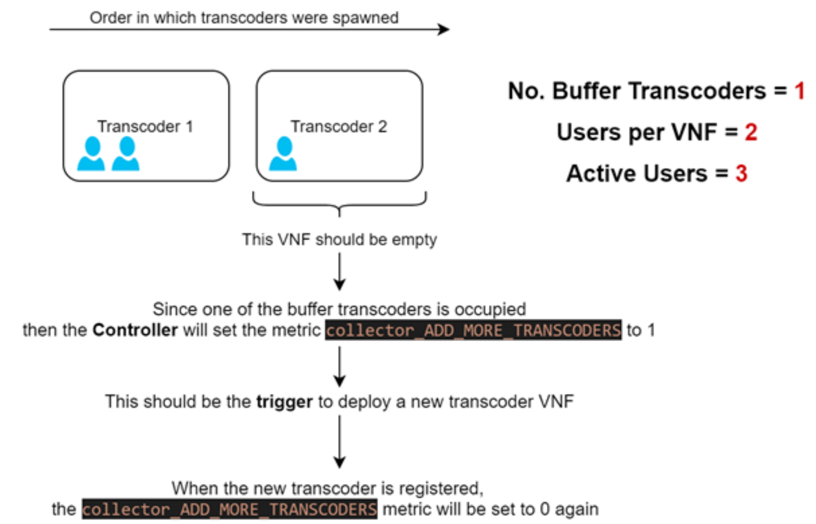


Figure 70 - Scale out test scenario

In order to enable the release of resources that are no longer being used, a scale in mechanism was also implemented. Like the scale out process, the logic to the scale in mechanism is present in the Resource Manager. If the last transcoder VNFs corresponding to the transcoders' pool size (and one more transcoder) are completely free, then the trigger to delete the last transcoder should be fired. This process, called scale in mechanism, is illustrated in **Figure 71**, in which the transcoders' pool size is set to 1. The example illustrated in the referred figure is the same scenario that was used in the remote tests to validate the scale in process.

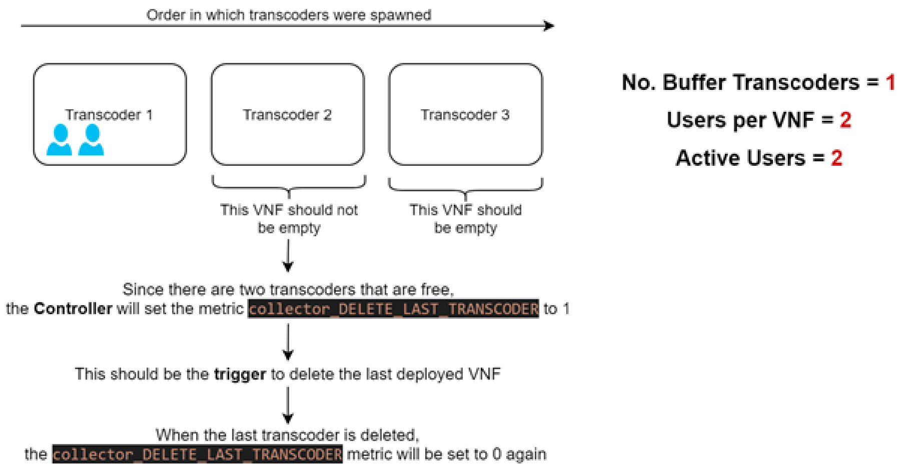


Figure 71 - Scale in test scenario

Just like the scale out mechanism, the 5GCity's Monitoring system was used to integrate the scale in mechanism in the 5GCity platform. Therefore, when there are transcoding resources that can be freed, the Resource Manager will set the custom metric **collector_DELETE_LAST_TRANSCODER** to 1 in the controller VNF's metrics exporter. This will generate a new alert called *DecreaseTranscoders* in 5GCity's Monitoring server. This alert will be the trigger to manually delete the last transcoder VNF that was deployed. When the last transcoder VNF is unregistered from the Resource Manager, the metric **collector_DELETE_LAST_TRANSCODER** will be set to 0, turning off the *DecreaseTranscoders* alert, which will allow this process to be repeated when transcoding resources are free again.

In short, the remote tests in the Barcelona infrastructure performed between 11th and 20th of December 2019 allow us to:

- Validate the DNS service so that the UC3's scaling solution works without post-deployment configurations in the transcoders' VNFs;
- Validate the scale out mechanism using the scenario represented in **Figure 70**;
- Validate the scale in mechanism using the scenario represented in **Figure 71**;
- Improve and validate the integration of UC3 with 5GCity's Monitoring system.

5.4.2 Results Analysis

In this section, we will expose the metrics we retrieved from the street trials performed in Barcelona between 29th and 31st of October 2019. We will also disclose the results for the remote tests performed in the Barcelona infrastructure.

5.4.2.1 Barcelona Trial Results

In this section, we expose the relevant metrics and KPIs collected during the outdoor trials executed in Barcelona. The Barcelona trial was divided in two sessions; this section only covers the first part of the trial.

It is important to mention that the UC3 trial was the first one made in the Barcelona infrastructure. This was a relevant step for the project and its feedback allowed to mature the modules of the platform. However, being the first adds additional challenges and the next list summarizes the points that conditioned somehow the execution of the trial:

- The first result we retrieved, and it was not something we wanted to measure during the tests, is that weather has a significant impact in the experience. During the trial's day, it rained a few times and when it happened, we saw visual artefacts, lower video resolutions, and some disconnections on the smartphones. This conditioned the trial do be conducted only when it did not rain;

- Another fact that conditioned the trial was the available bandwidth. With the UEs and the setup used for the trial, around 50 Mbps of bandwidth were obtained in the experiment for all the mobile devices and the switcher web page (lamp posts Wi-Fi AP settings: 2x2 MIMO with IEEE 802.11ac, operating on an unlicensed 40 MHz channel). Considering that the producer needs to be able to play all the available streams on the switcher GUI and playing each stream consumes around 12 Mbps, the physical limitation to this average throughput reduced significantly the number of streaming devices that could be connected at the same time.
- The monitoring module stopped during the trial. However, the consortium had a mitigation plan in case this happened, and the metrics could be collected and processed offline.

Despite the challenges we faced, the deployment of the UC3 in Barcelona was a success and the most relevant features of the UC3 were validated. Therefore, it was possible to recreate the scenario previously represented in **Figure 66**, creating three live streams simultaneously and sending the selected feed to *YouTube Live*.

Regarding the application-specific metrics, the results collected during the experiment are presented below. However, the second part of Barcelona's trial (the remote tests) will extend these results with some results that were obtained after the scaling was tested.

- **CPU and RAM usage per VNF**

The amount of used RAM and CPU changes during the time, because users enter and leave the platform. During the trial the VNFs did not scale vertically, in other words, the UC used the same number of vCPUs during the trial. The controller and the switcher used 4 vCPUs and the transcoder used 8 vCPUs. Likewise, each VNF was instantiated with a fixed amount of RAM; the controller and switcher were deployed with 4GB of RAM and both transcoders were deployed with 8GB of RAM. The variance of the CPU and RAM usage when the number of users increases is exposed in **Table 30**, **Table 31**, **Table 32** and **Table 33** on each VNF.

Controller Metrics	Number of Users					
	1		2		3	
	w/o YouTube	w/ YouTube	w/o YouTube	w/ YouTube	w/o YouTube	w/ YouTube
CPU usage	4.3%	4.4%	8%	8.5%	8.9%	9%
RAM usage	6%	6.1%	5.8%	6%	6.1%	6%

Table 30 - Overall usage of CPU and RAM on controller VNF, when more users are added

Switcher Metrics	Number of Users					
	1		2		3	
	w/o YouTube	w/ YouTube	w/o YouTube	w/ YouTube	w/o YouTube	w/ YouTube
CPU usage	4,20%	5,95%	4,20%	4,60%	5,10%	5,90%
RAM usage	4,80%	5,10%	4,80%	4,80%	4,90%	5%

Table 31 - Overall usage of CPU and RAM on switcher VNF, when more users are added

Transcoder 1 Metrics	Number of Users					
	1		2		3	
	w/o YouTube	w/ YouTube	w/o YouTube	w/ YouTube	w/o YouTube	w/ YouTube
CPU usage	22,20%	71,90%	36,60%	75,20%	78,90%	86,70%
RAM usage	5,90%	10,40%	6,60%	11,10%	11,20%	12,50%

Table 32 - Overall usage of CPU and RAM on transcoder1 VNF, when more users are added

Transcoder 2 Metrics	Number of Users					
	1		2		3	
	w/o YouTube	w/ YouTube	w/o YouTube	w/ YouTube	w/o YouTube	w/ YouTube
CPU usage	0,16%	0,16%	0,16%	0,17%	19,90%	21,10%

RAM usage	3,80%	3,90%	3,90%	3,90%	4,40%	8,30%

Table 33 - Overall usage of CPU and RAM on transcoder2 VNF, when more users are added

- **Network throughput of each VNF**

The network throughput is pictured on Figure 72, Figure 73, Figure 74 and Figure 75 for the four VNFs during one life cycle of the UC. It is possible to observe that each VNF uses different amount of network throughput but all of them increase their value when more users enter in the platform. Several important events occur during this period. At 11h06m, the UC was started on the platform and the first user enters at 11h10m. The second user enters around 11h35m and the third one at 11h47m. The private live feed to *YouTube* starts at 11h48m and is stopped at 11h58m and a few seconds later, all the users stop the streaming. The last event registered is the shutdown of the UC at 12h10m.

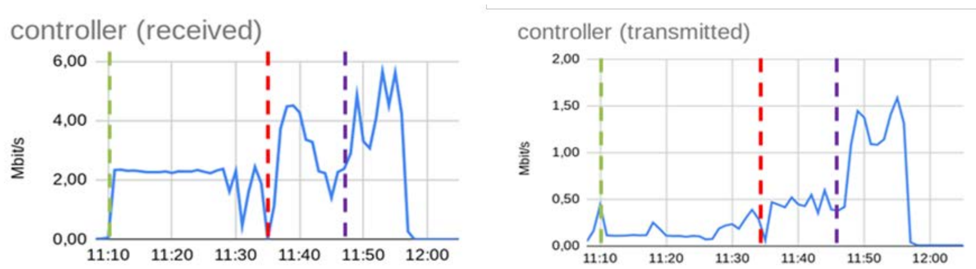


Figure 72 - The received and transmitted throughput of controller VNF

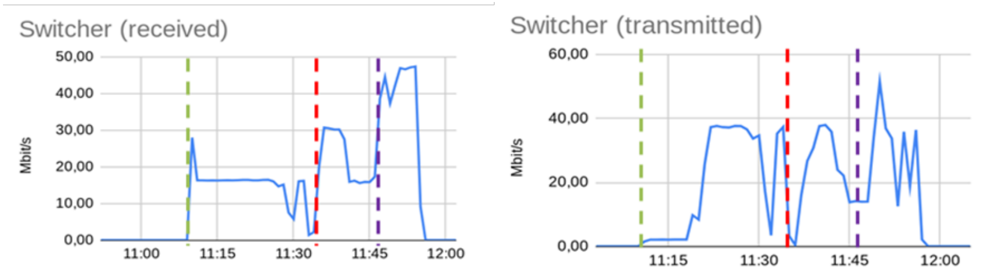


Figure 73 - The received and transmitted throughput of switcher VNF

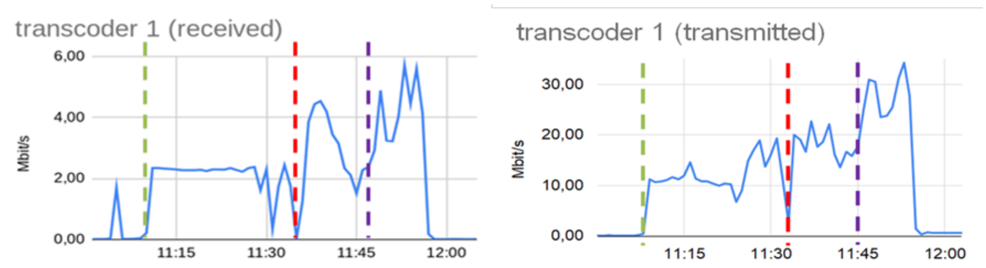


Figure 74 - The received and transmitted throughput of transcoder1 VNF

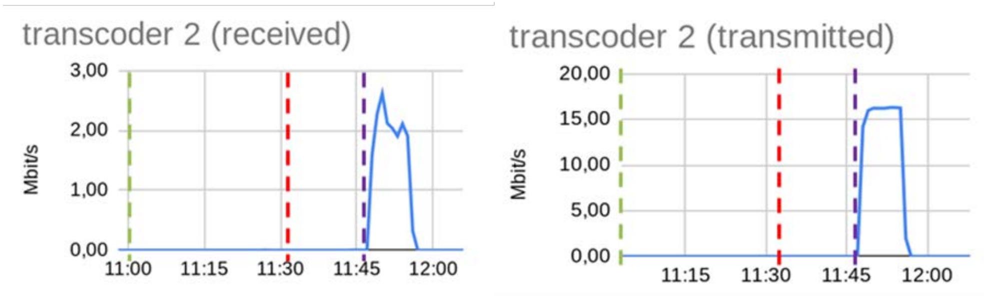


Figure 75 - The received and transmitted throughput of transcoder2 VNF

Still regarding the network throughput, it is also important to note that the network throughput increases significantly when the streams go through the transcoder VNFs. In order to understand this, recall the diagram of UC3's architecture that was presented in **Figure 55**. As seen in the referred figure, the entry point for the live feeds is the controller VNF. After that, they are relayed to the transcoder VNFs and thereafter they reach the switcher VNF. The increment of the network throughput in this media flow is due to the transcoding processing that occurs for each video feed in the transcoders. The transcoding process in these VNFs standardizes the video specs and the bandwidth of the live feeds to a fixed value of 12Mbps, which typically increases the video throughput. In fact, we can see lower network throughput in the controller VNF observed in **Figure 72** and in the received throughput for both transcoders observed in **Figure 74** and **Figure 75**. However, in the transmitted throughput for both transcoders, also seen in **Figure 74** and **Figure 75**, we can see a substantial increase of network throughput. Since the video output of the transcoder VNFs is relayed to the switcher VNF, we can also see higher network throughput in this component of our use case as verified in **Figure 73**.

- **Use case uptime**

The use case was running for one hour and four minutes. This is pictured in all graphs present in Figure 72, Figure 73, Figure 74 and Figure 75.

- **Number of VNFs running**

Four running VNFs were deployed in Barcelona's trial: one controller VNF, one switcher VNF and two transcoders, named transcoder1 and transcoder2. **Table 34** summarizes these values.

VNF Name	VCPUs	RAM (GB)	Disk (GB)	Image size (GB)
Controller	4	4	20	4,9
Switcher	4	4	10	4,9
Transcoder 1	8	8	10	5
Transcoder 2	8	8	10	5

Table 34 - Summary of number of vCPUs, amount of RAM, disk space and image size per VNF

- **Number of users**, **video resolution of live feeds** and **codecs of the live streams**

Table 35 summarizes this information for the three active users available during the trial. At the end, all the codecs were the same and the video resolution of the feeds obtained in the switcher was always HD.

	Video Resolution	Video Codec	Audio Codec
User 1	1280 x 720	H.264	OPUS
User 2	1280 x 720	H.264	OPUS
User 3	1280 x 720	H.264	OPUS

Table 35 - Number of users and their respective resolution and codecs

Regarding the generic metrics, the results collected during the experiment are presented below.

- **User experienced data rate**

As for the user experienced data rate, it is possible to identify the average amount of bandwidth used per mobile device with the help of **Figure 74** and **Figure 75**. The first mobile device used around 2.2 Mbps. It is possible to identify periods of time when the mobile device adapts the quality of the video to cope with the available bandwidth, especially when the other devices enter in the platform. The second device uses the same 2.2 Mbps at the beginning and reduces its bandwidth over time. After the second device started streaming, the weather changed and it started to rain a little bit. This event is registered in both graphs and it is possible to identify, in the graph, when the rains starts and when it stops. In **Figure 74**, between 11:38 to 11:46, the bandwidth that arrives to transcoder 1 is reduced significantly and this matches when it rained.

As seen in **Figure 75,** the third device starts streaming when the rain is stopping and it is possible to see that the third device uses about 2.1 Mbps.

- **Service Latency**

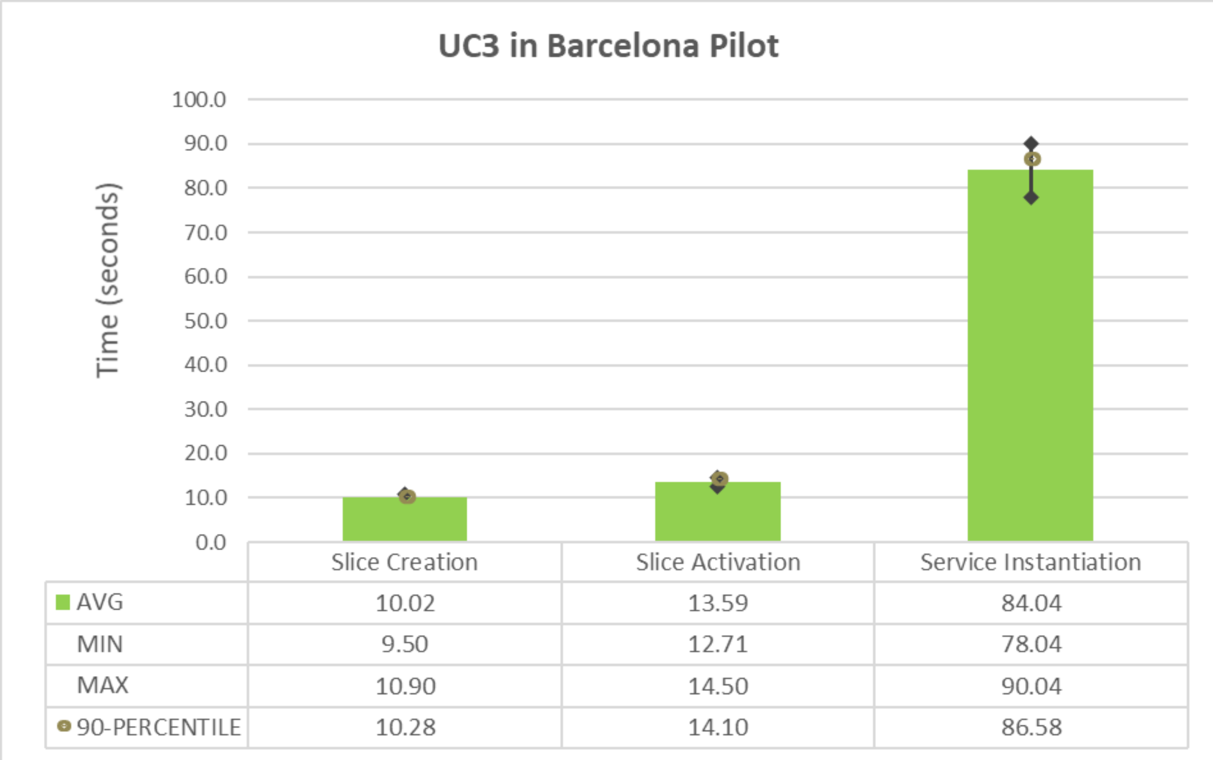
For the **service latency**, we follow the methodology described at 5.3. With the **Figure 76** taken, was possible to say the service latency is 2 seconds and 320 milliseconds. If we take into consideration the *YouTube* delay, it increases to 6 seconds and 10 milliseconds, but *YouTube* also do some transcoding on their side and it takes some time.

Figure 76 - Service latency

- **Service Instantiation Time**

The instantiation of the four different VNFs composing the use case service took during the trial **80 seconds**, as reported by the platform logs. In order to provide a more exhaustive analysis of the times required by the platform to deploy the use case, the results computed after running 30 iterations of the different involved operation with an automated script are presented in **Figure 77**. In particular, the average instantiation time of UC3 network service in the Barcelona Pilot was around 84 seconds, meeting the target set for this KPI.

In general, the entire deployment process of a network service requires the performance of different steps in the 5GCity platform, namely: Slice Creation, Slice Activation and Service Instantiation. For the sake of completeness, the required times for each one of those steps are also included in **Figure 77.**



	Slice Creation	Slice Activation	Service Instantiation
AVG	10.02	13.59	84.04
MIN	9.50	12.71	78.04
MAX	10.90	14.50	90.04
90-PERCENTILE	10.28	14.10	86.58

Figure 77 - Time required by the 5GCity platform to deploy the UC3 in Barcelona pilot

In Barcelona's trial, we conducted several integration tests with UC3 and UC5. This integration was not initially proposed but turned out to be a great way to explore joint exploration between consortium partners. The extension of Barcelona's technical tests is somehow shadowed by the more grateful results obtained during EuCNC 2019. The tests conducted during EuCNC 2019 are demonstrated by the successful number of live interviews conducted and the observed interest in the UC3 and UC5 integration in the 5GCity booth. For these EuCNC 2019 tests 5GCity deployed one indoor and outdoor Accelleran Small Cell operating in 3.5GHz spectrum (see **Figure 78**) together with the 5GCity platform demonstrating the use cases.

Figure 78 - Outdoor Accelleran Small Cell and Indoor Accelleran Small Cell in 5GCity portable radome.

This synergy was also made public and disseminated in the television during the news. **Figure 79** and **Figure 80** show screens of the news that cover the 5GCity platform and the synergy of UC3 with UC5.

Figure 79 - A viewer seeing a live interview promoted by the 5GCity project[10].

Figure 80 - The switcher interface of UC3, receiving a feed from a professional camera[10].

The series of experiments during Barcelona's trial, mixing these two use cases, validated how disrupted these platforms could be for the media industry. We successfully tested the mix of footage from the professional video camera with the ones from mobile devices, as pictured in **Figure 81**. This kind of experiment allowed us to identify new ways to explore the potential of mixing established professional workflows with amateur video signals and doing it before arriving to a traditional video production room.

Figure 81 - Taking footage from a smartphone and from a professional camera simultaneously

[10] This picture is taken from the *betevé notícies*, a television news program of betevé, broadcasted at 18 June of 2019.

5.4.2.2 *Remote Scaling Tests Results*

All of the objectives that were set for the remote tests in the Barcelona infrastructure were accomplished successfully. First, we will talk about the results of the scale out and scale in mechanisms, while also referring the DNS validation. Further down in the document, we also examine the results of the integration of our use case with 5GCity's Monitoring system.

Firstly, it is important to mention that the initial deploy of UC3 that was used for our remote tests had four VNFs: one controller VNF, one switcher VNF and two transcoders, named transcoder1 and transcoder2. **Table 36** summarizes these values.

VNF Name	VCPUs	RAM (GB)	Disk (GB)	Image size (GB)
Controller	2	2	10	10
Switcher	2	2	4	2,5
Transcoder 1	2	2	10	7,5
Transcoder 2	2	2	10	7,5

Table 36 - Summary of number of vCPUs, amount of RAM, Disk space and image size per VNF

For the validation of the scale out mechanism, MOG simulated a scenario in which the transcoding resources were depleted as depicted in **Figure 70**. After that, i2CAT confirmed that the *IncreaseTranscoders* alert had been generated properly in the *Prometheus* server when the metric **collector_ADD_MORE_TRANSCODERS** was set to 1. The referred alert can be seen **Figure 82**.

Figure 82 - *IncreaseTranscoders* alert in the *Prometheus* server

After the alert was fired, i2CAT performed the "reaction" to the alert. The reaction to the alert consisted in deploying a new transcoder VNF with the same image and resources as the other transcoders. The alert was removed from the *Prometheus* server after performing its reaction.

After a while, MOG saw the new transcoder VNF in the Resource Manager as seen in **Figure 83**. The fact that the new transcoder appeared in the Resource Manager GUI meant that a new transcoder VNF was successfully deployed and that this new transcoder successfully registered itself in the Resource Manager. It also meant that the usage of DNS to communicate with the controller VNF was successful. That is because the transcoder VNFs were using the controller's DNS to reach the Resource Manager, a service running in the controller VNF.

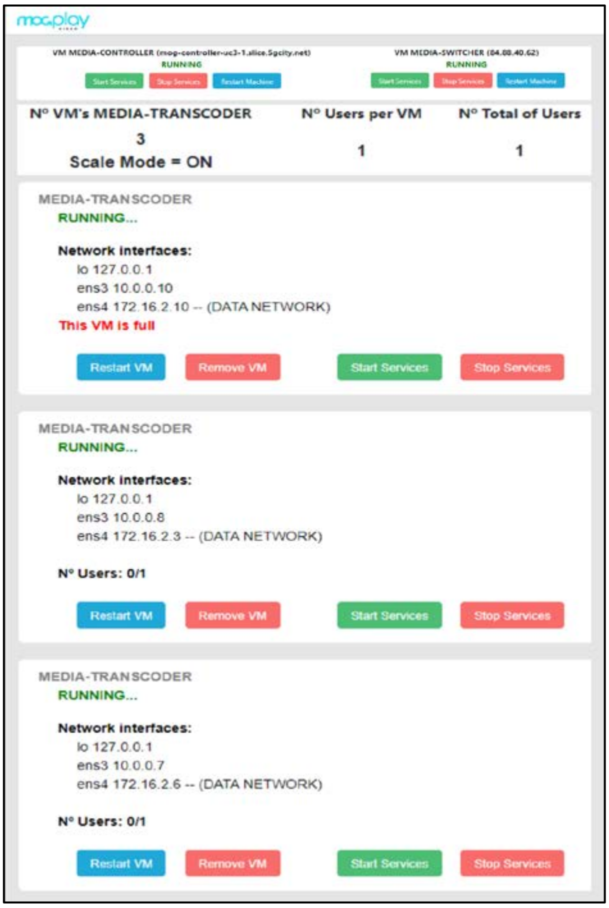


Figure 83 - Resource Manager web page after transcoders' scale-out took place

After validating the scale out mechanism, the next step was to validate the scale in process. For that purpose, MOG simulated a scenario in which there were transcoding resources that could be freed, as depicted in **Figure 71**. After that, i2CAT confirmed that the *DecreaseTranscoders* alert had been generated properly in the *Prometheus* server when the metric **collector_DELETE_LAST_TRANSCODER** was set to 1. The referred alert can be seen **Figure 84**.

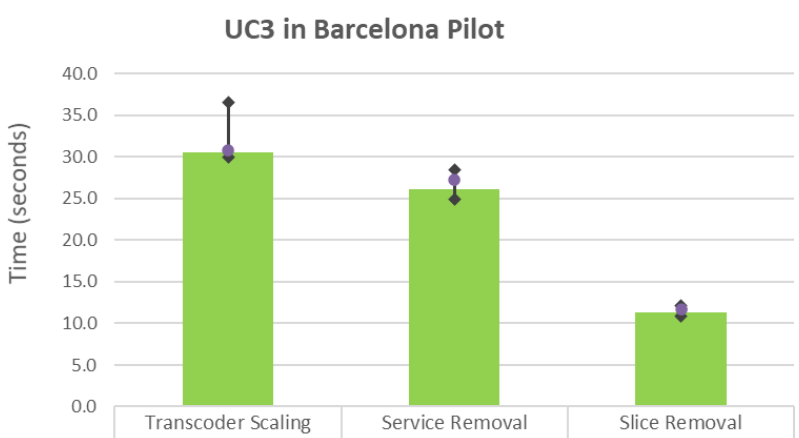
Figure 84 - *DecreaseTranscoders* alert in the *Prometheus* server

After the alert was fired, i2CAT performed the reaction to the alert and it was removed from the *Prometheus* server. The reaction to the *DecreaseTranscoders* alert consisted in scaling in the solution. After a while, MOG saw that the last transcoder VNF that was deployed had been deleted from the Resource Manager as depicted in **Figure 85**. The fact that the last deployed transcoder was removed from the Resource Manager GUI meant that the last transcoder VNF was successfully removed from *OpenStack* and that the deleted transcoder unregistered itself from the Resource Manager.

Figure 85 - Resource Manager web page after transcoders' scale-in took place

The validation of the scale out and scale in mechanisms allowed both parties to improve its implementation. This validation also enabled the integration of this process in the 5GCity dashboard, so that the reaction action could be performed directly in this dashboard through a "React" button in the generated alerts. In the Bristol trials, MOG tested this feature using the 5GCity dashboard as will be described later in this document.

While the focus of these remote tests was to scale the use case 3 solution, some metrics were also collected. One of the most important metrics that was collected during these tests was the Transcoder Scaling Time (TST). Following the same procedure that was explained for the collection of time values using an automated script, the resulting average TST after 30 iterations is **30.59 secs** as shown in **Figure 86.** We have also included in this figure the measurements about Service Removal and Slice Removal to give an overall overview of the times required by the different operations done by the 5GCity platform.



	Transcoder Scaling	Service Removal	Slice Removal
AVG	30.59	26.14	11.38
MIN	30.03	24.96	10.85
MAX	36.56	28.47	12.08
90-PERCENTILE	30.74	27.21	11.72

Figure 86 - Transcoder Scaling Time in Barcelona pilot

During these remote tests, we also validated the integration of our use case VNFs with the 5GCity's Monitoring module. In fact, we verified that the metrics collected over time on the controller and transcoders VNFs could be seen in the 5GCity's Monitoring dashboard. With the TST measurements provided by I2CAT, we were able to collect all the metrics necessary for the use case 3's KPIs.

Table 37 summarizes the results collected during the trial with respect to their respective target values. In general, the values we collected during the trials are aligned with the values we set for the UC3 KPIs, meaning that all the targets were successfully reached.

KPI	Target	Measurement
Video Resolution	1280x720	1280x720
User Experienced Data Rate	2-8 Mbps per mobile device	≈ 2.2 Mbps
Service Latency	<= 2.5 s	2.32 s
Service Instantiation Time (SIT)	<= 120 s	84.04 s
Transcoder Scaling Time (TST)	<= 60 s	30.59 s

Table 37 - UC3 KPI results in Barcelona Pilot

5.5 Bristol Pilot Validation

The pilot validation in the city is a very important step to verify the integrity of the solution and the ecosystem that supports the use case. It also allows us to collect real data, outside of the laboratory environment, for the key performance indicators (KPIs). The trials conducted in Bristol were divided in two parts: indoor calibration tests and outdoor validation tests. The indoor tests were performed on the 5th and 6th of February 2020 in the *University of Bristol* in preparation for the street trial that was held on the 7th of February of 2020.

5.5.1 Scenario and Trials Description

The scenario used for validating the MOG's use case deployment in the Bristol pilot, was composed of several Wi-Fi access points available in different locations across the city, namely: the *University of Bristol*, the *Millennium Square* and the *M Shed*. In **Figure 87**, we can see the referred radio infrastructure deployed in Bristol in which the trial took place.

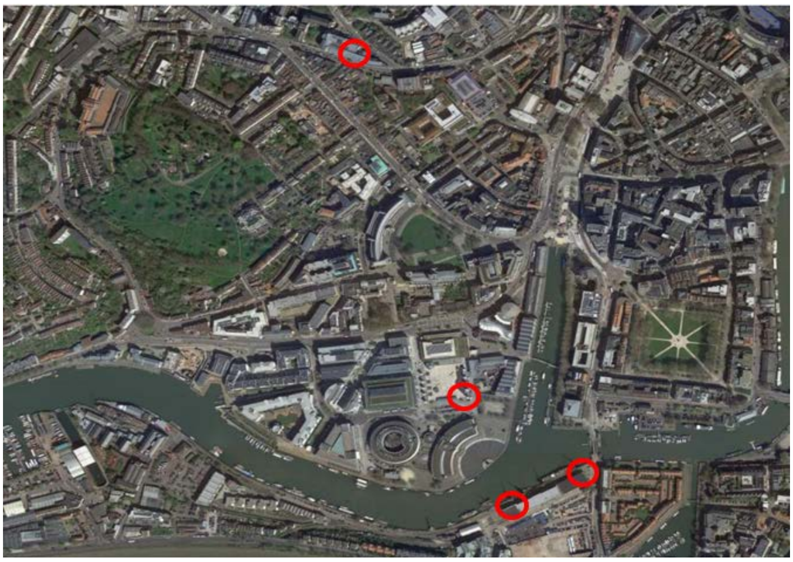


Figure 87 - Location of the Wi-Fi access points in Bristol where the trial took place

In order to support a higher number of users, all four access points represented in **Figure 87** (red circles) were used during the trial: one in *University of Bristol*, one in the south part of the *Millennium Square* and, finally, two others in *M Shed* (one to the east and the other to the west). These Wi-Fi APs are connected to the computing resources in the Saturn datacentre located in *M Shed*.

5.5.1.1 Bristol Trial – Indoor Test Scenario

During the indoor tests in Bristol, only the Wi-Fi access point located in the *University of Bristol* was used. The purpose of this testing phase was to ensure the correct operation of the deployed service in advance of going to the exterior facilities. To conduct these tests, six mobile devices were connected to the referred access point and used to stream video content to the MOG's platform, as depicted in **Figure 88**.

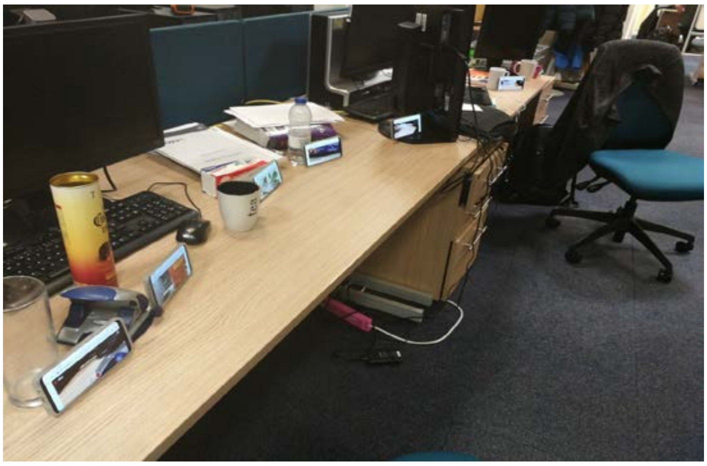


Figure 88 - Six live feeds created using UC3 in the *University of Bristol*

In the trials held in Bristol, we were able to successfully test all the features the use case has to offer. The most relevant features we validated during the indoor trials were to:

- Create a live feed using our use case's recorder page depicted in **Figure 89**;
- Watch the live feeds on the switcher page as depicted in **Figure 90**;
- Send the selected feed to YouTube.

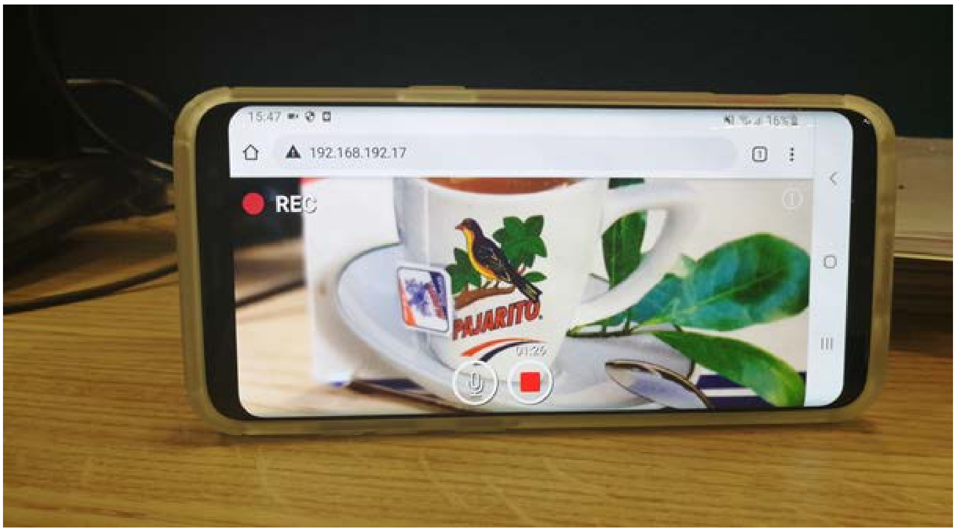


Figure 89 - Live feed created using UC3 in the *University of Bristol*

Figure 90 - Switcher page with live feeds created during indoor tests

Besides validating the operation of our use case, another important objective of the indoor tests in Bristol was to validate the scaling mechanism using the 5GCity dashboard. Although the scaling mechanism was previously validated in the Barcelona infrastructure, as previously described in Sections 5.4.1.2 and 5.4.2.2, this feature was not fully integrated in the 5GCity platform at that time. As such, one of the objectives of the trial in Bristol was to validate the integration of the scale out and scale in mechanisms with the 5GCity dashboard.

Furthermore, the test scenario used to validate the scaling mechanism in Barcelona was limited to only three transcoders deployed after scaling out the solution. With the test scenario depicted in **Figure 70** and **Figure 71**, our solution could only support three users at maximum. During the trials in Bristol, we wanted to extend this scenario and add even more transcoders, so that our solution could support at least ten users simultaneously.

To validate the integration of the scale out mechanism in the 5GCity dashboard, we add more mobile devices until one of the buffer transcoders is occupied by at least one live stream. In such scenario, in which each transcoder VNF can process two live feeds, when three users are using our use case, the metric called **collector_ADD_MORE_TRANSCODERS** will be set to 1 in the controller VNF. This will be the trigger to deploy a new transcoder VNF, generating an alert called *IncreaseTranscoders* in 5GCity's Monitoring server.

After a while, the *IncreaseTranscoders* alert should appear in the 5GCity dashboard associated with a "React" button. This "React" button will allow performing the response action associated to the alert. In the case of the *IncreaseTranscoders* alert, the response action associated to it is to deploy a new transcoder VNF for MOG's use case. When the new transcoder VNF is deployed, the metric called **collector_ADD_MORE_TRANSCODERS** will be set to 0.

To validate the integration of the scale in mechanism in the 5GCity dashboard, we stop live feeds until the two last transcoders VNFs corresponding to the transcoder's pool size are completely free. When there are transcoding resources that can be freed, the metric **collector_DELETE_LAST_TRANSCODER** will be set to 1 in the controller VNF. This will be the trigger to delete the last transcoder VNF that was deployed, generating an alert called *DecreaseTranscoders* in the 5GCity's Monitoring server.

After a while, the *DecreaseTranscoders* alert should appear in the 5GCity dashboard associated with a "React" button. This "React" button will allow performing the response action associated to the alert. In the case of the *DecreaseTranscoders* alert, the response action associated to it is to delete the last transcoder VNF that was deployed for MOG's use case. When the transcoder VNF is deleted, the metric called **collector_DELETE_LAST_TRANSCODER** will be set to 0.

5.5.1.2 Bristol Trial – Outdoor Test Scenario

We will now describe the scenario used during the outdoor trials. During these tests, eleven mobile devices were distributed among the four access points included in the use case slice. The distribution of the eleven devices among the available access points is described below:

- Three devices connected to the AP in the east of *M Shed*;
- Three devices connected to the AP in the west of *M Shed*;
- Three devices connected to the AP in the south of the Millennium Square;
- Two devices connected to the AP in the University of Bristol.

The distribution of mobile devices among the available access points described above is depicted in **Figure 91.** In the trials in Bristol, the main objective was to start a live feed one by one on all the available devices until all of them were recording.

Figure 91 - Distribution of mobile devices among the available APs during the trials

To sum up, the most relevant validations that were made during these trials were:

- Test UC3 on several Wi-Fi access points, positioned in distinct points over Bristol city;
- Create several live transmissions using the available mobile phones;
- Watch the live transmissions using the switcher page;
- Publish the output feed selected in the switcher page to YouTube;
- Validate the integration of the scale out mechanism in the 5GCity dashboard;
- Validate the integration of the scale in mechanism in the 5GCity dashboard;
- Validate the scaling of our solution so that it supports at least ten users simultaneously.

5.5.2 Results Analysis

In this section, we will expose the relevant results we retrieved from the street trial performed in Bristol on the 7th of February 2020. Firstly, we will present the results for the validation of the basic operation of our use case and for the validation of the solution scaling mechanism. After that, we will report the generic and application-specific metrics collected during the trials and, finally, we will present and analyse the KPIs.

5.5.2.1 UC3 deployment & scaling validation

The deployment of the UC3 in the Bristol infrastructure was a success and its most relevant features were validated during the outdoor validation tests. It was also possible to distribute the mobile devices among the four access points as previously depicted in **Figure 91**. Additionally, it was possible to scale our solution several times so that our solution could support at least ten users simultaneously. In fact, the UC3 platform was able to support 11 live feeds being created simultaneously during the trial as can be seen in **Figure 92**.

Figure 92 - Switcher page with 11 live feeds and active YouTube feed

The live feed selected in the switcher page was also being sent to *YouTube* as seen in **Figure 93**.

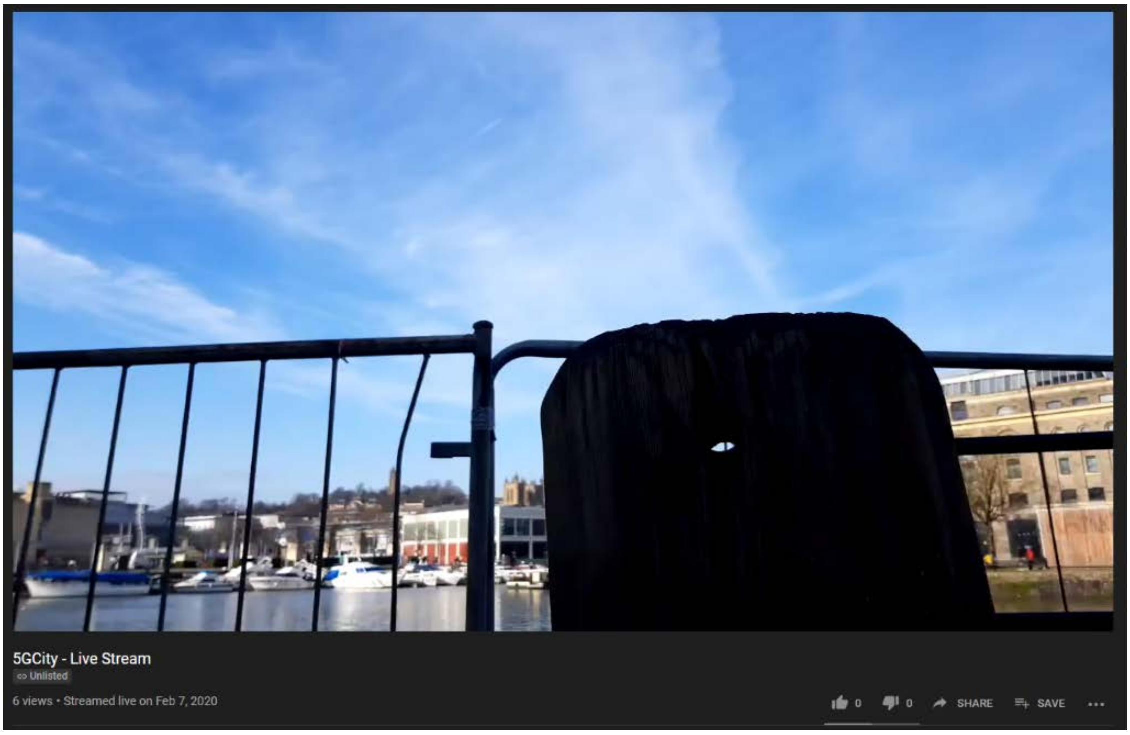


Figure 93 - *YouTube* feed created during the Bristol trial

In **Figure 94**, is demonstrated a user creating two live feeds, simultaneously, using MOG's use case.

Figure 94 - Team member creating two simultaneous live feeds during the Bristol trial

Before reporting the metrics collected during the trials in Bristol, we will report the results of the validation of the scaling mechanism using the 5GCity dashboard.

Firstly, it is important to mention that the initial deployment of use case 3 that was used during the trial had four VNFs: one controller VNF, one switcher VNF and two transcoders, named transcoder1 and transcoder2. The **Table 38** summarizes these values.

VNF Name	VCPUs	RAM (GB)	Disk (GB)	Image size (GB)
Controller	2	2	10	9,8
Switcher	2	2	4	2,8
Transcoder 1	2	2	10	8,0
Transcoder 2	2	2	10	8,0

Table 38 - Resources used for the initial deployment

For the first validation of the scale out mechanism, MOG simulated a scenario in which the transcoding resources were depleted with three users creating live streams simultaneously. After a while, we confirmed that the *IncreaseTranscoders* alert appeared in the "Alerts" page in the 5G City dashboard as can be seen in **Figure 95**.

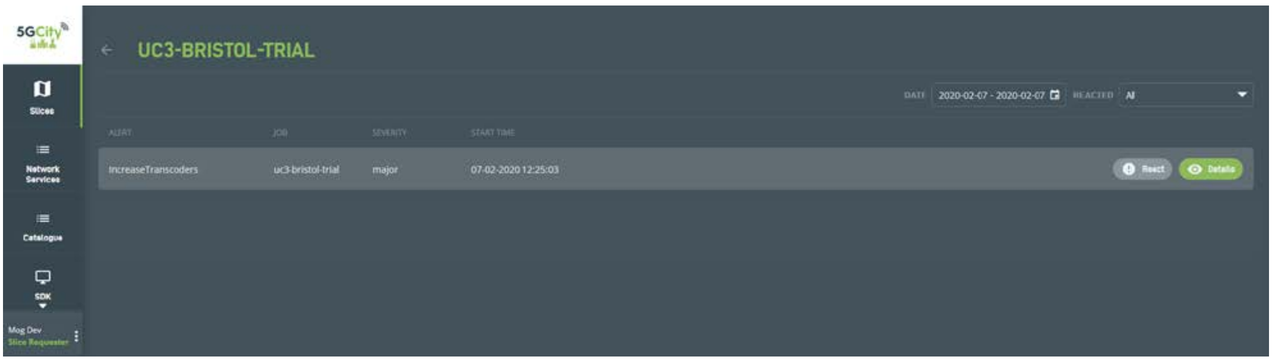


Figure 95 - *IncreaseTranscoders* alert in the 5GCity dashboard

When we pressed the "React" button associated to the alert, a new transcoder VNF was deployed with the same image and resources as the other transcoders. After a while, we saw the newly deployed transcoder in the Resource Manager GUI as seen in **Figure 96**. After the first scale out of our solution, we had 3 transcoder VNFs running that were able to process 6 live feeds simultaneously at maximum.

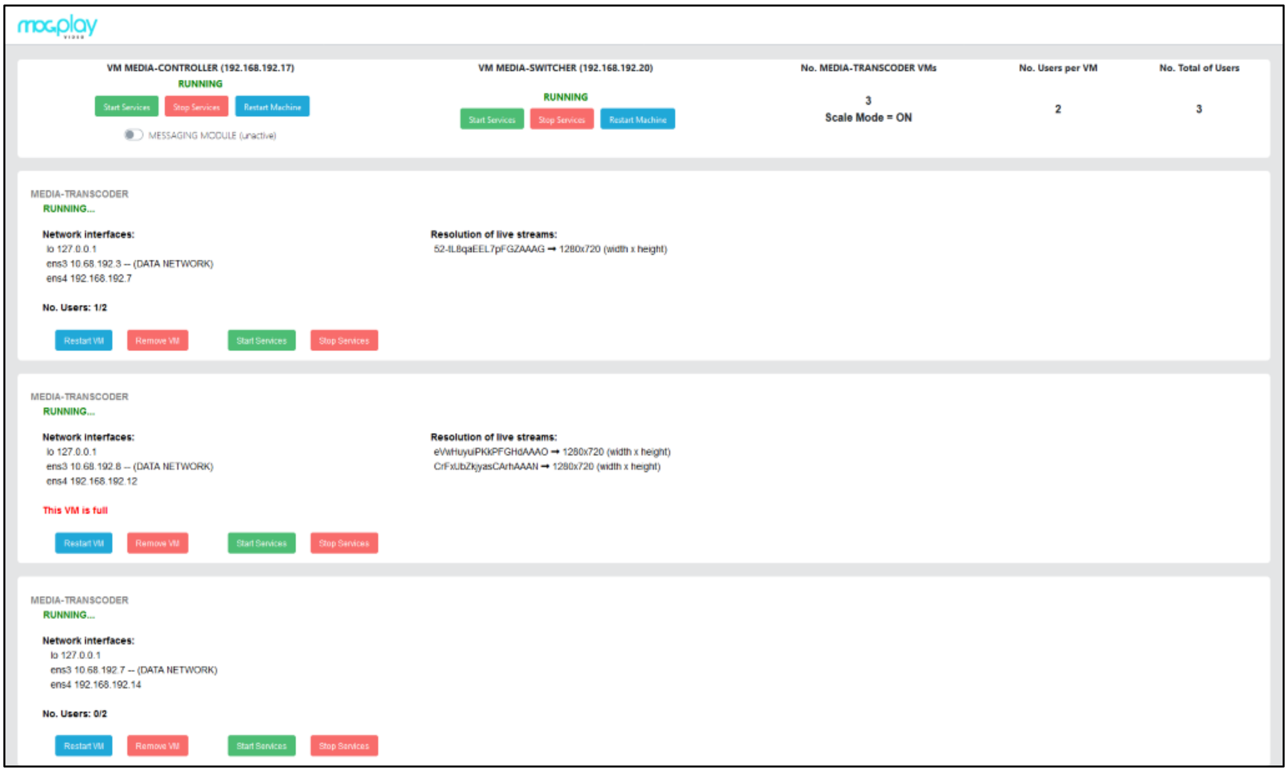


Figure 96 - Resource Manager GUI after performing the first scale out

After this, we repeated the process described previously until our use case could support all the 11 mobile devices and the *YouTube* feed. For this to be possible, we had to perform the scale out of our solution 4 times in a row. At the end, our solution had 6 transcoder VNFs that were able to process 12 live feeds simultaneously. In **Figure 97**, we can see the Resource Manager GUI with 11 live feeds being created simultaneously and the active *YouTube* feed. Note that the *YouTube* feed can also consume a lot of resources, so it counts as a transcoding slot, i.e., it counts as a user.

Note that the Resource Manager page shown in **Figure 97** depicts the resources that were being used by the live streams shown in the switcher page previously shown in **Figure 92**.

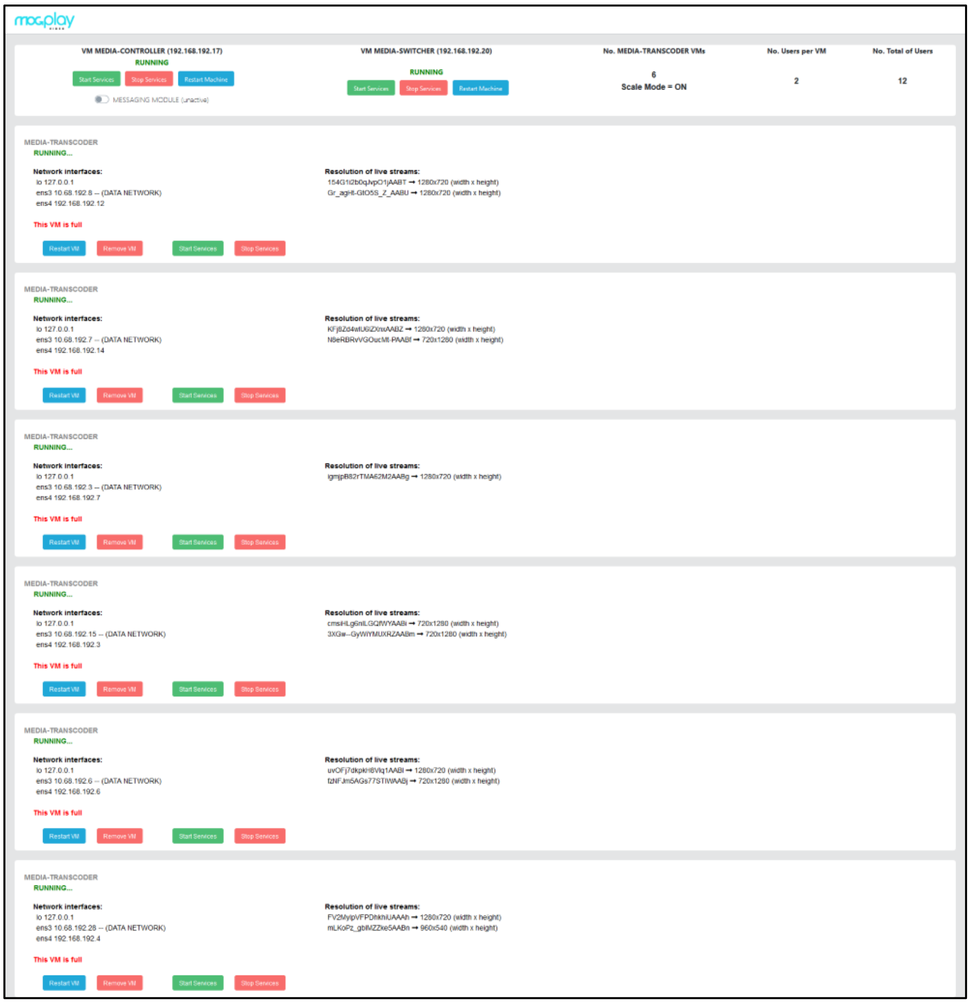


Figure 97 - Resource Manager GUI with 11 live feeds being created and active *YouTube* feed

After successfully validating the scale out mechanism, the next step was to validate the scale in process. For that purpose, the transcoding resources were freed from the last two transcoder VNFs that were deployed. That is, four live feeds from the last two transcoders were stopped. After a while, we confirmed that the *DecreaseTranscoders* alert appeared in the "Alerts" page in the 5G City dashboard as is shown in **Figure 98**.

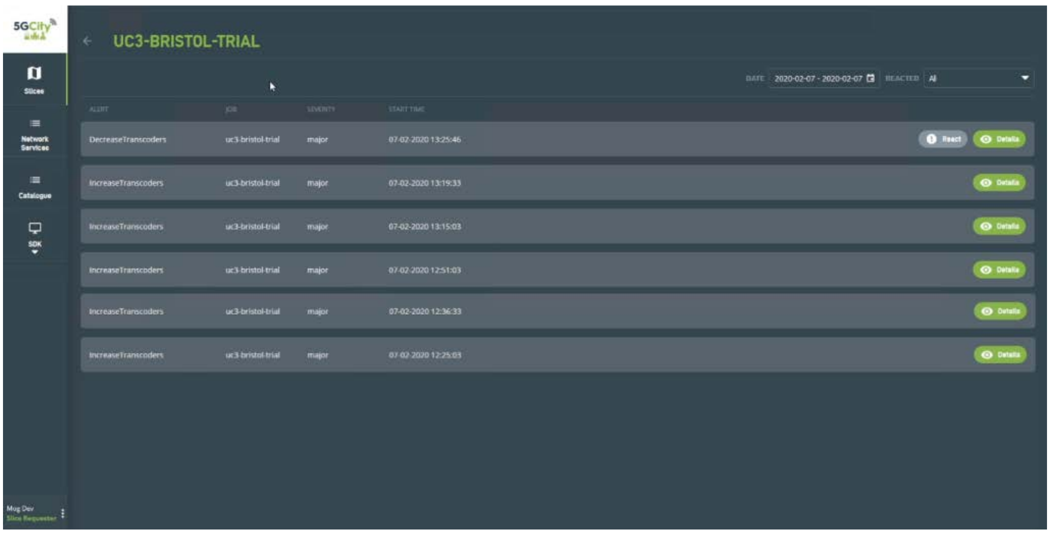


Figure 98 - Decrease*Transcoders* alert in the 5GCity dashboard

When we pressed the "React" button associated to the alert, the last transcoder VNF was deleted. As such, after scaling in our solution, we had 5 transcoder VNFs running that were able to process 10 live feeds simultaneously at maximum. In **Figure 99**, we can see the Resource Manager GUI with 5 transcoder VNFs after scaling in our solution. After all of this, one more scale in of our solution was performed. At the end of the trial, we had 4 transcoder VNFs running.

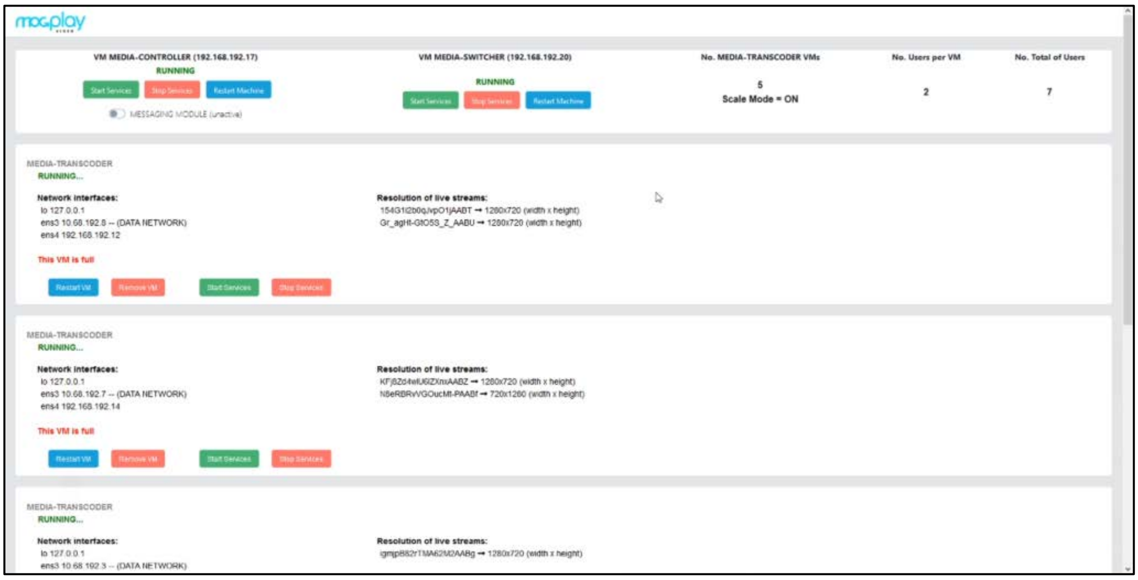


Figure 99 - Resource Manager GUI after scaling in MOG's use case

In short, we successfully validated the integration of the scaling mechanism in the 5GCity dashboard.

5.5.2.2 Generic & application-specific metrics

Regarding the generic metrics, the results collected during the experiment are presented below.

- **User experienced data rate**

As for the throughput achieved per mobile device, it is possible to identify the amount of bandwidth used with the help of **Figure 100**, in which the network throughput for the controller VNF is shown. Considering the peak that was hit by the inbound throughput Mbps when 11 live feeds were created is 143.04 Mbps, the bandwidth used per mobile device was approximately **2.05 Mbps** on average.

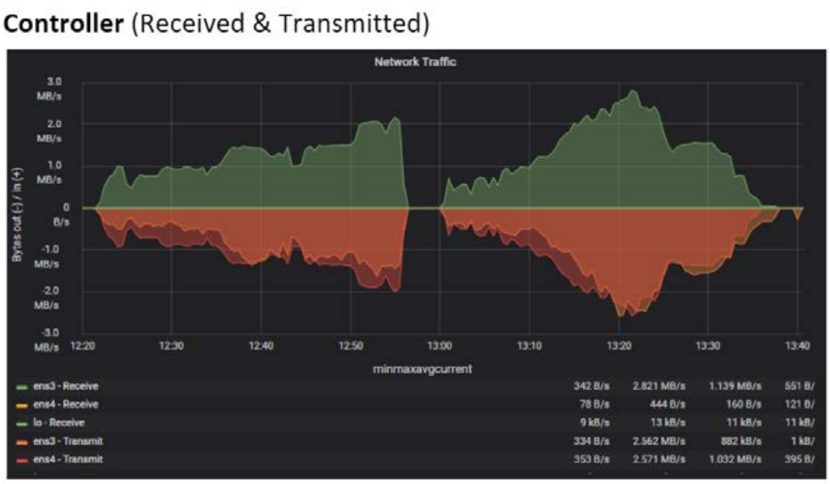


Figure 100 - Network throughput (inbound/outbound) of the controller VNF

- **Service latency**

For the service latency, we follow the methodology described at Section 5.3. As seen in **Figure 101**, the service latency is 1 second and 410 milliseconds. As for the *YouTube* delay, it increases to 4 seconds and 430 milliseconds, but *YouTube* also does some transcoding on their side and the value we measured also contains this transcoding step. The measurement made with the delay to *YouTube* is visible in **Figure 102**.

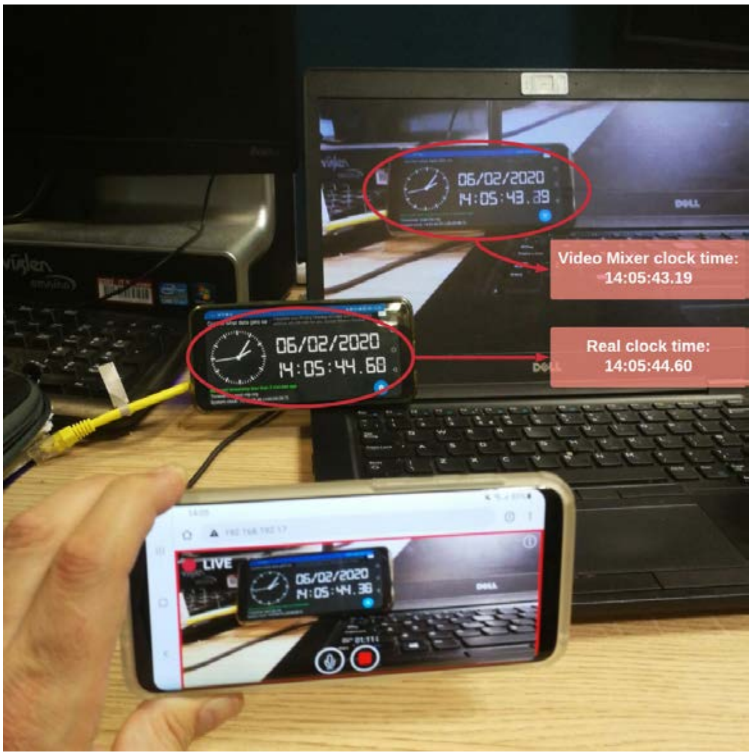


Figure 101 - Delay between the mobile device and the video mixer

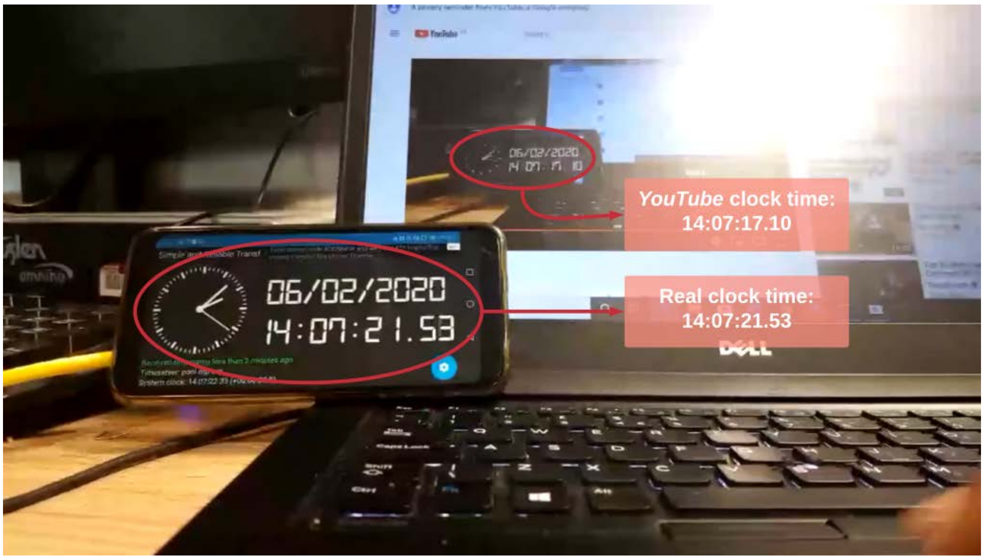
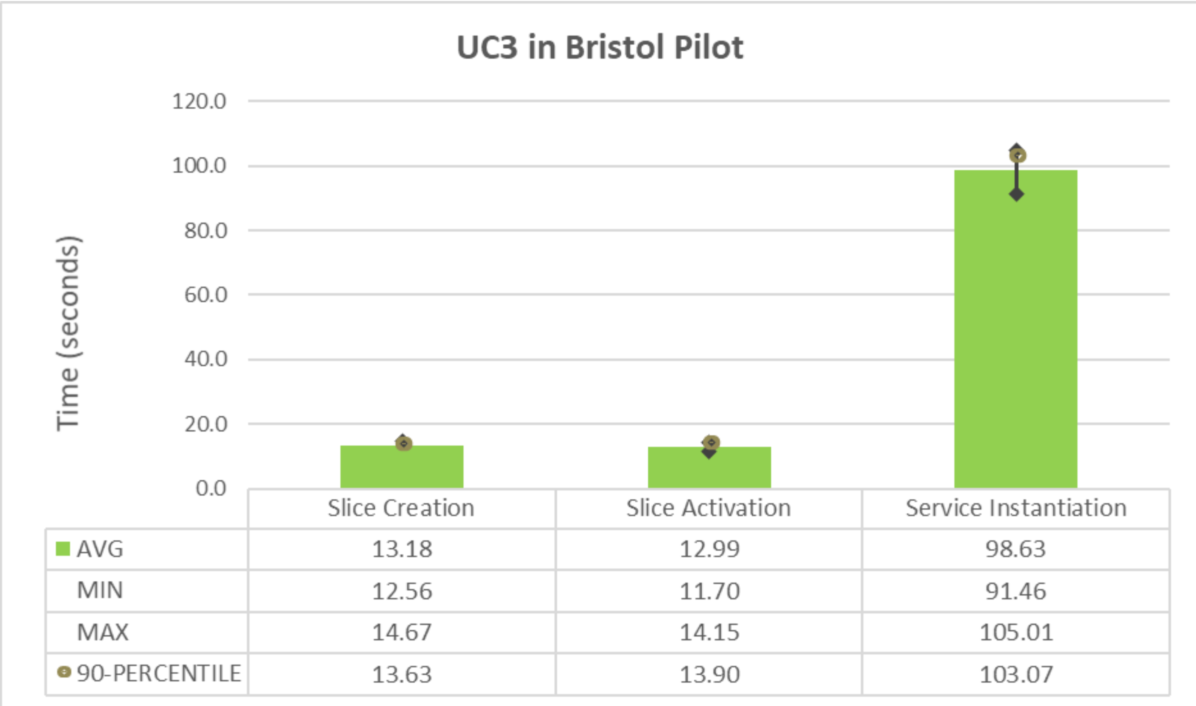


Figure 102 - Delay between the mobile device and the YouTube feed

- **Service instantiation time**

In **Figure 103,** we gather the results computed after running 30 iterations of the different operation performed by the automated script in order to complete the deployment of the UC3 network service. In particular, the average instantiation time achieved in the Bristol Pilot was 98.63 seconds, value that is under the target set for this KPI (i.e. 120 seconds).



	Slice Creation	Slice Activation	Service Instantiation
AVG	13.18	12.99	98.63
MIN	12.56	11.70	91.46
MAX	14.67	14.15	105.01
90-PERCENTILE	13.63	13.90	103.07

Figure 103 - Times required by the 5GCity platform to deploy the UC3 in Bristol pilot

Regarding the application-specific metrics, the results collected during the experiment are presented below. It should be noted that in the graphics presented below for the fifth and sixth transcoders, we only have information for a limited amount of time. This is the case because these two transcoder VNFs were deleted after scaling in our solution.

- **CPU usage per VNF**

The **Figure 104**, **Figure 105** and **Figure 106** depict CPU usage over time on all the VNFs of MOG's use case. In all the referred figures, we verify that the CPU usage increases when more users create live feeds. By comparing the CPU usage of the transcoder VNFs with the controller and switcher VNFs, we can verify that the transcoders consume much more resources than the other two types of VNFs. In fact, the transcoders consume 70% to 90% of the CPU when processing live feeds. The only transcoder that does not consume that much amount of CPU is the 3rd transcoder that is also responsible for the YouTube feed, which consumes less resources.

Controller

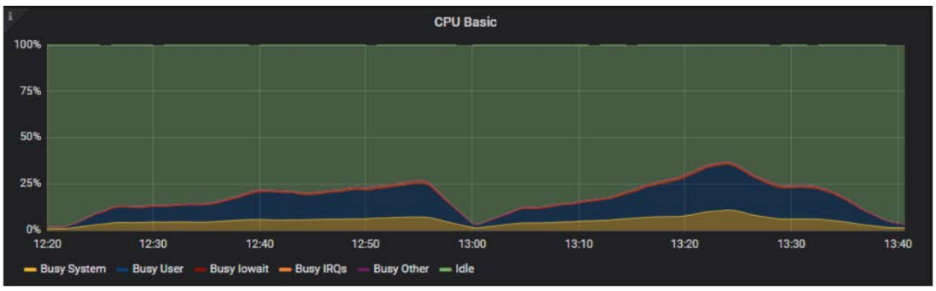


Figure 104 - CPU usage on the controller VNF

Switcher

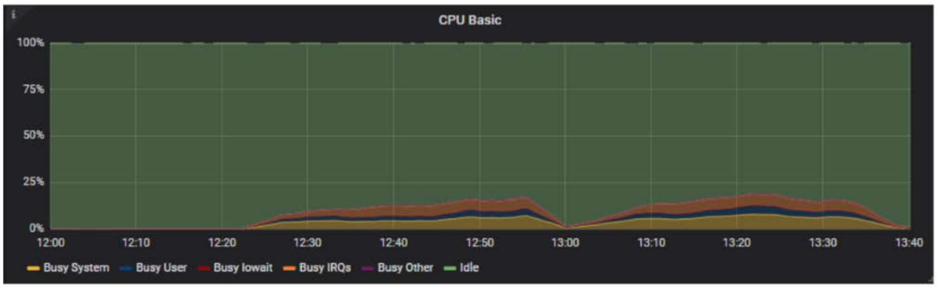


Figure 105 - CPU usage on the switcher VNF

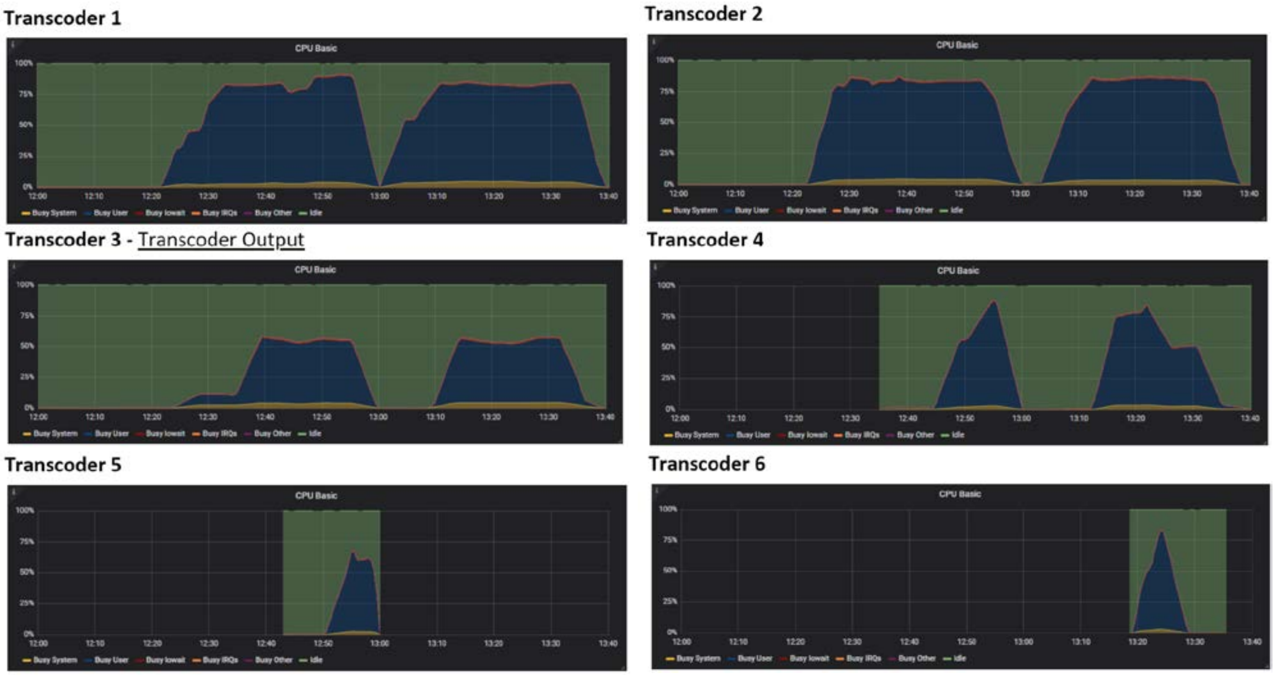


Figure 106 - CPU usage on the six transcoder VNFs

- **RAM usage per VNF**

The **Figure 107**, **Figure 108** and **Figure 109** depict RAM usage over time on all the VNFs of MOG's use case. The RAM consumption does not change much over time, especially when comparing it to CPU usage. We can only verify slight increases in RAM usage on the transcoders when more users added to our platform.

Controller

Figure 107 - RAM usage on the controller VNF

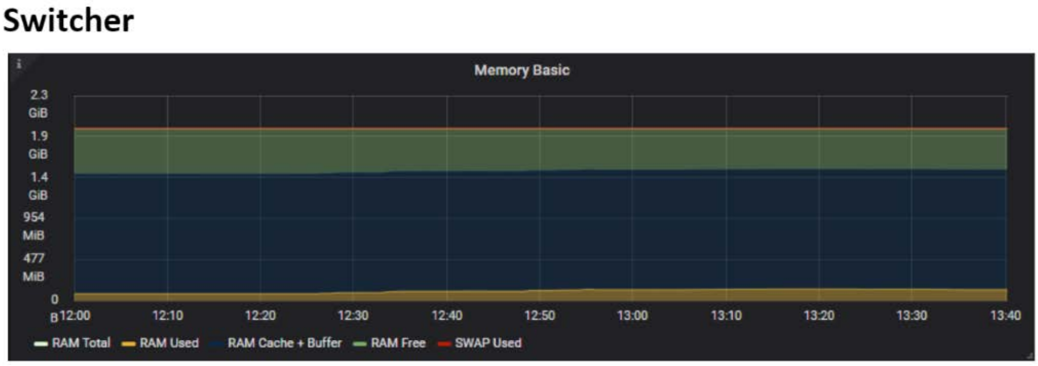


Figure 108 - RAM usage on the switcher VNF

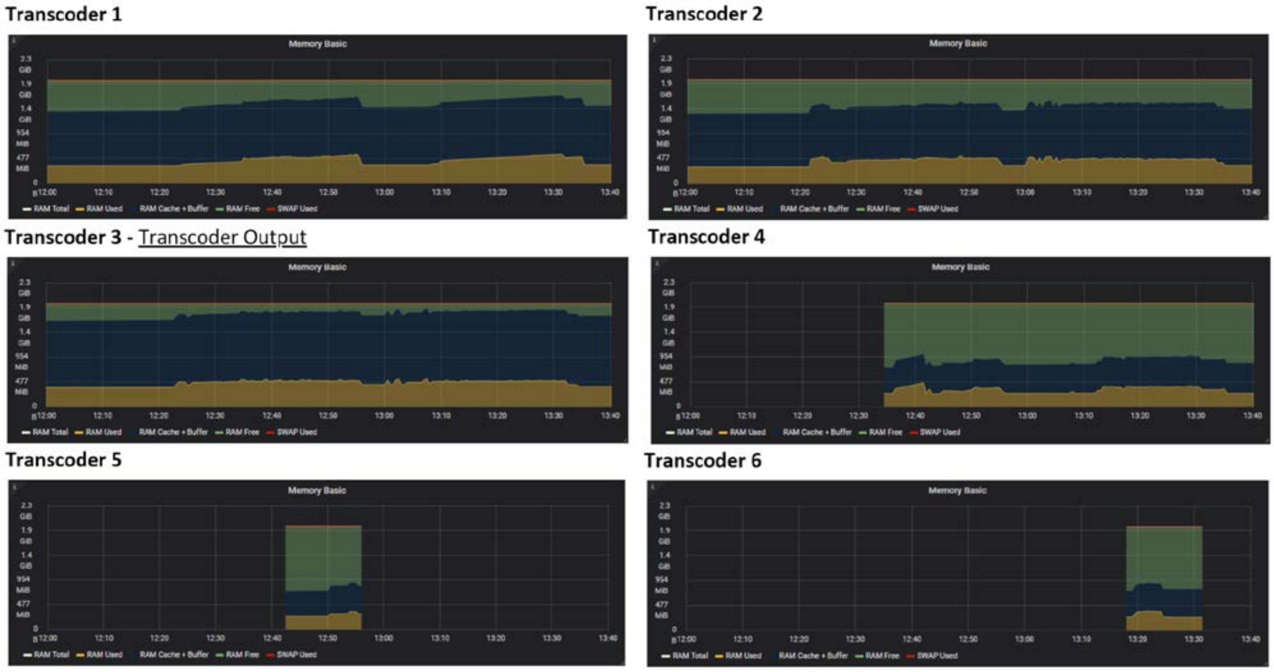


Figure 109 - RAM usage on the transcoder VNFs

- **Network throughput of each VNF**

Network data rate is pictured on **Figure 100**, **Figure 110** and **Figure 111**. As we can see in all graphics, it is possible to observe that the amount of network throughput increases when more users enter in the platform. Additionally, there is a time span in which all streams are stopped from 12:57 to 13:00. Below, we will analyse the network throughput for each type of VNF.

- **Controller** - The network throughput for the controller VNF was previously pictured in **Figure 100**. The controller VNF is the entry point for the live feeds so it receives the data directly from the mobile devices. The peak data rate of the controller VNF is 2.821 MB/s corresponding to 22.568 Mbps. This peak was hit when 11 live streams were feeding the controller VNF simultaneously around 13:30.

- **Switcher** - The network throughput for the switcher VNF is pictured in **Figure 110**. The switcher VNF receives the live feeds from the transcoders after they are processed. The switcher VNF also provides the live feeds to the switcher GUI and the mixer feed that is sent to *YouTube*. The peak data rate of the switcher VNF is 17.88 MB/s corresponding to 143.04 Mbps. This peak was hit when 11 live feeds were created. This means that playing each live stream on the switcher GUI consumed on average 13 Mbps of the network bandwidth. It is also important to note that the outbound network throughput varies depending on the live feeds being played on the switcher page at a time.

Switcher (Received & Transmitted)

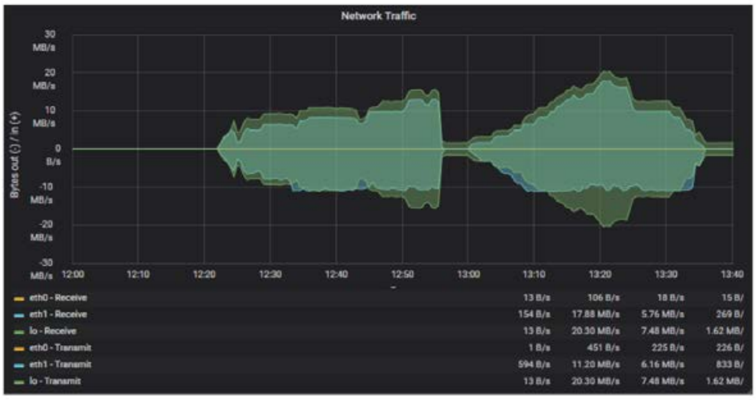
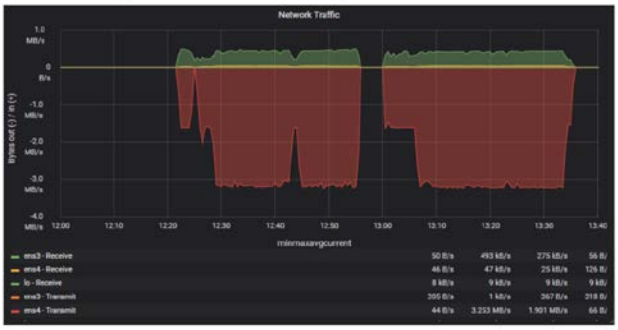


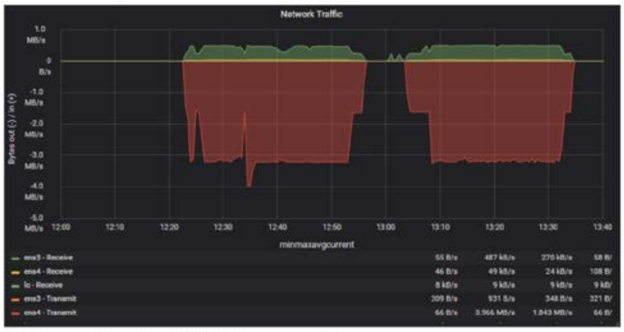
Figure 110 - Network throughput (inbound/outbound) of the switcher VNF

- **Transcoders** - The network throughput of the transcoders in pictured on **Figure 111**. As it can be seen on all transcoders, the inbound throughput is much lower than the output throughput. That is because the transcoders receive the data of the live feeds from the controller VNF (around 2 Mbps per stream) and processes each live feed, which typically increases the video throughput. The only transcoder with higher inbound throughput is the 3rd transcoder which also receives the feed to relay to *YouTube*.

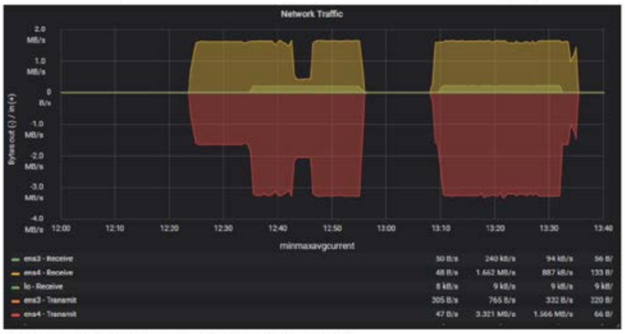
Transcoder 1 (Received & Transmitted)



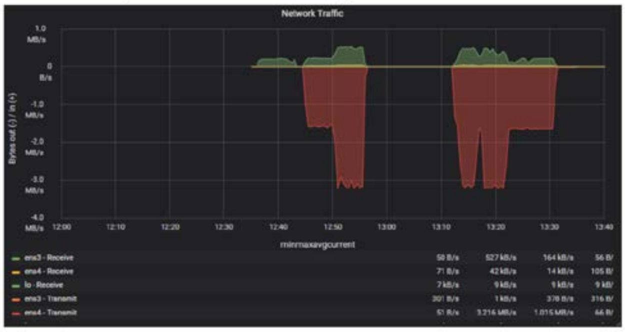
Transcoder 2 (Received & Transmitted)



Transcoder 3 (Received & Transmitted) - Transcoder Output



Transcoder 4 (Received & Transmitted)



Transcoder 5 (Received & Transmitted)

Transcoder 6 (Received & Transmitted)

Figure 111 - Network throughput (inbound/outbound) of the transcoder VNFs

An overview of the most relevant generic metrics is presented on **Table 39**. The values present in the table refer to the time span in which 11 live streams were created simultaneously with the active *YouTube* feed.

Metrics		CPU Usage	RAM Usage	Peak Data Rate (Inbound)	Peak Data Rate (Outbound)
VNF	*Controller*	38%	29%	22,56 Mbps	20,48 Mbps
	Switcher	22%	19%	143,04 Mbps	89,6 Mbps
	Transcoder 1	82%	25%	3,85 Mbps	26,00 Mbps
	Transcoder 2	89%	26%	3,80 Mbps	31,76 Mbps
	Transcoder 3	53%	29%	15,12 Mbps[11]	26,56 Mbps
	Transcoder 4	78%	24%	4,12 Mbps	25,68 Mbps
	Transcoder 5	85%	22%	4,10 Mbps	25,76 Mbps
	Transcoder 6	88%	23%	3,93 Mbps	25,84 Mbps
Total	---	---	---	**200,52 Mbps**	**271,68 Mbps**

Table 39 - Maximum CPU/RAM usage and network throughput with 11 live streams and *YouTube* feed

- **Use case uptime**

The use case was running for 2 days, 2 hours and 44 minutes until the end of trial on 7th of February 2020. The use case started running on 5th of February 2020. The use case was running for so long due to the indoor tests carried out before the outdoor trials.

- **Number of VNFs running**

In the initial deployment, UC3 had **four VNFs running** as was described previously in **Table 38**. After scaling out our solution four times in a row, UC3 had **eight VNFs running**: one controller VNF, one switcher VNF and six transcoder VNFs. The resources in use after scaling our solution are listed in **Table 40**.

VNF Name	vCPUs	RAM (GB)	Disk (GB)	Image size (GB)
Controller	2	2	10	9,8
Switcher	2	2	4	2,8
Transcoder 1	2	2	10	8,0
Transcoder 2	2	2	10	8,0
Transcoder 3	2	2	10	8,0
Transcoder 4	2	2	10	8,0
Transcoder 5	2	2	10	8,0
Transcoder 6	2	2	10	8,0
TOTAL	**16**	**16**	**74**	**60.6**

Table 40 - Maximum amount of resources used after scaling

[11] This VNF was also handling the output signal to feed *YouTube*. The amount of bandwidth was about 15,12 Mbps and it can be decomposed with 1,84 Mbps from the UE and 13,28 Mbps from the selected feed from the switcher VNF.

- **Number of users**

Figure 112 shows the number of live feeds that were processed using our use case over time. Note that the *YouTube* feed counts as a live feed since it can also consume a large amount of resources. The maximum number of users of our use case was 12 users and it was achieved from 13:20 to 13:25 as can be in **Figure 112**.

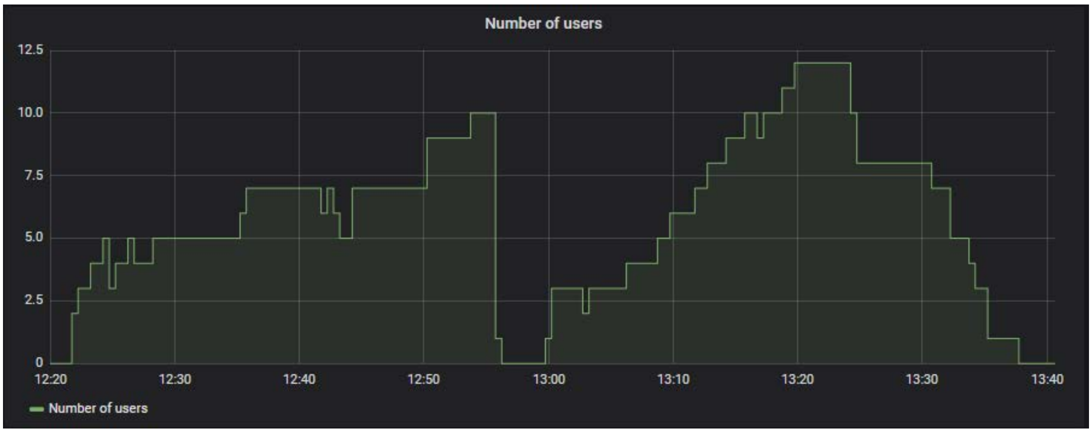


Figure 112 - Number of users using UC3 over time

- **Number of free transcoding slots**

Figure 113 depicts the amount of resources that were used over time. When the number of free transcoding slots reached 0, it meant that all transcoder VNFs were out of resources. Note that the maximum number of free transcoding slots varies over time due to scaling out and scaling in our solution several times.

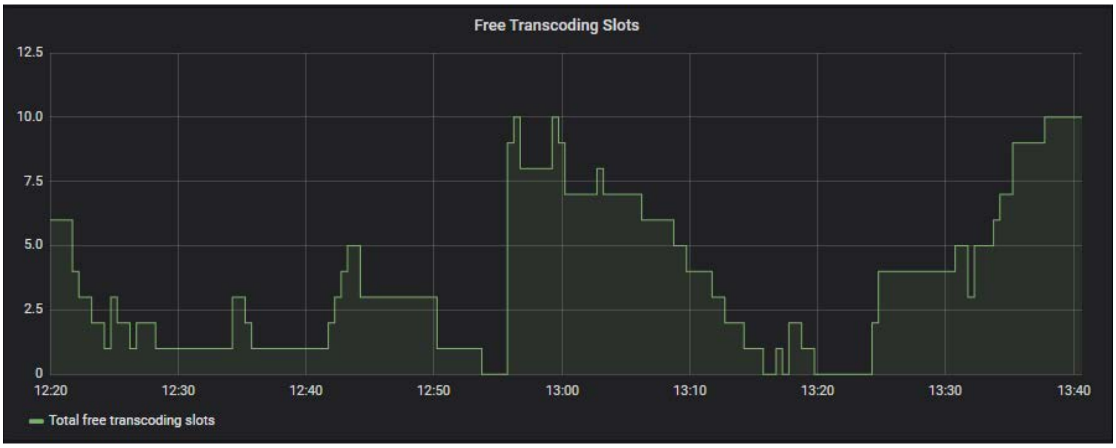


Figure 113 - Number of free transcoding slots over time

- **Video resolution**

UC3 did a good job to scale all the video essences to the standardized video resolution of 1280 x 720 pixels. The **Figure 114** summarize the values collected during the tests. Most of the devices sent video at 1280 x 720 or 720 x 1280 pixels, so, in HD resolution. Also is possible to understand in the graphs when the user changed the orientation of the device. In **Figure 114,** an example of orientation change is highlighted.

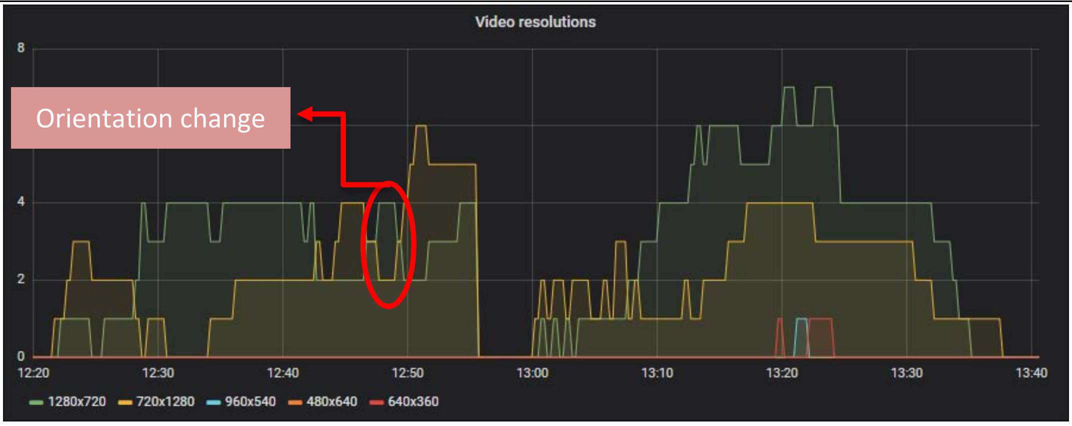


Figure 114 - Video resolution of acquired scenes

- **Video codecs**

Figure 115 shows the video codecs of the created live feeds. As seen in the referred figure, almost all devices used the H.264 video codec, except one device that entered at 13:20. This device is the only one that used the VP8 video codec during the trials in Bristol.

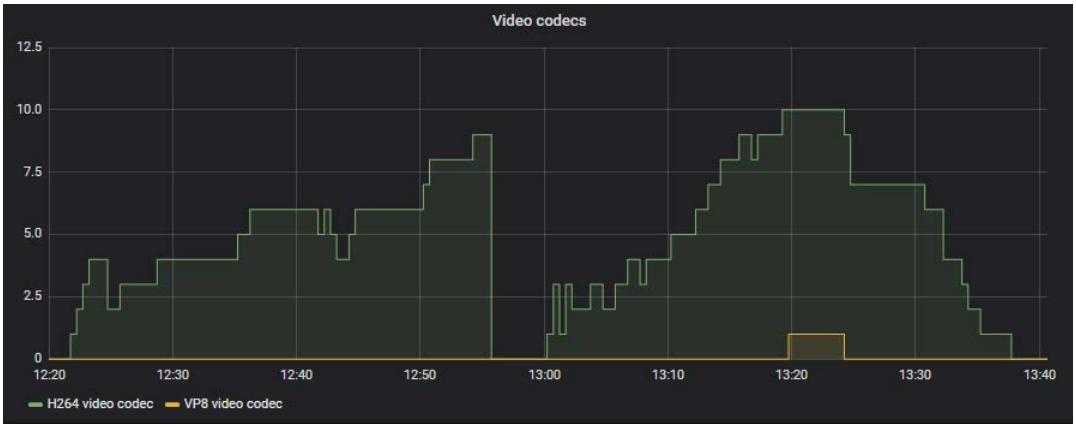


Figure 115 - Video codecs of the live feeds created over time

- **Audio codecs**

Figure 116 shows the audio codecs of the created live feeds. As seen in the referred figure, all devices used the OPUS audio codec.

Figure 116 - Audio codecs of the live feeds created over time

- **Transcoder scaling time**

Figure 117 shows the statistics obtained for TST after 30 consecutive iterations. The average result achieved in the Bristol pilot is **38.74 seconds**, value that is under the target set for this KPI (i.e. 60 seconds).

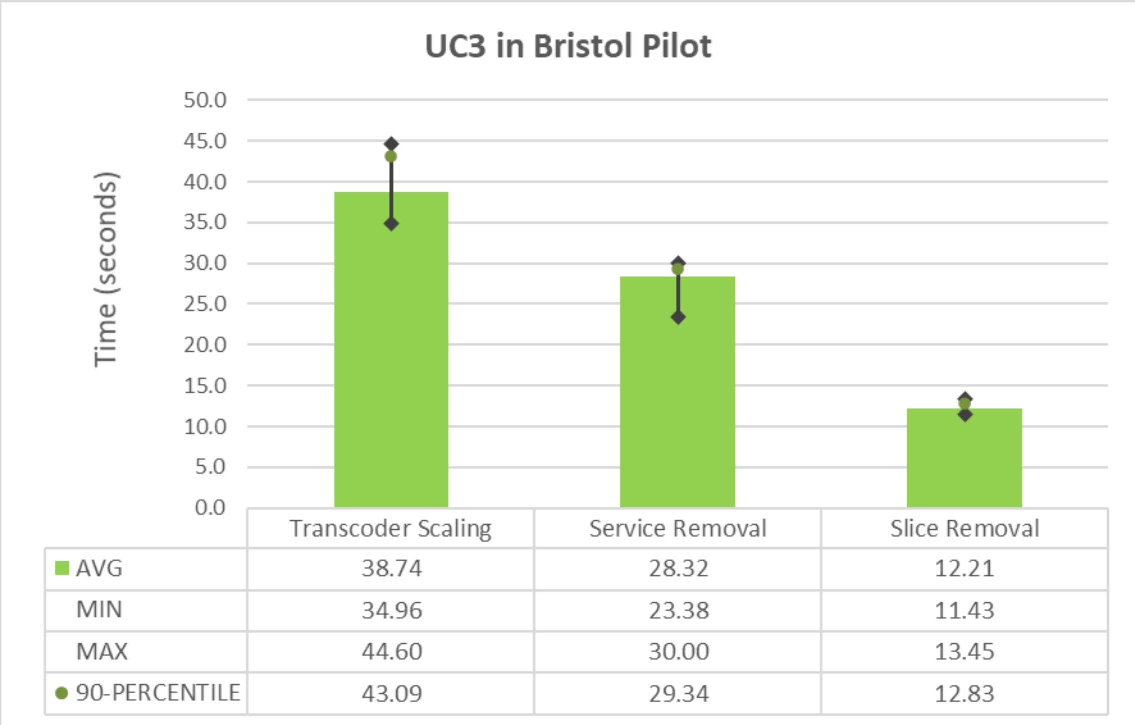


Figure 117 - Transcoder Scaling Time in Barcelona pilot

Table 41 summarizes the results collected during the trial with respect to their respective target values. In general, the values we collected during the trials are aligned with the values we set for the UC3 KPIs, meaning that all the targets were successfully reached.

KPI	Target	Measurement
Video Resolution	1280x720	1280x720
User Experienced Data Rate	2-8 Mbps per mobile device	≈ 2.05 Mbps
Service Latency	<= 2.5 s	1.41 s
Service Instantiation Time (SIT)	<= 120 s	98.63 s
Transcoder Scaling Time (TST)	<= 60 s	38.74 s

Table 41 - UC3 KPI results in Bristol Pilot

The value obtained to the latency KPI is within the threshold defined for it and the value obtained during the Bristol trials was reduced by a second when compared to the KPI obtained in Barcelona (which is 2.32 seconds). The values obtained for the video resolution KPI were also achieved and almost all the video streams obtained from the UEs were HD as well.

6. UHD Video Distribution and Immersive Services Use Case Trials (UC4)

The UHD Video Distribution and Immersive Service Use Case is aimed to develop an application that uses Mixed Reality, user movement tracking and computer vision algorithms to create an augmented tourist guide that can work both indoors and outdoors. The immersive part of the use case could be arranged in order to allow the end-user moving in a city to obtain additional content related to the surrounding environment (monuments, objects, etc.) by using smartphones and/or Hololens-like devices. With the production of 360° video contents, we improve the immersivity of the user in the show. The service diagram for the UC4 is shown in **Figure 118**.

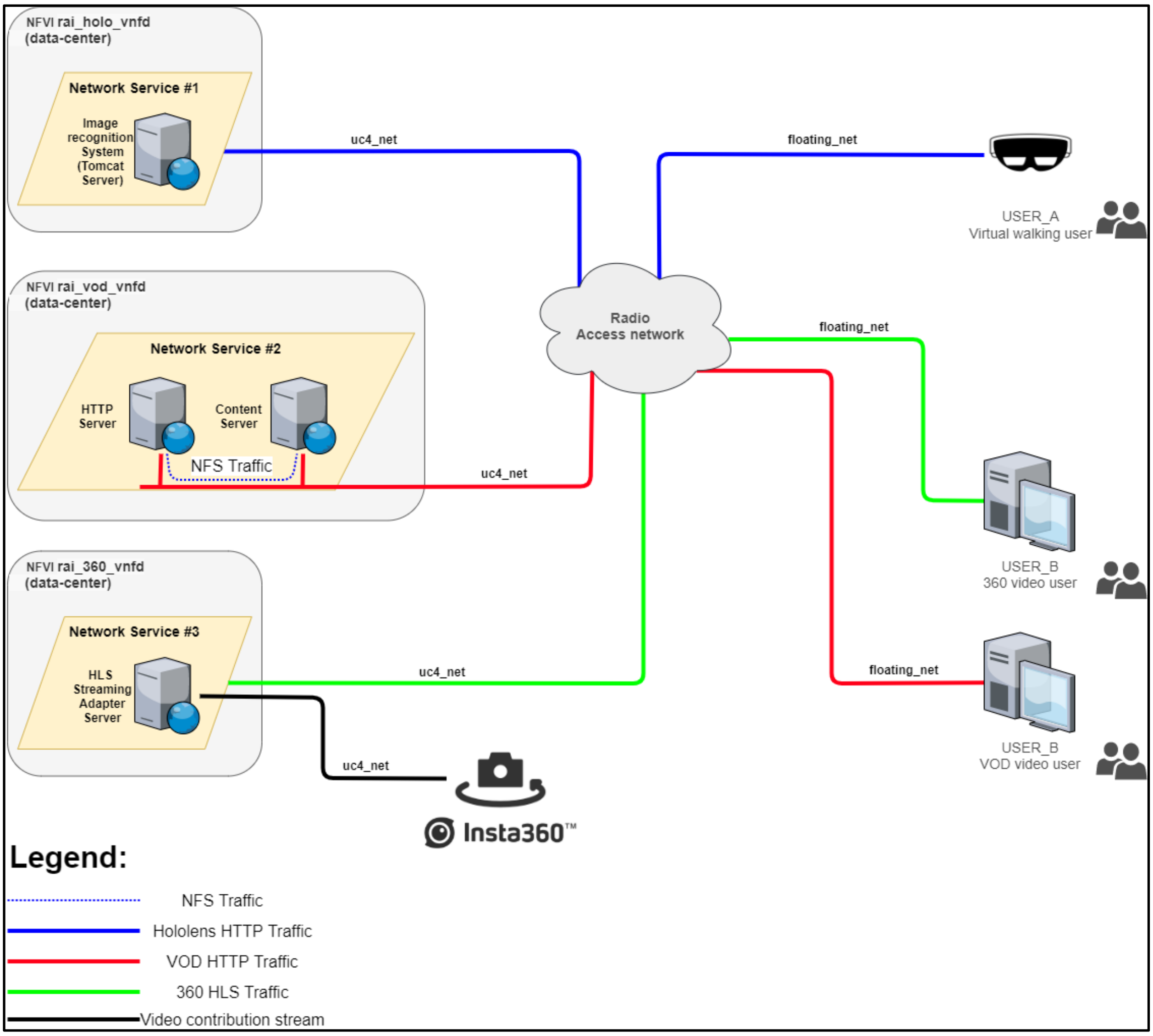


Figure 118 - Service diagram for UC4

This use case is formed by three NS, which are described next.

- **NS#1 (rai-holo):** This service is dedicated to the image recognition and description of the augmented reality experience. Leveraging on Hololens augmented reality capabilities, this service will provide a monument recognition system that is capable to enhance users' journey of cities. The developed software for this particular service is a two-part application, one running in the backend server (VNF) and one on HoloLens device. The VNF receives images from HoloLens and, leveraging a CDVS image search, provides the related media content (see **Figure 119**). On the VNF side, we have a Tomcat 8 Apache Tomcat/8.0.32 with a Java-Spring API application and an image recognition system based on Mpeg CDVS. On the HoloLens device, we have onboarded a Rai software, developed mainly with Unity Game Engine 2017.4, with Holo-toolkit SDK and Vuforia library.

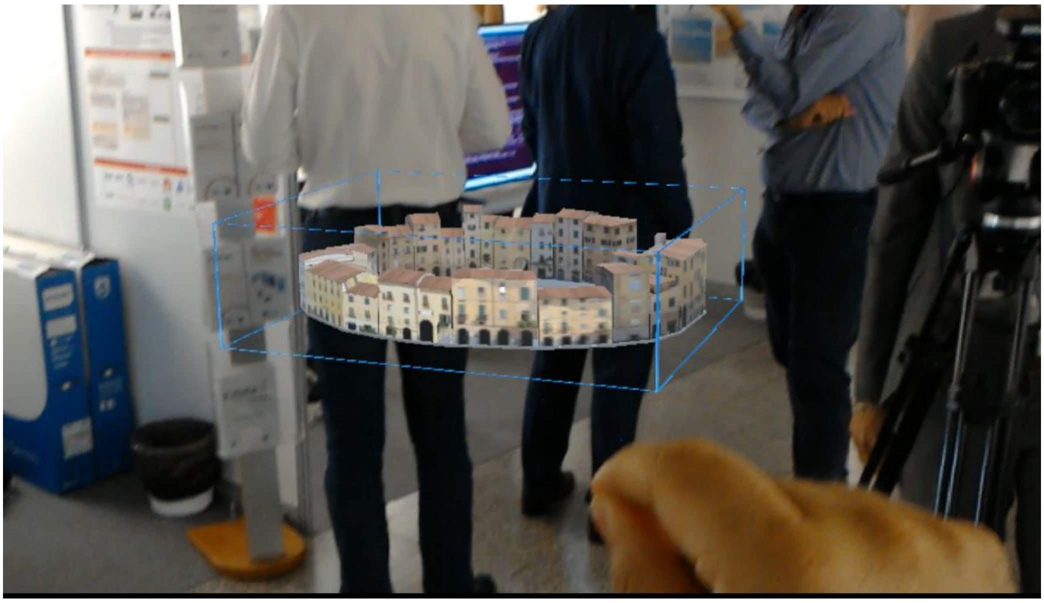


Figure 119 - Example of manipulation with during our demo at EUCNC19 in Valencia

- **NS#2 (rai-vod):** This service is dedicated to leverage on demand 360° immersive video and 360° interactive virtual tour. The VNF composing this service involves two components, namely: rai-vod-cloud that hosts an http-server used to access and stream the immersive 360° content, and rai-vod-content that hosts the repository of 360° contents in order to share the actuals files to the http-host. A set of UHD 360° contents has been produced in Lucca and Bristol cities and stored in the aforementioned repository. In order to maximise the portability and compatibility, the service is realized as web portal where the user can start the VoD experience as shown **Figure 120**.

Figure 120 - 360° virtual tour of Bristol city

- **NS#3 (rai-360):** This service is related to Live 360° video streaming. In essence, a 360° live stream is produced by an Insta360 Pro camera and packed into HLS protocol (see **Figure 121**). In order to maximize the portability of the system we developed a web portal with a 360° player. Therefore, the VNF composing this service includes an http server and a service based on FFmpeg software that takes care of connecting to the live 360° video stream and packing it in HLS protocol.

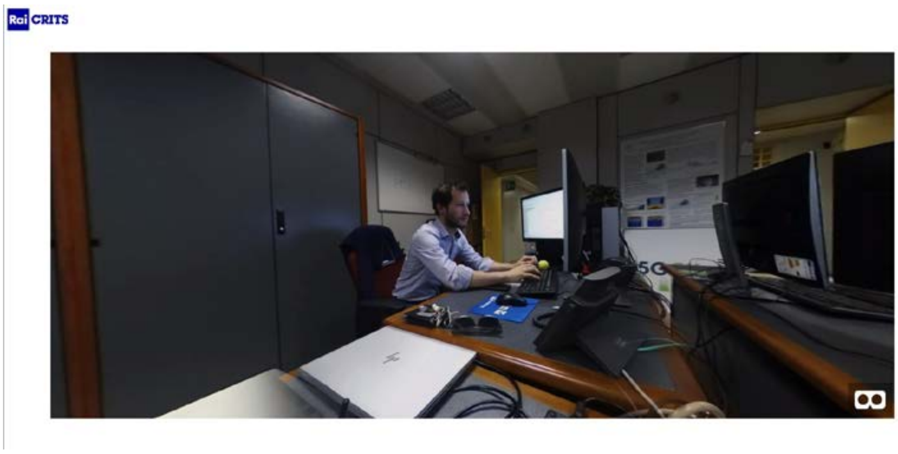


Figure 121 - Sample 360° laboratory stream

6.1 Use case deployment using the 5GCity platform

In order to deploy the UC4 using the 5GCity platform, the first step was the creation of the different VNFs and NSs with the help of the 5GCity SDK. The resulting VNFs and NSs can be observed in **Figure 122** and **Figure 123,** respectively, as presented in the 5GCity Dashboard.

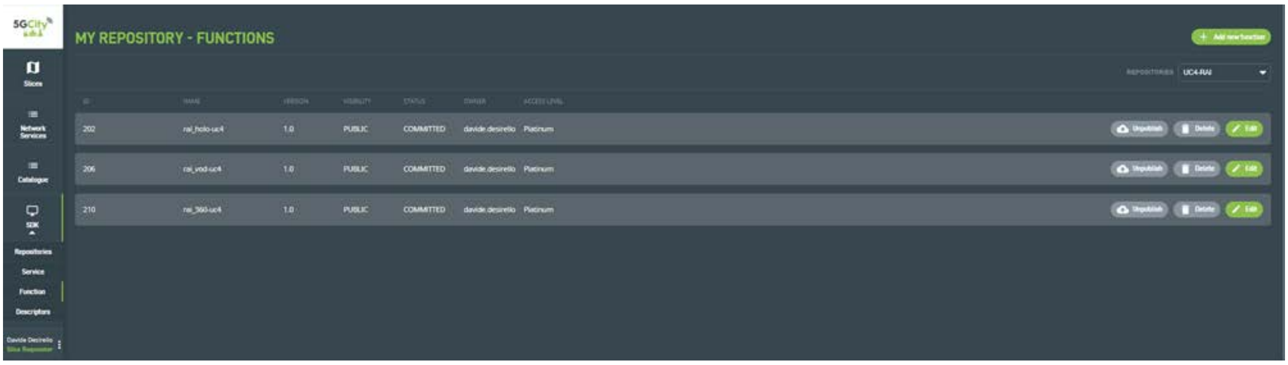


Figure 122 - UC4 functions created using the 5GCity platform

Figure 123 - UC4 network services created using the 5GCity platform

Next, an isolated slice is delivered to host the services developed for this use case. In **Figure 124**, we can see the UC4 slice in the 5GCity Dashboard, together with the location of the selected slice components in each one of the pilots where this use case is validated (i.e. Bristol and Lucca).

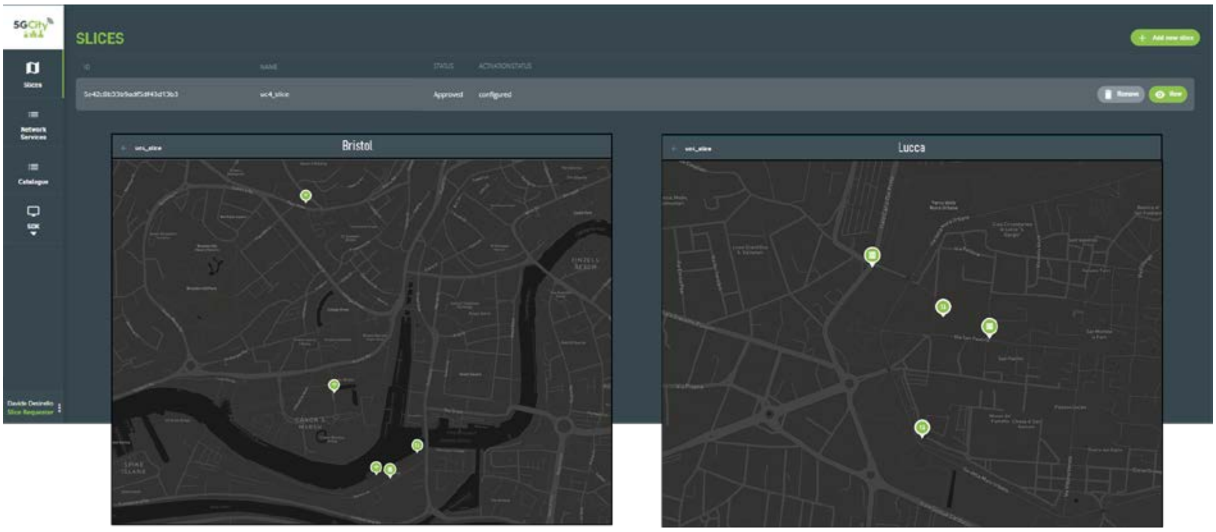


Figure 124 - Slice created for UC4 with location of nodes over the map in both cities.

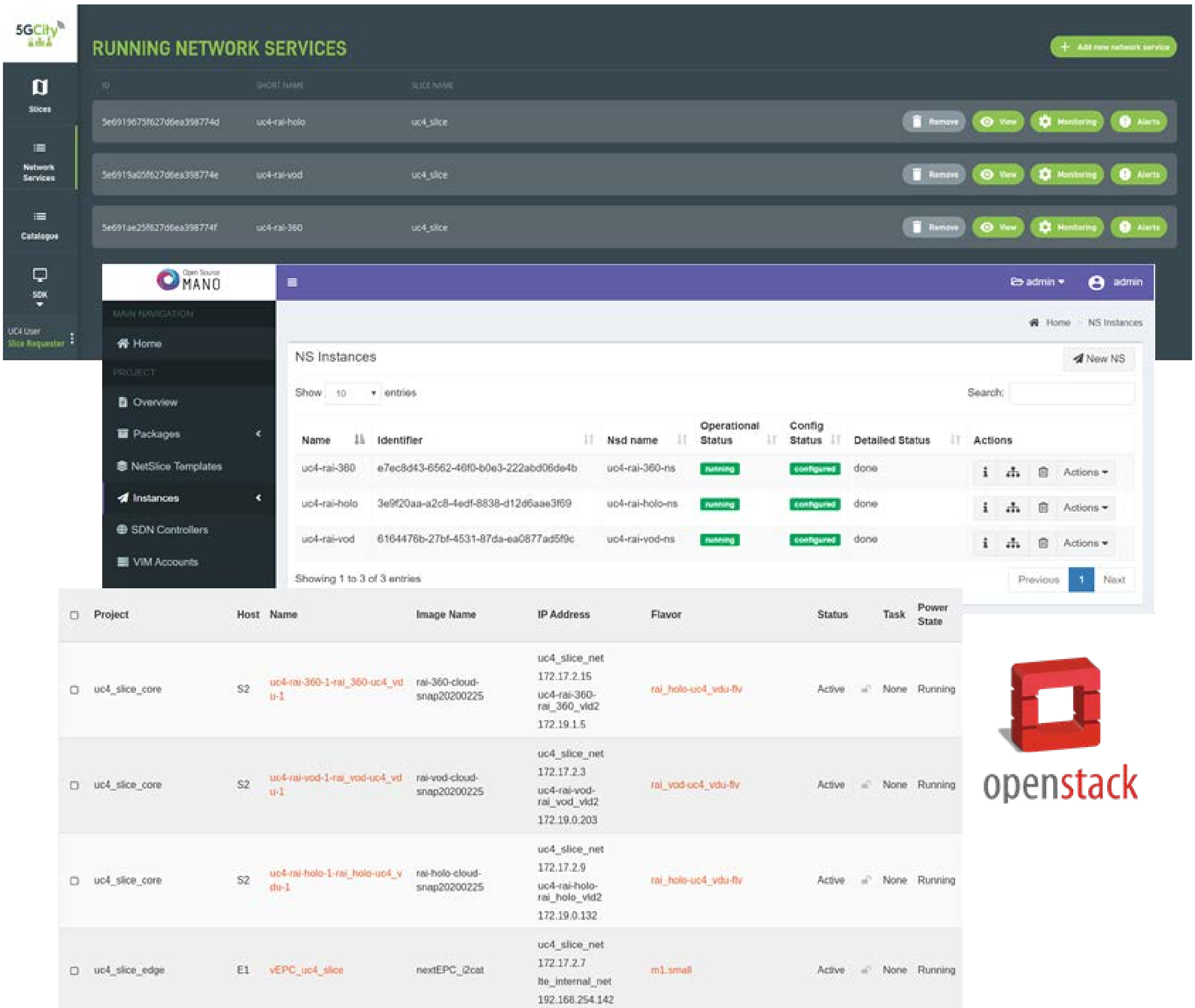


Figure 125 - View of the deployed UC4 in the 5GCity Dashboard, OSM and OpenStack

In **Figure 124**, it can be noted that the composition of the both slices differs between the two pilots. More details about these two scenarios used for the UC4 validation in each city will be given in Sections 6.4 and 6.5 for Bristol and Lucca pilots, respectively.

Once the services and the slices were available, the instantiation of the service over the corresponding slice was conducted. The successful instantiation of the UC4 services can be corroborated in **Figure 125,** in which we can see the services running in the 5GCity Dashboard and in OSM, as well as the different VMs created in OpenStack. In the referred figure, we can also appreciate that in addition to the different VNFs composing the services, a vEPC was deployed, which is automatically launched by the platform after the slice activation to support LTE as radio access technology.

6.2 Considered Metrics and KPI

The metrics collected during the UC4 trial can be divided in two categories: **generic metrics** and **application-specific metrics**.

The generic metrics for the UC4 are summarized in **Table 42**.

Generic Metric	Description
User Experienced Data Rate	Relevant for two of the NS composing the UC4: a) Throughput used during the real time transmission of 4K video. b) Throughput used when a VoD is displayed over a single device.
Service Latency (HoloLens NS)	The service latency is calculated from the call of the HoloLens device to the response from the relevant VNF. This metric is therefore the result of call time + calculation time.
Service Instantiation Time (SIT)	Time when the service is ready to start the use case.

Table 42 - UC4 generic metrics

The application-specific metric considered for UC4 that was collected during the trials is outline below in **Table 43**.

Application-specific Metric	Description
Real Time Video Buffering	The video Buffering used during the real time transmission of 4K video to understand the quality of the transmission.

Table 43 - Application-specific metrics considered for the UC4 trials

It is also important to define the KPIs for our platform to gauge whether the use case objectives were met or not. Taking into account the aforementioned metrics, the KPIs we set to measure the performance of our application are listed below in **Table 44**.

KPI ID	Definition	Description	Target	Priority [H/M/L]
UC4_KPI#1	**User experienced data rate**	Throughput used during the real time transmission and VoD.	**>= 15 Mbps**	H

UC4_KPI#2	**Real Time Video Buffering**	Buffering size used during the real time transmission of 4K video.	**> 20 s**	H
UC4_KPI#3	**HoloLens service latency**	Delay between the call from HoloLens device, plus the process time.	**<= 500 ms**	H
UC4_KPI#4	**Service Instantiation Time (SIT)**	Amount of time (seconds) needed to have the entire use case up and running.	**<= 120 s**	M

Table 44 - KPIs considered for UC4

6.3 Measurement Methodology

In this subsection, we describe the measurement methodology used during the execution of the tests designed to validate the UC4 operation. In general, we performed all the tests using a smartphone provided by the consortium, which was equipped with the corresponding SIM card and connected via LTE to the 5GCity small cells that were included in the UC4 slice deployed in each city testbed.

In order to record the metrics, we want to test we used the 5GCity Monitoring service offered by the platform. The VMs used in our NS are provided with Node Exporter in order to collect general metrics like CPU, RAM, Disk, I/O and NIC bandwidth used. We customized ours VNF virtual machines with additional exporters. **Table 45** summarizes the exporter installed in each VM.

VM	Node Exporter	Apache Exporter	Tomcat Exporter
uc4-rai-holo-ns	X	X	-
uc4-rai-vod-ns	X	X	-
uc4-rai-360-ns	X	-	X

Table 45 - Installed exporter per NS *(X represent installed)*

For others metrics, such as the service latency for the HoloLens service (i.e. NS#1), as well as for the user experienced data rate and buffering time for the HLS stream service (i.e. NS#3), we used a JavaScript client approach. Given that every VNF has, in addition to the server side, a client-side, two custom scripts were also used to measure all the important metrics on client side.

For the assessment of the service latency of the HoloLens service in Bristol and Lucca, the JavaScript software wrote to test the system allowed us to leverage the remote image recognition server and record the incurred service latency. To conduct the test, the first step consisted in downloading an image from Wikipedia on the smartphone connected to the UC4 slice. The image used to perform this test was selected taking into account properties that are useful for the system. In particular, the size of 70KB is the average size requested by our image recognition system.

After completing the previous setup task, the steps conducted during the trial to measure the performance of this NS follows:

- Access from google chrome to: http://<VM-IP-ADDRESS>:8080/hololens-backend/test.html. The interface presented to the user when accessing to the previous URL can be shown in **Figure 126**.

Figure 126 - Benchmark interface for the HoloLens service

- Click on choose file and use the previously downloaded image to run the test.
- Click on Upload to run the test.
- Wait some seconds while the test is being performed and save the file *metrics.json* when asked.
- Check if the generated *metrics.json* file is not empty.

For the assessment of the video stream metrics (i.e. data rate and video buffering) for the 360° service in Bristol and Lucca, part of the HLS.js JavaScript library used to play the live stream was optimized to export a downloadable text file, which allows the storage and posterior analysis of the streaming performance.

The setup to measure the performance of this NS was different between on-site and remote tests. For the on-site assessment, we attached the camera to the 5GCity infrastructure in order to provide a video stream. Meanwhile, during remote test, we used a set of pre-recorded video streams in order to assess the system like having a camera attached in it.

After connecting the UE to the UC4 slice, the procedure followed to measure the streaming system is described in the following steps:

- Access from google chrome to this address: http://<VM-IP-ADDRESS>/benchmark/demo/. The interface presented to the user when accessing to the previous URL can be shown in **Figure 127.**

Figure 127 - Benchmark interface for the streaming service

- Click on Play button to start the video and on Real-Time metrics to open the HLS streaming stats.
- Wait a while in order to collect some packets and then click on download metrics (see **Figure 128**).

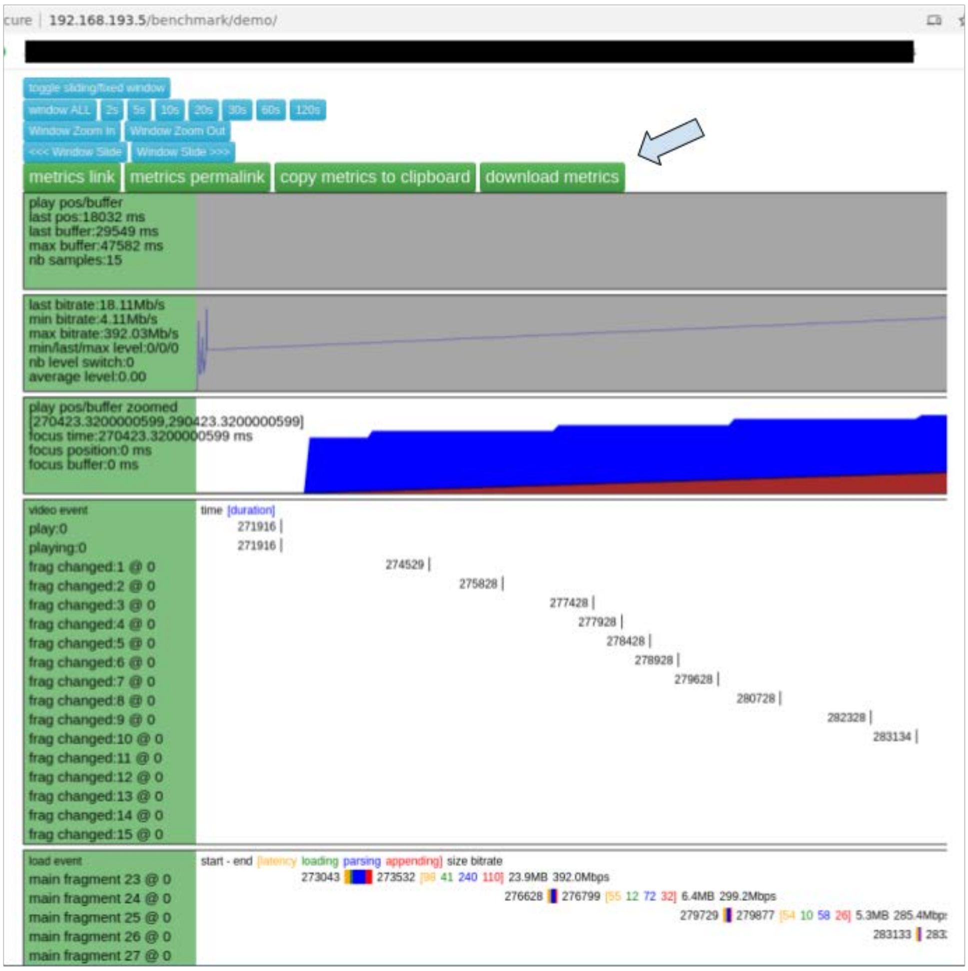


Figure 128 - HLS streaming stats

- If asked accept to download multiple files.
- Check if the generated *metrics.json* file is not empty.

Being this test aimed to check the HLS quality of the stream over the 5GCity infrastructure, we repeated the previously described procedure considering different video bitrates. In terms of video bitrates, we tested the system with 15 Mbps, 20 Mbps and 25 Mbps with a fixed distance of 10 meters between the small cell and the smartphone.

6.4 Bristol Pilot Validation

6.4.1 Scenario and Trials Description

The remote validation trial performed in the city of Bristol took place during February 2020 with the on-site presence of the University of Bristol team. We assessed our deployed services remotely. After performing an initial calibration test using the several Wi-Fi access points included in the UC4 slice, which was intended to conduct a functional test of the services and identify any possible network and software issue, we moved to the outdoor test using LTE as radio access technology. During the remote trial, we performed the assessment of the UC4 services using the small cell located near M Shed, which is highlighted in **Figure 129**.

Figure 129 - *M Shed* trial site in Bristol

During the remote test in Bristol, we tested the HoloLens backend server of the image recognition service and the 360° streaming service (see **Figure 130**). The latter NS was tested with three different bitrates for the end user stream video, namely: 15 Mbps, 20 Mbps and 25 Mbps. To do so, we were synchronized with the Bristol team and we performed the switching of the video bitrate directly on the VM in order to assess the system with different bitrates.

Figure 130 - Trial performed in Bristol with smartphone accessing the 360° endpoint

6.4.2 Results Analysis

In this section, we expose all the result we collected during remote trial performed in Bristol. Please note that every test we did on each VNF is designed in order to produce the load on VNF as a single user. We did not assess the VNF as a load test benchmark.

For the HLS streaming service of the UC4 NS#3, we assessed the system using three different video bitrates: 15 Mbps, 20 Mbps and 25 Mbps, as explained in subsection 6.3. For each video bitrate, we recorded the buffer time and the download data rate perceived by the user.

- **User Experienced Data Rate**

The User Experienced Data Rate, i.e. the throughput used during the real time transmission of 4K video, (from HLS streaming server to user), has been collected in real-time during the video transmission.

With 15 Mbps as video bitrate, the collected data rate is graphed in **Figure 131**.

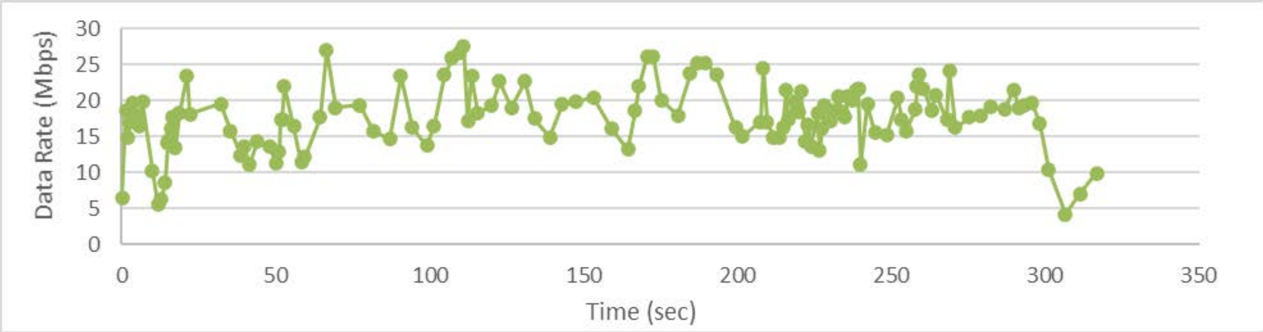


Figure 131 - User Experienced Data Rate of UC4 NS#3 in Bristol pilot for 15 Mbps of video bitrate

With 20 Mbps as video bitrate, the collected data rate is graphed in **Figure 132**.

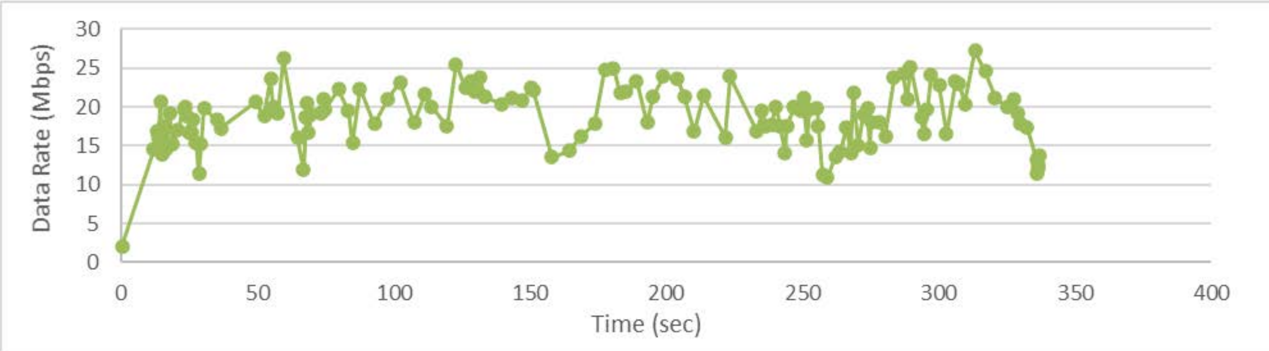


Figure 132 - User Experienced Data Rate of UC4 NS#3 in Bristol pilot for 20 Mbps of video bitrate

With 25 Mbps as video bitrate, the collected data rate is graphed in **Figure 133**.

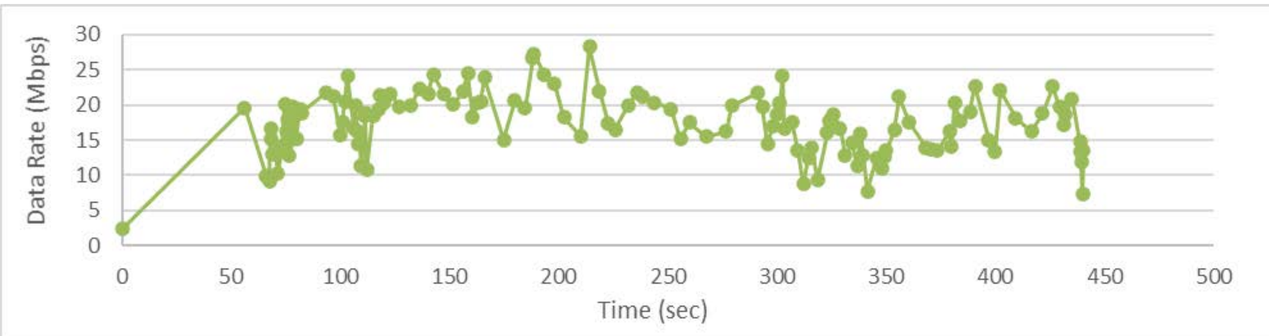


Figure 133 - User Experienced Data Rate of UC4 NS#3 in Bristol pilot for 25 Mbps of video bitrate

As observed in the previous plots, the download data rate of each encoded chunk of HLS stream is constant. We can also appreciate that the trend of the data rate perceived from the end user is similar for the different video bitrates considered. **Table 46** summarizes the obtained data rates for the different video bitrates, which are representative values used in UHD streaming services and contribute to analyse more deeply the pilot performance.

Video Bitrate	Average	Min	Max	Standard Deviation
15 Mbps	17.73	4.17	27.57	4.47
20 Mbps	18.83	2.09	27.18	3.79

25 Mbps	17.31	2.43	28.26	4.30

Table 46 - Data rate (Mbps) comparison with different video bitrates

- **Real Time Video Buffering**

Likewise, the buffer size has been collected in real-time during the transmission of 4K video in order to understand the quality of the transmission. The buffer is the amount of time (in ms) preloaded from the client application in order to provide a best experience to the end user.

With 15 Mbps as video bitrate, the collected buffer size is graphed in **Figure 134**. In this plot, we can see a stable video stream where the buffer remains stable and with a best level and never empty condition for a good viewing of the video.

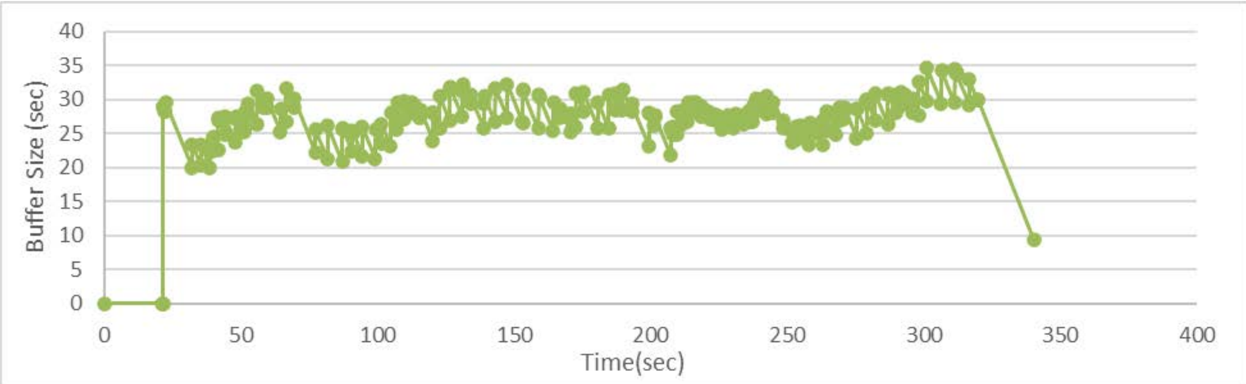


Figure 134 - Real Time Video Buffering of UC4 NS#3 in Bristol pilot for 15 Mbps of video bitrate

With 20 Mbps as video bitrate, the collected buffer size is graphed in **Figure 135**. In this case, we have a borderline situation where the bandwidth is enough to follow the stream, but the buffer after the start is getting empty and went to 0 on second 233. This result means that some video freeze was experienced during the watching. Therefore, with this bitrate, the video is still watchable but with a reduced user experience.

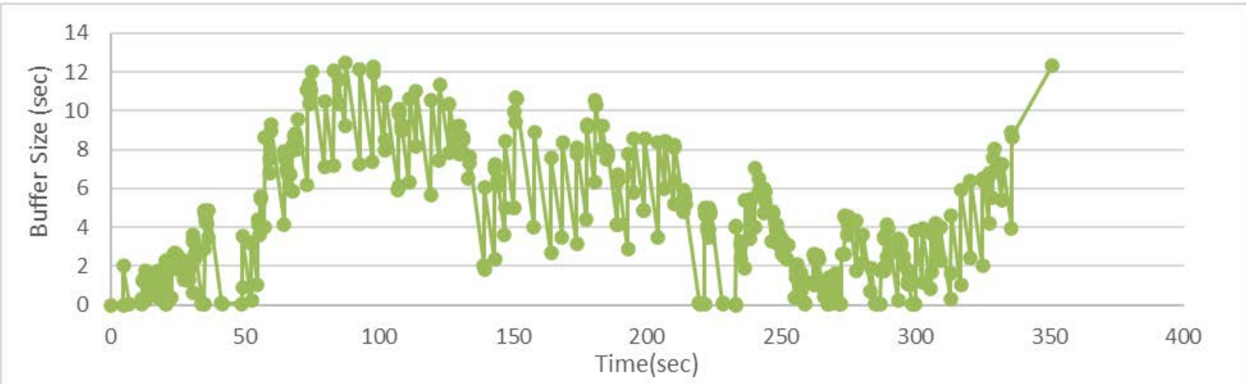


Figure 135 - Real Time Video Buffering of UC4 NS#3 in Bristol pilot for 20 Mbps of video bitrate

With 25 Mbps as video bitrate, the collected buffer size is graphed in **Figure 136**. In this plot, we can appreciate that after a first phase of buffering where the client try to download a good amount of buffer in order to provide a good flow of the video, the bandwidth is not enough to keep the buffer full enough for all the video duration. In particular, near the 290 seconds, the buffer touches the 0 and the player starts to try to refill the buffer during the stream.

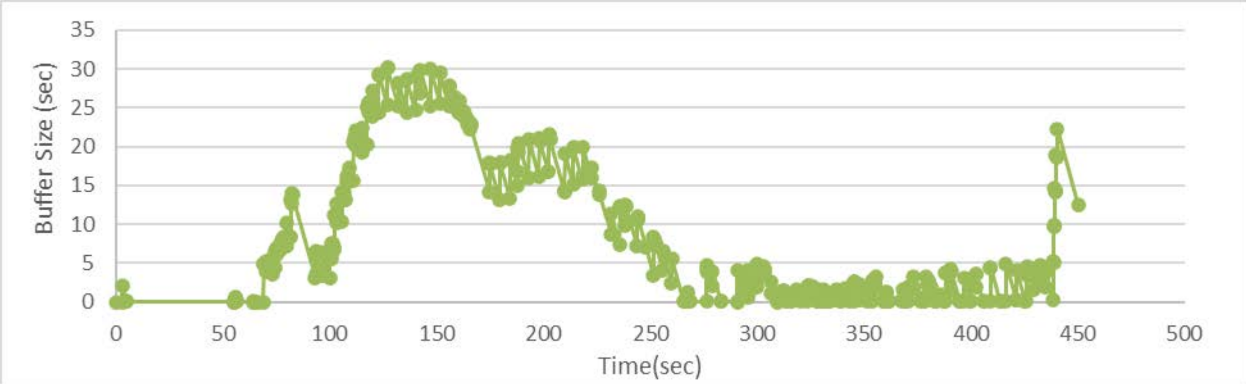


Figure 136 - Real Time Video Buffering of UC4 NS#3 in Bristol pilot for 25 Mbps of video bitrate

In **Table 47,** we can appreciate statistical values of buffer metric. We can see that the 15 Mbps stream with an average value of 27.37 sec and a stable trend without getting empty satisfies our target KPI. For the two other measurements, we cannot say the same, for the 25 Mbps the buffer is constantly empty and therefore the quality of the user experience is not sufficient. For the 20 Mbps we have a borderline case where the user experience is still acceptable at cost of some event of buffering during the stream. Therefore, the buffer KPI is partially achieved.

Video Bitrate	Average	Min	Max	Standard Deviation	Count buffer < 100 ms
15 Mbps	27.37	0	34.65	3.92	3
20 Mbps	4.73	0	26.39	3.95	31
25 Mbps	7.73	0	30.25	8.66	71

Table 47 - Video buffering (s) comparison with different video bitrates

- **HoloLens service latency**

Regarding the evaluation of the service latency of the HoloLens image recognition service, the collected values are presented in **Figure 137**. This measurement was recorded by a JavaScript script running on the smartphone used in the trial.

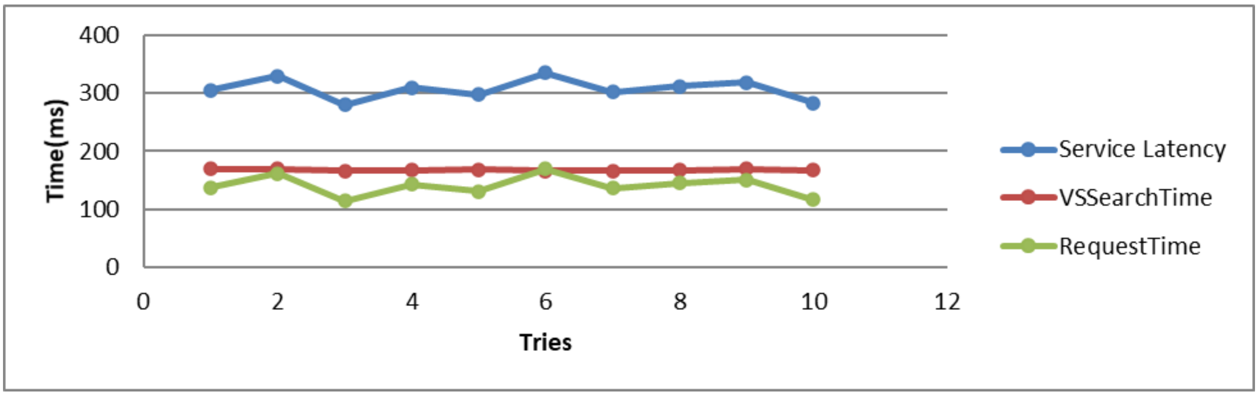


Figure 137 - HoloLens service latency in the Bristol pilot

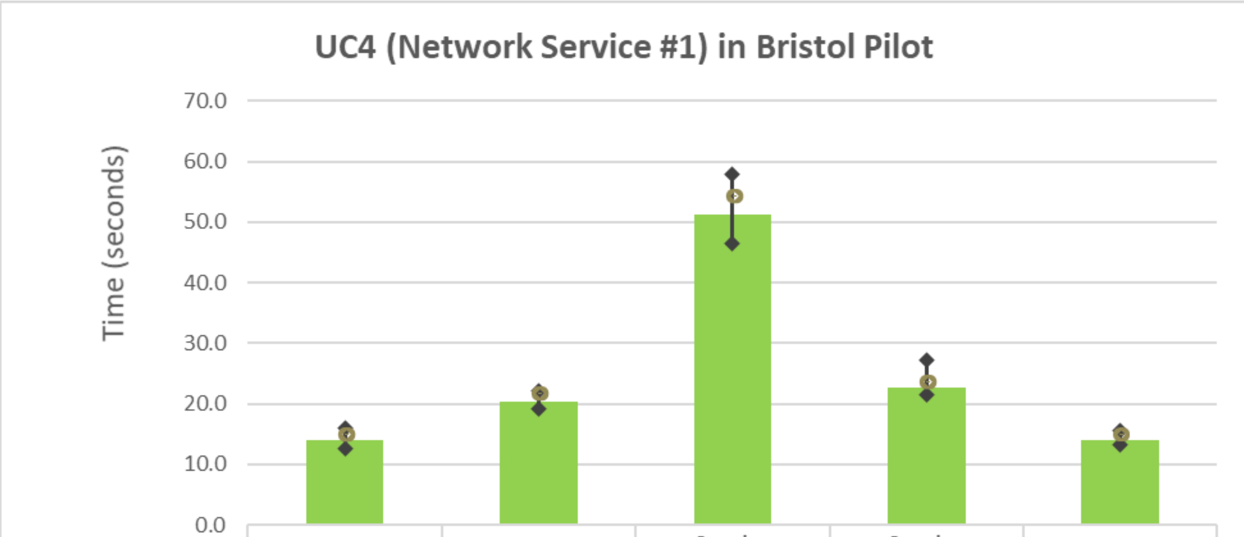
This test records, for each try, the time to send the downloaded image from the mobile phone to the server (i.e. RequestTime), and the time for the server to process such request (i.e. VSSearchTime). Using these two measurements, the service latency KPI was computed as the sum of both values. As can be observed in the plots, the obtained results are very constant and not fluctuating. **Table 48** summarizes the data recorded during the test. The average value of Visual Search time is 167.4 secs, and the average value of the service latency is of 307.5 secs, which is consistent with laboratory performances.

	Average	Min	Max	Standard Deviation
Request time	140.1	114	169	16.71
VS search time	167.4	166	169	1.2
Service latency	307.5	280	335	17.03

Table 48 - HoloLens service latency (ms) statistical summary

- **Service Instantiation Time (SIT)**

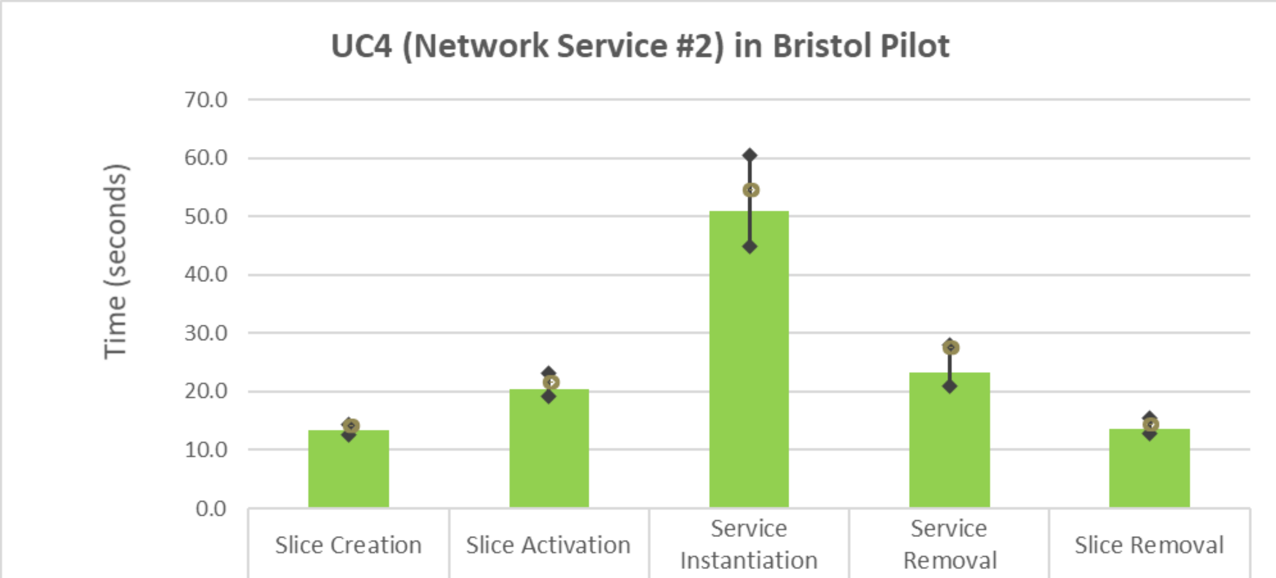
As described at the beginning of this section, UC4 is composed of three network services. Therefore, the measurements for the Service Instantiation Time KPI were collected independently for each one of the three network services. In **Figure 138**, the instantiation times obtained for the first network service of UC4, after running the automated script at the 5GCity Slice Manager 30 times, are plotted.



	Slice Creation	Slice Activation	Service Instantiation	Service Removal	Slice Removal
AVG	13.97	20.42	51.24	22.60	14.04
MIN	12.67	19.13	46.56	21.60	13.20
MAX	16.08	22.17	57.81	27.24	15.54
90-PERCENTILE	14.77	21.64	54.29	23.46	14.79

Figure 138 - Service Instantiation Time KPI of UC4 Network Service #1 in Bristol pilot

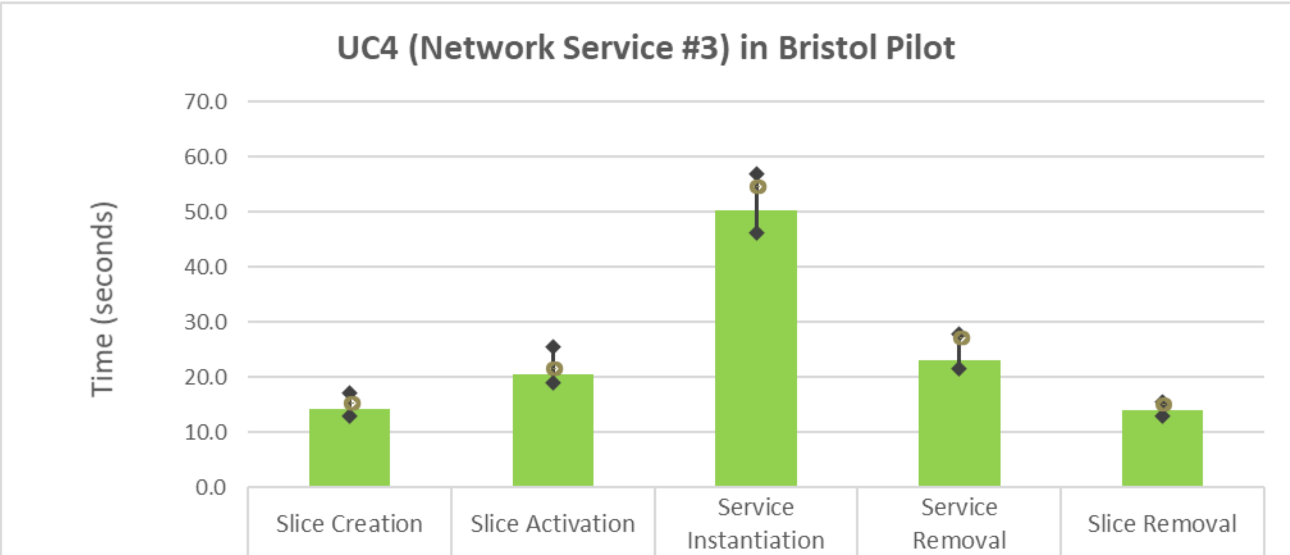
Similarly, **Figure 139** shows the same measurements for the case of the second network services.



	Slice Creation	Slice Activation	Service Instantiation	Service Removal	Slice Removal
AVG	13.42	20.51	51.00	23.38	13.53
MIN	12.57	19.29	44.91	21.00	12.92
MAX	14.33	23.23	60.48	27.93	15.43
90-PERCENTILE	14.01	21.59	54.52	27.37	14.10

Figure 139 - Service Instantiation Time KPI of UC4 Network Service #2 in Bristol pilot

Lastly, **Figure 140** shows the same measurements for the case of the second network services.



	Slice Creation	Slice Activation	Service Instantiation	Service Removal	Slice Removal
AVG	14.35	20.58	50.28	23.14	14.11
MIN	13.11	19.04	46.36	21.51	13.04
MAX	17.25	25.50	56.84	27.97	15.49
90-PERCENTILE	15.30	21.58	54.55	27.11	14.79

Figure 140 - Service Instantiation Time KPI of UC4 Network Service #3 in Bristol pilot

A comparison between **Figure 138**, **Figure 139** and **Figure 140** reveals that the collected time measurements are very similar for the three network services of UC4. More importantly, the average time values required to instantiate the three network services are below 120 seconds, hence this KPI target has been achieved.

Table 49 summarizes the results collected during the trial in Bristol with respect to their respective target values. In general, the values we collected during the trials are aligned with the values we set for the UC4 KPIs. In particular, the target for the buffer KPI is reached only for the case of the lower video quality bitrate (i.e. 15 Mbps). Therefore, we can say that this KPI is partially reached.

KPI	Target	Measurement
User experienced data rate	>= 15 Mbps	17.73 Mbps
Real Time Video Buffering	> 20 s	27.37 s
HoloLens service latency	<= 500 ms	307.5 ms
Service Instantiation Time (SIT)	<= 120 s	51.24 s, 51.00 s and 50.28 s

Table 49 - UC4 KPI results in Bristol Pilot

6.5 Lucca Pilot Validation

6.5.1 Scenario and Trials Description

The scenario used in the City of Lucca for the UC4 validation consisted in the surroundings of the small cell placed near Baluardo San Paolino, as shown in **Figure 141**. For such validation, two rounds of trials were conducted: the first one was performed during the F2F meeting on 21 November 2019 with the physical assistance of Rai (on-site validation) and the second one took place on 26 February 2020 with the physical assistance of NXW team and the remote support from Rai (remote validation). We will describe both tests in this document.

Figure 141 - Scenario of UC4 trials in Lucca pilot

As explained in Section 6.3, the UC4 performance was assessed from the point of view of video streaming and image recognition services. As for the 360-streaming service, the performances were measured using a modified HLS.js library in order to download all the metrics necessary to understand the quality of the stream. Regarding the HoloLens-backend trial assessment, an ad-hoc JavaScript benchmark script was provided from the server in order to record the service latency. We accessed to the services by using an LG V30 smartphone provided by Wind partner that was connected to the 5GCity infrastructure from the aforementioned small cell.

During the on-site trial, in addition to considering different video bitrates, we measured the services performance also with different distances between the small cell and the smartphone. For the HoloLens VNF, we ran the tests at 5 m, 20 m, 50 m and 90 m; while for the video stream VNF, we ran the tests at 5 and 50 meters. Additionally, we did a third test with bitrate fixed at 15 Mbps, and distance changing from 5 m to around 135 m (i.e. until we lost the signal) in order to simulate a common walk of an end-user.

In order to provide a safe place under raining conditions for our Insta 360° Pro camera we placed it inside the server farm of Lucca City Hall during the on-site trial (see **Figure 142)**. The camera provides a video stream for the 360° service that is playable as an HLS stream by client devices like the smartphone used in our trial. We were able to set the Bitrate with the dedicated WebApp of Insta 360° Pro.

Figure 142 - Insta 360° Pro camera placed at Comune di Lucca

6.5.2 Results Analysis

In this section, we expose all the result we collected during on-site trial performed in 21 November 2019 and remote trials performed in 26 February 2020. Please note that every test did on each VNF is designed in order to produce the load on VNF as a single user. We did not assess the VNF as a load test benchmark.

6.5.2.1 On-site test in Lucca November 2019

During this trial, we tested the HLS streaming service of the UC4 NS#3 using different bitrates as well as different distances from the small cell. Therefore, we did two types of tests: a) fixed distance, variable bitrates and b) fixed bitrate, variable distances. In addition, for the sake of completeness, we did a test with fixed bitrate of 15 Mbps, in which, starting from 5 meters, we walked away from the small cell reaching the distance of 135m.

In **Figure 143**, you can see the path of the end-user during the walking UC test. Please note that in this test the small cell antenna (yellow arrow in the image) was behind a wall during the test, situation that can produce different values of SNR and attenuation.

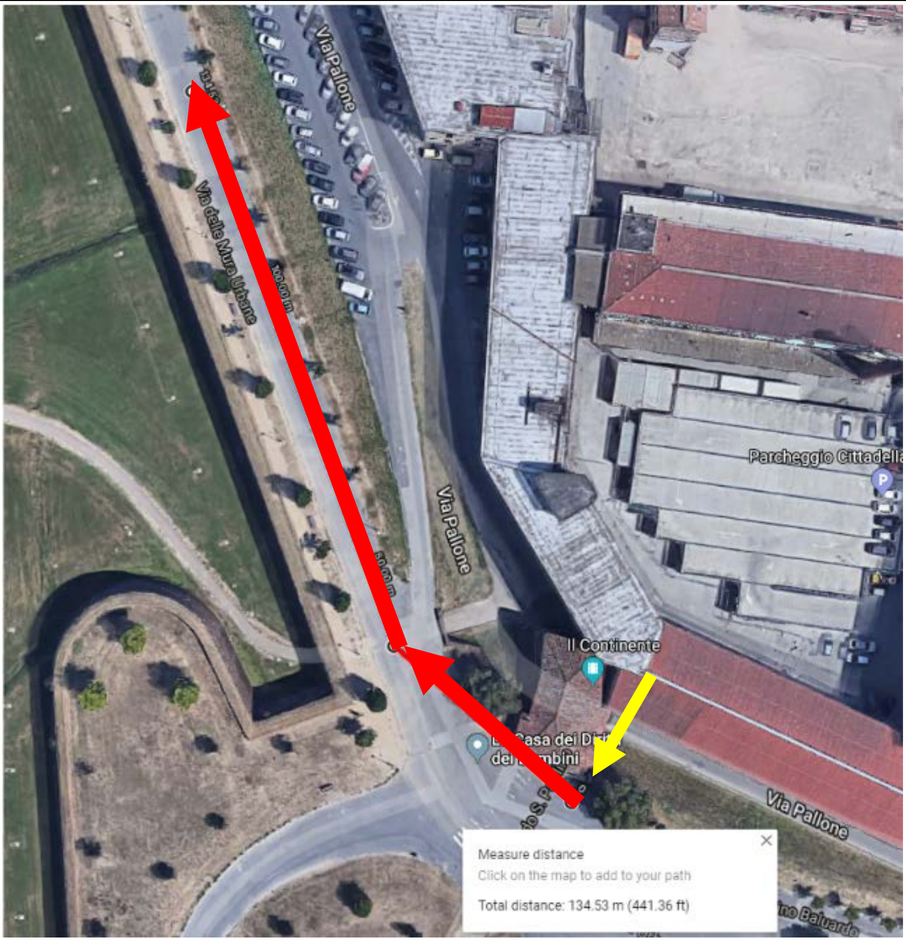


Figure 143 - Path of the end-user during the test

For each test, we recorded the download data rate perceived by the user and the buffer time.

- **User Experienced Data Rate**

The User Experienced Data Rate, i.e. the throughput used during the real time transmission of 4K video, has been collected in real-time during the video transmission.

a) Results obtained with a fixed distance and variable bitrates

With 15 Mbps as video bitrate and 10 meters of distance, the collected data rate is graphed in **Figure 144**.

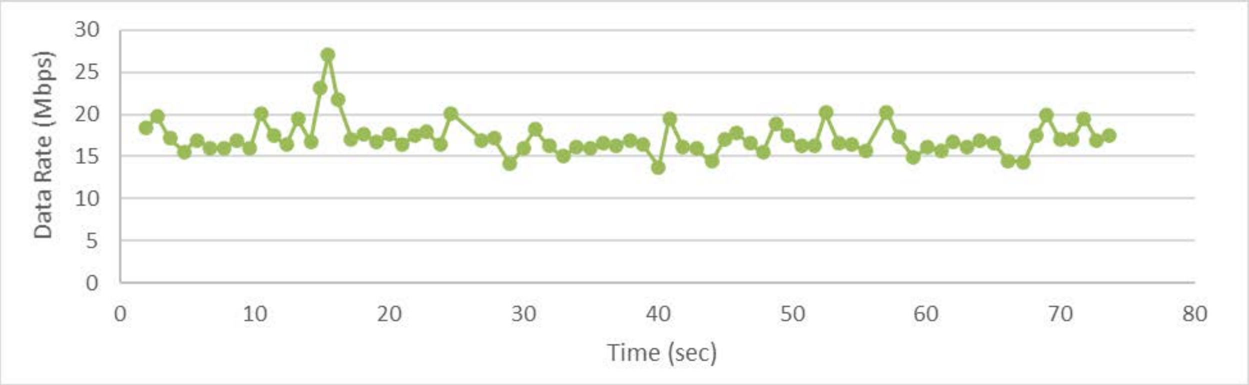


Figure 144 - Data Rate of UC4 NS#3 in Lucca with 15 Mbps of bitrate and 10 meters of distance

With 20 Mbps as video bitrate and 10 meters of distance, the collected data rate is graphed in **Figure 145**.

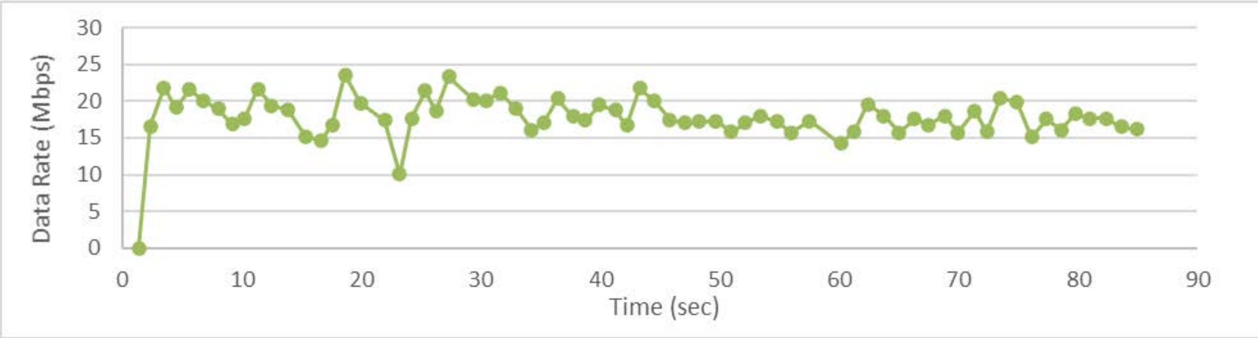


Figure 145 - Data Rate of UC4 NS#3 in Lucca with 20 Mbps of bitrate and 10 meters of distance

With 25 Mbps as video bitrate and 10 meters of distance, the collected data rate is graphed in **Figure 146**.

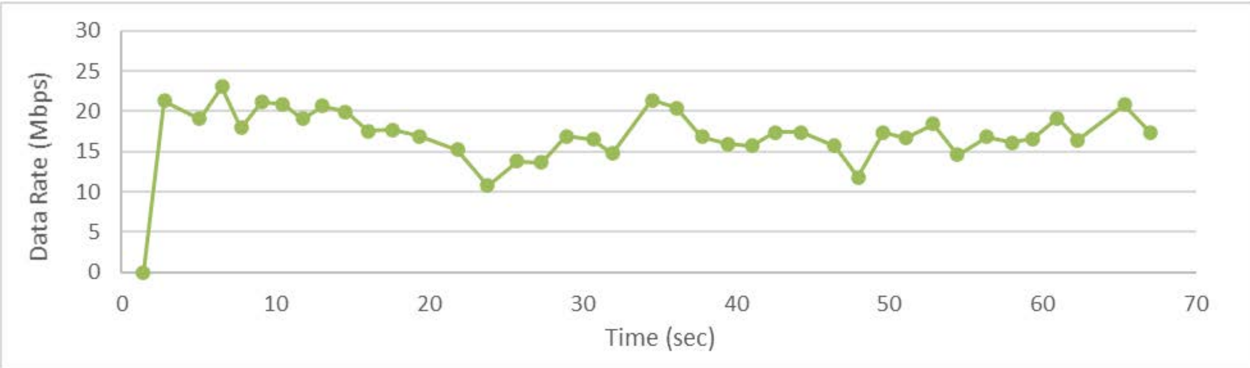


Figure 146 - Data Rate of UC4 NS#3 in Lucca with 25 Mbps of bitrate and 10 meters of distance

Since it is difficult to appreciate the difference between the previous measurements, in **Table 50** we can see the statistical values of data rates with fixed distance and using different video bitrates.

Video Bitrate	Average	Min	Max	Standard Deviation
15 Mbps	17.21	13.72	27.15	2.06
20 Mbps	18.01	10.05	23.59	2.25
25 Mbps	17.46	10.76	23.07	2.58

Table 50 - Data rate (Mbps) comparison with fixed distance and different video bitrates

It is interesting to see that the data rate is quite constant during the stream and comparable with the ones obtained in Bristol. Therefore, we have similar streaming quality and user experience.

b) Results obtained with a fixed bitrate and variable distances

With 5 meters as distance and 15 Mbps of video bitrate, the collected data rate is graphed in **Figure 147**.

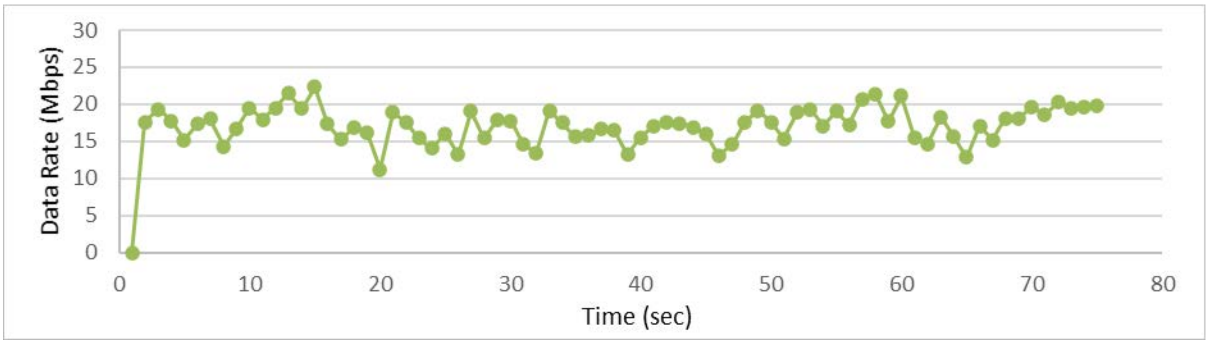


Figure 147 - Data Rate of UC4 NS#3 in Lucca with 5 meters of distance and 15 Mbps of bitrate

With 50 meters as distance and 15 Mbps of video bitrate, the collected data rate is graphed in **Figure 148**.

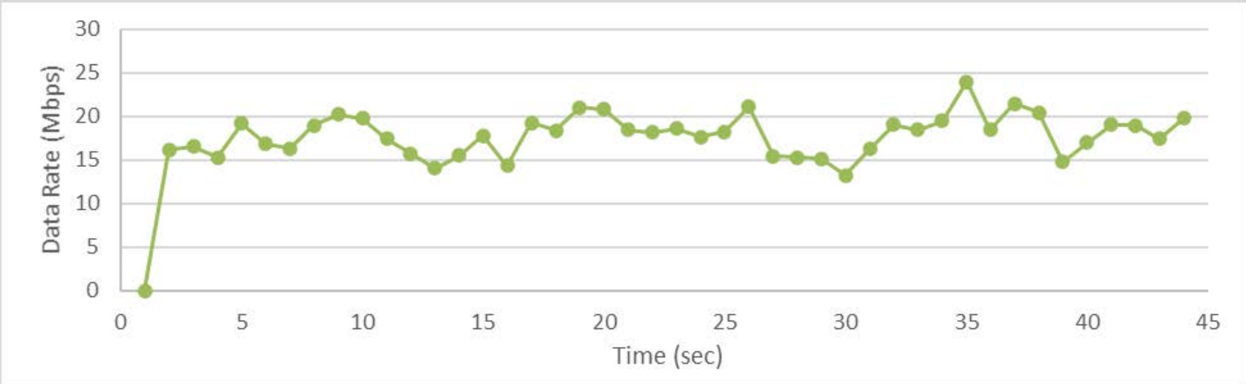


Figure 148 - Data Rate of UC4 NS#3 in Lucca with 50 meters of distance and 15 Mbps of bitrate

Since it is difficult to appreciate the difference between the previous measurements, in **Table 51** we can see the statistical values of Data Rates with a fixed bitrate and different distances between smartphone and SC.

Distance	Average	Min	Max	Standard Deviation
5 m	18.69	11.22	22.38	7.91
50 m	18.45	13.26	23.99	4.25

Table 51 - Data rate (Mbps) comparison with fixed bitrates and variable distances

The data rates obtained in this assessment tell us that with a distance of 50 m from the small cell and with a bit rate of 15 Mbps the HLS stream has enough bandwidth to stream with effective quality and to provide a good user experience without problem during the buffering.

c) Results obtained in the walking test

Regarding the experienced data rate while moving away from the small cell, the collected values are graphed in **Figure 149**.

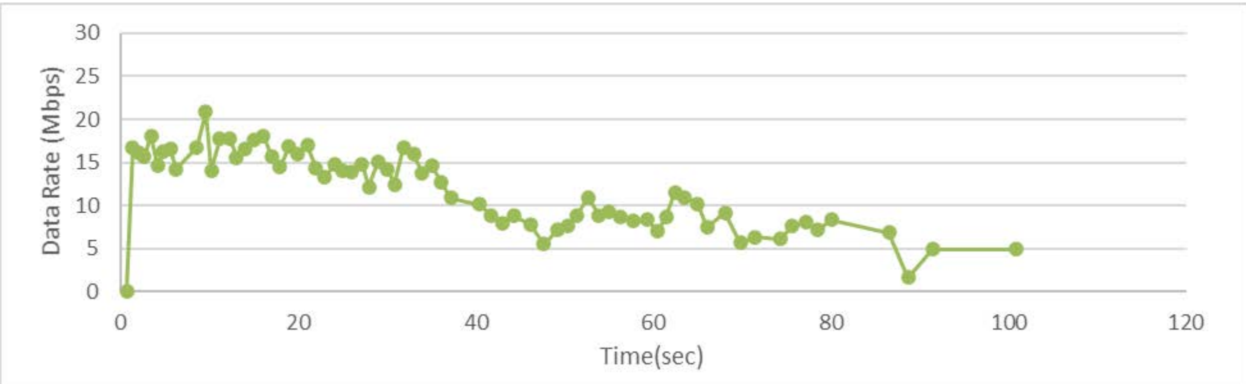


Figure 149 - Data Rate of UC4 NS#3 in Lucca with 15 Mbps of bitrate and moving away from SC

In this plot, it is interesting to appreciate the dropping of bitrate during the test we did with fixed bitrate (at 15 Mbps) and with the distance between smartphone and SC increasing from 5 m and 135 m, following the path shown in **Figure 143**. In the plot, we can see that the experienced data rate starts to decrease, and around 36-40 seconds it decreases under the target of 15 Mbps. **Table 52** summarizes this test.

Average	Min	Max	Standard Deviation
11.76	1.11	20.83	4.41

Table 52 - Data rate (Mbps) statistical data for walking test

- **Real Time Video Buffering**

Likewise, the buffer size has been collected in real-time during the transmission of 4K video in order to understand the quality of the transmission.

a) Results obtained with a fixed distance and variable bitrates

With 15 Mbps as video bitrate and 10 meters of distance, the collected buffer size is graphed in **Figure 150**.

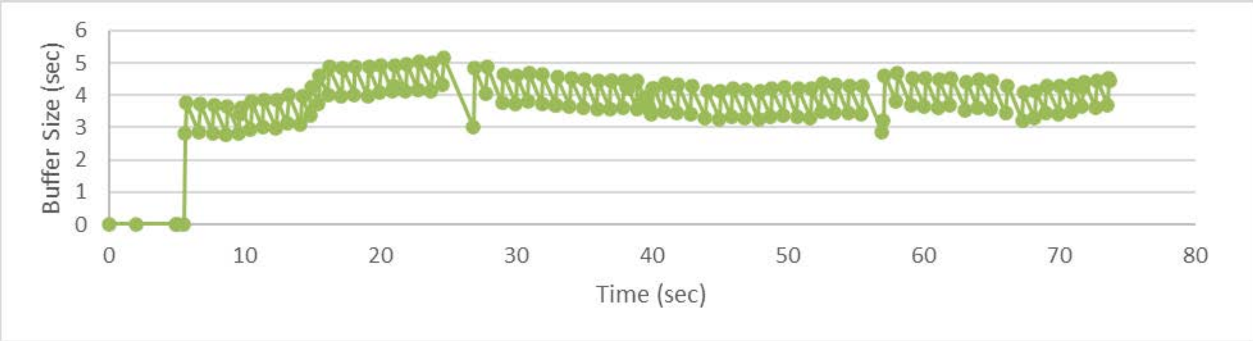


Figure 150 - Video Buffering of UC4 NS#3 in Lucca with 15 Mbps of bitrate and 10 meters of distance

With 20 Mbps as video bitrate and 10 meters of distance, the collected buffer size is graphed in **Figure 151**. In this case, we have a borderline situation where the bandwidth is not enough to follow the stream so the buffer after the start keeps trying to download some chunks but it touches 0 second after 40-50 seconds, which means that some video freeze was experienced during watching. The video is still watchable but with a reduced user experience.

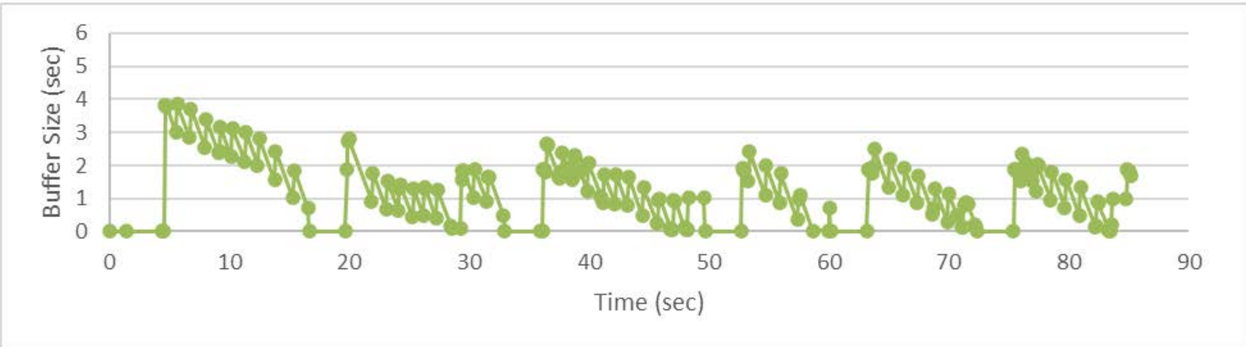


Figure 151 - Video Buffering of UC4 NS#3 in Lucca with 20 Mbps of bitrate and 10 meters of distance

With 25 Mbps as video bitrate and 10 meters of distance, the collected buffer size is graphed in **Figure 152**. In this situation, we are far over the bandwidth offered by the small cell and therefore the buffer is constantly empty and the video is unwatchable.

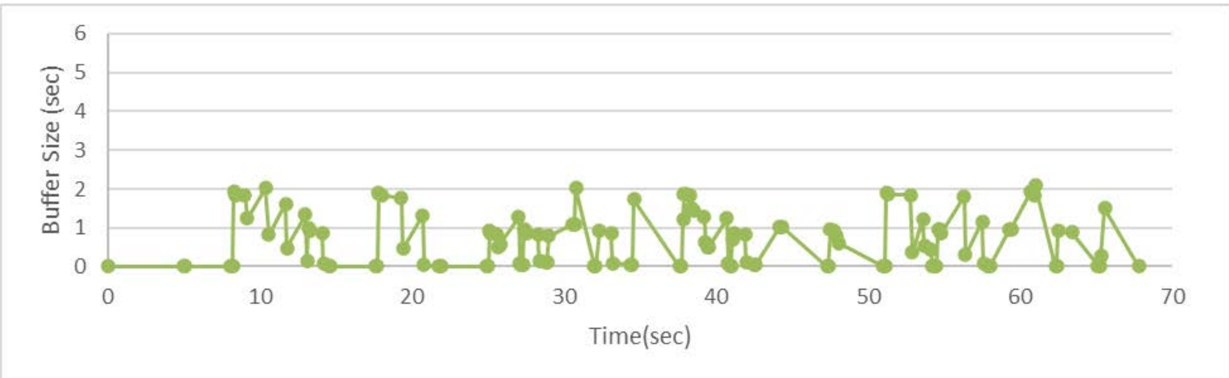


Figure 152 - Video Buffering of UC4 NS#3 in Lucca with 25 Mbps of bitrate and 10 meters of distance

b) Results obtained with a fixed bitrate and variable distances

With 5 meters as distance and 15 Mbps of video bitrate, the collected buffer size is graphed in **Figure 153**. What we have seen in this case is a stable video stream, where the buffer is stable and with a best level. The video stream is good and the user experience is good.

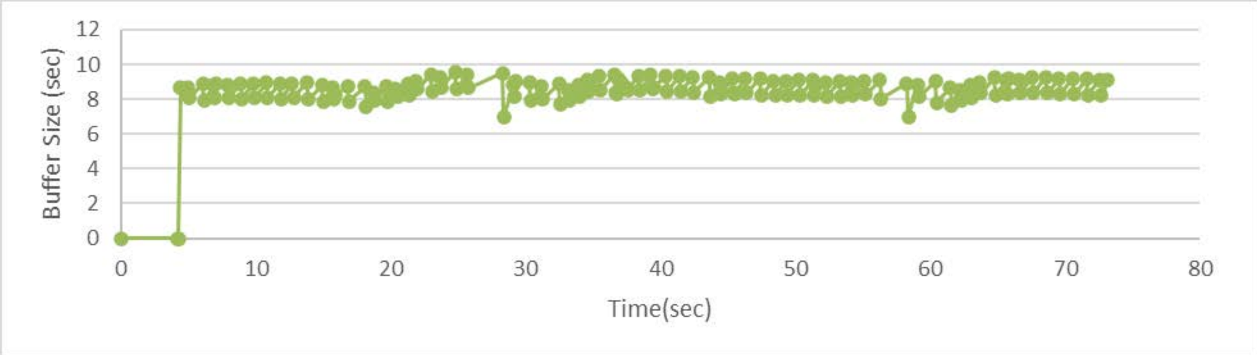


Figure 153 - Video Buffering of UC4 NS#3 in Lucca with 5 meters of distance and 15 Mbps of bitrate

With 50 meters as distance and 15 Mbps of video bitrate, the collected buffer size is graphed in **Figure 154**. In this case, we can observe a stable video stream where the buffer is stable and with a good level. The video stream is good and the user experience is good.

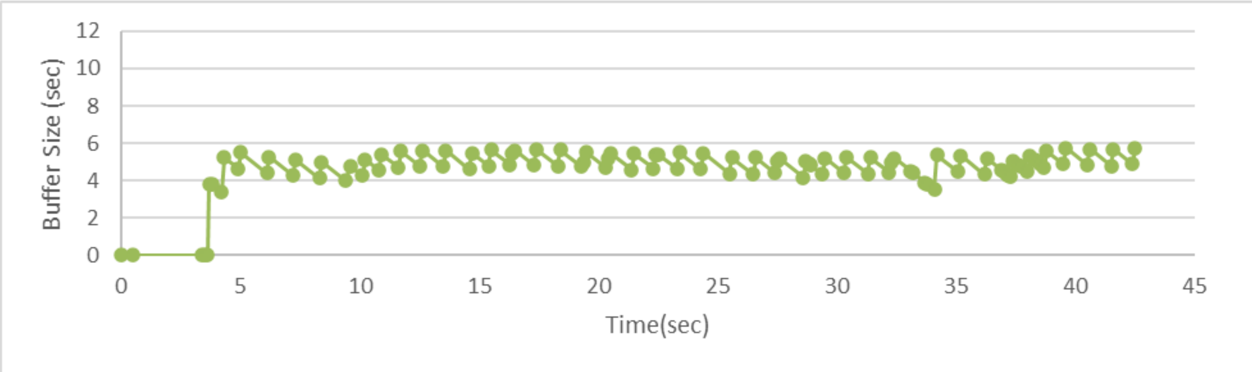


Figure 154 - Video Buffering of UC4 NS#3 in Lucca with 50 meters of distance and 15 Mbps of bitrate

c) Results obtained in the walking test

Regarding the buffer size while moving away from the small cell, the collected values are graphed in **Figure 155**. In this case, you can see the buffer getting empty due to the download bitrate reduction when the distance to the SC increases. In particular, comparing this plot with **Figure 149**, we can corroborate that when the experienced data rate starts going down 15Mbps the buffer starts to getting empty until it reaches the value of 0 seconds. With this trend, the buffer starts decreasing and making the video unwatchable.

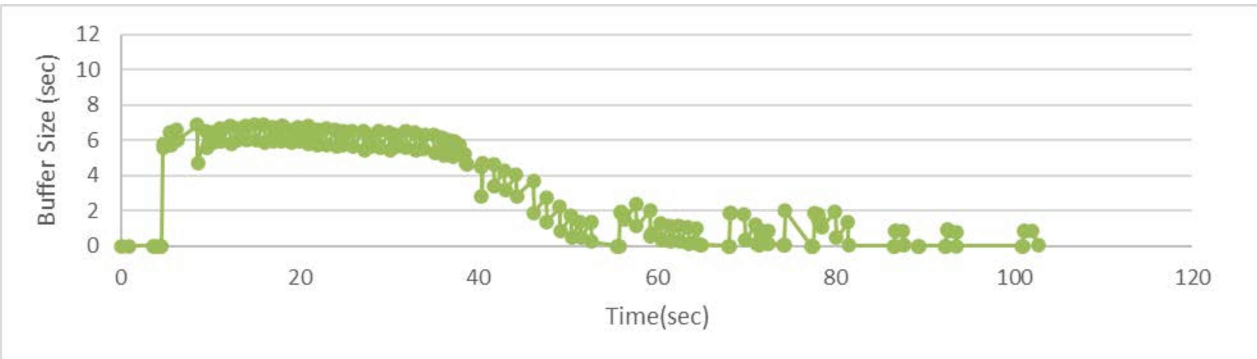


Figure 155 - Video Buffering of UC4 NS#3 in Lucca with 15 Mbps of bitrate and moving away from SC

Table 53 summarizes the previous results regarding the buffer size metric. It is important to see not only the statistical data on this table but also the trend of the plots. In particular, in the tests considering a fixed distance of 10 meters between SC and smartphone, we can conclude that the user experienced data rate is not enough to provide a good amount of buffer with a stable value, situation where the user experience is degraded. Nonetheless, in the test performed with 5 m of distance and 15 Mbps of bitrate, we obtained a good constant trend of the buffer, which reflects that the data rate in that case was enough to provide a good experience for the end user.

Scenario	Average	Min	Max	Standard Deviation	Count buffer < 100 ms
10 m – 15 Mbps	3.83	0	5.16	0.87	5
10 m – 20 Mbps	1.31	0	3.86	0.92	25
10 m – 25 Mbps	0.72	0	2.10	0.68	45
5 m – 15 Mbps	7.53	0	9.57	1.08	2
50 m – 15 Mbps	4.64	0	5.73	1.14	5
Moving – 15 Mbps	3.31	0	6.92	2.64	33

Table 53 - Video buffering (s) comparison with different video bitrates and different distances

- **HoloLens service latency**

Regarding the collected metrics for the service latency of HoloLens images recognition service, we collected the values plotted in **Figure 156**.

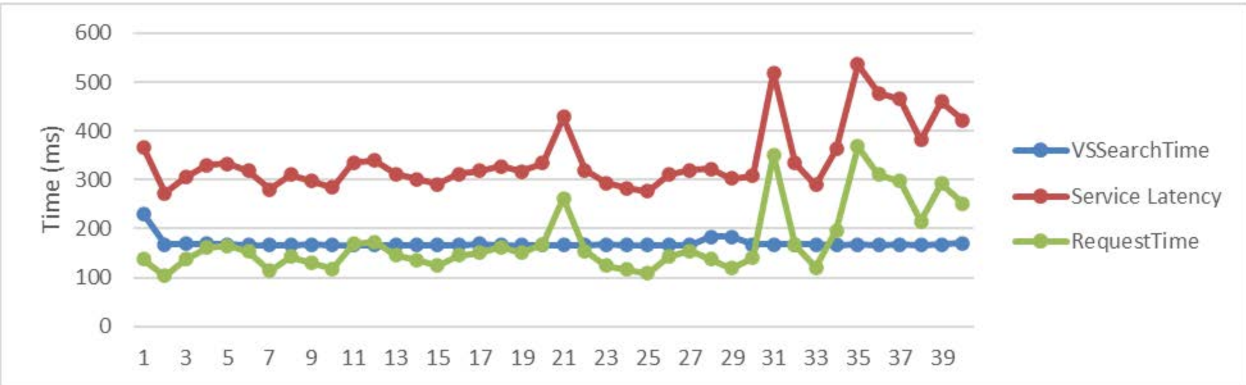


Figure 156 - HoloLens service latency in the Lucca pilot

In **Figure 156**, we measured the service latency with different distances. In the first 10 samples, we measured the service latency with a distance between smartphone and small cell of 5 meters. In the samples from 11 to 20, we measured the service latency with a distance between smartphone and small cell of 20 meters. In the samples from 21 to 30, we measured the service latency with a distance between smartphone and small cell of 50 meters. In the samples from 31 to 40, we measured the service latency with a distance between smartphone and small cell of 90 meters. What we can appreciate here is the difficult for the system to upload the payload (downloaded image in this case) to the server and therefore a degradation in the performance, but the system is still functional with a decent amount of service latency and still usable for the end user.

6.5.2.2 Remote test in Lucca February 2020

During this trial we conducted the remote test without attach directly the camera to the 5GCity platform. Anyway, this is not an issue because in order to perform our measurements we provided three pre-encoded sample videos. During this remote test, we tested three different bitrates (15 Mbps, 20 Mbps and 25 Mbps) with fixed distance of approximately 5 meters.

- **User Experienced Data Rate – Streaming service**

The User Experienced Data Rate, i.e. the throughput used during the real time transmission of 4K video, has been collected in real-time during the video transmission.

With 15 Mbps as video bitrate, the collected data rate is graphed in **Figure 157**.

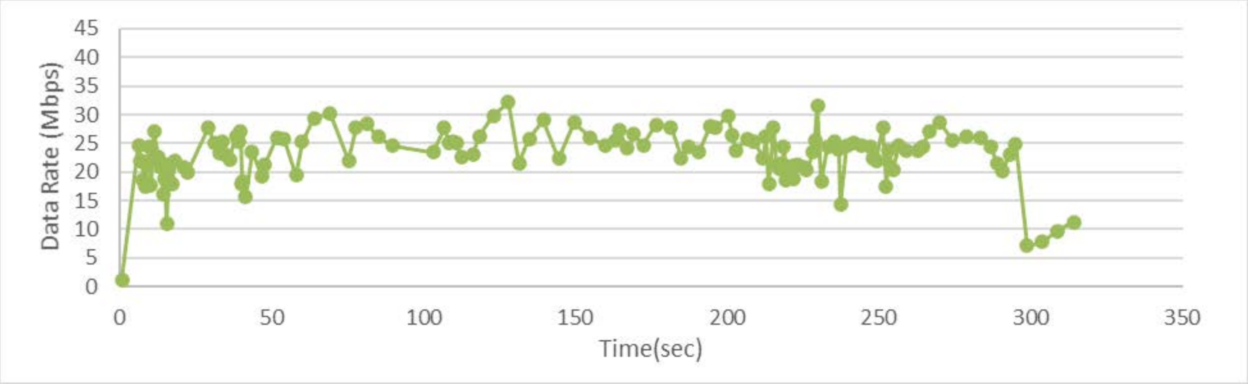


Figure 157 - Data Rate of UC4 NS#3 in Lucca pilot (remote test) for 15 Mbps of video bitrate

With 20 Mbps as video bitrate, the collected data rate is graphed in **Figure 158**.

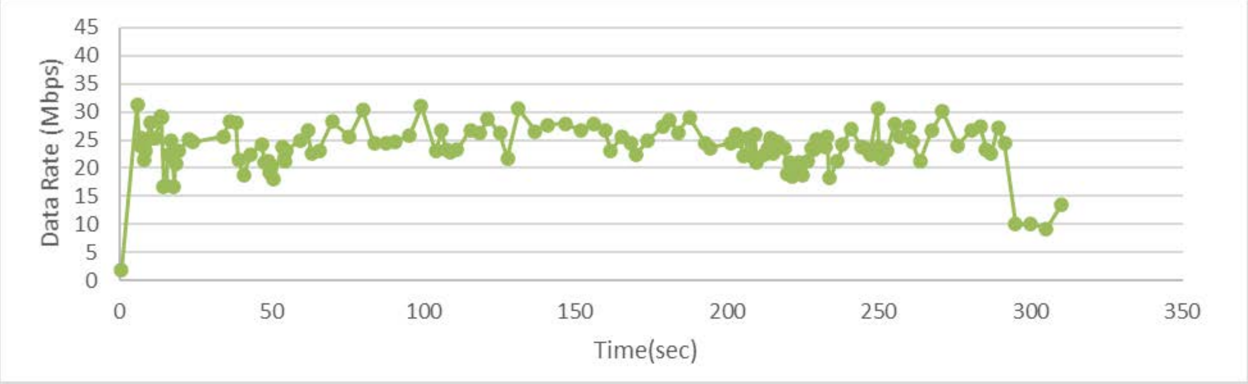


Figure 158 - Data Rate of UC4 NS#3 in Lucca pilot (remote test) for 20 Mbps of video bitrate

With 25 Mbps as video bitrate, the collected data rate is graphed in **Figure 159**.

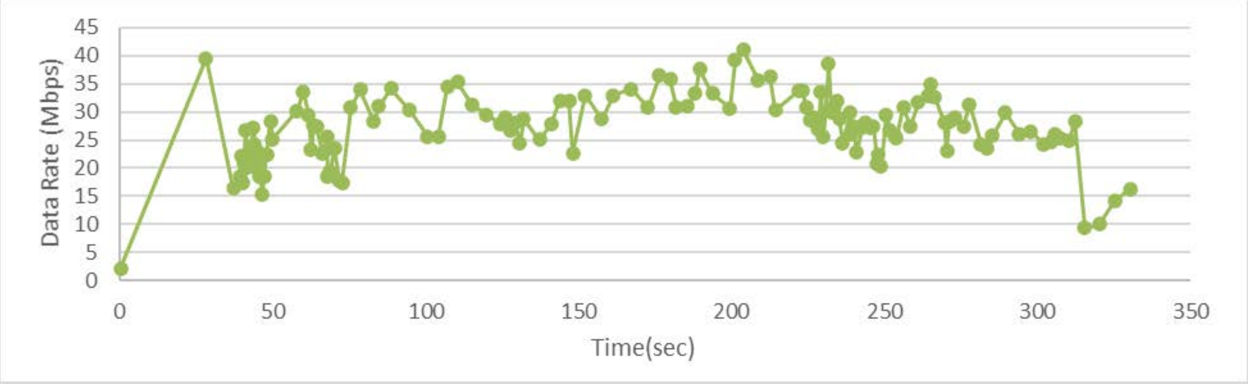


Figure 159 - Data Rate of UC4 NS#3 in Lucca pilot (remote test) for 25 Mbps of video bitrate

As observed in the previous figures, the downloading data rate was good in all the tests and satisfied the requirement of 15 Mbps video bitrate. Therefore, the obtained result is a good user experience and a smooth video.

As observed in the previous plots, the download data rate of each encoded chunk of HLS stream is constant. We can also appreciate that the trend of the data rate perceived from the end user is similar for the different video bitrates considered. **Table 54** summarizes the obtained data rates for the different video bitrates, which are representative values used in UHD streaming services and contribute to validate if it is possible for an end user watch the content without any problem.

Video Bitrate	Average	Min	Max	Standard Deviation
15 Mbps	22.94	1.20	32.23	4.75
20 Mbps	23.74	1.88	31.22	4.23
25 Mbps	26.89	2.06	41.02	6.28

Table 54 - Data rate (Mbps) comparison with different video bitrates

- **User Experienced Data Rate – Video on demand service**

Another trial performed on Lucca infrastructure was conducted over the VoD VNF. In this case, we were not able to measure any type of QoS from client point of view during the site navigation. Therefore, we performed an analysis on network throughput thanks to the 5GCity Monitoring service (see **Figure 160**) during a normal navigation recorded using the Windows10 embedded record software.

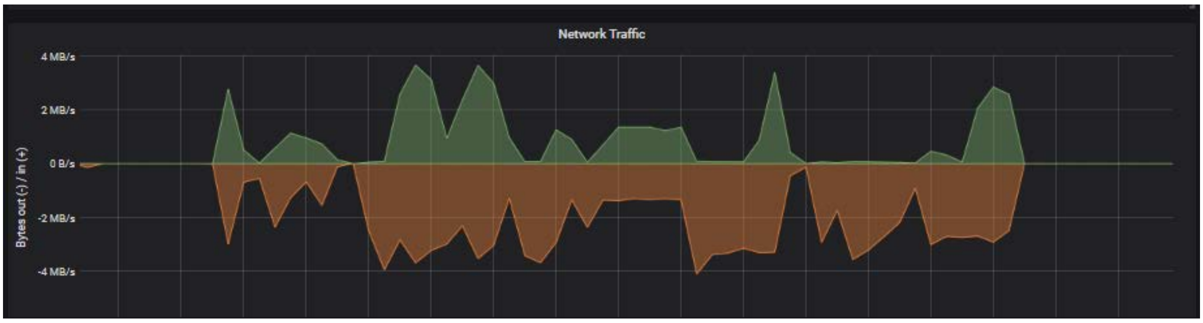


Figure 160 - VoD network throughput

In this case, we registered a maximum value of outgoing traffic of 4.095 MB/s (i.e. 34.35 Mbps), which is the throughput experienced by the user accessing to this service. The ingoing traffic (green line) is the result of the NFS mounting system, in other words the interconnection between the VM whit the Http server and the static VM where the large video contents actually are stored.

- **Real Time Video Buffering**

Likewise, the buffer size has been collected in real-time during the transmission of 4K video, in order to understand the quality of the transmission.

With 15 Mbps as video bitrate, the collected buffer size is graphed in **Figure 161**. In this case, what we can see is a stable video stream where the buffer is stable and with his best level.

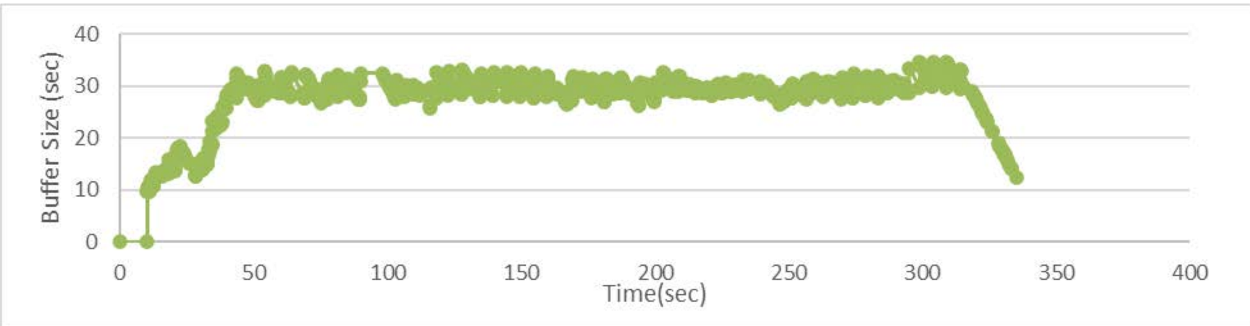


Figure 161 - Video Buffering of UC4 NS#3 in Lucca pilot (remote test) for 15 Mbps of video bitrate

With 20 Mbps as video bitrate, the collected buffer size is graphed in **Figure 162**. In this case, what we can see is a stable video stream where the buffer is stable and with his best level.

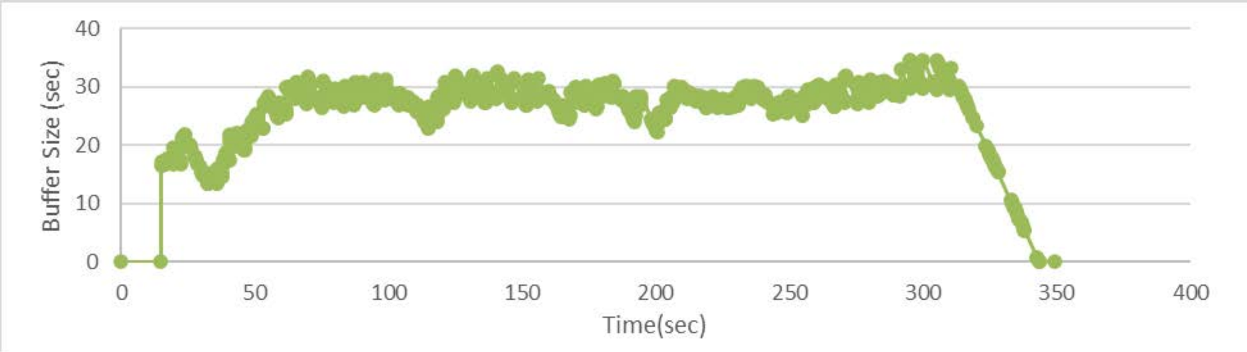


Figure 162 - Video Buffering of UC4 NS#3 in Lucca pilot (remote test) for 20 Mbps of video bitrate

With 25 Mbps as video bitrate, the collected buffer size is graphed in **Figure 163**. In this case, what we can see is a stable video stream where the buffer is stable and with his best level. The result is a good user experience and a smooth video.

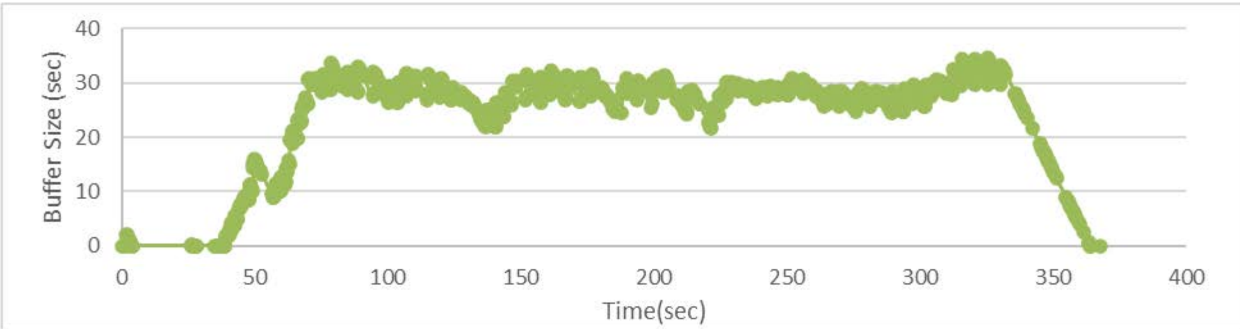


Figure 163 - Video Buffering of UC4 NS#3 in Lucca pilot (remote test) for 25 Mbps of video bitrate

During the remote test performed in Lucca, we collected the best performances in terms of data rates. Therefore, the Buffer amount in the end user player is at the best, in all tests performed the buffer looks filled and without empty spaces. The number of times where the buffer is under 100 ms are grouped at the start and the end of the video, which means that it had no issues with the user experience and, therefore, satisfy the requirements. We can say that with this setup the platform is able to provide a good stream quality without major issues during the streaming with the higher bitrate of 25 Mbps. **Table 55** outlines a summary of the buffer size metric obtained in previous figures.

Bitrate	Average	Min	Max	Standard Deviation	Count buffer < 100 ms
15 Mbps	27.72	0	34.62	5.27	2
20 Mbps	26.19	0	34.51	5.28	5
25 Mbps	24.46	0	34.58	8.63	23

Table 55 - Video buffering (s) comparison with different video bitrates.

- **HoloLens service latency**

Regarding the collected metrics for the service latency of images recognition service, we collected the values shown in **Figure 164**. The performances measured are in range with no spikes regarding the network response. VSSearchTime is the time required for image recognition to process the image sent by the client during the assessment. Note that during this type of test the images sent to the server are sequential and not concurrent in order to stimulate the VNF as a single end user.

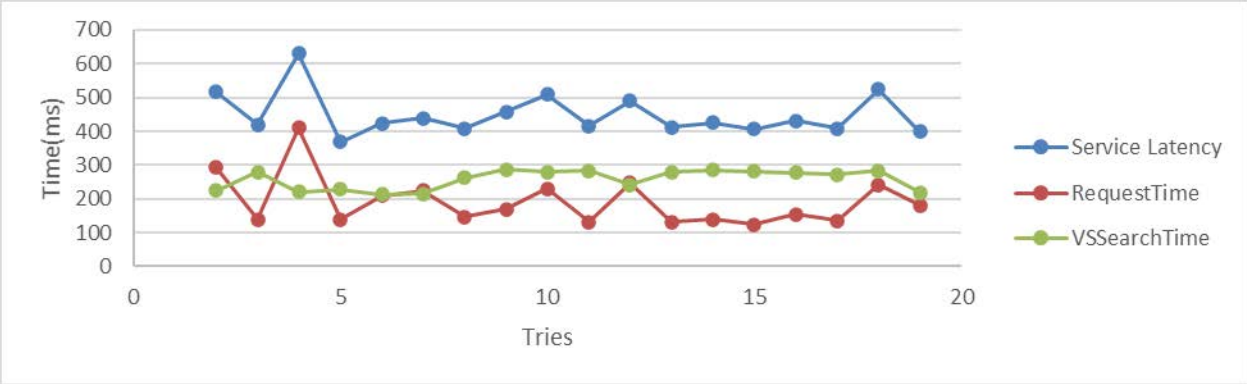


Figure 164 - HoloLens service latency in the Lucca pilot (remote test)

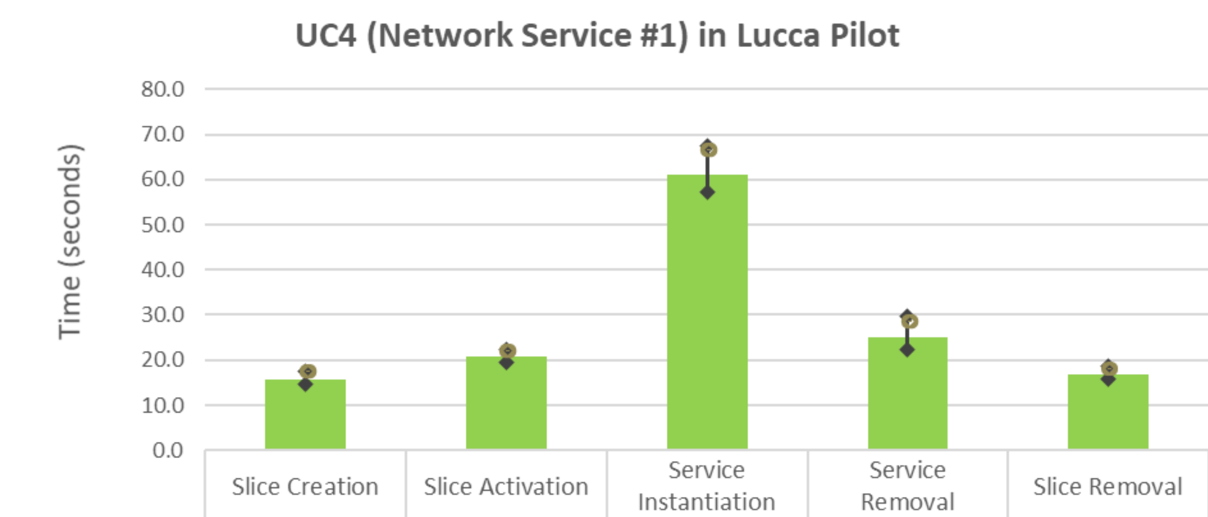
In **Figure 164**, we can appreciate a stable trend of the service latency with an average value of 449.33 ms and the average value of Visual Search server is 257.66 ms, values that respect the expected laboratory performances. **Table 56** summarizes the data recorded during the test.

	Average	Min	Max	Standard Deviation
Request time	192	125	410	71.90
VS search time	257.66	214	288	28.48
Service Latency	449.33	368	630	61.23

Table 56 - Service latency (ms) statistical summary

- **Service Instantiation Time (SIT)**

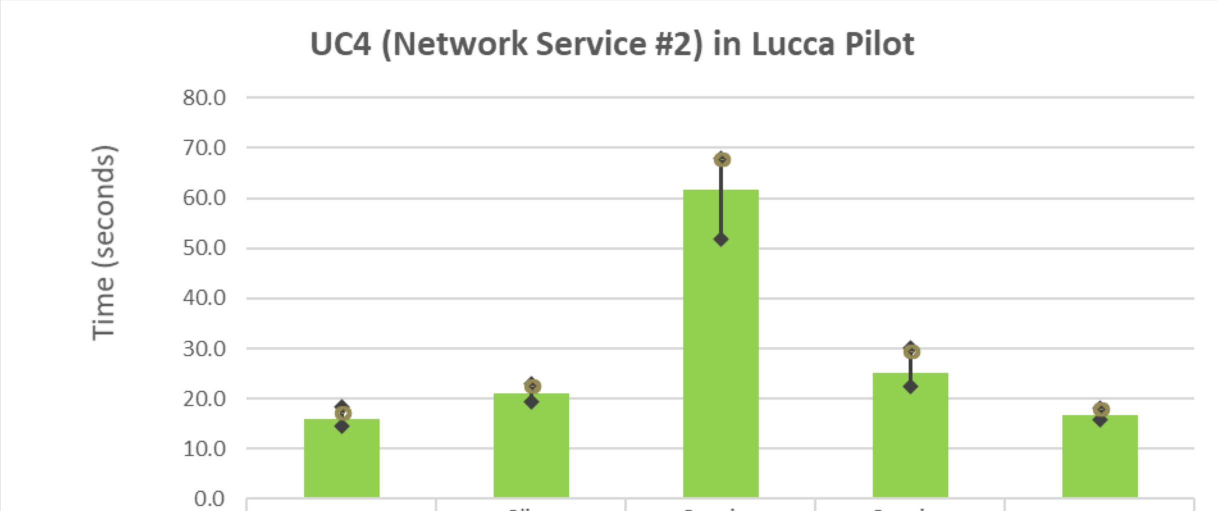
In **Figure 165**, the instantiation times obtained for the first network service of UC4, after running the automated script at the 5GCity Slice Manager 30 times, are plotted.



	Slice Creation	Slice Activation	Service Instantiation	Service Removal	Slice Removal
AVG	15.79	20.87	60.95	25.12	16.87
MIN	14.65	19.53	57.18	22.29	15.67
MAX	17.41	22.33	67.52	29.58	18.67
90-PERCENTILE	17.24	21.89	66.37	28.54	17.89

Figure 165 - Service Instantiation Time KPI of UC4 Network Service #1 in Lucca pilot

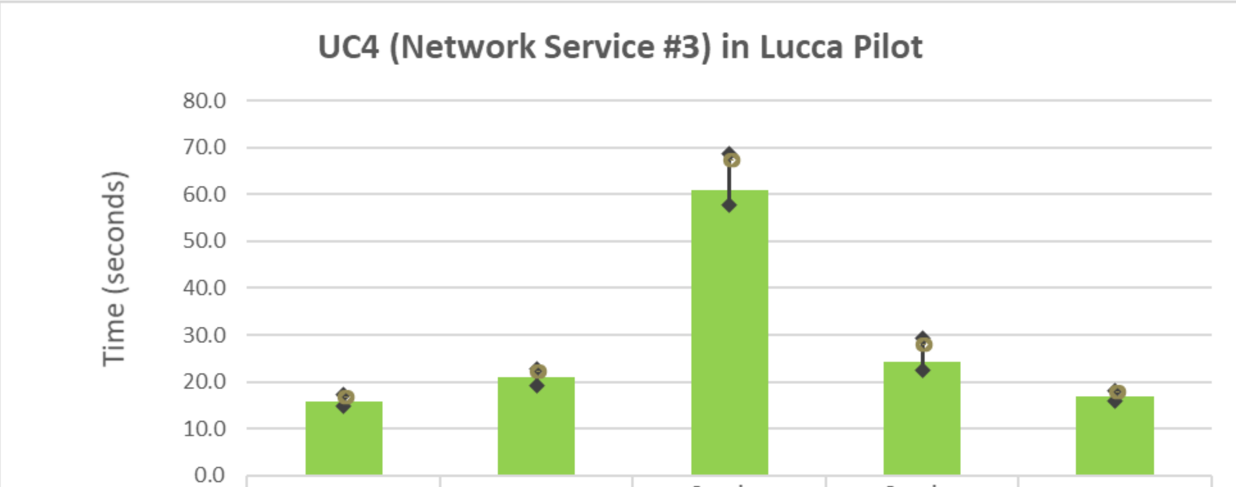
Similarly, **Figure 166** shows the same measurements for the case of the second network services.



	Slice Creation	Slice Activation	Service Instantiation	Service Removal	Slice Removal
AVG	15.84	21.09	61.60	25.22	16.74
MIN	14.45	19.49	51.85	22.44	15.72
MAX	18.28	23.03	67.96	30.13	18.01
90-PERCENTILE	16.95	22.36	67.57	29.16	17.63

Figure 166 - Service Instantiation Time KPI of UC4 Network Service #2 in Lucca pilot

Lastly, **Figure 167** shows the same measurements for the case of the second network services.



	Slice Creation	Slice Activation	Service Instantiation	Service Removal	Slice Removal
AVG	15.68	21.06	60.96	24.20	16.78
MIN	14.86	19.28	57.67	22.56	15.77
MAX	17.38	22.86	68.77	29.44	18.03
90-PERCENTILE	16.55	22.13	67.21	27.79	17.73

Figure 167 - Service Instantiation Time KPI of UC4 Network Service #3 in Lucca pilot

A comparison between **Figure 165**, **Figure 166** and **Figure 167** reveals that the collected time measurements are very similar the three network services of UC4. More importantly, the average time values required to instantiate the three network services are below 120 seconds, hence this KPI target has been achieved.

Table 57 summarizes the results collected during the remote trial in Lucca with respect to their respective target values. In general, the values we collected during the trials are aligned with the values we set for the UC4 KPIs, meaning that all the targets were successfully reached.

KPI	Target	Measurement
User experienced data rate	>= 15 Mbps	26.89 Mbps
Real Time Video Buffering	> 20 s	26.12 s
HoloLens service latency	<= 500 ms	449.33 ms
Service Instantiation Time (SIT)	<= 120 s	60.95 s, 61.90 s and 60.96 s

Table 57 - UC4 KPI results in Lucca Pilot

7. Mobile Backpack Unit for Real-time Transmission Use Case Trial

As a TV broadcaster, betevé faces a series of challenges when sending out teams to provide live coverage on the field. One of the core challenges faced during a real time transmission is to have a sufficiently stable and performing connection to send the recorded signal towards the TV station. Nowadays, 4G is mostly used as relay technology. For redundancy, not one, but several modems and for a variety of network operators are hooked up to a camera.

In betevé system, these modems are aggregated in a mobile backpack that runs an operating system with intelligent functions that select the best available connectivity among all modems or apply smart signal aggregation. However, in spite of these features, a stable and high performing connection cannot always be achieved with these mobile backpacks. In crowd events, where hundreds or even thousands of people, or even other TV broadcasters are present, all relying on the same 4G technology and thus sharing the radio medium with each other, even using multiple modems and signal aggregation might not be sufficient to deliver the required performance.

It's because of the limitations of the current 4G-based solution that betevé is keen on using the features provided by 5GCity to be able to perform their real time transmissions. An illustrative diagram of the deployment of this real-time video transmission use case over the 5GCity architecture is shown in **Figure 168**.

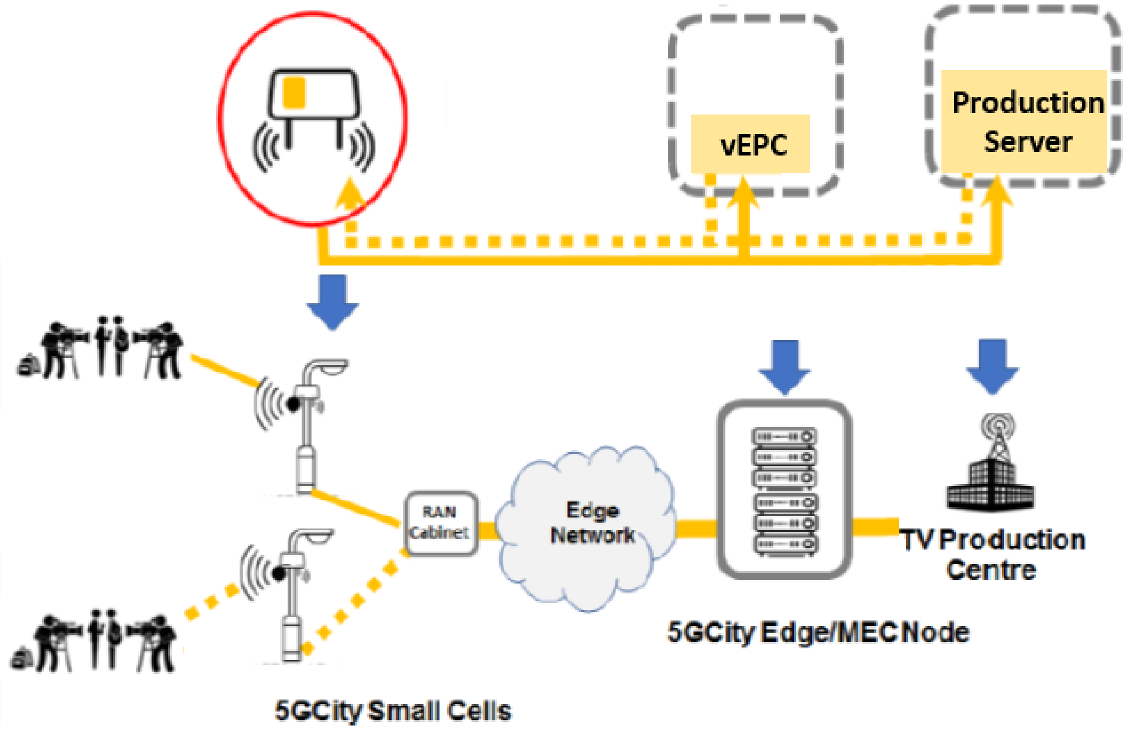


Figure 168 - Illustrative diagram of UC5 deployment

With 5GCity, betevé can request a dedicated slice that includes the desired resources (in particular, radio access for their modems), e.g. when a festival or protest is happening in a specific location, and obtain the necessary QoS. The UC trial validates this, by deploying the dedicated slice and by performing a live transmission to the TV station while measuring KPIs such as the achieve bandwidth, the latency and signal stability.

7.1 Use case deployment using the 5GCity platform

The deployment of this use case using the 5GCity platform required the creation of an on-demand slice that allows the connection of mobile backpacks to the TV studio premises where the production servers are located. The required slice for this use case is composed of one compute chunk at the edge compute resources, where a vEPC is instantiated, a network chunk, which provides the required end-to-end connectivity, and two LTE small cells as the radio chunk. The resulting slice, together with the position of the aforementioned nodes over the map, are depicted in **Figure 169**.

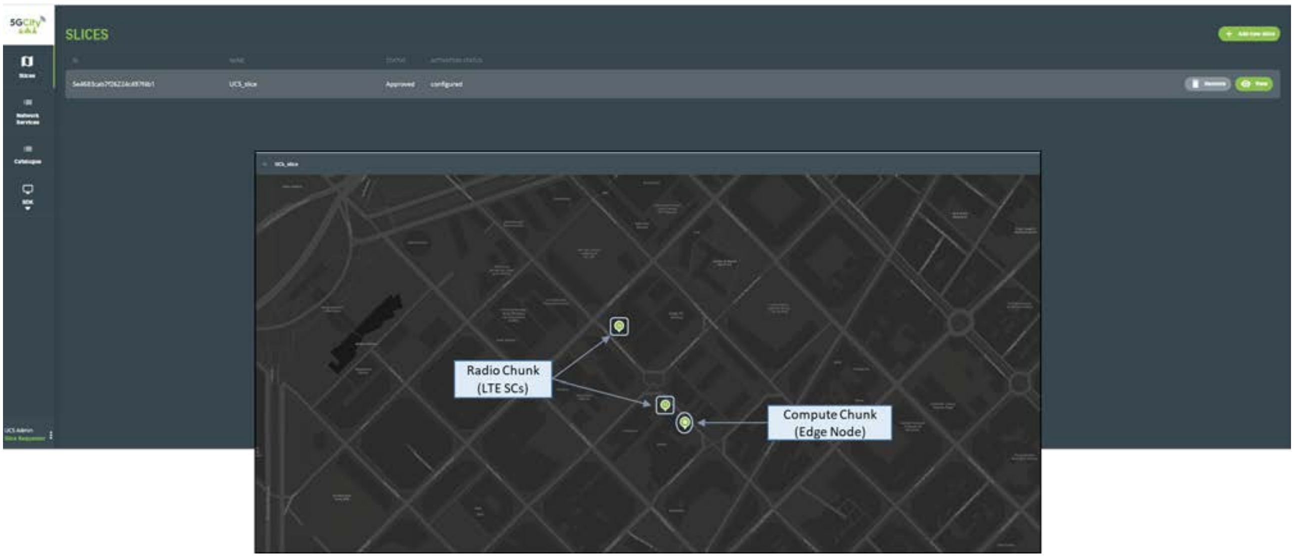


Figure 169 - Slice created for UC5 with location of compute and radio nodes over the map

7.2 Considered Metrics and KPI

To evaluate this UC, different metrics are considered, which can be classified into two main categories: **generic metrics** and **application-specific metrics**.

The generic metrics for UC5 are summarized in Table 58.

Generic Metric	Description
User Experienced Data Rate	Throughput achieved by the backpack cameras when doing a signal transmission. This metric gives us an indication of the quality of the transmission.
Service Latency	Time between capturing the signal and broadcasting it. This metric is especially important for doing remote interviews or dialogs between the studio reporter and the remote reporter. In other words, as less the latency better interviews can be done over this network.
Slice Deployment Time (SDT)	Time to deliver an active slice. This metric is very important for on-demand deployments to support transmissions from reporters covering unplanned news.

Table 58 - UC5 generic metrics

The application-specific metrics considered for UC5 are some of the most relevant performance parameters to ensure the quality of a TV signal transmission, which are outlined in **Table 59**.

Application-specific Metric	Description
Handover	Seamless jump of UEs between adjacent small cells during a transmission. When transmitting a video signal in the street, could be necessary to move the shooting location while in transmission. The availability of the network to perform a clean handover is very important to do so.

Table 59 - Application-specific metrics considered for the UC5 trials

Finally, **Table 60** describes the KPIs to be measured for UC5.

KPI ID	Definition	Description	Target	Priority [H/M/L]
UC5_KPI#1	**User Experienced Data Rate**	Throughput used in the transmission.	**>= 8 Mbps (sustained)**	H
UC5_KPI#2	**Service Latency**	Delay in the transmission of the video signal, it should be as small as possible.	**<= 1 s**	H
UC5_KPI#3	**Slice Deployment Time (SDT)**	Time required to delivering an active slice to the users.	**<= 30 s**	H
UC5_KPI#4	**Handover**	Seamless jump of video signal between adjacent small cells.	**Seamless**	H

Table 60 - KPIs considered for UC5

7.3 Measurement Methodology

In order to stablish the measurement methodology, the TVU GUI will be used. The TVU is a combination of dedicated server and software for capturing video signal transmitted by the betevé cameras. It serves to monitor and configure parameters of captured streams (apart from providing previews of the transmitted signal). In the dashboard shown in **Figure 170,** we can adjust all the relevant parameters for the transmission. The green-coloured plot monitors the used bandwidth in the transmission over time. In the Setting window, we can adjust the desired bandwidth and the delay.

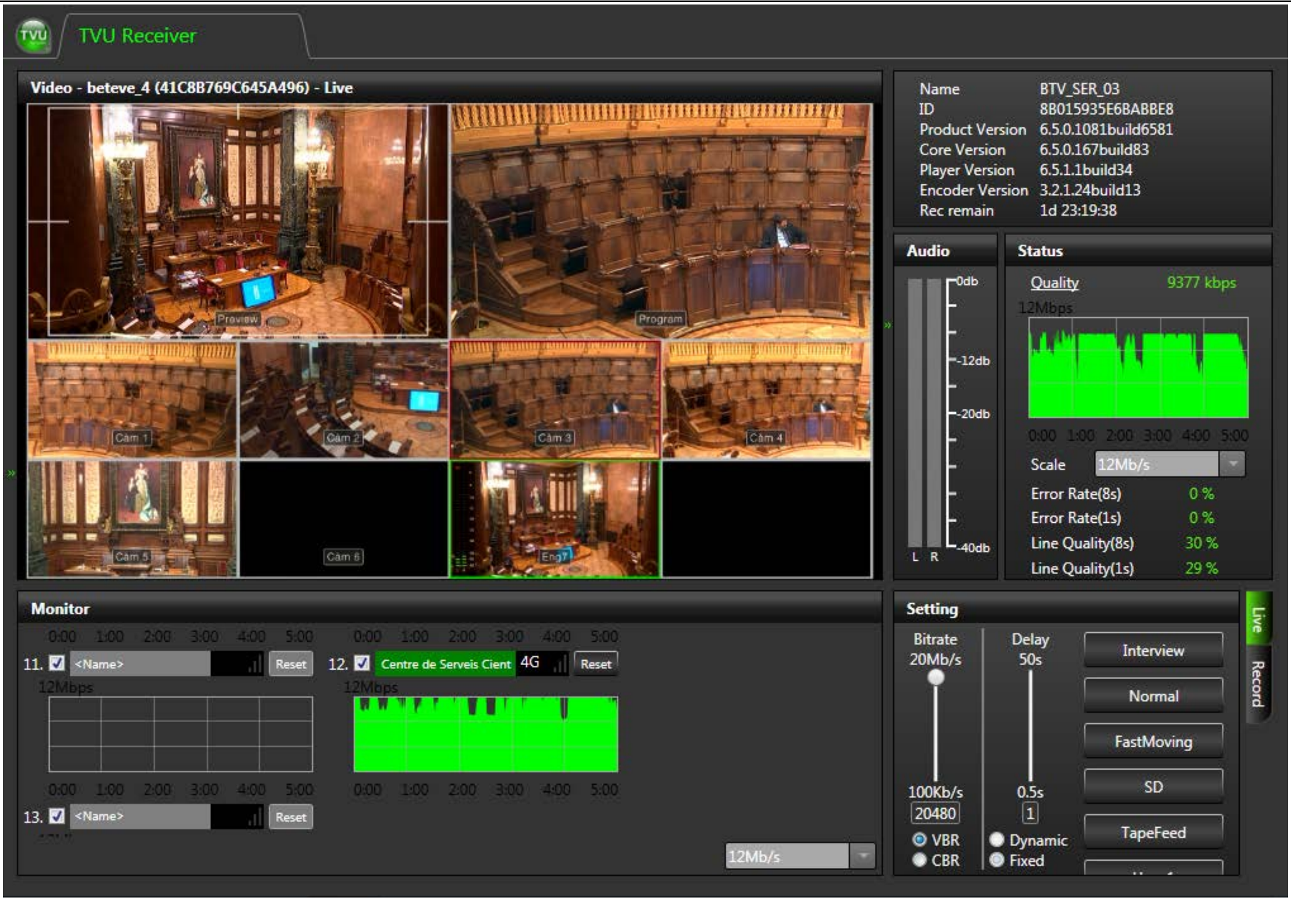


Figure 170 - TVU GUI/Dashboard

The green plots indicate the received bandwidth of the video streams. For further reference in the result section below, the plot on the lower left is the contribution of different modems connected to the backpack (approach used in traditional transmissions with multiple modems per camera), whereas the green plot on the right side is the sum of the bandwidth of all the modems. The aggregate and per-modem plots show the same values in our evaluations, though note that there is a slight visual difference as a different scaling is used in each plot.

Once the connection between a camera and the TVU server is established, the different parameters from the backpack control application are adjusted. Afterwards we heck for the accomplishment of the KPIs.

Regarding the data rate experienced by the user (in this case the camera), it will be measured with the backpack managing application. Using the TVU server interface, we can measure the real transmission speed in the green graph over time. In general, in video transmissions, the higher the bandwidth, the better the quality of the video, as more information can be transported (more pixels, less compression). For the transmission of a live video with betevé cameras, the bandwidth has to be at least 8 to 10 Mbps. This data rate is required to send a HD TV signal with a minimum acceptable quality for broadcast purposes.

The latency cannot be measured directly in the interface, but what can be done is to adjust the delay of the system. When the latency of the network is bigger than the receiver delay, the received image becomes noisy and pixelated. Therefore, the procedure followed to measure this KPI, consists in adjusting the total transmission delay and looking for the signal quality and consistence.

The handover between small cells is relevant for the case where a UE is transmitting a video signal in the street and it becomes necessary to move the shooting location while in transmission. This metric evaluates if there are any signal losses or cuts during such a transmission. During the UC validation, it will be measured in an empirical way by observing the received signal and the Bandwidth/time graph. Additionally, in the received video signal no cut or freeze has to be observed, and the graph has to be continuous.

To execute the handover there were two possibilities, in the context of the 5GCity pilot, namely: the manual handover, where you can switch manually from one small cell to the next one with the push of a button in Accelleran dRAX™ Dashboard, and automatic handover, which is triggered automatically by Accelleran dRAX™ based on configured mobility robustness optimisation (MRO) parameters. While the automatic handover is decided directly by the system based on configured MRO parameters, the manual handover can be performed via the dRAX™ Dashboard as illustrated in **Figure 171**. Lastly, a handover can only be performed between small cells belonging to the same slice in current 5GCity platform configuration.

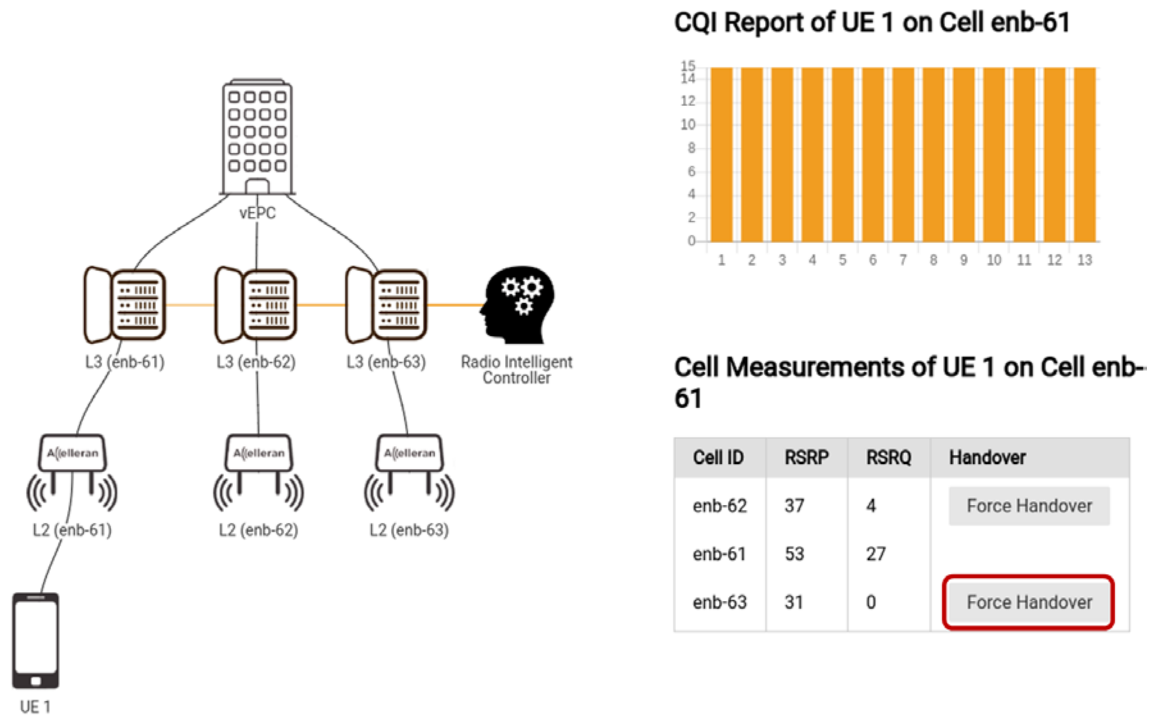


Figure 171 - dRAX™ Dashboard for executing a manual handover approach

Note that the handover was not planned to be supported in 5GCity and that it has been added as an additional feature to the repertoire of supported features of the LTE RAN. Further, it is not a fully lossless handover in the current 5GCity platform configuration since data packets are not buffered in coordination between source and target small cells and vEPC.

7.4 Barcelona Pilot Validation

7.4.1 Scenario and Trials Description

The UC is deployed entirely in the 22@ district from Barcelona, where three Accelleran Small Cells as Radio Units are installed along Ciutat de Granada Street, connected to the edge computing system in the betevé data center which hosts Accelleran dRAX™ vRAN/vL3 controlling the cluster of Accelleran Radio Units and the vEPC associated to the slice. **Figure 172** shows a street diagram, highlighting where the two small cells used in the trial are located and where the video is filmed.

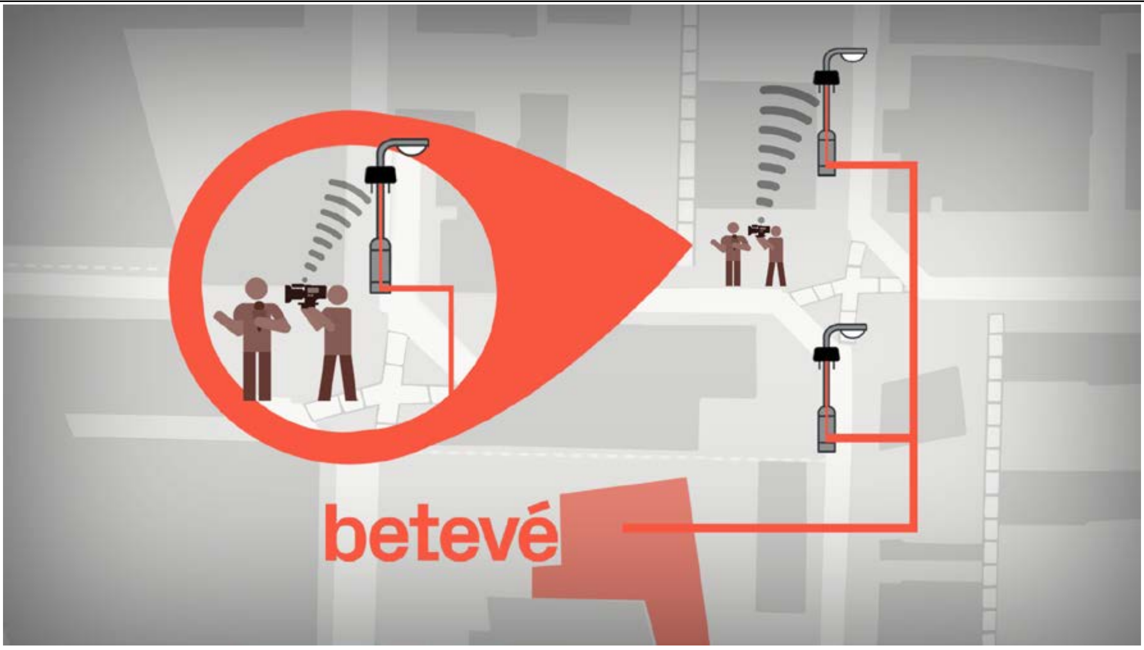


Figure 172 - Street diagram showing where UC5 is validated

Unlike other UCs in 5GCity, where the most common commercial TDD UL/DL Ratio 2 was used for the Accelleran Small Cells, for this UC both the TDD UL/DL Ratio 2 and the TDD UL/DL Ratio 1, a less downlink intensive configuration, was used in order to provide up to 20 Mbps UL throughput.

The trial mainly consists in the transmission of a HD video signal. Instead of using the transmission system already used by betevé (and almost all the TV broadcasters) over 4Gm using the bonding technology, with multiple modems with their SIM cards (up to 6), we substitute all these modems just by 1 modem with one SIM card that is connected to the 5GCity small cells that are part of the dedicated betevé slice.

The equipment used on street is composed of one video camera and one "backpack" transmitter (TVU system from TVU Networks), which is a dedicated computer with a video input, a video compression system and the bonding system. This UC works just with one MiFi device connected to the backpack. The captured signal is transmitted over the 5GCity network and received at the betevé studios, where it is decoded by a TVU server connected to the 5GCity network.

The validation trial was performed on January 17th, 2020 using the following equipment:

- Camera: Panasonic AJ-PX270
- Transmitter (Backpack): TVU ONE
- MiFi: HUAWEI E5788u-96a
- Network: 5GCity network deployed in Barcelona 22@ with 2 Accelleran Small Cells as Radio Units, Accelleran dRAX™ vRAN/vL3 and vEPC, and L2 connectivity to the TVU server
- Receiver: TVU server receiver

With this setup, the three main KPIs can be measured. To measure the additional handover KPI, the team filming on street would move from one small cell to the other while recording and streaming the signal to the betevé studio.

In addition to the experiments used to validate the aforementioned KPIs, the betevé UC is also trialled in the city hall (St. Jaume) extension introduced in D5.2. At the time of writing this deliverable, the two additional Accelleran Small Cells were not installed yet, but a temporary setup was performed using the mobile demo column used in other occasions, such as conferences or expos. **Figure 173** shows a conceptual diagram of the connection from betevé to the city hall, and **Figure 174** the Saló de Cent, which is the historic room were the measurements were performed and where the two additional small cells will be deployed.

Figure 173 - City Hall connection diagram

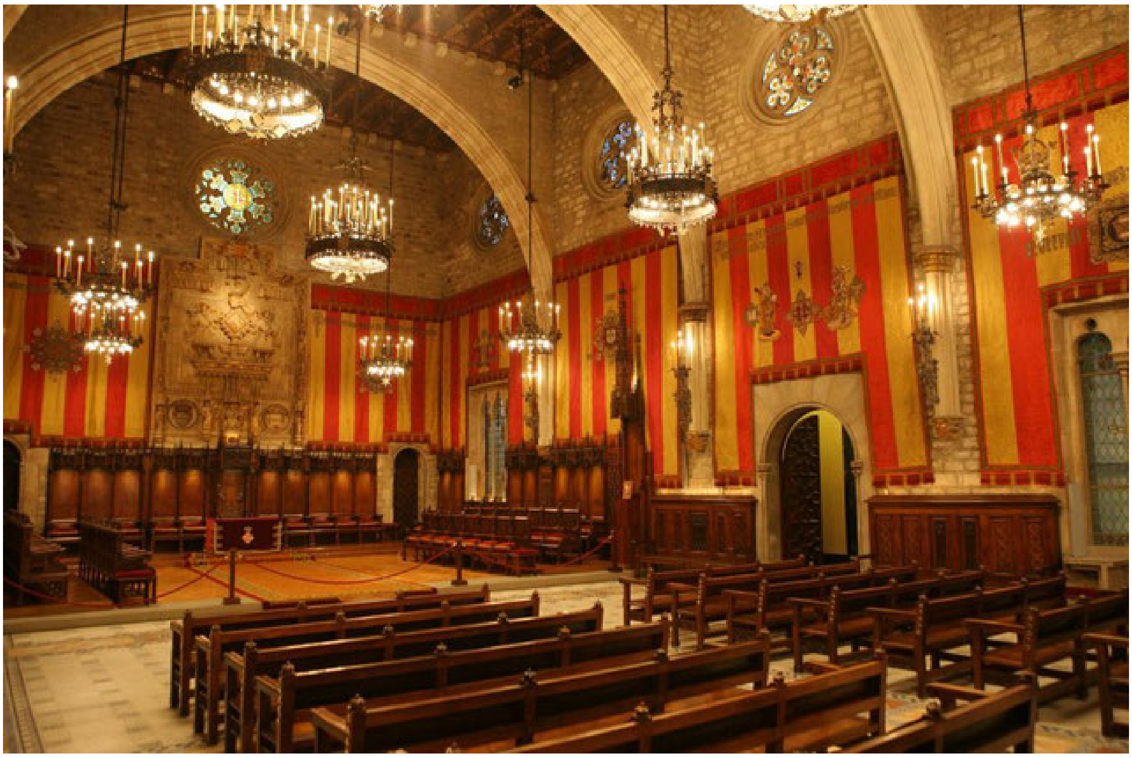


Figure 174 - Saló de Cent

7.4.2 Results Analysis

This section presents the results obtained for the four metrics relevant to UC5 during the execution of the trial.

- **User Experienced Data Rate, Latency and Handover**

Overall, the trial was repeated several times to provide meaningful results. In the following subsections, the outcomes of these repetitions are presented.

A. Test run 1

The first test was made configuring the transmission at a fix rate of 8 Mbps with 0.5 sec of delay and using a 1080i 50 PAL-standard high-definition signal. The information provided by the TVU GUI during the test is presented in **Figure 175.**

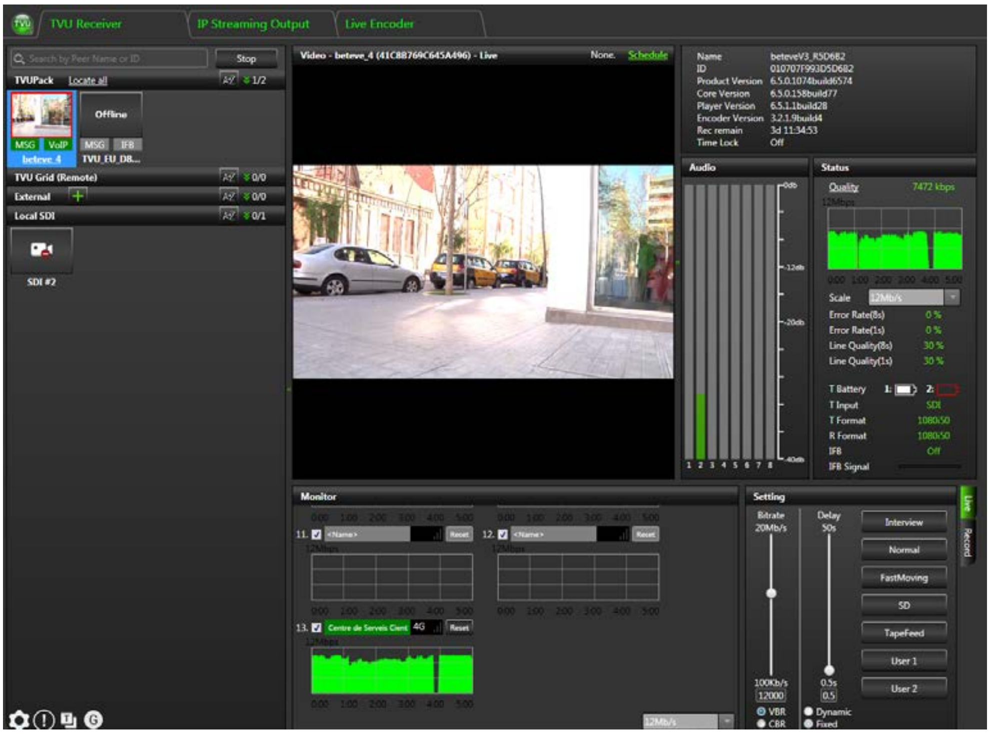


Figure 175 - TVU GUI screenshot for the test number 1

In **Figure 175,** we can see that the user experienced data rate is between 8 and 10 Mbps nearly continuously (green plot in the bottom of the figure). There is a short drop of the signal, which is caused by a short interruption of the LoS towards a small cell due to a truck passing by on-street.

The delay of the system is fixed to 0.5 seconds and no image interruptions or pixellations are observed. This means that the network latency is under 0.5 seconds value. A separate test that is not captured in the deliverable with 2 cameras and a 20/80 TDD setting of the small cell (20 Mbps upload / 80 Mbps download) yields that up to two 8 Mbps streams can be transmitted at the same time without any issues.

Regarding the handover, when walking from one small cell to another during the transmission the signal was not lost and the seamless transition did not cause any cuts on the video transmission.

B. Test run 2

The same settings as in test run 1 are used. However, at the end of the test, the camera team moves away from the small cells towards an area without coverage, to observe how RAN signal degradation affects the transmission. Again, during then normal transmission, no image interrupts or pixellation is observed, this means that the network latency is under 0.5 seconds value and the experienced data rate remains steadily near to 8 Mbps during the first 3 minutes of the test.

During the handover there is a small video cut off with a duration of 5 frames. As stated before the handover function was included as an added feature and was not configured in 5GCity as a lossless handover. As such, the loss of 5 frames (which were not buffered in coordination between small cells and vEPC) is not optimal, but falls within the expected outcomes of the experiment. After the handover and as the camera team moves away from the small cell, the data rate begins to drop, which is reflected in the right part of the green plots in **Figure 176**. The signal begins to degrade and eventually is lost completely.

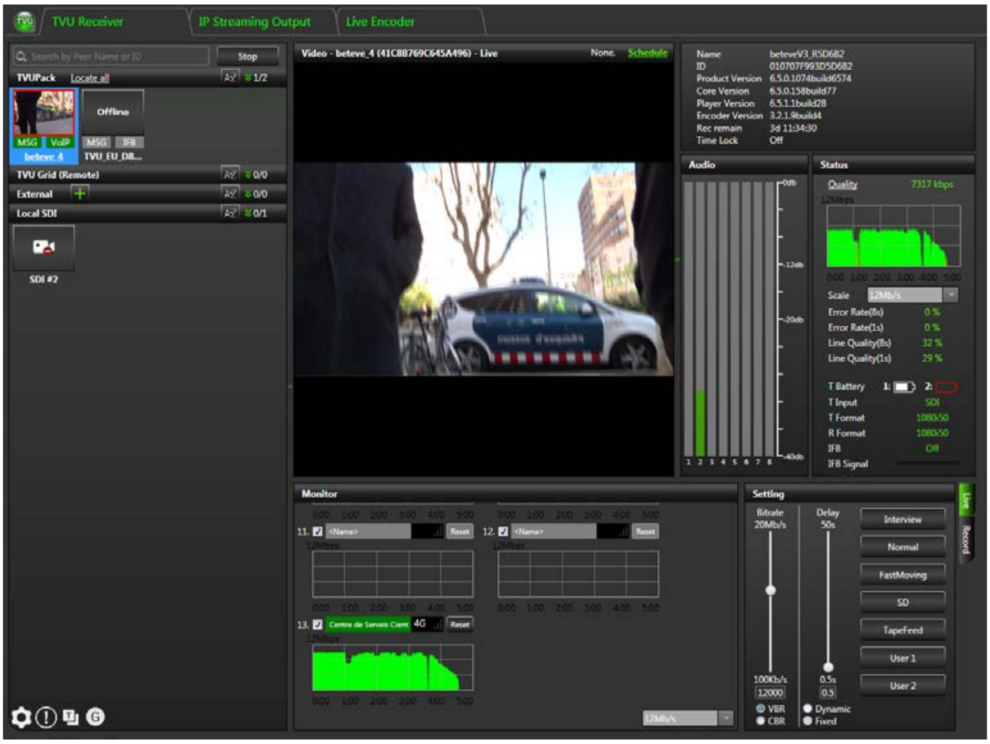


Figure 176 - TVU GUI screenshot for the test number 2

C. Test run 3

Repeating the same test as in test run 1, we obtain very similar results. The only difference is that in this run we change the direction in which the camera team walks (and thus handover). By altering the initial small cell and the one to which the handover takes place, the handover does not work smoothly and a 1 second video signal loss is observed (big gap observed in the green plots in **Figure 177**). After this loss however, the signal recovers. We attribute this loss to the suboptimal tuning of the mobility robustness optimisation parameters, since for the 5GCity platform, the version of dRAX™ did not incorporate the smart handover algorithms.

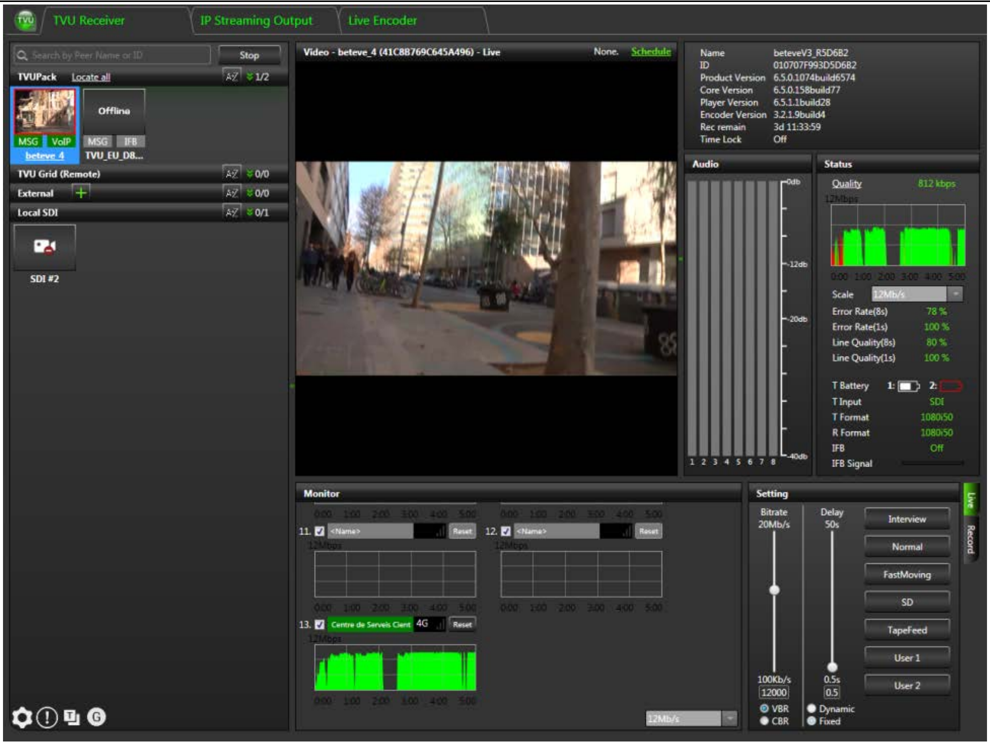


Figure 177 - TVU GUI screenshot for the test number 3

D. Test run 4 (city hall validation)

On February the 28 of 2020, an additional test run was made in the city hall. This location extends the 5GCity RAN infrastructure to the city center, providing coverage for transmissions during plenary meetings, special events and for interviews with local politicians. The test performed only validates the basic connectivity and that the betevé slice can be extended to the city center. The equipment used in this test is listed below:

- HD Video feed from the multiviewer output of a Blackmagic video mixer
- Transmitter (Backpack): TVU ONE
- MiFi: HUAWEI E5788u-96a
- Network: 5GCity network deployed in the city hall, connected to the 22@ area
- Receiver: TVU server receiver

Figure 178 shows the small cell used for the validation.

Figure 178 - "Portable" small cell

The delay of the system was fixed to 0.5 seconds, and since no image interrupts or pixellations was observed, this means that the network latency is under these 0.5 seconds value. Moreover, the experience user date was between 8 and 10 Mbps as can be observed in **Figure 179.** As such, the extension to the 5GCity infrastructure in the city hall was validated successfully, obtaining the required performance for the real time transmissions. Please note that the outcomes of this additional test are not included in the summary of the results.

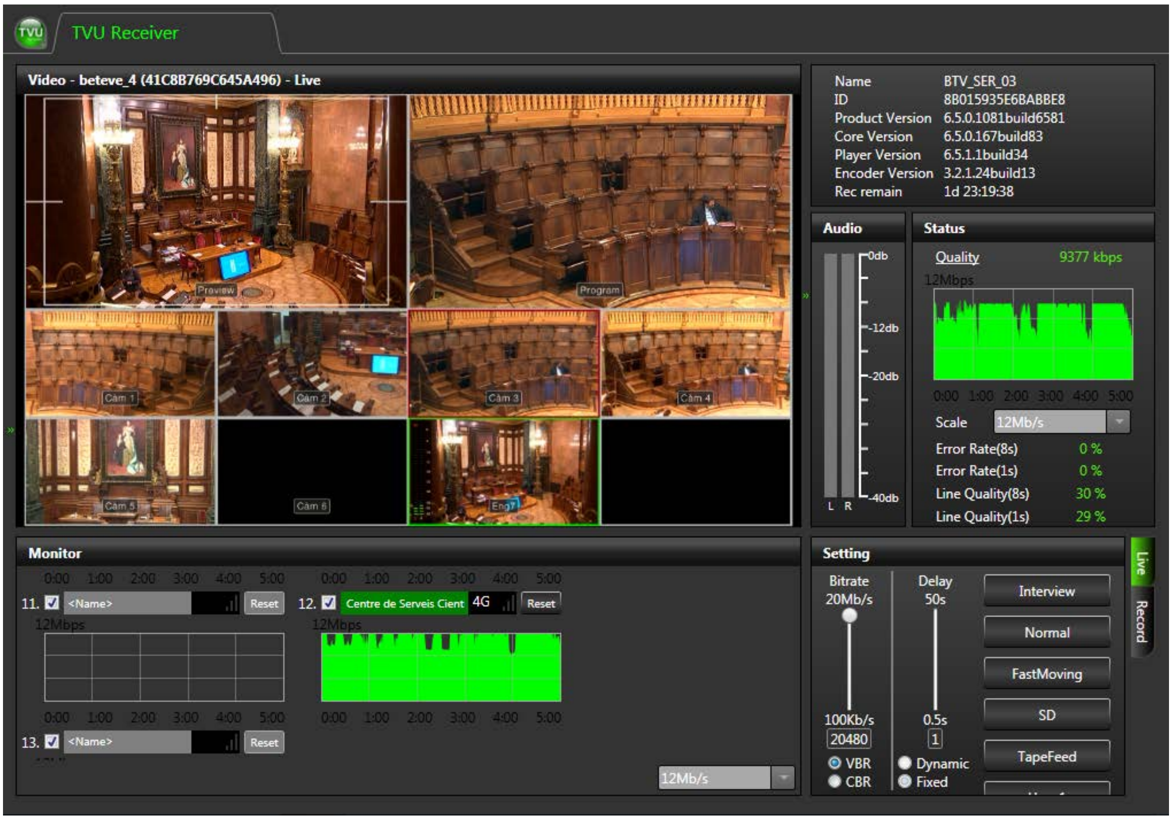
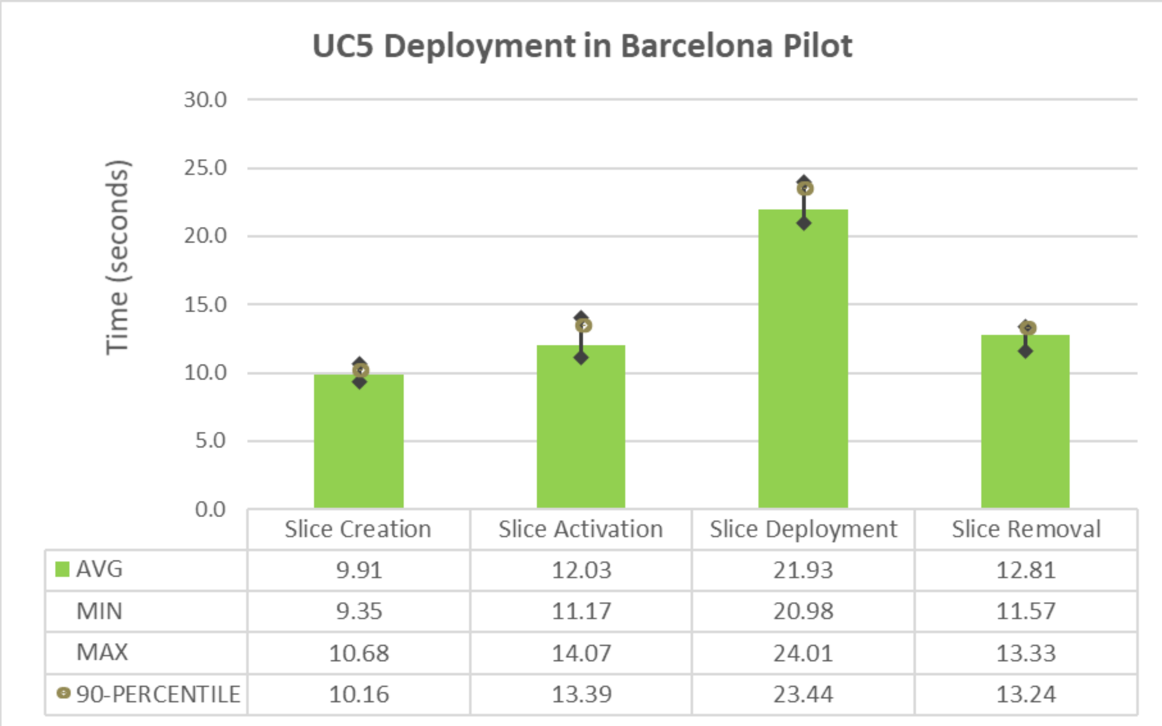


Figure 179 - TVU GUI screenshot for the test

- **Slice Deployment Time**

The measurements for the Slice Deployment Time (SDT) KPI were computed as indicated in Section 2.2. In **Figure 180** we can see the slice deployment times obtained for the Barcelona pilot by running the automated script at the 5GCity Slice Manager 30 times. Additionally, the times required for removing the slice are also plotted in the referred figure. As can be observed in **Figure 180**, the average SDT obtained for UC5 in the Barcelona pilot is of 21.93 seconds, value that also meets the target set for this KPI (i.e. 30 seconds).



	Slice Creation	Slice Activation	Slice Deployment	Slice Removal
AVG	9.91	12.03	21.93	12.81
MIN	9.35	11.17	20.98	11.57
MAX	10.68	14.07	24.01	13.33
90-PERCENTILE	10.16	13.39	23.44	13.24

Figure 180 - Slice Deployment Time KPI of UC5 in Barcelona Pilot

Overall, the three test runs performed for UC5 reveal that the main KPIs can be achieved without issues. The data rate experienced during the trial allows for high quality video transmissions with 1 or 2 cameras, respectively. Regarding the SDT, the observed behaviour of this KPI after simulating 30 iterations of such operation was less than the target value of 30 seconds. Further, a constant, overall delay of less than 0.5 seconds is observed throughout the test runs, which indicates that the dedicated betevé slice is providing continuously high performance. Some issues have been observed with the experimental handover feature, providing good results in some test runs, but less satisfying in others (temporary cut of the signal). The metrics gathered during this test run will be used to improve this feature in post-5GCity deployments of the Accelleran solution.

Table 61 summarizes the results obtained in the trials.

KPI	Target	Measurement
User Experienced Data Rate	>= 8 Mbps (sustained)	8 to 10 Mbps (sustained)
Service Latency	<= 500 ms	<= 0.5 s
Slice Deployment Time (SDT)	<= 30 s	21.93 s
Handover	Seamless	Partially (lossless handover functionality not deployed)

Table 61 - UC5 KPI results

8. Cooperative, Connected and Automated Mobility Use Case Trial (UC6)

This Cooperative, Connected and Automated Mobility (CCAM) use case has been designed to demonstrate the benefits of the Neutral Hosting model for the Automotive sector. Specifically, the use case showcases how this industry could make use of widely available neutral and distributed infrastructure to effective and efficiently deploy V2X services supporting a number of scenarios which are valuable to a large number of stakeholders: the city itself, citizens, drivers and pedestrians, as an example.

In this case, a simple CCAM scenario has been deployed: the ability to relay information to vehicles using different Radio Access Technology (RAT) such as Wi-Fi and LTE in a single network using less powerful hardware (ARM-based Single Board Computers) installed in urban furniture such as lampposts and street cabinets. This infrastructure coordinates both "standard" and "critical" information with connected vehicles to disseminate data such as the speed limit for a given geographical area, infringements reported by vehicles themselves and critical warnings that should be distributed to other vehicles, by leveraging the infrastructure itself as a relay.

To this end, and because the use case relies on Far Edge nodes located inside a street cabinet (which could also be deployed inside Barcelona's lampposts), fog05 has been used as the orchestrator capable of instantiating and handling lifecycle management this particular use case's ARM-based Linux Containers (lxc). As such, all services designed and implemented have been made available as Linux Container and because the ITS-G5 stack has been used (based on OpenC2X[12]), we have effectively deployed an RSU (Road Side Unit) on an Odroid device (as further described in section 8.4). **Figure 181** illustrates this at a high-level: two different vehicles, connected using multiple RAT to equipment installed at street furniture, coordinating data with an application running on the Far Edge node (RSU).

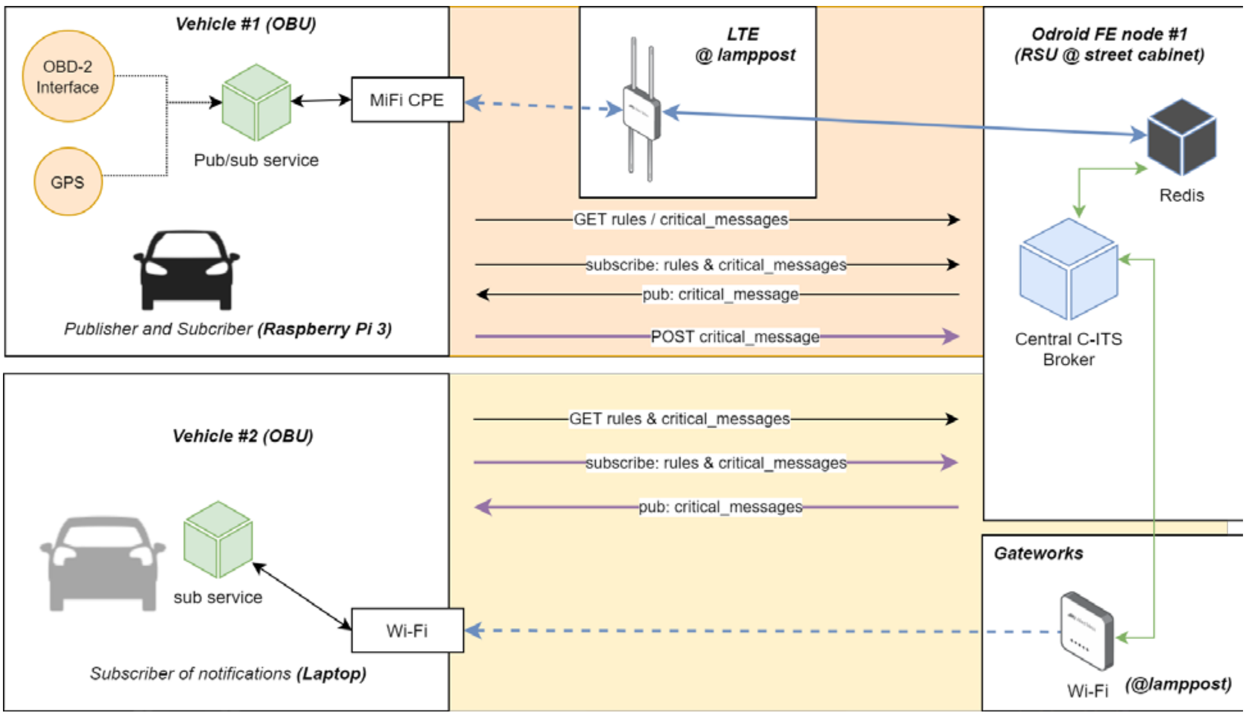


Figure 181 - Sequence diagram for UC6 operation

[12] https://github.com/florianklingler/OpenC2X-standalone/blob/master/LICENSE

8.1 Use case deployment using the 5GCity platform

As with the other use cases, the UC6 deployment using the 5GCity platform was performed following the conceived workflow. As mentioned before, the first step was to create the VNF and NS involved in this UC with the help of the 5GCity SDK. The resulting VNF and NS, inside the repository assigned to this UC (i.e. UC6_repo), can be observed in **Figure 182** and **Figure 183,** respectively, as presented in the 5GCity Dashboard.

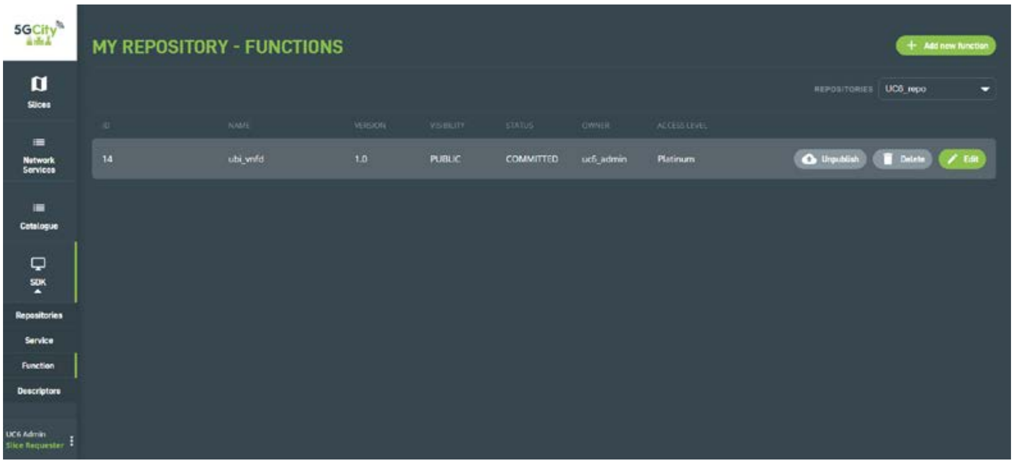


Figure 182 - UC6 function created using the 5GCity platform

Figure 183 - UC6 network service created using the 5GCity platform

Then, a dedicated slice is delivered to host the services developed for this use case. In **Figure 184**, we can see the UC6 slice in the 5GCity Dashboard, together with the location of the selected slice components in the 22@ area in the Barcelona pilot.

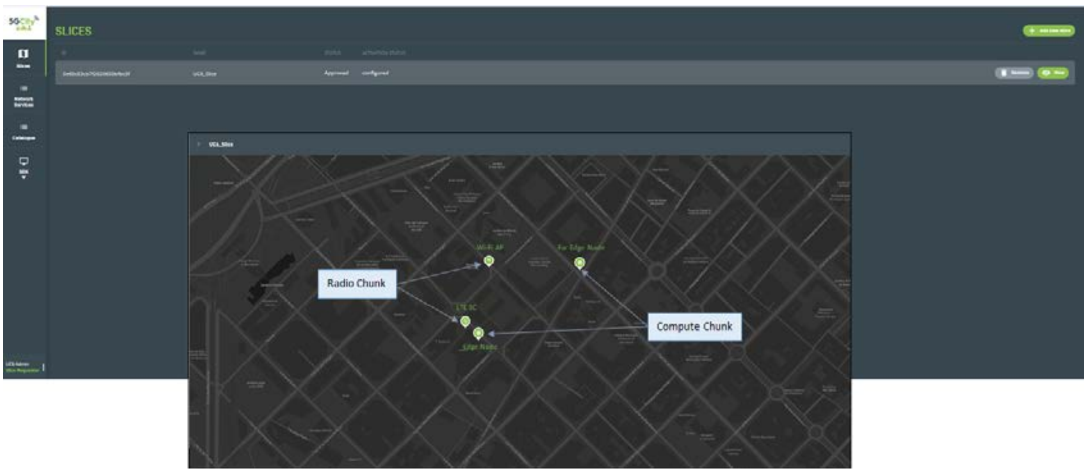


Figure 184 - Slice created for UC6 with location of nodes over the map

Taking a look at **Figure 184**, taken from 5GCity Dashboard, it is possible to understand the components that make up for this UC slice:

- Wi-Fi Access Point
- Accelleran LTE Small Cell as Radio Unit
- Far Edge node – being orchestrated by the MEAO component (fog05 integration) to host the RSU service (Odroid device, depicted in **Figure 185**)
- Edge node – being managed by OpenStack (another VIM), to host the vEPC, as required by the LTE RAT

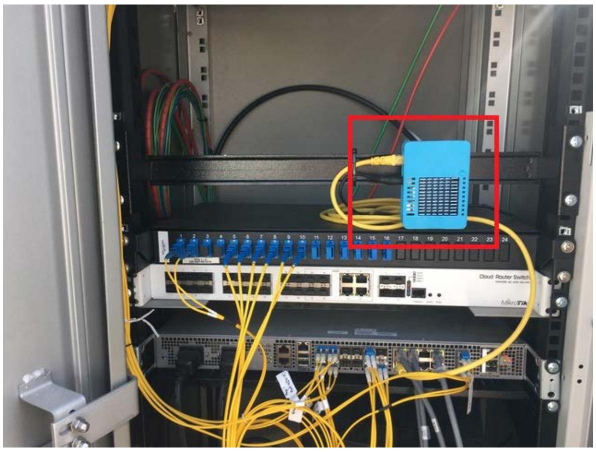


Figure 185 - Odroid node (RSU, highlighted in red) installed inside a street cabinet

Being the service and the slice available, the next step was the instantiation of the service. As mentioned in previous deliverables, the use case does make use of fog05 to orchestrate Far Edge ARM-based nodes. For this reason, and as reported in D3.1 and D4.1 , support for ETSI MEC (Multi-access Edge Computing) has been added to 5GCity Orchestrator, by integrating three different components: MEAO (Multi-access Edge Application Orchestrator), MEPM-V (Multi-access Edge Platform Virtual Manager) and the ME platform (Multi-access Edge Platform, as a VNF running on edge hosts). Once these components have been integrated into 5GCity Orchestrator and, thus the OSM, the whole orchestration of such MEC app (set of Linux Containers designed and implemented for this particular use case) could be instantiated via 5GCity Dashboard, as shown below (services uploaded to catalogue and dedicated slice).

The successful instantiation of the UC6 service can be corroborated in **Figure 186,** in which we can see the services running in the 5GCity Dashboard and in OSM.

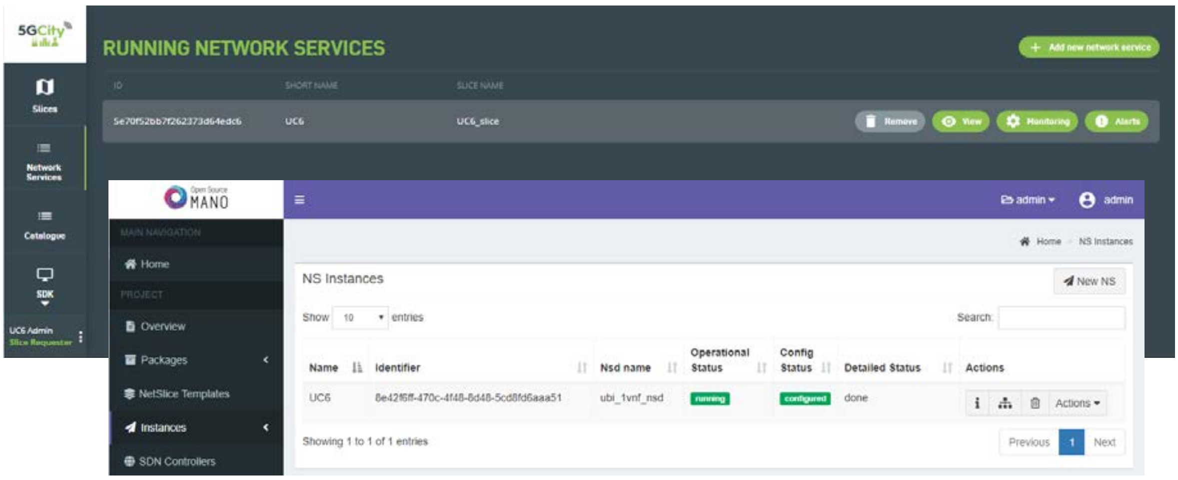


Figure 186 - View of the deployed UC6 in the 5GCity Dashboard and OSM

8.2 Considered Metrics and KPI

Being a V2X use case that makes use of LTE connections (and also Wi-Fi), the baseline reference for the KPIs related with end-to-end latency were based on [11] entitled "Service requirements for next generation new services and markets" (July 2018) (which, in turn, follows [2]). Specifically, the "Intelligent transport systems" (ITS) scenario has been used as reference, as stated in the "Performance requirements for low-latency and high-reliability scenarios" table.

In this section, a list of generic metrics (more related to 5GCity infrastructure, modules and networking) are identified (see **Table 62**), as well as application-level ones (see **Table 63**). The considered metrics should indicate if such service is suitable for the targeted scenario, having in mind the low-cost hardware used (general-purpose Odroid ARM SbC – Singleboard Computer). For this, based on such metrics, a set of KPIs have been designed and implemented at the service layer, to extrapolate how performant such design and implemented system is.

Generic Metrics	Description
Service Latency	The latency between the different equipment (OBU and RSU). This metric will be measured differently in the different LTE and Wi-Fi links.
Service Instantiation Time	The time it takes for the service to be instantiated at the targeted node, once deployed from the Dashboard

Table 62 - Generic metrics considered for UC6

Application-specific Metric	Description
Delivery latency of rules from Infrastructure to Vehicle (ACK_delta_OBU)	The time it takes for a list of rules to reach a given vehicle. The time it takes to be connected to the network is not measured, so this metric refers only to the time that takes our OBU application to receive the critical requested data from the RSU.
Delivery latency of critical messages from Vehicle to Infrastructure (ACK_delta_RSU)	Once the vehicle detects an infringement or hazard (categorised as "critical message"), a warning should be immediately sent to the RSU. This allows to us better understand how much time it takes for the RSU to receive such critical message, once detected by the Vehicle.
End-to-end critical message delivery latency (V2I2V_delta)	Because the use case makes use of different RAT technology, it is crucial to determine how much time it takes for a critical message to be sent to the infrastructure using a specific RAT and the time it then takes to relay such same message to a second vehicle via a different RAT. In this case, the originated message is sent via LTE (V2I) and received via Wi-Fi (I2V).
Message throughput in a dense environment (messages/s)	Number of messages the application can handle, per second. In a dense urban environment, it is crucial to serve as much vehicles as possible, without losing needed reliability and increasing equipment processing power and cost. For the considered scenario we are reporting this metric in relation to the number of vehicles used during the trial.
Reliability of critical messages delivery (ack_waiting)	Percentage of critical messages that are not correctly received by the receiving party (acknowledge)

Table 63 - Application-specific metrics considered for UC6

Based on the different set of metrics mentioned before, the KPIs described below in **Table 64** have been identified and implemented. With these measurable KPIs, we could better evaluate if general objectives would be met. For this, a target and a priority has been defined per each measurable KPI.

KPI ID	Definition	Description	Target	Priority [H/M/L]
UC6_KPI#1	**Service Latency** The latency perceived from the two connected entities: Vehicle (OBU) and Infrastructure (RSU). The two KPIs refer to the delivery latency of critical messages from Vehicle to Infrastructure and the other way around, initially described in the table before.	**ACK_delta_OBU:** Latency measured at the OBU to indicate how much time it took for a RSU-originated message to reach the target (OBU). Because two different RAT have been used (Wi-Fi and LTE), the latency in this flow has been recorded separately for further analysis. (see **Figure 187 b**) **ACK_delta_RSU:** The same as ACK_delta_OBU above, but following the opposite flow (measured in the RSU). (see **Figure 187 c**)	**<= 30 ms**	H
UC6_KPI#2	**Service Instantiation Time (SIT)**	Amount of time (seconds) needed to have the entire use case up and running.	**<= 120 s**	M
UC6_KPI#3	**V2I2V_delta** End-to-end latency when a critical message is sent from one vehicle to the other, relayed by another service instantiated in the middle. (see **Figure 187 a**)	The KPI takes into account different timestamps registered at various domain. Because it is measured end-to-end, three measurements are taken into account: first at the LTE-connected vehicle, secondly at the RSU and then at the second Wi-Fi-connected vehicle.	**<= 60 ms**	H
UC6_KPI#4	**messages/s** This KPI refers to the throughput in a dense environment, mentioned in the table before.	The KPI allows us to monitor the number of messages the RSU can process, before packets start being dropped (not being capable of handling the reliability indicated below).	**<= 10 messages/s per vehicle**	L
UC6_KPI#5	**ack_waiting** Number of messages that are still missing an ACK. (see **Figure 187 d**)	This metric may imply that the system cannot cope with current throughput or that messages are being lost. This KPI determines how reliable the system is to deliver critical messages.	**<= 1% of all received messages**	M

Table 64 - Targeted KPIs considered for UC6

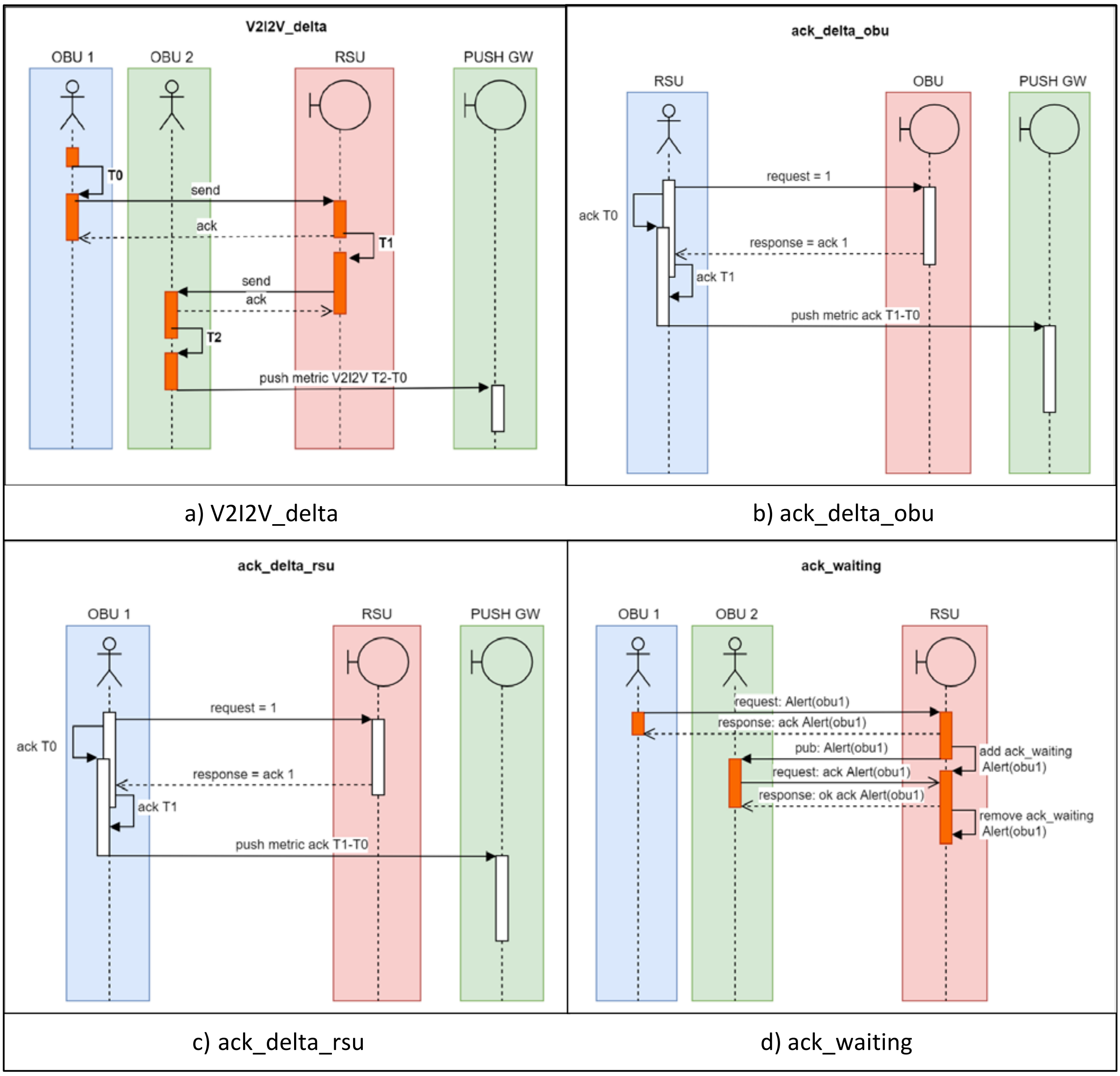


Figure 187 - Message sequence diagram of UC6 KPIs

8.3 Measurement Methodology

Providing the intrinsic safety driving characteristics associated with this use case (vehicles relaying relevant information with others, via the Infrastructure, so these can act accordingly in a timely manner), we position these use case under the uRLLC (ultra-Reliable and Low Latency Communications) spectrum of 5G triangle of use cases (listed below). Furthermore, as mentioned before, the baseline for targeted KPIs were mostly taken from 3GPP TS 22.261. For this reason, specific application-level performance parameters had to be defined and collected to (i) evaluate how scalable such solution is when deployed in general-purpose constrained devices deployed in urban furniture such as lampposts and (ii) if the combination of such services, infrastructure and networking could deliver the much-required latency, end-to-end. The latter is of utmost importance, given the fact that in such scenarios, such information must be delivered not only as reliably as possible, but also in the most timely manner, so targeted nodes can act accordingly to, for instance, in some cases avoid an accident or collision.

To make sure we collect all KPIs listed in the sub-section before, Push Gateway[13] has been deployed at the RSU, in order to aggregate metrics that are asynchronously sent via the OBUs. This way, 5GCity Monitoring System (based on Prometheus) can periodically query our Push Gateway and have a single interface to collect different data which are reported from the Vehicles themselves (which, on their own, would never be able to reach Prometheus, nor the other way around). More details on this implementation can be found in the diagram presented below in **Figure 188**, illustrating also the different KPIs collected and queried by 5GCity Monitoring System.

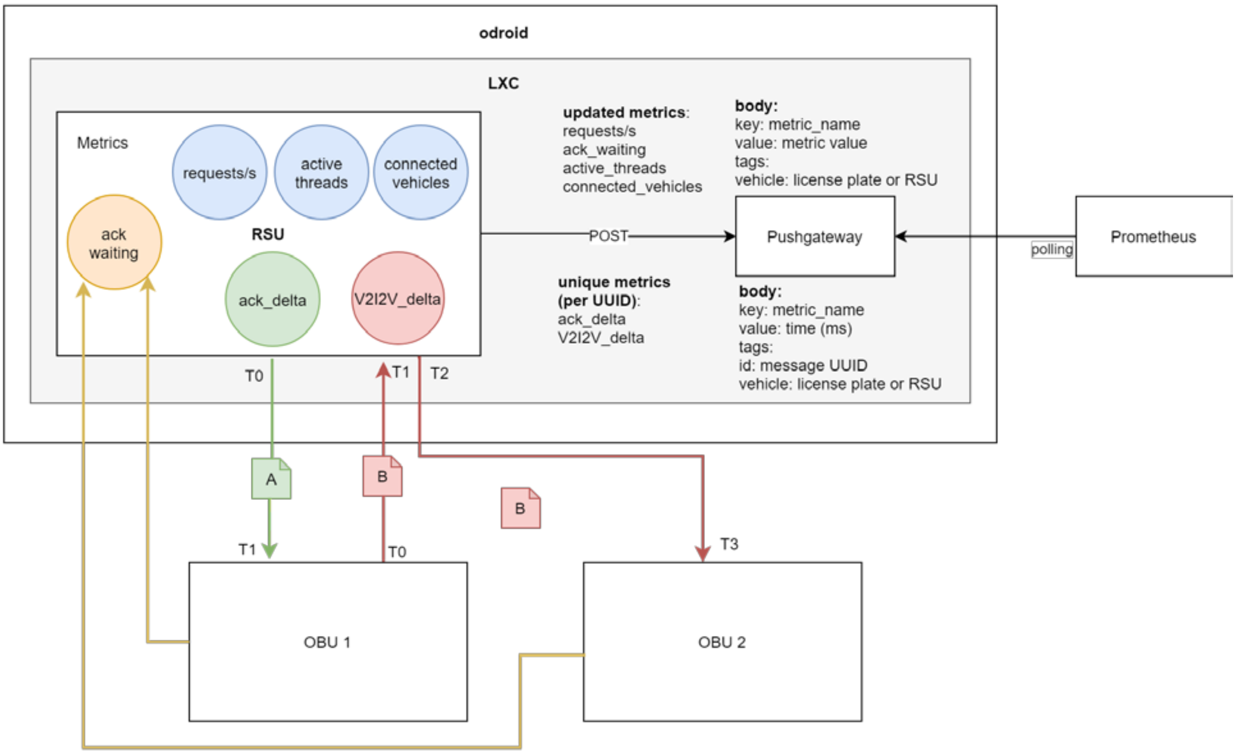


Figure 188 - UC6 KPIs collection diagram

8.4 Barcelona Pilot Validation

The following sub-sections detail the conducted trials, which took place in Barcelona, January 2020, and an analysis of the extrapolated results.

8.4.1 Scenario and Trials Description

This use case has been deployed in Barcelona's infrastructure and everything has been tested with a moving vehicle equipped with an in-house built ETSI ITS-G5 compliant stack, in the form of a Raspberry Pi. **Figure 189** illustrates the vehicle in question, and **Figure 190** the equipment used (which is detailed next).

[13] https://github.com/prometheus/pushgateway

Figure 189 - Vehicle used during UC6 validation trial in Barcelona

Figure 190 - OBU and OBD-II installed inside the vehicle (UC6 deployment)

The setup has already been depicted **Figure 181**, in section 8, and the flow can be summarized as the following:

1. Vehicle #1 is equipped with an OBD II device, which relays such real-time information to the Raspberry Pi (OBU), using Bluetooth. This same OBU also collects GPS data from an external GPS receiver.
    a. Vehicle #1 connects to the network via LTE, using a MiFi device connected via USB to the RPi (seen as an Ethernet interface, by the OBU)
    b. Vehicle #1 receives *rules* from the RSU (a list of polygons indicating the speed limit for a given area)
    c. Vehicle #2 receives also critical messages that have been temporarily stored by the RSU
    d. Once the vehicle detects it is moving at a speed higher than the one indicated in the rules for the current area (using data OBD II and GPS, respectively), a message is sent to the RSU as

an *infringement* (also considered a *critical message*, which, as an example, could also be triggered by something else like a detected accident or road hazard). This message happens asynchronously, not really after or before neither b) nor c), mentioned before.

2. RSU picks up the message previously sent by Vehicle #1 and:
    a. Relays to all connected vehicles (optimisations are possible, and unicast/multicast limitations are detailed in the following sub section), regardless if they are connected via LTE or Wi-Fi.
    b. Temporarily stores such critical message (to later on be automatically sent to all newly connected vehicles)
3. Vehicle #2, connected via Wi-Fi, receives message originally sent by Vehicle #1 and acts accordingly. In this case, as we are merely validating the scenario, a laptop has been used to simulate another real moving vehicle. In a real-life scenario, the car's internal system would have to react to this event, or simply present the driver (if not a fully autonomous vehicle) with such information.

To make sure we could safely test such system, a traffic path the vehicle could move in has been planned, having in mind the required network coverage, capacity, and also the different possible traffic directions. Knowing this, and testing the LTE coverage with a Smartphone (as shown in **Figure 191**), we could map the different speed limit for the possible routes to take (**Figure 192**).

Figure 191 - Smartphone showcasing UC6 dedicated LTE slice

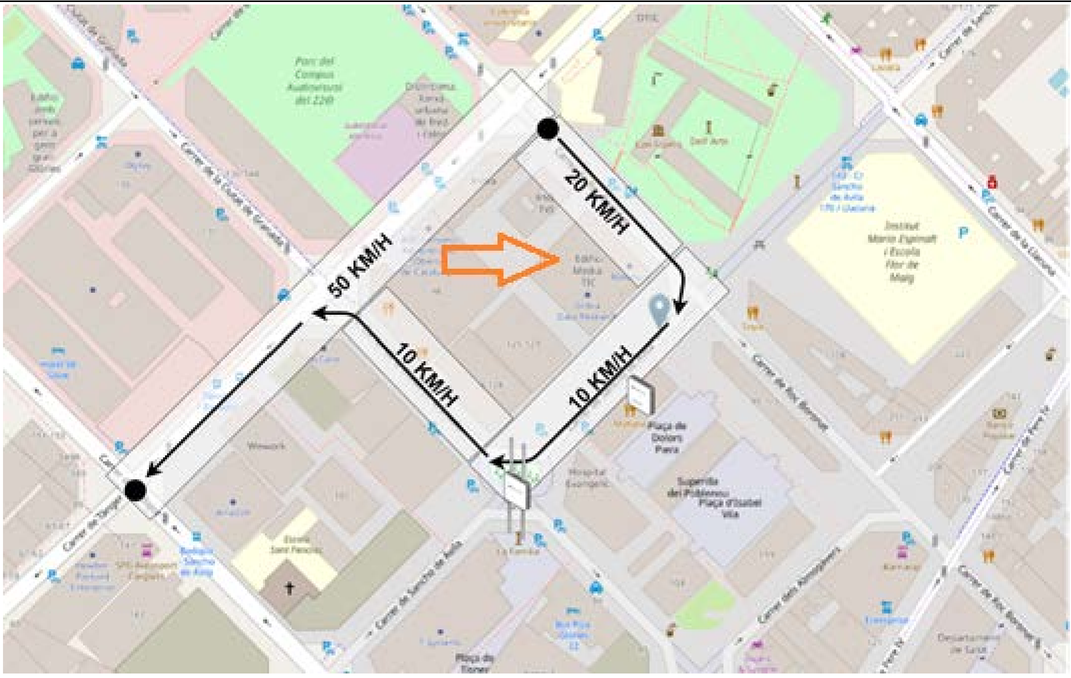


Figure 192 - Use case 6 deployment location and vehicle's flow

As mentioned before, the Vehicle #2 is a laptop connected via Wi-Fi and running the same ITS-G5 stack running on the Raspbery Pi inside Vehicle #1. This laptop was actually placed inside the *Edificio Media TIC*, as illustrated in the map diagram in **Figure 192**, while the moving Vehicle #1 was moving along the traffic route also highlighted in the same picture.

8.4.2 Results Analysis

From the 22nd of January to the 24th, the services have been deployed multiple times and a clear plan has been laid out which would allow us to remain under Wi-Fi coverage while, at the same time, having the vehicle moving around the LTE-covered streets, as indicated in the previous section. Once settled, we closely monitored Grafana (Prometheus' data, more precisely) which allowed us to monitor the metrics previously mentioned in Section 8.2.

By having Prometheus pulling data from PushGateway as detailed in Section 8.3, the following results could be extrapolated, when running the scenario and flow detailed in 8.4.1, for a total time of 4.5 mins. All of the following data has been taken from Grafana, as indicated in the screenshots taken and indicated below.

- **Service Latency**

As previously described in **Table 64**, this service latency can be actually be broken down into several latency perceived in different link and, thus, specific metrics have been collected: ACK_delta_OBU (LTE), ACK_delta_OBU (WiF) and ACK_delta_RSU, whose results are analysed next.

  - ACK_delta_OBU (LTE)

Measuring the perceived latency from RSU to OBU (roundtrip time at application) level allows us to determine how performant such link is when using the required equipment to provide the OBU with such LTE link (the Huawei MiFi device as also used in other use case deployments and already described before). To better understand what is measured here, one can refer to **Figure 187**. As the RSU is responsible for sending both the *rules* and all other *critical messages* (which may have been initially transferred by other vehicles), it is important for such RSU to determine how much time it is taking an OBU to acknowledge the receiving of such messages (application-level ACKs). This is important in mission critical scenarios such as this one, as the RSU may react accordingly, if a timeout occurred.

- ACK_delta_OBU (Wi-Fi)

The latency in such link follows the exact same principle as the one described previously, with the only difference being that, in this case, a Wi-Fi link is used, and not LTE. It is important to differentiate the two (Wi-Fi and LTE), due to the intrinsic nature of such links and inferred QoS. Knowing the typical latency would allow both RSU and OBU to timeout differently after a specific period of time when dealing with LTE and Wi-Fi connected vehicles. However, in this specific case, the application does not take into account such differences – it was measured only to assess how the network and the whole platform performs for such multi-RAT scenarios.

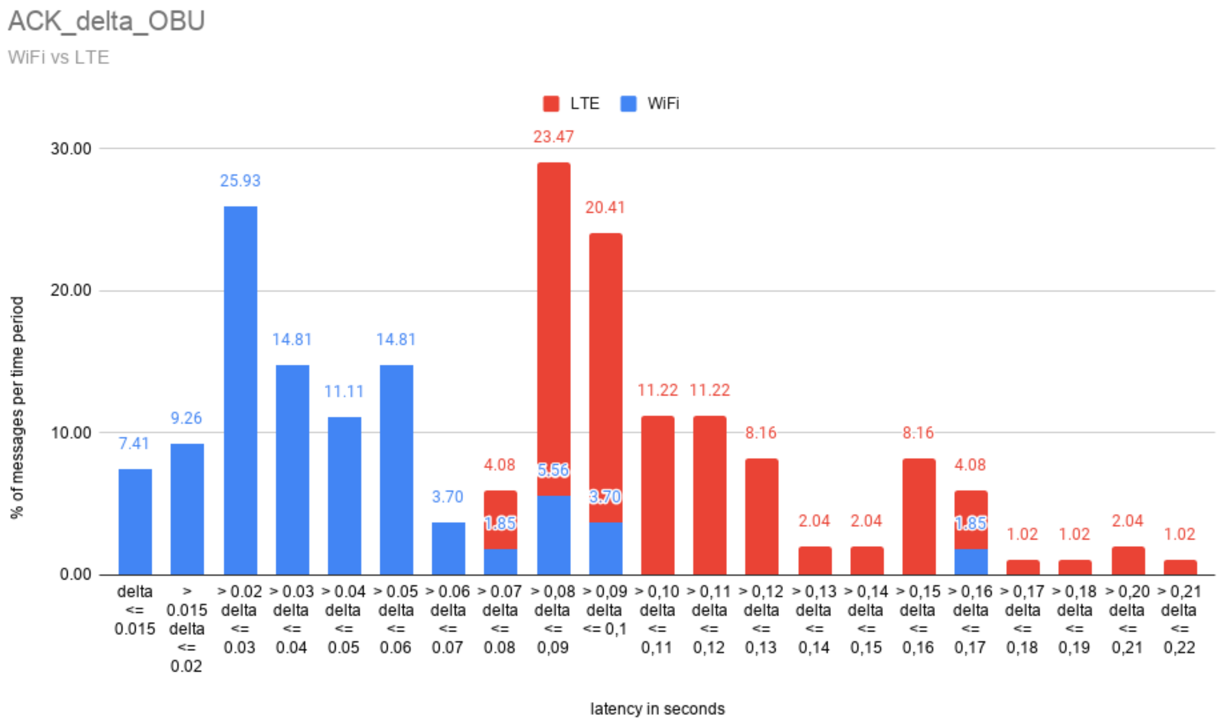


Figure 193 - ACK_delay_OBU latency analysis in Wi-Fi vs LTE links

As depicted in **Figure 193**, whose original data was gathered from Prometheus and later on analysed with different tools, the induced latency in Wi-Fi links is much lower than the one perceived when using LTE links. For this reason, when analysing the overall ACK_delta_OBU and ignoring the specific RAT, there is no consistency in the delay due to the wild fluctuation. Being able to understand the different implications of using multiple RAT is crucial to understand the expected latency end-to-end (V2I2V), where different RATs are used.

With this graph, it is easy to visualize that 42.6% of all messages sent via Wi-Fi stayed below the 30 ms mark; while with LTE this number is dropped to 0. The performance between both cases is fairly different and we believe that most of such discrepancy may have been caused by the CPE itself - the Huawei MiFi device which allows the Raspberry Pi (OBU) to be connected to the LTE network (attached to the OBU via USB, interpreted as a new Ethernet interface). Also, the Wi-Fi link was used in a real laptop (the other Vehicle running the same C-ITS stack), which has greater performance than the Raspberry Pi.

- ACK_delta_RSU

Similar to the *ACK_delta_OBU* mentioned before, this one measures the latency from OBU to RSU. This one reflects the general (regardless of the RAT used) latency in OBU to RSU communications when sending, for instance, the critical message (originated at the sender node). The graphical representation of such flow can be seen in **Figure 187**.

The latency performance in such case is much lower when compared to ACK_delta_OBU. In this case, it was not possible to measure such latency in the different RAT, so the extrapolated figures apply to both LTE and Wi-Fi which have been used concurrently. Similar to the ACK_deta_OBU LTE, whose performance was lower when compared to the node which used Wi-Fi, such low performance is also reflected in this case where all exchanged packages originate from the OBU. It was impossible to have a latency below 30 ms in this case (0% occurrence), being the vast majority (37.02%) between the 120 to 250 ms range, as shown in **Figure 194** below.

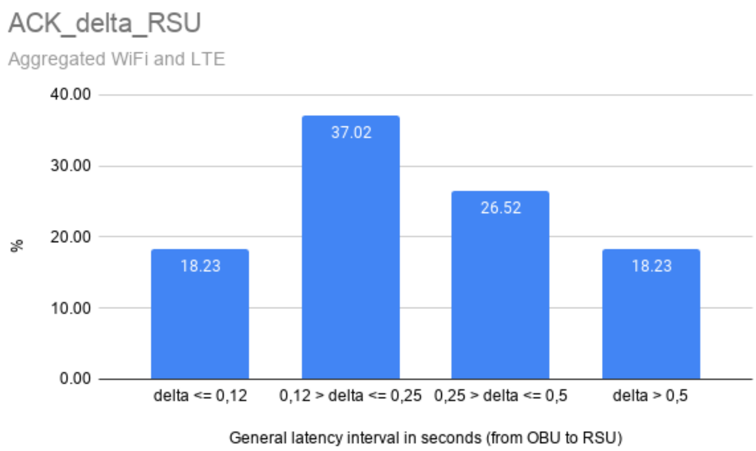
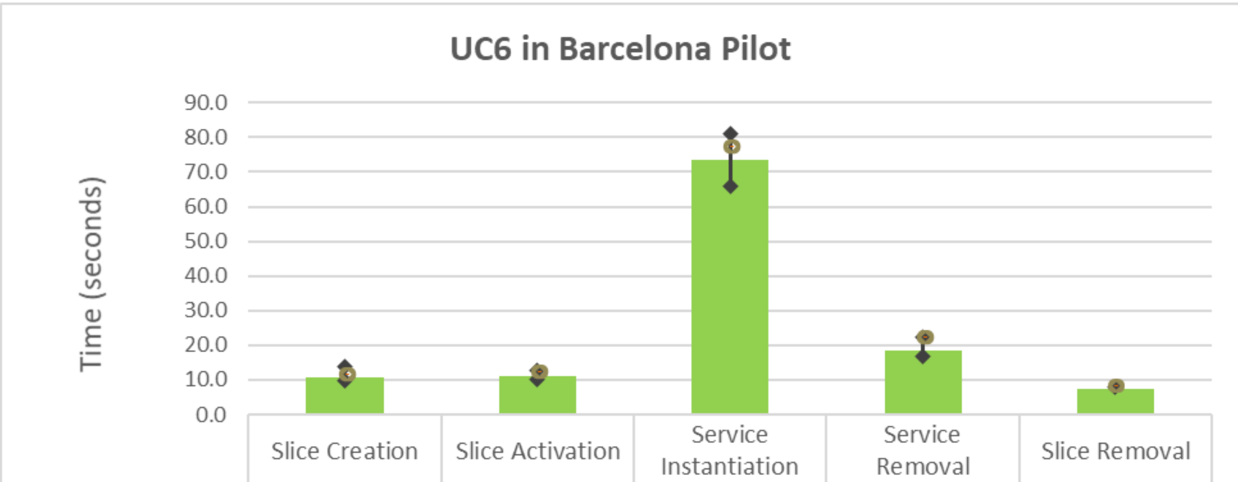


Figure 194 - ACK_delta_RSU aggregated latency metrics (from OBU to RSU)

- **Service Instantiation Time (SIT)**

In **Figure 195**, the instantiation times obtained for the network service of UC6, after running the automated script at the 5GCity Slice Manager 30 times, are plotted. As with the other UCs, the times required to complete each one of the steps conducted at each iteration of the automated script (i.e. Slice Creation, Slice Activation, Service Instantiation, Service Removal and Slice Removal) are also included in the referred figure. In particular, the average instantiation time of UC6 NS achieved in the Barcelona pilot was 73.31 seconds, value that is under the target set for this KPI (i.e. 120 seconds).



	Slice Creation	Slice Activation	Service Instantiation	Service Removal	Slice Removal
AVG	10.71	10.94	73.31	18.61	7.54
MIN	9.87	10.08	65.86	16.72	6.99
MAX	13.95	12.84	81.13	22.17	8.04
90-PERCENTILE	11.27	12.22	77.03	22.05	7.82

Figure 195 - Service Instantiation Time KPI of UC6 in Barcelona pilot

It is import to highlight that in this UC the network service is deployed over a compute node (far-edge node) with fewer resources than the one located at the edge and core of the 5GCity 3-tier architecture, which represents a very optimistic results in the context of smart cities vertical services.

- **V2I2V_delta**

As previously described in section 8.2, with **Table 64**, this metric allows us to determine the end-to-end latency between the time a critical message is sent by one vehicle to the RSU (V2I) and further relayed to other vehicles (I2V). This metric covers the general end-to-end latency, regardless of the RAT. Monitored measurements indicate that 25.86% of all messages exchanged following the V2I2V links stayed below the targeted 60 ms latency, as depicted in **Figure 196**.

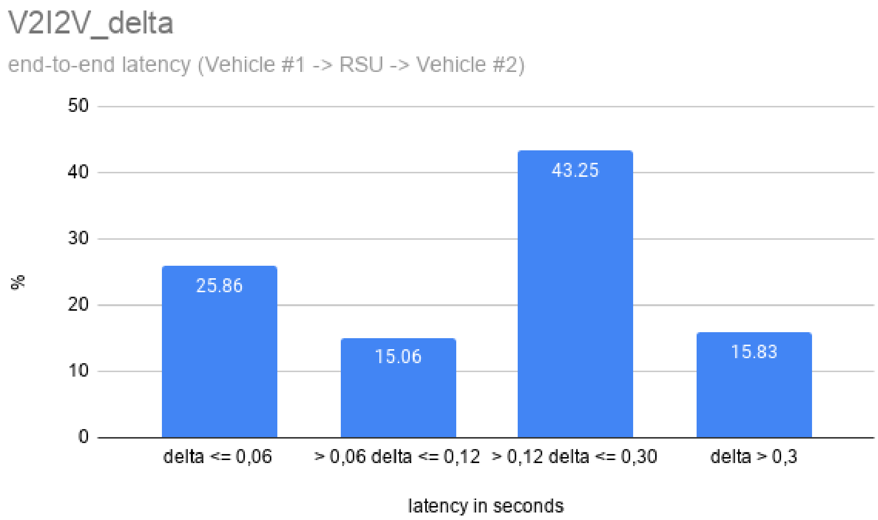


Figure 196 - End-to-end latency (V2I2V) data analysis

While **Figure 196** refers to the further analysis of such data, supporting the figures described before, **Figure 197** displays the original data extrapolated from the trial (Prometheus).

Figure 197 - V2I2V_delta KPI measurement (Prometheus)

- **messages/s**

This metric is measured in real-time and reflects all messages that are being sent and received at the RSU node. Monitoring such metric allows us to determine how performant the low-cost node is, when co-relating it with the system load and CPU usage, for instance. To better determine the maximum throughput at the RSU level, a large number of vehicles would have to be used in order to stress the network and the equipment. However, when monitoring the current deployment with two vehicles, an average of 26.41 messages/s have been monitored, while the CPU usage and system load remained at around 3% and 0.03, respectively, as shown in **Figure 198** and **Figure 199**.

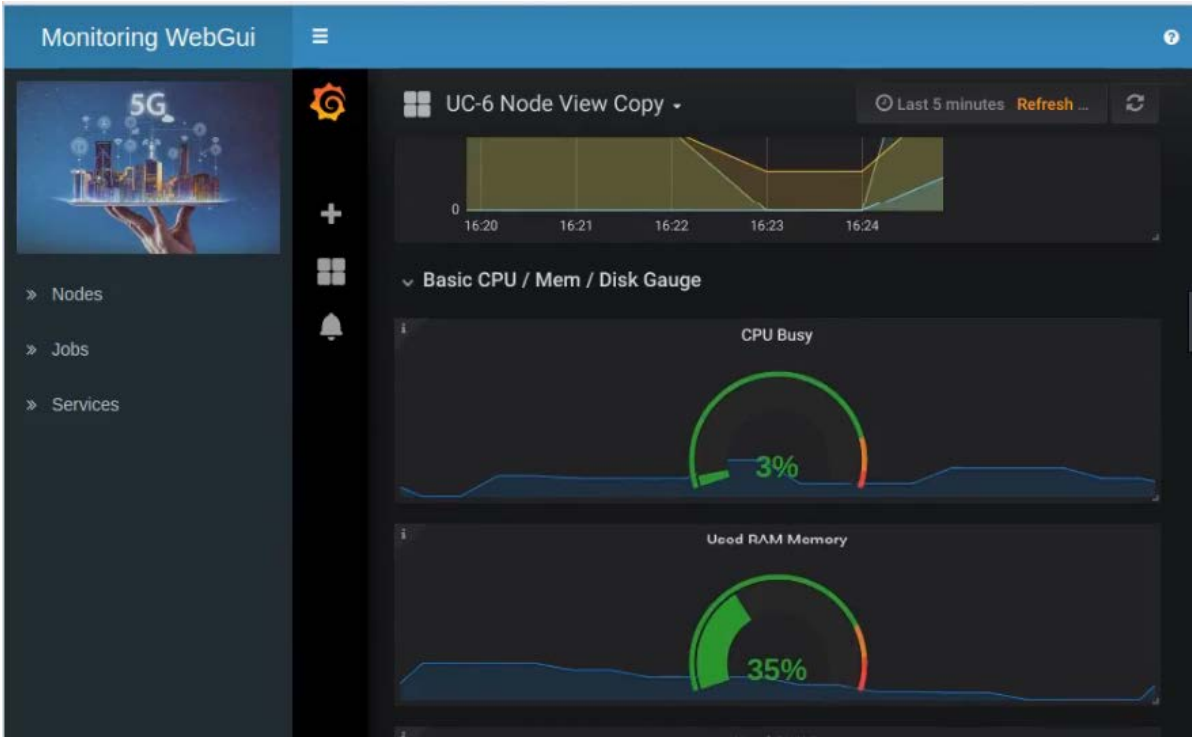


Figure 198 - CPU usage at RSU (Prometheus)

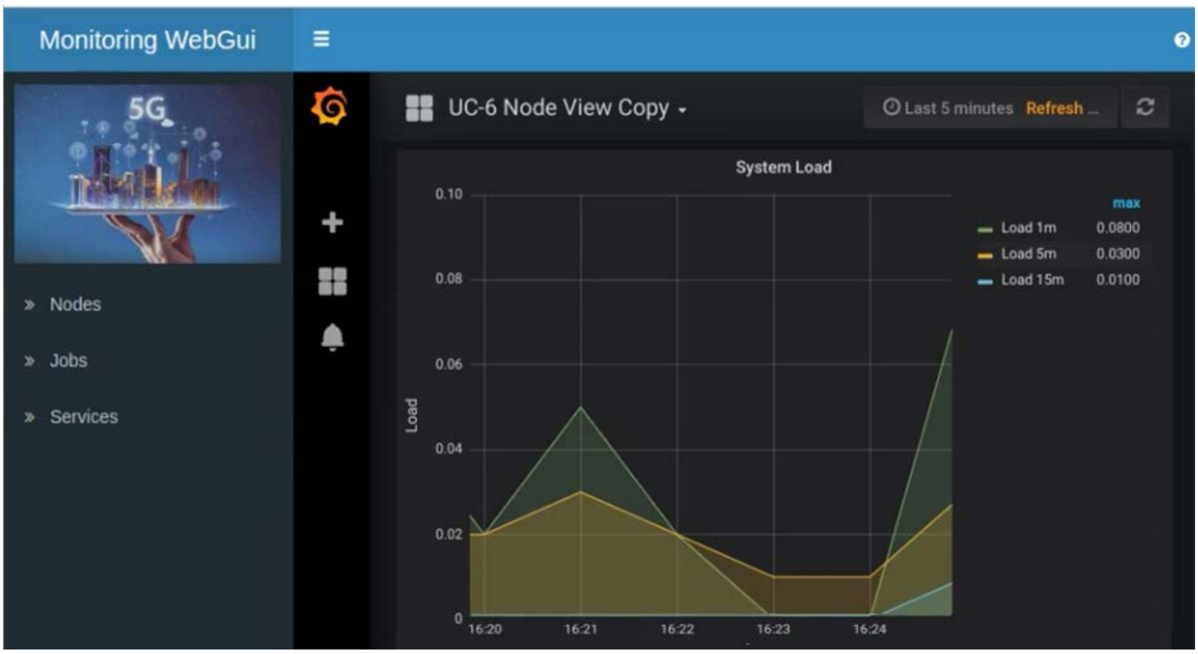


Figure 199 - System Load metric at RSU (Prometheus)

By monitoring the CPU usage (see **Figure 198**) and system load (see **Figure 199**), it was possible to determine that such a low-cost ARM-based node was able to handle such service and traffic with relatively no effort (3% total CPU usage and system load of 0.08).

- **ack_waiting**

This metric is highly relevant as it allows us to monitor the number of messages that did not receive an ACK back and, thus, may be considered lost. With this, it is possible to measure the perceived reliability of the system when it comes to delivery of messages. Taking into account that the trial lasted for 4:25 mins and that a total of 333 messages have been sent and received at the RSU during this time period (with a large amount of them being duplicate, because the goal really was to track all incoming and outcoming packets at application-level), we can extrapolate that 12.31% have been considered lost by the network, providing that only 41 of these did not receive the related ACK (41/333 = 12.31%). **Figure 200** below shows the collected metrics at Prometheus, which allowed us to then co-relate with the total amount of exchanged messages (333 metric, which was gathered via a simple *count* query on Prometheus).

Figure 200 - Total number of messages that have not been ACK'd

Once this data has been extracted, we could further analyse it and new diagrams have been drawn, supporting the aforementioned figures.

Table 65, below, summarizes the extrapolated data, comparing them to the targets initially defined in section 8.2. All measurements documented here and in the previous subsection have all been taken from a trial run, which lasted for 4:25 minutes.

KPI	Target	Measurement
Service Latency	ACK_delta_OBU <= 30 ms	• Only 42.6% in Wi-Fi • Most (55.1%) within the 80-100 ms range in LTE
	ACK_delta_RSU <= 30 ms	0% below the target 30 ms; The sample showcases that 50.8% of all messages suffered a delay of up to 220 ms
Service Instantiation Time (SIT)	<= 120 seconds	73.31 s

V2I2V_delta	<= 60 ms	Only 25.86% of all exchanged messages stayed below, or equal to, the 60 ms target
messages/s	10 messages/s per vehicle	26.41 msgs/s (for two vehicles)
ack_waiting	<= 1% of all received messages	12.31%

Table 65 - UC6 KPI results

For all KPIs related to latency measurement in different links, it is worth mentioning the overhead induced by including an additional application-level ACK message when dealing with messages tagged as critical. If such extra layer of reliability had been removed, the overhaul network usage would decrease, if reliability would solely be relied on low level QoS provided by the TCP layer, for instance. One other aspect that should not be overlook is the fact that with this specific flow, requirements and network topology, the developed services could not rely on multicast networking, as originally envisioned. The reason for this was that the network was dropping almost 80% of all traffic in the Wi-Fi downlink (measured at the RSU node). As such, the networking was not the most efficient one for such a scenario where a large amount of data must be equally distributed to a vast number of connected nodes. This also adds up to the observed latencies. Regardless, it was also relevant to monitor the system load on the Odroid node (used to host the RSU services) which was reporting to Prometheus a system load of 0.08, during the whole experiment. This is a good indicative that such low-powered device could be able to handle a great number of connected vehicles and traffic, providing that only 2 out of a total of 8 cores have been assigned to such service.

All in all, the pilot has showcased the added value of using low cost single board computers to host numerous different applications, which may serve different needs, and the added-value of the Neutral Hosting platform. By using 5GCity dashboard, the deployment process was greatly facilitated, taking into account the complexity of the underlying network management (LTE and Wi-Fi networks) and also the usage of a specific orchestrator, such as fog05, capable to orchestrate and manage ARM-based Linux containers (lxc).

9. Validation of Guest optimizations with Unikernels

One of the key 5GCity objectives (Objective 2) refers to the 5GCity MEC node virtualization platform and guest optimizations made possible through the project. The technology tested during the project relies on unikernels, i.e. specialised, single-address-space virtual machine images virtualized at the library operating system level.

For guest optimization via unikernels, the project has contributed to the development of Unikraft (www.unikraft.org), a comprehensive toolchain and library operating system which builds highly specialized unikernels.

The specific KPIs of interest for optimised MEC node virtualization platform included:

(1) Development of a tool able to build automated, purpose built unikernels;
(2) Optimizations to guests with
   a. VM images in the range of few MBs or even hundreds of KBs,
   b. RTTs of a few milliseconds,
   c. throughput in the tens of Gb/s;
(3) Optimizations to virtualization platforms in order to achieve
   a. boot times in hundreds of milliseconds (ARM32) and tens of milliseconds (x86) or less

Related to these targets, given that unikraft implelements the poitn (1), we present in the following some relevant measures which give evidence of the KPI achievement.

9.1 Unikernel-KPI#2.a: Memory Consumption

(Low) memory consumption is critical to resource-constrained edge and embedded devices. Unikraft, thanks to its fully modular architecture, is particularly well suited to building specialized images that have low memory consumption.

Test setup: Raspberry Pi 3 b+ (ARM64 CPU) with an LCD screen attached to it. Unikraft-built image boots bare metal and runs an application that boots, measures stats, and displays them on an RPI LCD screen.

> **Result:** Tiny code size of just 29KB (plus 1.7KB for images for prettifying the LCD display), and memory usage of only 1104 bytes.

9.2 Unikernel-KPI#2.b: KPI: IRQ/Scheduling Delay

Low IRQ delay is critical to building reactive platforms, and to be able to build applications that have real-time requirements.

Test setup: Raspberry Pi 3 b+ (ARM64 CPU) with an LCD screen attached to it. Unikraft-built image boots bare metal and runs an application that boots, measures IRQ delay, and display it on an RPI LCD screen.

> **Result:** Tiny IRQ delay of only 404 cycles.

9.3 Unikernel-KPI#2.c: Network Performance

The performance of a huge range of applications is network-bound, including smart city and edge deployments. In these tests we showcase the performance of our Unikraft system.

Test setup: Unikraft-build image running on QEMU/KVM using virtio drivers and the lightweight IP (lwip) embedded network stack. Tests are done using the popular nginx high performance web server software. We run the tests using a number of different memory allocators, since the server's overall performance (in terms of serviced requests per second) is partly dependent on the performance of the underlying memory allocator. In this case, we test against the four memory allocators currently supported by Unikraft: the buddy allocator, TLSF, Tiny allocator and Microsoft's mimalloc. We also compare the Unikraft results with the performance of Linux *bare metal* (i.e., without virtualization overheads).

Result: As shown in Figure 201 and Figure 202, Unikraft with the mimalloc memory allocators ***outperforms bare metal Linux by as much as 15% despite running virtualized/with virtualization overheads.*** This guarantees high application throughputs of the krafted unikernels running as VMs and performing better that base Linux images.

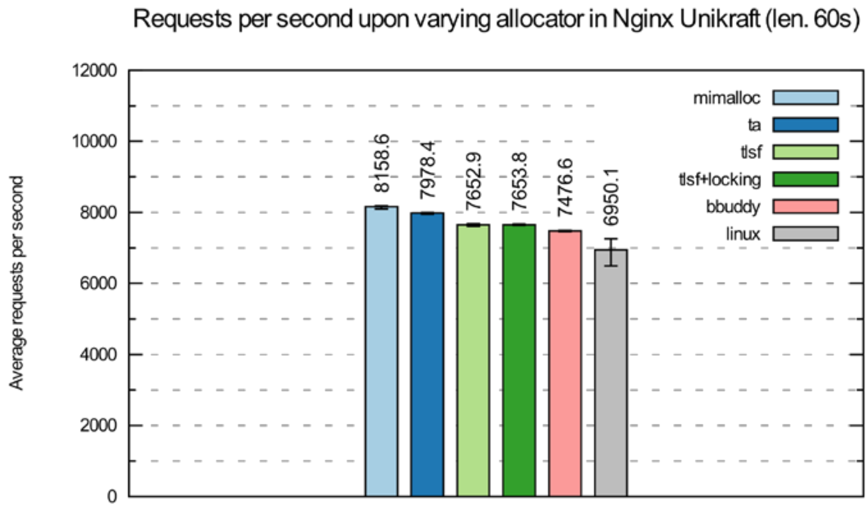


Figure 201 - Average requests per second in Nginx Unikraft

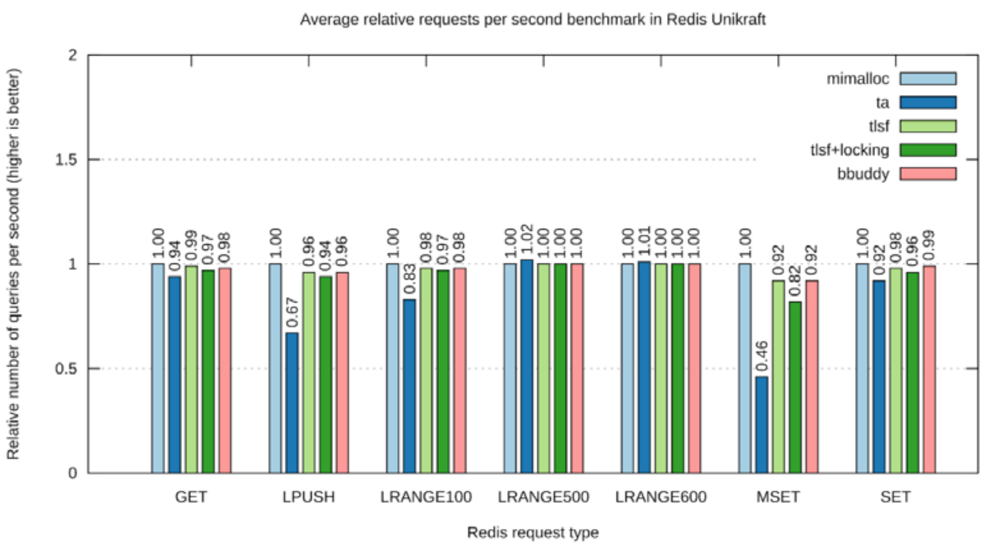


Figure 202 - Average queries per second in Redis Unikraft

9.4 Unikernel-KPI#3: Boot Times

Fast boot times are critical for being able to provide a number of cloud and edge-based services, including Function-as-a-Service, just-in-time virtualized network functions and fast edge-based services, to name a few. In these tests, we perform a number of boot time tests using Unikraft, and present its results.

Test setup #1: x86_64 server running at 3GHz with turbo boost. Host is Linux, Solo5/KVM is used to run Unikraft-generated, minimalistic virtual machines. The virtual machines do nothing more than boot and print a hello world message; no more functionality is added in order to be able to measure the raw boot time needed to get a Unikraft VM up and running. Note: Solo5 is a minimalistic VMM (virtual machine monitor) from IBM.

> **Result:** Unikraft is able to boot in as little as **2.5 milliseconds**. To put this in perspective, it is not uncommon for Linux-based VMs (even Alpine-based ones) to boot in 30 seconds or more. For even further perspective, creating a Linux user-space process takes in the order of a few milliseconds, so 2.5 milliseconds for a virtual machine is a rather promising result.

Test setup #2: Raspberry Pi 3 b+ (ARM64 CPU) with an LCD screen attached to it. Unikraft-built image boots *bare metal* (i.e., without any virtualization/hypervisor), and runs an "application" that measures boot time.

> **Result**: Total boot time of just **5.5 milliseconds**, compared to minutes when booting a Raspbian image (Raspian is the official Linux distribution for the Raspberry Pi). Note that there's an initial ~3 seconds delay when the device powers on: this is because the RPI's SoC boots the GPU first, which takes 3 seconds to initialize, before powering up the CPU.

10. Conclusions and Lessons Learned

In this deliverable, we presented the final effort of 5GCity Project to validate the Neutral Host Platform and Infrastructure through live trial pilots with six Use Cases.

With reference to the four baseline 5GCity KPIs in common across the various use cases, a summary of the achieved performances based on the results obtained in the trials is summarized in the following tables **Table 66, Table 67, Table 68** and **Table 69.**

5GCity KPI	UC1	UC2	UC3	UC4	UC5	UC6
Gen-KPI#1: User Experienced Data Rate	**Target**: 4 Mbps per camera	**Target**: 30 Mbps cumulative across slices	**Target**: 2 Mbps per mobile device	**Target**: 15 Mbps per HD, UHD, 4K and Video-360	**Target**: 8 Mbps per camera for a HD transmission	*Not applicable*
	Results Lucca **4.04 Mbps**	**Results** Barcelona **≈ 44.7 Mbps on 3 slices** Bristol **≈ 45.5 Mbps on 3 slices** Lucca **≈ 44.7 Mbps on 3 slices**	**Results** Barcelona **≈ 2.2 Mbps** Bristol **≈ 2.05 Mbps**	**Results** Bristol **17.73 Mbps** Lucca **26.89 Mbps**	**Results** Barcelona **≈ 10 Mbps**	*Not applicable*
ACHIEVED?	OK	OK	OK	OK	OK	*Not applicable*

Table 66 - Summary of Trial Results on User Experienced Data Rate.

5GCity KPI	UC1	UC2	UC3	UC4	UC5	UC6
Gen-KPI#2: Service Latency	*Not applicable*	**Target:** <= 15 ms	**Target:** <= 2.5 s	**Target:** <= 500 ms	**Target**: <= 500 ms	**Target**: <= 30 ms
	Not applicable	**Results** Barcelona **11.3 ms** Bristol **11.5 ms** Lucca **8 ms (edge)** **10 ms (core)**	**Results** Barcelona **2.32 s** Bristol **1.41 s**	**Results** Bristol **307.5 ms** Lucca **449.33 ms**	**Result** Barcelona **0.5 s**	**Results** Barcelona Achieved by **42.6%** of messages exchanged using Wi-Fi * * most likely due to unnecessary ACK overhead

						enforced at application level
ACHIEVED?	*Not applicable*	**OK**	**OK**	**OK**	**OK**	**PARTIALLY**

Table 67 - Summary of Trial Results on Service Latency.

5GCity KPI	UC1	UC2	UC3	UC4	UC5	UC6
Gen-KPI#3: Slice Deployment Time (SDT)	**As per UC2**	**Target:** <= 30 s	**As per UC2**	**As per UC2**	**As per UC2**	**As per UC2**
	As per UC2	**Results** Barcelona: **21.35 s** Bristol: **26.53 s** Lucca: **36.72 s *** * issues with platform resources	*As per UC2*	*As per UC2*	**Results** Barcelona: **21.93 s**	*As per UC2*
ACHIEVED?	*Not applicable*	**PARTIALLY** **2/3 achieved**	*Not applicable*	*Not applicable*	**OK**	*Not applicable*

Table 68 - Summary of Trial Results on Slice Deployment Time.

5GCity KPI	UC1	UC2	UC3	UC4	UC5	UC6
Gen-KPI#4: Service Instantiation Time (SIT)	**Target:** <= 120 s	*Not applicable*	**Target:** <= 120 s	**Target:** <= 120 s	*Not applicable*	**Target:** <= 120 s
	Results Lucca **86.45 s**	*Not applicable*	**Results** Barcelona **84.04 s** Bristol **98.63 s**	**Results** Bristol **51.24 s** Lucca **61.60 s**	*Not applicable*	**Results** Barcelona **73.31 s**
ACHIEVED?	**OK**	*Not applicable*	**OK**	**OK**	*Not applicable*	**OK**

Table 69 - Summary of Trial Results on Service Instantiation Time.

Some more specific summary analyses for the three categories of 5GCity use cases is provided in the following, which covers Media services (UC3, UC4, and UC5), Neutral Host services (UC2) and Smart City services (UC1 and UC6).

10.1 Performance summary for Media services

In addition to the successful achievement of the general performance KPIs, Media services have strict requirements to maintain a correct video quality during the streaming across the public Internet or shared network like the 5GCity one. In the following, performance analysis is presented for video quality KPIs and transcoder instantiation time which are critical to the execution of media use cases.

Video Quality KPIs

Video quality is impacted by the levels of video resolution in continue video streaming. To achieve this KPIs, user experience data rate and real time video buffering need to be optimised. During the UC3 trials conducted in Bristol and Barcelona, the user experience data rate per recording device got **over 4 Mbps by maintaining the video resolution of 1280x720** (**Table 67**). Similarly, UC4 trials in Bristol and Lucca achieved user experienced **data rates higher than 15 Mbps** (**Table 66**) as required **for 4K video of immersive reality services**. The UC5 trial in Barcelona also achieved the expected user **data rate larger than 8 Mbps to ensure live news reporting with not drops**. In addition, Immersive Services required > 20 seconds real time video buffering, as a result during the UC4 trials an **average 26 seconds of real time video buffering by allowing 4K videos in a smart phone**. These results confirm the feasibility of the 5GCity Infrastructure to maintain high data rate and enough buffering time to ensure video quality.

Media services deployments in 5G enabled infrastructure will require specific delay or latency compliance in the control plane. As a result, we collected the 5GCity KPIs measurement related services during the trials of UC3, UC4, and UC5. The trials in Barcelona, Bristol, and Lucca achieved the targeted service latency for UC3 (< 5 seconds), and for UC4 and UC5 (< 1 second). The service instantiation time (SIT) of UC3 and UC4 were much less than 120 seconds by confirming the capacity of the 5GCity Platform to orchestrate media services with virtualized resources through a city wide 5G infrastructure.

UC3 requires to scale transcoders at the Edge (e.g., MEC server) to increase the number of smartphones recording video in real-time. In this use case, transcoder instantiation time (TST) below 60 seconds will be essential to keep the systems in proper working condition for real-time media producers and broadcasters in a shared infrastructure. As a result, during the trials in Barcelona and Bristol, the 5GCity Platform demonstrated its strength by allowing **TSTs below 60 seconds**. UC5 also requires fast slice creation in the case of multiple television or broadcaster providers needs to use the 5G network to produce and broadcast breaking news. In this regard, the trial in Barcelona confirmed UC5 slice instantiation time bellow 30 seconds. Obtained result are summarized in **Table 70**.

KPIs Media UCs	Target	Barcelona	Bristol	Lucca	Achieved?
Video Resolution	1280x720	**1280x720**	**1280x720**	**4K**	**OK**
Transcoder Scaling Time (TST)	<= 60 s	**30.59 s**	**38.74**	*Not collected*	**OK**
Real Time Video Buffering (only UC4)	=> 20 s	**No collected**	**27.37 s**	**26.12 s**	**OK**

Table 70 - Summary of trials results and media related KPIs.

In conclusion, the proposed 5GCity Platform and Infrastructure can allow Neutral Host providers to deploy in real-time multiple media services and applications.

10.2 Performance summary for Neutral Host Use Case

KPIs measured during UC2 trials in Barcelona, Bristol and Lucca were mostly related to the generic 5GCity KPIs (SCT, SIT, service latency and user experienced data rate) which have been just summarised. In terms of slice instantiation times, the three cities obtained times below (or very close to) 30 seconds, as a result the

5GCity platform can create and expand slices for new and existing tenants. For data plane delays, the platform added marginal delay between 1-3 ms to the baseline LTE delay of 10 ms.

In addition, the Neutral Host use case has specific KPIs on multitenancy and isolation guarantees, which are reported in the following **Table 71**, i.e. three to more slices with proper isolation by confirming the applicability of our 5GCity Platform and Infrastructure for Neutral Host providers' deployments.

KPIs	Target	Barcelona	Bristol	Lucca	Achieved?
Number of Slices	>= 3 slices	**3 slices successfully in service**	**3 slices successfully in service**	**3 slices successfully in service**	**OK**
Isolation guarantees	Ensured	**Verified**	**Verified**	**Verified**	**OK**

Table 71 - Summary of performance measurements on Neutral Host.

10.3 Performance summary for Smart City services

Smart city is an important application for our 5GCity Neutral Host Platform, as a result we deployed and validated two UCs focused on Smart City.

UC1 was deployed and validated in 5GCity Infrastructure in the city of Lucca. The user data rate achieved was over 4 Mbps (**Table 66**) and the service instantiation time lower than 120 seconds resulted into a time to detect infringement in the order of 62.07 seconds (**Table 72**). As a result, multiple Police officers could expect alerts of an infringement in a minute after the infringement occurs. However, the application might need improvements in the software and data (**Table 72**).

KPIs	Target Value	Obtained Value	Achieved?
Accuracy	> 80%	**83.3% before field trial in Feb-2020** 73% in Feb-2020 * * reduced accuracy due to changed trial scene during tests caused by roadworks	**OK**
F1Score	> 90%	**90.9% before field trial in Feb-2020** 44% in Feb-2020 * * reduced accuracy due to changed trial scene during tests caused by roadworks	**OK**
Time to detect infringement	< 2 mins	**62.07 s**	**OK**

Table 72 - Summary of UC1 related KPIs

As discussed in the document, the image detection system did not perform well during the trials in street at the end of Feb-2020 due to changed scene conditions, which made the trained ML model underperforming; however, trends and results from previous preparatory tests showed full achievement of the KPIs.

For UC6, low instantiation time and a reasonable service latency were achieved during a UC6 trial in Barcelona. The instantiation time was below 120 seconds while, the service latency was below the target for only specific situations given the complexity of the setup and ongoing improvement still required in the system. A final summary of specific KPIs for UC6 is presented in **Table 73**.

KPIs	Target Value	Obtained Value	Achieved?
V2I2V_delta	<= 60 ms	Target partially achieved by **25.86%** of exchanged messages * * most likely due to unnecessary acknowledgement overhead enforced at application level	**PARTIALLY**
messages/s	10 messages/s per vehicle	**26.41 msgs/s** (for two vehicles)	**OK**
ack_waiting	<= 1% of all received messages	**12.31%** * * possible design flaw as ACKs that were still to be received once we stop the trial were not measured	**FAIL**

Table 73 - Summary of UC6 related KPIs

A combination of multiple variables could explain why some metrics have not been met, when analysing the overall end-to-end latency (V2I2V_delta) and packet loss (ack_waiting). To summarise, it is important to note that for reliability sake, an Acknowledgement verification mechanism has been implemented at application-level, which could be considered unnecessary overhead and, thus, impacting the overall measurement – had we rely on reliability provided by lower-layers, this latency could be greatly improved. In any case, the metrics also reflect the performance in a multi-RAT environment and, as noted in subsection 8.4.2, there is a high discrepancy between perceived latency in Wi-Fi and LTE links which, we have concluded, may be related to the fact that there is a potential bottleneck introduced by the CPE device when connecting the OBU (Raspberry Pi) to the Small Cell. This is also notorious in the ack_waiting metric, which reflects a high loss of messages – even though it is impossible to determine the reason why, based on monitored data, we suspect that this is also a reflection of the poor LTE performance observed during the trial (equipment used). Furthermore, there is a margin error that must be accounted for, due to the fact that our measurement methodology does not deal with the acknowledgements that were still to be received once we stop the trial – in other words, the software does not finishes gracefully and pending acknowledgment should not be accounted. Unfortunately, we could not determine how severe this design flaw actually is and, thus, what the margin error could be.

10.4 Lessons Learned

Trial results confirm the feasibility of the proposed 5GCity Platform and Infrastructure to be deployed as Neutral Host solution in city-wide 5G infrastructures. Validation activities across the six use cases give evidence of the feasibility of a Neutral Host model and, with focus on the KPIs related to orchestration (main 5GCity research topic) there is also evidence that the developed platform performs well and it truly achieves the 5G PPP programmatic KPI for

Service Creation Times in minutes instead of hours ⇒ **ACHIEVED**

It is unquestionable that use of new radio technologies like 5GNR and WiFi6 can increase up to 20x data rate and reduce latency near 50x with respect to what we achieved with 5GCity platform and infrastructures. Similarly, the availability of more dense deployments of small cells can increase the coverage offered in city districts.

However, the densification of radio elements requires a corresponding upgrade also in available edge resources, aimed to host the multiple various services. In 5GCity, resources were sized to host the planned use cases. An upgrade would be required (above all in the edge segments) in case the Neutral Host intends to instantiate more than 3 slices and multiple services in parallel.

Plans for upgrade of the virtualization and radio infrastructures towards 5GNR and WiFi6 are being discussed at the time of release of this deliverable in Barcelona and Bristol. In these cities, other overarching and long-lasting 5G initiatives, respectively 5GBarcelona and 5GUK test programs, will take over the 5GCity legacy of know-how, platforms and infrastructures to extend resources and validation to other use cases.

Finally, the work across three live infrastructures with six use cases deployed and testing in street has allowed to derive some important lessons for close to real life validation activities, briefly reported in the following:

- Efforts required to deploy a virtualization infrastructure with integrated orchestration for network slicing is not negligible and requires careful coordination
    - Mechanism for automation of installations and possibly models for easy replication of platform software are recommended to optimise delivery time
- Differences in the underlying virtualization infrastructure should be avoided as they might require additional time to debug unexpected conditions and lead to potential impacts on orchestration software to be developed. Where possible, it would be recommended to follow a reference infrastructure design and bill of materials, in order to have a reference infrastructure for trials and avoid to support diverse set of hardware and try to integrate with existing legacy infrastructures.
- Realization of trials in field requires significant additional resources for planning, procurement, delivery and operations which can easily go beyond the technical scope of a research projects. Organizational and legal aspects related to spectrum access, use to public spaces, roadworks planning and management, relations with public (citizens impacted from construction and delivery works) need to be carefully considered and decision makers from within the municipalities properly involved to avoid lock-in and delays.
- For the realization of trials with users or in public spaces, aspects of data management and GPDR require long time to be legally defined and need to be considered from use case design stage, in order to properly identify with the help of legal teams and data protection officers which roles (Data Processor, Data Controller), what specific data to manage, and the conditions in which they will be generated.

11. References

[1] 5GCity Project Deliverable D2.1: "5GCity System Requirements and Use Cases", Dec. 2017.

[2] 5GCity Project Deliverable D2.4: "5GCity Final Architecture, and Interfaces", Jul. 2019.

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

[4] 5GCity Project Deliverable D4.4: "5GCity Virtualization Infrastructure Final Release", Sept. 2019.

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

[6] 5GCity Project Deliverable D5.2: "Validation and Integration of the Developed Modules and Solutions", Oct. 2019.

[7] 5G PPP, "5G-PPP use cases and performance evaluation", Version: 2.0, July 2017

[8] DG-CONNECT, Trinity College Dublin, "A Framework for monitoring the impact of 5G Public Private Partnership and the associated Key Performance Indicators (KPIs)", SMART 2015/0013, DOI: 10.2759/79440, online: https://op.europa.eu/s/n2v3

[9] 3GPP, "Service requirements for the 5G system," 3rd Generation Partnership Project (3GPP), Technical Specification (TS) 22.261, version 16.10.0. [Online]. Available: https://portal.3gpp.org/desktopmodules/Specifications/SpecificationDetails.aspx?specificationId=3107

[10] Qualcomm 5G predictions, online: https://www.qualcomm.com/news/onq/2018/03/07/predicting-real-world-5g-performanceMcKinsey&Company, "The road to 5G: The inevitable growth of infrastructure cost", 2018.

[11] ETSI "5G; Service requirements for next generation new services and markets", Technical Specification (TS) 122 261, version V15.5.0 (2018-07). [Online]. Available: https://www.etsi.org/deliver/etsi_ts/122200_122299/122261/15.05.00_60/ts_122261v150500p.pdf

12. Abbreviations and Definitions

12.1 Abbreviations

3GPP	3rd Generation Partnership Project
5GNR	5G New Radio
AAC	Advanced Audio Coding
AP	Access Point
API	Application Programming Interface
APN	Access Point Name
ARM	Advanced RISC Machine
CCAM	Cooperative, Connected and Automated Mobility
CDVS	Compact Descriptor For Visual Search
CPE	Customer Premise Equipment
CPU	Central Processing Unit
DHCP	Dynamic Host Configuration Protocol
DL	Downlink
DMP	Data Management Plan
DNS	Domain Name System
EuCNC	European Conference on Networks and Communications
F2F	Face to Face
GPS	Global Positioning System
GPU	Graphics Processing Unit
GUI	Graphical User Interface
H.264	MPEG-4 Part 10 or Advanced Video Coding (MPEG-4 AVC)
HD	High Definition
HLS	HTTP Live Streaming
HSS	Home Subscriber System
HTTP	Hypertext Transfer Protocol
ICMP	Internet Control Message Protocol
ICT	Information Communication Technology
IMSI	International Mobile Subscriber Identity
IP	Internet Protocol
ITS	Intelligent Transportation System
KPI	Key Performance Indicator (KPI)
LTE	Long-Term Evolution
MCS	Modulation Coding Scheme
MEAO	Multi-access Edge Application Orchestrator
MEC	Multi-access Edge Computing
MEPM-V	Multi-access Edge Platform Virtual Manager
MIMO	Multiple Input Multiple Output
ML	Machine Learning
MNO	Mobile Network Operator
MME	Mobility Management Entity
MOCN	Multi-Operator Core Networks
MRO	Mobility Robustness Optimisation
MWC	Mobile World Congress
NAT	Network Address Translation
NIC	Network Interface Card

NFVI	Network Function Virtualization Infrastructure
NFVO	Network Functions Virtualisation Orchestrator
NNSF	Network Node Selection Function
NS	Network Service
NSD	Network Service Descriptor
OBD	On Board Diagnostics
OBU	On-Board Unit
OFDMA	Orthogonal Frequency-Division Multiple Access
OSM	Open Source MANO
PLMNID	Public Land Mobile Network Identifier
PNF	Physical Network Function
QAM	Quadrature Amplitude Modulation
QoS	Quality of Service
RAM	Random-access memory
RAN	Radio Access Network
RAT	Radio Access Technology
REST	Representational State Transfer
RF	Radio Frequency
RPi	Raspberry Pi
RSU	Road Side Unit
RTMP	Real-Time Messaging Protocol
RTT	Round Trip Time
SbC	Singleboard Computer
SC	Small Cell
SDK	Software Development Kit
SDT	Slice Deployment Time
SIM	Subscriber Identity Module
SINR	Signal-To-Interference-Plus-Noise Ratio
SIT	Service Instantiation Time
SLA	Service Level Agreement
SNR	Signal-to-Noise Ratio
TCP	Transmission Control Protocol
TDD	Time Division Duplexing
TST	Transcoder Scaling Time
UC	Use Case
UE	User Equipment
UHD	Ultra High Definition
UL	Uplink
uRLLC	ultra-Reliable and Low Latency Communications
vCPU	virtual Central Processing Unit
vEPC	Virtual Evolved Packet Core
VIM	Virtualized Infrastructure Manager
VM	Virtual Machine
VNF	Virtual Network Function
VNFD	Virtual Network Function Descriptor
VoD	Video on Demand
V2I	Vehicle-to-Infrastructure
V2X	Vehicle-to-everything communication

13. APPENDIX A – LTE-based RAN radio performances

13.1 Theoretical Pilot Link Budget Estimations for 5GCity pilots

During the 5GCity project Accelleran provided initial estimations of expected link budgets for the different Small Cell configurations of the 5GCity pilots in Barcelona, Bristol and Lucca in order to have an initial idea of achievable throughput rates at different distances. These calculations were based on Small Cell and UE RF parameters according to the capabilities of the Accelleran Small Cells available in different bands, their corresponding omnidirectional antennas delivered to the project and the usual capabilities of commercial UEs to be used during the pilots. These link budgets estimations where done for the following deployments:

City	Small Cells
Barcelona	Accelleran B42 TDD Local Area E1010 Small Cells using 20 MHz BW and TDD DL/UL Cfg 2
Bristol	Accelleran B42 TDD Local Area E1010 Small Cell using 20 MHz BW and TDD DL/UL Cfg 2 Accelleran B7 FDD Local Area E1020 Small Cell using 15 MHz BW
Lucca	Accelleran B38 TDD Local Area E1013 Small Cell using 15 MHz BW and TDD DL/UL Cfg 2

The throughput at range calculations where done considering the following parameters:

- Accelleran Small Cell maximum connected power
- Accelleran Small Cell transmitter loss
- Accelleran Small Cell omnidirectional antenna gain
- Accelleran Small Cell receive sensitivity
- Typical UE (Smartphone) maximum connected power
- Typical UE (Smartphone) transmitter loss
- Typical UE (Smartphone) antenna gain
- Typical UE (Smartphone) receive sensitivity
- Spectrum Frequency
- Spectrum Bandwidth
- TDD DL/UL Configuration (for TDD Small Cells only)
- Typical urban fade margin and penetration loss

The calculations used a Free Space Path Loss model considering typical urban fade and penetration margins and deriving expected SINR which mapped on typical LTE MCS lead to throughput achievable at different distances.

The estimations are shown in Figure A.1, Figure A.2 and Figure A.3.

Besides these estimations, there were walk tests and coverage maps done with different applications such as CellMapper and GNetTracker. In particular, since in Barcelona pilot one of the main aspects to study was the use of ultra dense lamppost deployment (3 lampposts with a distance separation of 64m), more thorough field tests were done at different Accelleran Small Cell power levels to characterize the optimal power levels to maximize throughput and coverage while minimizing small cell overlapping and interference as described in next section 13.2.

			DL	Downlink	TDD Cfg 2	Distance
MCS Index	TBS Index	Mod & CR	SINR	Sensitivity	Real Bit Rate*	
0	0	QPSK 0.117	-3.98 dB	-99.6717 dBm	2.02 Mbps	1825 m
1	1	QPSK 0.153	-2.68 dB	-98.3787 dBm	2.64 Mbps	1573 m
2	2	QPSK 0.189	-1.63 dB	-97.3277 dBm	3.25 Mbps	1393 m
3	3	QPSK 0.245	-0.27 dB	-95.9707 dBm	4.24 Mbps	1192 m
4	4	QPSK 0.301	0.85 dB	-94.8457 dBm	5.17 Mbps	1047 m
5	5	QPSK 0.37	2.03 dB	-93.6657 dBm	6.48 Mbps	914 m
6	6	QPSK 0.439	3.06 dB	-92.6357 dBm	7.47 Mbps	812 m
7	7	QPSK 0.514	4.06 dB	-91.6327 dBm	8.83 Mbps	723 m
8	8	QPSK 0.588	4.98 dB	-90.7177 dBm	10.32 Mbps	651 m
9	9	QPSK 0.663	5.84 dB	-89.8617 dBm	11.43 Mbps	590 m
10	9	16QAM 0.332	6.34 dB	-89.3617 dBm	11.43 Mbps	557 m
11	10	16QAM 0.369	7.14 dB	-88.5567 dBm	12.52 Mbps	508 m
12	11	16QAM 0.424	8.24 dB	-87.4537 dBm	14.75 Mbps	447 m
13	12	16QAM 0.479	9.29 dB	-86.4117 dBm	16.41 Mbps	397 m
14	13	16QAM 0.54	10.40 dB	-85.2937 dBm	18.43 Mbps	349 m
15	14	16QAM 0.602	11.48 dB	-84.2187 dBm	20.66 Mbps	308 m
16	15	16QAM 0.643	12.17 dB	-83.5287 dBm	22.14 Mbps	285 m
17	15	64QAM 0.428	13.17 dB	-82.5287 dBm	22.14 Mbps	254 m
18	16	64QAM 0.455	13.85 dB	-81.8507 dBm	23.66 Mbps	235 m
19	17	64QAM 0.505	15.06 dB	-80.6367 dBm	26.45 Mbps	204 m
20	18	64QAM 0.554	16.25 dB	-79.4467 dBm	28.30 Mbps	178 m
21	19	64QAM 0.602	17.40 dB	-78.2987 dBm	31.74 Mbps	156 m
22	20	64QAM 0.65	18.53 dB	-77.1627 dBm	33.97 Mbps	137 m
23	21	64QAM 0.702	19.74 dB	-75.9587 dBm	36.60 Mbps	119 m
24	22	64QAM 0.754	20.93 dB	-74.7627 dBm	39.20 Mbps	104 m
25	23	64QAM 0.803	22.07 dB	-73.6297 dBm	42.33 Mbps	91 m
26	24	64QAM 0.853	23.20 dB	-72.5007 dBm	43.81 Mbps	80 m
27	25	64QAM 0.889	24.03 dB	-71.6647 dBm	45.29 Mbps	73 m
28	26	64QAM 0.926	24.87 dB	-70.8307 dBm	53.19 Mbps	66 m

			UL	Uplink	TDD Cfg 2	Distance
MCS Index	BS Index	Mod & CR	SINR	Sensitivity	Real Bit Rate*	
0	0	QPSK 0.1	-4.73 dB	-103.428 dBm	0.42 Mbps	2507 m
1	1	QPSK 0.125	-3.66 dB	-102.361 dBm	0.55 Mbps	2217 m
2	2	QPSK 0.155	-2.61 dB	-101.31 dBm	0.67 Mbps	1964 m
3	3	QPSK 0.205	-1.20 dB	-99.8977 dBm	0.88 Mbps	1669 m
4	4	QPSK 0.25	-0.16 dB	-98.8547 dBm	1.07 Mbps	1481 m
5	5	QPSK 0.31	1.02 dB	-97.6767 dBm	1.34 Mbps	1293 m
6	6	QPSK 0.365	1.96 dB	-96.7407 dBm	1.55 Mbps	1161 m
7	7	QPSK 0.43	2.94 dB	-95.7567 dBm	1.83 Mbps	1036 m
8	8	QPSK 0.49	3.76 dB	-94.9337 dBm	2.14 Mbps	943 m
9	9	QPSK 0.555	4.59 dB	-94.1117 dBm	2.37 Mbps	858 m
10	10	QPSK 0.615	5.79 dB	-92.9027 dBm	2.59 Mbps	746 m
11	10	16QAM 0.308	5.79 dB	-92.9027 dBm	2.59 Mbps	746 m
12	11	16QAM 0.353	6.79 dB	-91.9077 dBm	3.05 Mbps	665 m
13	12	16QAM 0.4	7.77 dB	-90.9257 dBm	3.40 Mbps	594 m
14	13	16QAM 0.45	8.75 dB	-89.9487 dBm	3.82 Mbps	531 m
15	14	16QAM 0.503	9.73 dB	-88.9697 dBm	4.28 Mbps	474 m
16	15	16QAM 0.535	10.31 dB	-88.3837 dBm	4.58 Mbps	443 m
17	16	16QAM 0.57	11.93 dB	-86.7657 dBm	4.90 Mbps	368 m
18	17	16QAM 0.63	12.96 dB	-85.7337 dBm	5.48 Mbps	327 m
19	18	16QAM 0.693	14.01 dB	-84.6867 dBm	5.86 Mbps	290 m
20	19	16QAM 0.753	14.99 dB	-83.7027 dBm	6.57 Mbps	259 m

Figure A.1 - Downlink and Uplink throughout estimation at distances for B42 TDD

			DL	Downlink	FDD	Distance
MCS Index	TBS Index	Mod & CR	SINR	Sensitivity	Real B.R	
0	0	QPSK 0.117	-3.98 dB	-99.6717 dBm	3.36 Mbps	1152 m
1	1	QPSK 0.153	-2.68 dB	-98.3787 dBm	4.39 Mbps	992 m
2	2	QPSK 0.189	-1.63 dB	-97.3277 dBm	5.42 Mbps	879 m
3	3	QPSK 0.245	-0.27 dB	-95.9707 dBm	7.07 Mbps	752 m
4	4	QPSK 0.301	0.85 dB	-94.8457 dBm	8.62 Mbps	661 m
5	5	QPSK 0.37	2.03 dB	-93.6657 dBm	10.81 Mbps	577 m
6	6	QPSK 0.439	3.06 dB	-92.6357 dBm	12.46 Mbps	512 m
7	7	QPSK 0.514	4.06 dB	-91.6327 dBm	14.72 Mbps	456 m
8	8	QPSK 0.588	4.98 dB	-90.7177 dBm	17.20 Mbps	411 m
9	9	QPSK 0.663	5.84 dB	-89.8617 dBm	19.05 Mbps	372 m
10	9	16QAM 0.332	6.34 dB	-89.3617 dBm	19.05 Mbps	351 m
11	10	16QAM 0.369	7.14 dB	-88.5567 dBm	20.87 Mbps	320 m
12	11	16QAM 0.424	8.24 dB	-87.4537 dBm	24.58 Mbps	282 m
13	12	16QAM 0.479	9.29 dB	-86.4117 dBm	27.36 Mbps	250 m
14	13	16QAM 0.54	10.40 dB	-85.2937 dBm	30.72 Mbps	220 m
15	14	16QAM 0.602	11.48 dB	-84.2187 dBm	34.43 Mbps	194 m
16	15	16QAM 0.643	12.17 dB	-83.5287 dBm	36.90 Mbps	180 m
17	15	64QAM 0.428	13.17 dB	-82.5287 dBm	36.90 Mbps	160 m
18	16	64QAM 0.455	13.85 dB	-81.8507 dBm	39.44 Mbps	148 m
19	17	64QAM 0.505	15.06 dB	-80.6367 dBm	44.08 Mbps	129 m
20	18	64QAM 0.554	16.25 dB	-79.4467 dBm	47.17 Mbps	112 m
21	19	64QAM 0.602	17.40 dB	-78.2987 dBm	52.90 Mbps	98 m
22	20	64QAM 0.65	18.53 dB	-77.1627 dBm	56.61 Mbps	86 m
23	21	64QAM 0.702	19.74 dB	-75.9587 dBm	61.00 Mbps	75 m
24	22	64QAM 0.754	20.93 dB	-74.7627 dBm	65.33 Mbps	65 m
25	23	64QAM 0.803	22.07 dB	-73.6297 dBm	70.55 Mbps	57 m
26	24	64QAM 0.853	23.20 dB	-72.5007 dBm	73.02 Mbps	50 m
27	25	64QAM 0.889	24.03 dB	-71.6647 dBm	75.49 Mbps	46 m
28	26	64QAM 0.926	24.87 dB	-70.8307 dBm	88.64 Mbps	42 m

			UL	Uplink	FDD	Distance
MCS Index	BS Index	Mod & CR	SINR	Sensitivity	Real Bit Rate*	
0	0	QPSK 0.1	-4.73 dB	-103.428 dBm	2.09 Mbps	2507 m
1	1	QPSK 0.125	-3.66 dB	-102.361 dBm	2.73 Mbps	2217 m
2	2	QPSK 0.155	-2.61 dB	-101.31 dBm	3.37 Mbps	1964 m
3	3	QPSK 0.205	-1.20 dB	-99.8977 dBm	4.39 Mbps	1669 m
4	4	QPSK 0.25	-0.16 dB	-98.8547 dBm	5.35 Mbps	1481 m
5	5	QPSK 0.31	1.02 dB	-97.6767 dBm	6.71 Mbps	1293 m
6	6	QPSK 0.365	1.96 dB	-96.7407 dBm	7.74 Mbps	1161 m
7	7	QPSK 0.43	2.94 dB	-95.7567 dBm	9.14 Mbps	1036 m
8	8	QPSK 0.49	3.76 dB	-94.9337 dBm	10.68 Mbps	943 m
9	9	QPSK 0.555	4.59 dB	-94.1117 dBm	11.83 Mbps	858 m
10	10	QPSK 0.615	5.79 dB	-92.9027 dBm	12.96 Mbps	746 m
11	10	16QAM 0.308	5.79 dB	-92.9027 dBm	12.96 Mbps	746 m
12	11	16QAM 0.353	6.79 dB	-91.9077 dBm	15.26 Mbps	665 m
13	12	16QAM 0.4	7.77 dB	-90.9257 dBm	16.99 Mbps	594 m
14	13	16QAM 0.45	8.75 dB	-89.9487 dBm	19.08 Mbps	531 m
15	14	16QAM 0.503	9.73 dB	-88.9697 dBm	21.38 Mbps	474 m
16	15	16QAM 0.535	10.31 dB	-88.3837 dBm	22.92 Mbps	443 m
17	16	16QAM 0.57	11.93 dB	-86.7657 dBm	24.50 Mbps	368 m
18	17	16QAM 0.63	12.96 dB	-85.7337 dBm	27.38 Mbps	327 m
19	18	16QAM 0.693	14.01 dB	-84.6867 dBm	29.30 Mbps	290 m
20	19	16QAM 0.753	14.99 dB	-83.7027 dBm	32.86 Mbps	259 m

Figure A.2 - Downlink and Uplink throughout estimation at distances for B7 FDD

			DL	Downlink	TDD Cfg 2	Distance
MCS Index	TBS Index	Mod & CR	SINR	Sensitivity	Real Bit Rate*	
0	0	QPSK 0.117	-3.98 dB	-98.4223 dBm	2.70 Mbps	1356 m
1	1	QPSK 0.153	-2.68 dB	-97.1293 dBm	3.51 Mbps	1168 m
2	2	QPSK 0.189	-1.63 dB	-96.0783 dBm	4.43 Mbps	1035 m
3	3	QPSK 0.245	-0.27 dB	-94.7213 dBm	5.55 Mbps	885 m
4	4	QPSK 0.301	0.85 dB	-93.5963 dBm	6.99 Mbps	778 m
5	5	QPSK 0.37	2.03 dB	-92.4163 dBm	8.47 Mbps	679 m
6	6	QPSK 0.439	3.06 dB	-91.3863 dBm	9.96 Mbps	603 m
7	7	QPSK 0.514	4.06 dB	-90.3833 dBm	11.82 Mbps	537 m
8	8	QPSK 0.588	4.98 dB	-89.4683 dBm	13.65 Mbps	484 m
9	9	QPSK 0.663	5.84 dB	-88.6123 dBm	15.32 Mbps	438 m
10	9	16QAM 0.332	6.34 dB	-88.1123 dBm	15.32 Mbps	414 m
11	10	16QAM 0.369	7.14 dB	-87.3073 dBm	16.99 Mbps	377 m
12	11	16QAM 0.424	8.24 dB	-86.2043 dBm	19.20 Mbps	332 m
13	12	16QAM 0.479	9.29 dB	-85.1623 dBm	22.17 Mbps	295 m
14	13	16QAM 0.54	10.40 dB	-84.0443 dBm	24.63 Mbps	259 m
15	14	16QAM 0.602	11.48 dB	-82.9693 dBm	27.41 Mbps	229 m
16	15	16QAM 0.643	12.17 dB	-82.2793 dBm	29.58 Mbps	211 m
17	15	64QAM 0.428	13.17 dB	-81.2793 dBm	29.58 Mbps	188 m
18	16	64QAM 0.455	13.85 dB	-80.6013 dBm	31.78 Mbps	174 m
19	17	64QAM 0.505	15.06 dB	-79.3873 dBm	35.50 Mbps	152 m
20	18	64QAM 0.554	16.25 dB	-78.1973 dBm	37.95 Mbps	132 m
21	19	64QAM 0.602	17.40 dB	-77.0493 dBm	42.39 Mbps	116 m
22	20	64QAM 0.65	18.53 dB	-75.9133 dBm	45.36 Mbps	102 m
23	21	64QAM 0.702	19.74 dB	-74.7093 dBm	49.36 Mbps	88 m
24	22	64QAM 0.754	20.93 dB	-73.5133 dBm	53.26 Mbps	77 m
25	23	64QAM 0.803	22.07 dB	-72.3803 dBm	55.47 Mbps	68 m
26	24	64QAM 0.853	23.20 dB	-71.2513 dBm	59.65 Mbps	59 m
27	25	64QAM 0.889	24.03 dB	-70.4153 dBm	61.70 Mbps	54 m
28	26	64QAM 0.926	24.87 dB	-69.5813 dBm	72.92 Mbps	49 m

			UL	Uplink	TDD Cfg 2	Distance
MCS Index	BS Index	Mod & CR	SINR	Sensitivity	Real Bit Rate*	
0	0	QPSK 0.1	-4.73 dB	-102.178 dBm	0.56 Mbps	1862 m
1	1	QPSK 0.125	-3.66 dB	-101.111 dBm	0.72 Mbps	1647 m
2	2	QPSK 0.155	-2.61 dB	-100.06 dBm	0.92 Mbps	1459 m
3	3	QPSK 0.205	-1.20 dB	-98.6483 dBm	1.15 Mbps	1240 m
4	4	QPSK 0.25	-0.16 dB	-97.6053 dBm	1.44 Mbps	1100 m
5	5	QPSK 0.31	1.02 dB	-96.4273 dBm	1.75 Mbps	960 m
6	6	QPSK 0.365	1.96 dB	-95.4913 dBm	2.06 Mbps	862 m
7	7	QPSK 0.43	2.94 dB	-94.5073 dBm	2.44 Mbps	770 m
8	8	QPSK 0.49	3.76 dB	-93.6843 dBm	2.82 Mbps	700 m
9	9	QPSK 0.555	4.59 dB	-92.8623 dBm	3.17 Mbps	637 m
10	10	QPSK 0.615	5.79 dB	-91.6533 dBm	3.51 Mbps	554 m
11	10	16QAM 0.308	5.79 dB	-91.6533 dBm	3.51 Mbps	554 m
12	11	16QAM 0.353	6.79 dB	-90.6583 dBm	3.97 Mbps	494 m
13	12	16QAM 0.4	7.77 dB	-89.6763 dBm	4.58 Mbps	441 m
14	13	16QAM 0.45	8.75 dB	-88.6993 dBm	5.09 Mbps	394 m
15	14	16QAM 0.503	9.73 dB	-87.7203 dBm	5.67 Mbps	352 m
16	15	16QAM 0.535	10.31 dB	-87.1343 dBm	6.12 Mbps	329 m
17	16	16QAM 0.57	11.93 dB	-85.5163 dBm	6.57 Mbps	273 m
18	17	16QAM 0.63	12.96 dB	-84.4843 dBm	7.34 Mbps	243 m
19	18	16QAM 0.693	14.01 dB	-83.4373 dBm	7.85 Mbps	215 m
20	19	16QAM 0.753	14.99 dB	-82.4533 dBm	8.76 Mbps	192 m

Figure A.3 – Downlink and Uplink throughout estimation at distances for B38 TDD

13.2 **Detailed Field Test Measurements in 5GCity Barcelona pilot**

In Barcelona City pilot deployment in District 22@ there were 3 lampposts with Accelleran Small Cells separated 64m between each other as shown in Figure A.4.

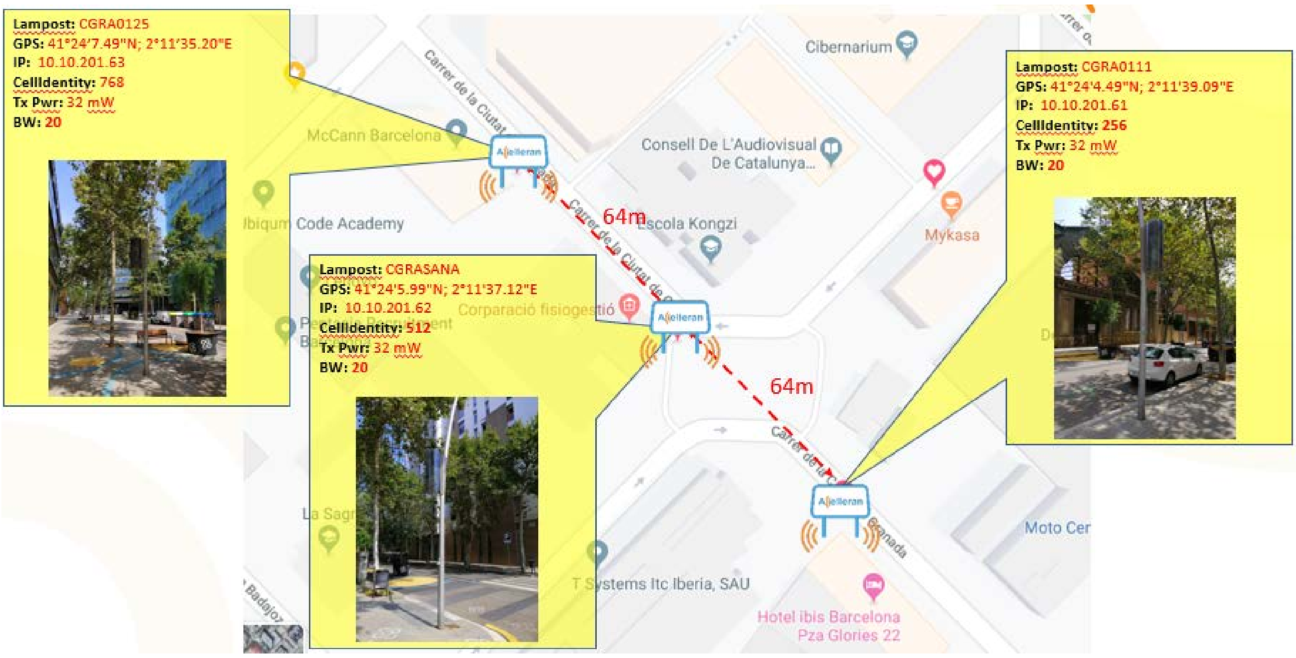


Figure A.4 - Accelleran Small Cells in lampposts at District 22@

The Accelleran B42 (3.5GHz) E1010 Small Cells were integrated in the City of Barcelona standard radome as per their standard mechanical connector as in Figure A.5. The Accelleran Small Cells were acting as Radio Units controlled by Accelleran Cloud Native dRAX™ Open Interface RAN Intelligence which run virtualized in 5GCity Edge/MEC infrastructure (city cabinets) as shown in Figure A.6.

Figure A.5 - Details of Accelleran B42 E1012 Small Cell integrated in Barcelona Radome

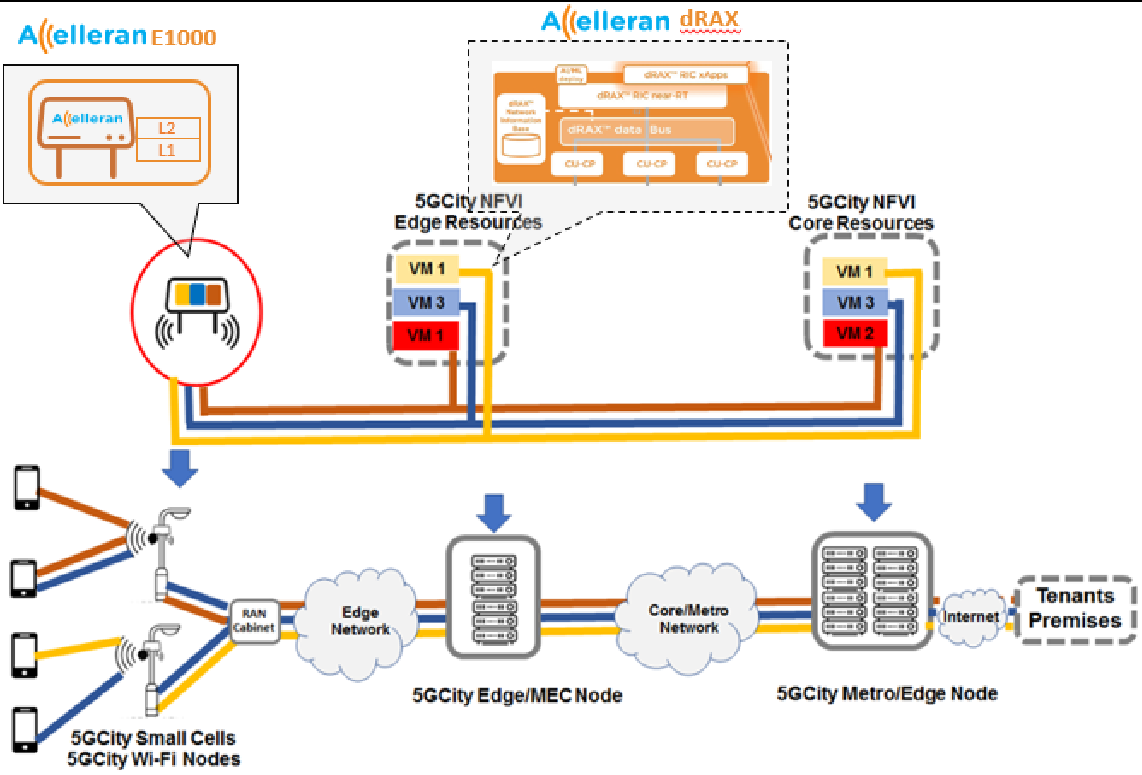


Figure A.6 - Accelleran dRAX™ vRAN and Radio Units in 5GCity infrastructure

For the field tests the Accelleran Small Call in CGRASANA (Figure A.7) lamppost was chosen as reference for the measurements while the other lampposts (CGRA0111 and CGRA0125) were inactive. The Accelleran Small Cell was configured with different output power and a walk tests were performed with different tools to show reference parameters such as SNR (Signal to Noise Ration), RSRP (Received Signal Reference Power) and RSRP (Received Signal Reference Quality).

Figure A.7 - CGRASANA lamppost in District 22@

13.2.1 GNetTracker Field Measurements

The field tests were performed by Accelleran using Essential Smartphone PH-1 which supports 3.5GHz B42 with GNetTracker Pro Android application capable of generating coverage maps showing different parameters. The walk tests all followed North to South footpaths on both sides of the streets until SNR value started to show cell edge conditions. The paths in the maps show certain deviations from the location of the measurements due to the GPS location errors even though the walk test followed footpaths in straight lines.

13.2.1.1 GNetTracker measurements at 250 mW per port

Figure A.8 shows the SNR, RSRQ and RSRP levels for a power configuration in Accelleran B42 E1010 Small Cell of 250 mW/port.

Figure A.8 - GNetTracker field measurements with Accelleran B42 E1010 Small Cell with 250 mW/port

13.2.1.2 GNetTracker measurements at 125 mW per port

Figure A.9 shows the SNR, RSRQ and RSRP levels for a power configuration in Accelleran B42 E1010 Small Cell of 125mW/port.

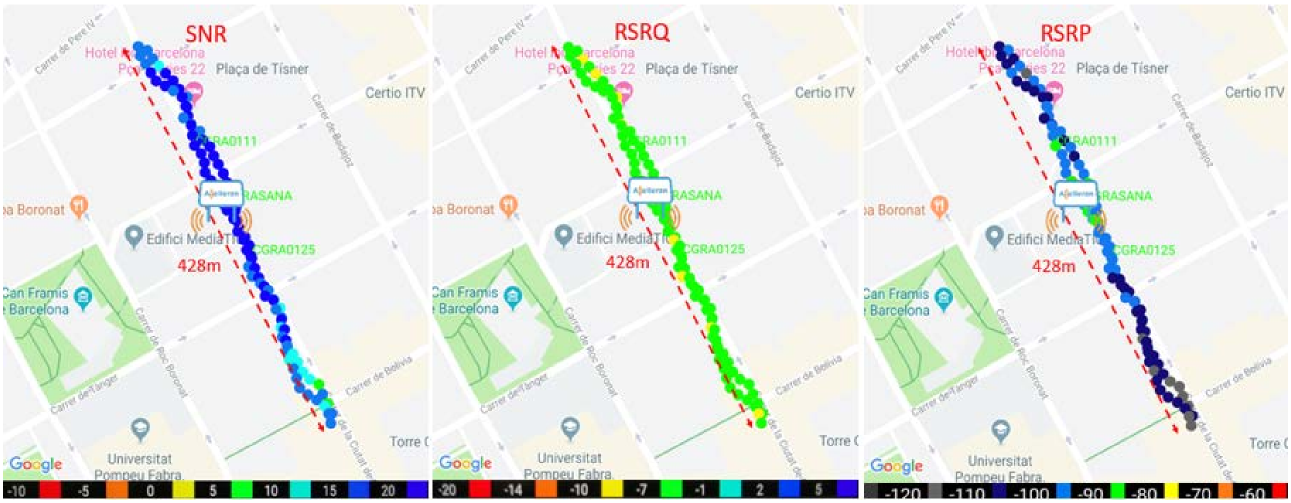


Figure A.9 - GNetTracker field measurements with Accelleran B42 E1010 Small Cell with 125 mW/port

13.2.1.3 GNetTracker measurements at 63 mW per port

Figure A.10 shows the SNR, RSRQ and RSRP levels for a power configuration in Accelleran B42 E1010 Small Cell of 63mW/port.

Figure A.10 - GNetTracker field measurements with Accelleran B42 E1010 Small Cell with 63 mW/port

13.2.1.4 GNetTracker measurements at 16 mW per port

Figure A.11 shows the SNR, RSRQ and RSRP levels for a power configuration in Accelleran B42 E1010 Small Cell of 16 mW/port.

Figure A.11 - GNetTracker field measurements with Accelleran B42 E1010 Small Cell with 16 mW/port

13.2.1.5 GNetTracker measurements at 4 mW per port

Figure A.12 shows the SNR, RSRQ and RSRP levels for a power configuration in Accelleran B42 E1010 Small Cell of 4 mW/port.

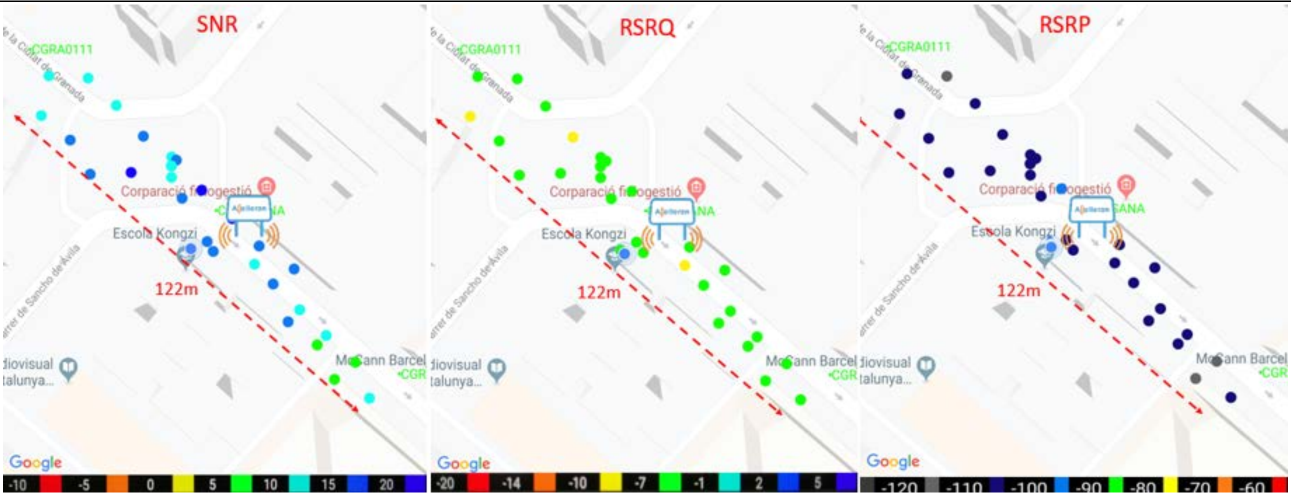


Figure A.12 - GNetTracker field measurements with Accelleran B42 E1010 Small Cell with 4 mW/port

13.2.2 TSMA Field Measurements

The field tests were performed jointly between Cellnex and Accelleran using R&S TSMA measurement equipment with 3.5GHz B42 support and capable of generating coverage maps showing RSRP.

13.2.2.1 TSMA measurements at 250 mW per port

Figure A.13 and Figure A.14show the RSRP levels for a power configuration in Accelleran B42 E1010 Small Cell of 250 mW/port.

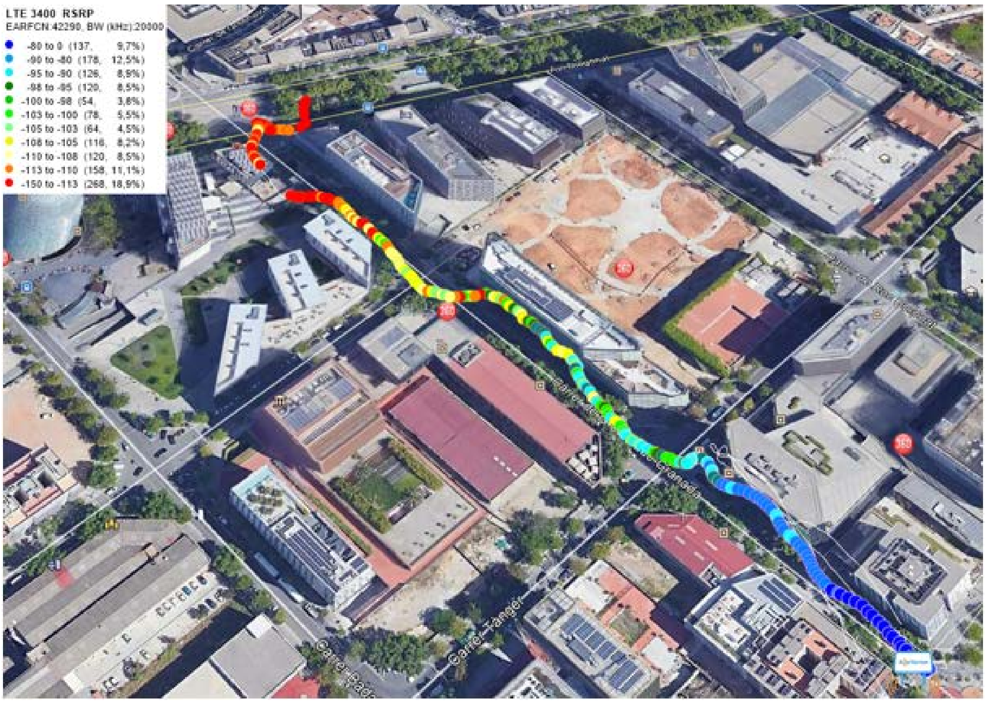


Figure A.13 - TSMA field measurements with Accelleran B42 E1010 Small Cell with 250 mW/port – crossroads

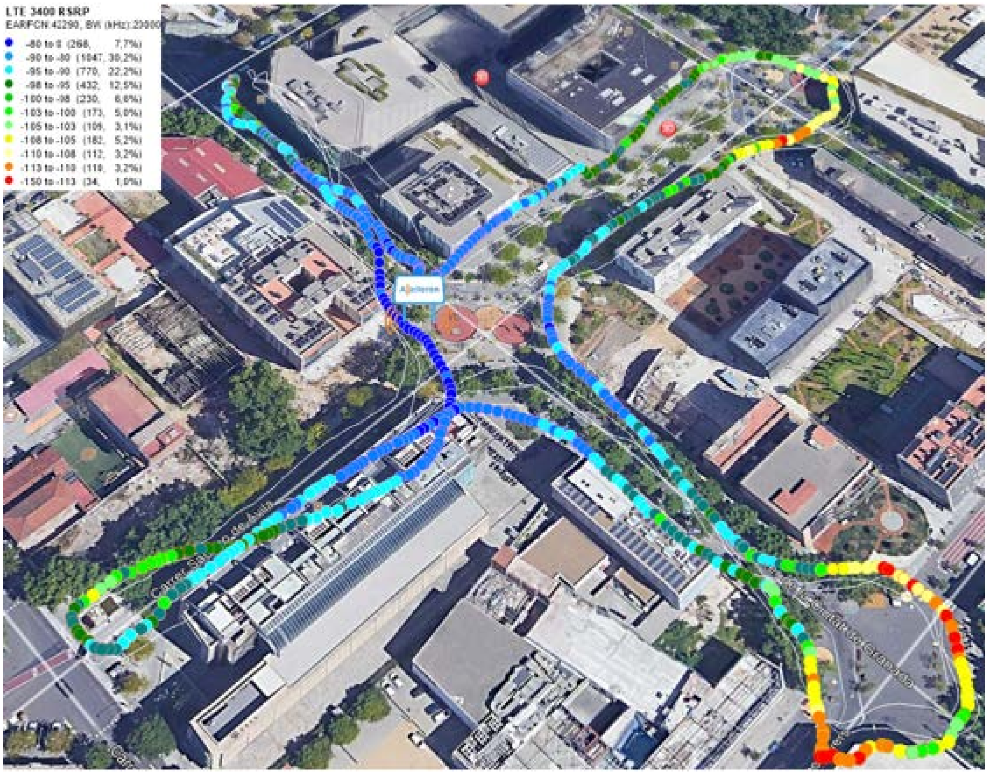


Figure A.14 - TSMA field measurements with Accelleran B42 E1010 Small Cell with 250 mW/port - long northbound only

13.2.2.2 TSMA measurements at 63 mW per port

Figure A.15 shows the RSRP levels for a power configuration in Accelleran B42 E1010 Small Cell of 63 mW/port.

Figure A.15 - TSMA field measurements with Accelleran B42 E1010 Small Cell with 63 mW/port

13.2.2.3 TSMA measurements at 4 mW per port

Figure A.16 shows the RSRP levels for a power configuration in Accelleran B42 E1010 Small Cell of 4 mW/port.

Figure A.16: TSMA field measurements with Accelleran B42 E1010 Small Cell with 4 mW/port

13.2.3 Conclusions

In general SNR, RSRQ and RSRQ values at different Tx power levels in the Accelleran B42 E1010 Small Cell seem to be consistent with regards to the expected cell center, mid cell and cell edge conditions as initially estimated with link budgets.

Even when Accelleran B42 E1010 Small Cell is configured with 18 dBm/63 mW per port the cell edge condition seem to be farther than the location of the other 2 small cells (with still quite good SNR, RSRQ and RSRP) at the vicinity of those neighbours small cells leading to some strong overlapping considering that they are located at just 64m from each other.

Recommendation is to configure the Tx power of the Small Cells to somewhere in between 18 dBm/63 mW and 12 dBm/16 mW, i.e to a Tx power value of 15 dBm / 32 mW per port (RefSignalPwr -16 dBm for 20 MHz channel) to avoid excessive overlapping for the 64m inter-site distance of this particular deployment.

14. APPENDIX B – Electric field measurements in the Superilla del Poblenou

14.1 Introduction

The "Municipal Institute of Information Technology" (IMI) is developing the 5GCity European project of the H2020 program (Ref number 761508) in the initiatives related to the 5GPPP program and the 5GBarcelona Consortium in the area known as the "Superilla del Poblenou". This development consists of putting into operation two radio technologies related to the future 5G in the B42 band and in the upper WI-FI band.

The "Agència d'Ecologia de Barcelona (BCN Ecologia)" would like to know if the radioelectric emissions of the antennas installed in the pilot test of this project meet with the sanitary protection measure requirements.

To this end, ADTEL Sistemas de Telecomunicación SL has carried out a series of electric field intensity measurements on the 2nd, 3rd and 4th of July to verify that the new stations comply with ·Real Decreto" 1066/2001, which establishes the conditions for public protection against radioelectric emissions, radioelectric emission restrictions, and health protection measures against radioelectric emissions.

This document presents the measures and the results obtained.

14.2 Objective

Carry out a series of radioelectric measurements in all the current points where 5G and WI-FI antennas have been installed to verify that the new stations comply with Real Decreto 1066/2001.

In addition, an estimate of what the radioelectric levels would be if an additional 5G or WI-FI stations were included in this space.

The study should present the results in the most visual way possible and using language that is understandable to people who are not specialists in the analysis of this type of report.

14.3 Background Information

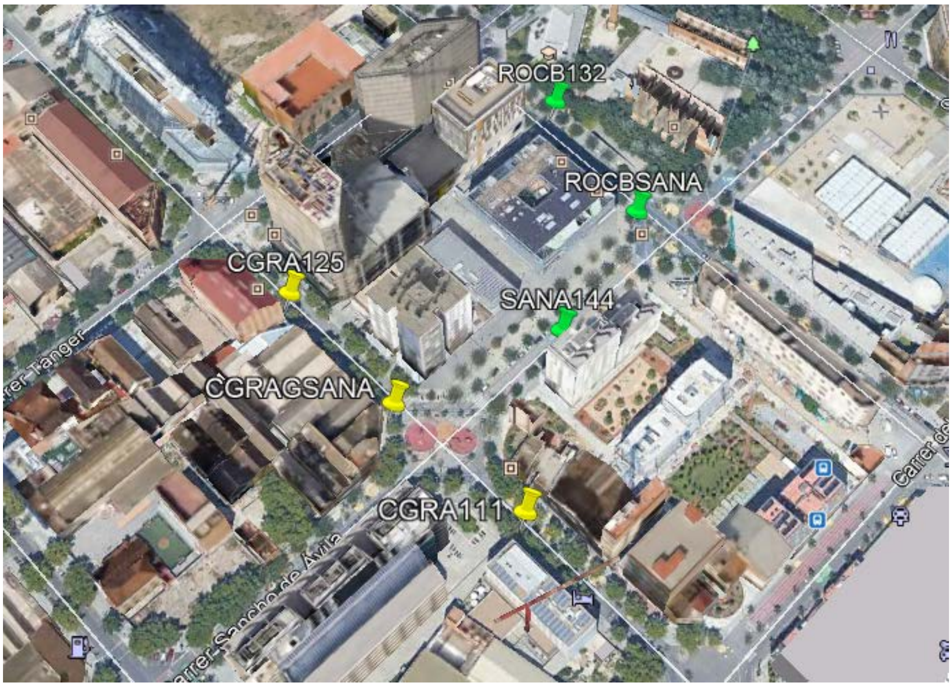
The 5G and WI-FI pilot tests consist of 3 Small 5G and 3 AP's (Access Point) WI-FI Small Cells. Below are brief details of this equipment

ID	Technology	Freq (GHZ)	RF Power	Radiation Pattern
CGRA125	5G	3.470	24 dBm per port	Omnidirectional
CGRASANA	5G	3.470	24 dBm per port	Omnidirectional
CGRA11	5G	3.470	24 dBm per port	Omnidirectional
ROCB132	WI-FI 5GHz	5.180 / 5.200	16 dBm / 23 dBm	Omnidirectional
ROCBSANA	WI-FI 5GHz	5.180 / 5.200	16 dBm / 23 dBm	Omnidirectional
SANA144	WI-FI 5GHz	5.180 / 5.200	16 dBm / 23 dBm	Omnidirectional

Table 14.1 Characteristics of emissions

The following image is a map showing these points.

. Figure 14.1 Map of 5G and WI-FI broadcast points:



Source: ADTEL

14.4 Measuring Equipment

To carry out the measurements, ADTEL has used the NARDA-3006, which is a selective high frequency electromagnetic field meter and the SRM Three-Axis electric field intensity probe, E-Field 420 MHz - 6 GHz, which includes a GPS to georeference the measurements. Below is a photo of the equipment and the probe:

. Figure 14.2 **Narda-3006 i Sonda SRM Three-Axis, E-Field**

Source: Narda

14.5 Definition of Frequency Bands

Since Narda 3006 is a selective type meter, it allows the breakdown of the total value of the measure, indicating the contribution of each of the frequency bands. All of the measures carried out are based on a table created by ADTEL, where the service associated with each of the bands is identified:

Name of Service	Fmin [GHz]	Fmax [GHz]	Description	Scope
Altres	0.42	0.47	N/A	N/A
DVB-T	0.47	0.68	TDT Television Service	private
BANDA800	0.79	0.862	All mobile telephone service providers within 800 MHz band	private
BANDA900	0.88	0.96	All mobile telephone service providers within 900 MHz band	private
BANDA1800	1.71	1.88	All mobile telephone service providers within 1800 MHz band	private
BANDA2100	1.9	2.17	All mobile telephone service providers within 2100 MHz band	private
WI-FI2.4G	2.4	2.4835	WI-FI Service 2.4GHz band	public
ISM	2.4835	2.5	For industrial, scientific or medical purposes	public
BANDA2600	2.5	2.69	All mobile telephone service providers within 2600 MHz band	private
BANDA3600A	3.4	3.46	All mobile telephone service providers within 3600 MHz-3800 band (in progress)	private
Pilot telefonia 5G	3.46	3.48	Frequency used in the 5G pilot test	private
BANDA3600B	3.48	3.8	All mobile telephone service providers within 3600 MHz-3800 band (in progress)	private
ALTRES	3.8	5.15	N/A	N/A
WI-FI5GA	5.15	5.17	WI-FI Service 5GHz band	public
PilotWI-FICH36	5.17	5.19	Channel 36 of the 5GHz Wi-Fi used in the pilot test	public
PilotWI-FICH40	5.19	5.21	Channel 40 of the 5GHz Wi-Fi used in the pilot test	public
WI-FI5GB	5.21	5.8	WI-FI Service 5GHz band	public

Table 14.2 Characteristics of emissions

From this table, it is necessary to clarify the following:

- The 3600-3800 band has been segmented into three sections, since the 5G telephone pilot test uses part of this band. Since it is a private band, the pilot test is the only one authorized to use it.:
    - Section A: from 3.4 to 3.46 GHz
    - Pilot Test Section: from 3.46 to 3.48 GHz
    - Section B: from 3.48 to 3.8 GHz
- The 5GHz WI-FI band has been segmented in 4 sections, since the WI-FI pilot test uses two channels of this band.
    - Section A: from 5.15 to 5.17 GHz
    - The WI-FI pilot test section, relative to Channel 36: from 5.17 to 5.19 GHz
    - The WI-FI pilot test section, relative to Channel 40: from 5.19 to 5.21 GHz

- Section B: from 5.21 to 5.8 GHz

14.6 Interpretation of results

As shown in Table 5.1, the value of a measure will not only depend on the levels of the pilot test, as at the same time other services are measured that vary the intensity of the electric field continuously depending on its needs, such as mobile phone services.

It is for this reason that a measurement at the same point with the pilot test equipment on will not always be greater than the measurement at the same point with the equipment off, as it may be the case that other services which are not the objective of this study, were emitting with more power, while the equipment was off. This would imply that they were emitting more electric field.

However, once this point has been clarified, what can be stated is that:

- In the stations of the 5G telephone pilot test, since it works in a private frequency and no other service can be used, the selective measurement in the band used in this test will always be greater with the equipment on than with the equipment turned off , and this is where the intensity of the electric field can be evaluated which contributes to the total measurement of the 5G pilot test.

- Since the stations of the WI-FI 5GHz pilot test, work on a public frequency and any domestic WI-FI can be used, the selective measurement of the band used in this test will not always be greater with the equipment on than with the equipment turned off,

- At the stations of the WI-FI 5GHz pilot test, since it works on a public frequency and any domestic WI-FI can be used, the selective measurement of the band used in this test will not always be greater with the equipment that is switched on with the equipment off, as there are other WI-FIs that vary their RF power depending on their needs in the same frequency band as the pilot test, it cannot be known exactly what intensity of electric field the pilot test contributes to the total measurement- this can only be estimated.

14.6.1 Total and broken-down values

The tables of the measures carried out are shown in appendix 10.2. In these tables, you can see the total value of the measurement and its broken-down value.

It could mistakenly be assumed that the sum total of the broken-down values will result in the average value of the measurement

Therefore, we should clarify that the measured value is calculated by the square root of the sum of all squared values of each of the frequency bands, as follows:

$$Measured\ Value = \sqrt{others^2 + DVBT^2 + BAND800^2 + BAND900^2 + \cdots WIFI5GB^2}$$

14.7 Electric Field Intensity Reference Levels

The electric field exposure reference levels are used to be compared with the measures carried out.

In item 3.1, in Table 2, of Real Decreto 1066/2001, it can be seen that for frequencies greater than 2GHz, which is the case of the pilot test that takes place in the Superilla del Poblenou, the reference value of the electric field intensity that cannot be exceeded is 61 V / m (highlighted in red):

. Figure 14.3 **Electric Field Reference Levels of the Real Decreto 1066/2001**

CUADRO 2

Niveles de referencia para campos eléctricos (0 Hz-300 GHz, valores rms imperturbados)

Gama de frecuencia	Intensidad de campo E (V/m)
0-1 Hz	
1-8 Hz	10.000
8-25 Hz	10.000
0,025-0,8 kHz	250/f
0,8-3 kHz	250/f
3-150 kHz	87
0,15-1 MHz	87
1-10 MHz	$87/f^{1/2}$
10-400 MHz	28
400-2.000 MHz	$1,375\ f^{1/2}$
2-300 GHz	61

Notas:

1. f según se indica en la columna de gama de frecuencia.

Source: BOE

14.8 Methodology

Given that the objective of the study is to measure the intensity of the electric field that the test pilot equipment brings to the existing electric field intensity, two types of measurements are made in each of the stations; one with the equipment off and another with the equipment on.

El Real Decreto 1066/2001 states that in the radioelectric certifications of a station, it is necessary to measure at least 5 points around it and that in each point it is necessary to measure for 6 minutes and when this time is finished the average value of the measurement must be noted.

The places chosen to carry out the measures are the most restrictive possible, that is to say, where the intensity of the electric field of the measured station is thought to have its maximum level and at the same time a place where there may be pedestrians.

These are places very close to the station and within what is considered a distant field. The radiation pattern diagrams of the antennas have been taken into account

For 5G telephone stations, a distance greater than 27cm is considered a far field and in 5GHz WI-FI stations the distance must be greater than 17cm.

14.8.1 Sensitive Spaces

Apart from the 5 measurements carried out around the station, the RD1066 / 2001 states that it is obligatory to take measurements in places called "Sensitive Spaces" which are less than 100 m from the antenna. These spaces are:

- Hospitals or health centres
- Nurseries, primary schools and secondary schools.
- Public Park
- Residential homes for the elderly

In these spaces there are no special level constraints, and the electric field intensity reference values are the same as at any other point.

Appendix 10.4 shows a photograph of the Sensitive Spaces measured in this report

All of the measures included in this report have been made in compliance with the guidelines set out in point 8, thus fulfilling the RD1066 / 2001.

14.8.2 Measurements taken at point 5G CGRA125

Measurements with the test pilot equipment OFF					
Measurement	Electrical Field Reference Value (V/m)	Total Measured Value (V/m)	Relation between reference value and measured value	Pre-existing Band Value Pilot 5G (V/m)	¿Sensitive Space?
M1	61	0.5515	111	0.00756	No
M2	61	0.4511	135	0.006837	No
M3	61	0.485	126	0.007649	No
M4	61	0.5246	116	0.007023	No
M5	61	0.4642	131	0.007653	No
M6	61	0.5288	115	0.006923	Yes

In the measurements carried out around point "CGRA125", with all of the 5G stations switched off, the measured value with respect to the reference value allowed is at least 111 times lower.

Measurements with the test pilot equipment ON						
Measurement	Electrical Field Reference Value (V/m)	Total Measured Value (V/m)	Relation between reference value and measured value	Value Measured in Pilot 5G Band)	Relation between reference value and 5G measured value (V/m)	¿Sensitive Space?
M1	61	0.5739	106	0.2363	258	No
M2	61	0.4771	128	0.1308	466	No
M3	61	0.4525	135	0.08688	702	No
M4	61	0.4961	123	0.1244	490	No
M5	61	0.4898	125	0.1657	368	No
M6	61	0.6958	88	0.04589	1329	Yes

In the measurements carried out around point "CGRA125", with all of the 5G stations switched on, the measured value with respect to the reference value allowed is at least **88** times lower.

The measured value that the pilot test brings to the total is, at least **258** times lower than the permitted reference value.

14.8.3 Measurements taken at point 5G CGRASANA

Measurements with the test pilot equipment OFF					
Measurement	Electrical Field Reference Value (V/m)	Total Measured Value (V/m)	Relation between reference value and measured value	Pre-existing Band Value Pilot 5G (V/m)	¿Sensitive Space?
M1	61	0.8845	69	0.007768	No
M2	61	0.7843	78	0.01245	No
M3	61	0.8946	68	0.01132	No
M4	61	0.8972	68	0.01287	No
M5	61	0.8078	76	0.01117	No
M6	61	0.8816	69	0.01274	Sí
M7	61	0.9404	65	0.01111	Sí
M8	61	0.6152	99	0.009048	Sí

In the measurements carried out around point “CGRASANA”, with all of the 5G stations switched off, the measured value with respect to the reference value allowed is at least **65** times lower.

Measurements with the test pilot equipment ON						
Measurement	Electrical Field Reference Value (V/m)	Total Measured Value (V/m)	Relation between reference value and measured value	Value Measured in Pilot 5G Band)	Relation between reference value and 5G measured value (V/m)	¿Sensitive Space?
M1	61	0.7331	83	0.1203	507	No
M2	61	0.7843	78	0.1158	527	No
M3	61	1.016	60	0.05858	1041	No
M4	61	0.8942	68	0.1111	549	No
M5	61	0.8082	75	0.1555	392	No
M6	61	0.8263	74	0.0536	1138	Sí
M7	61	1.011	60	0.1106	552	Sí
M8	61	0.6571	93	0.09101	670	Sí

In the measurements carried out around point "CGRASANA", with all of the 5G stations switched on, the measured value with respect to the reference value allowed is at least **60** times lower.

The measured value that the pilot test brings to the total is, at least **392** times lower than the permitted reference value.

14.8.4 Measurements taken at point 5G CGRA111

Measurements with the test pilot equipment OFF					
Measurement	Electrical Field Reference Value (V/m)	Total Measured Value (V/m)	Relation between reference value and measured value	Pre-existing Band Value Pilot 5G (V/m)	¿Sensitive Space?
M1	61	0.5259	116	0.007797	No
M2	61	0.4563	134	0.009595	No
M3	61	0.2647	230	0.01058	No
M4	61	0.2167	281	0.009966	No
M5	61	0.9594	64	0.01108	No

In the measurements carried out around point “CGRA111”, with all of the 5G stations switched off, the measured value with respect to the reference value allowed is at least **64** times lower.

Measurements with the test pilot equipment ON						
Measurement	Electrical Field Reference Value (V/m)	Total Measured Value (V/m)	Relation between reference value and measured value	Value Measured in Pilot 5G Band)	Relation between reference value and 5G measured value (V/m)	¿Sensitive Space?
M1	61	0.9708	63	0.313	195	No
M2	61	0.9009	68	0.1575	387	No
M3	61	0.9361	65	0.1026	595	No
M4	61	0.9615	63	0.05638	1082	No
M5	61	0.9036	68	0.0835	731	No

In the measurements carried out around point "CGRA111", with all of the 5G stations switched on, the measured value with respect to the reference value allowed is at least **63** times lower.

The measured value that the pilot test brings to the total is, at least **195** times lower than the permitted reference value.

14.8.5 Measurements taken at point WI-FI 5GHz SANA144

Measurements with the test pilot equipment OFF						
Measurement	Electrical Field Reference Value (V/m)	Total Measured Value (V/m)	Relation between reference value and measured value	Pre-existing Band Value Pilot WI-FI 5GHz CH36 (V/m)	Pre-existing Band Value Pilot WI-FI 5GHz CH40 (V/m)	¿Sensitive Space?
M1	61	0.9981	61	0.01921	0.01885	No
M2	61	0.9779	62	0.02211	0.02098	No
M3	61	0.879	69	0.01894	0.01851	No
M4	61	0.8559	71	0.01723	0.01689	No
M5	61	0.8494	72	0.01917	0.01937	No

In the measurements carried out around point WI-FI 5GHz “SANA144”, with all of the WI-FI 5GHz stations switched off, the measured value with respect to the reference value allowed is at least **61** times lower.

Measurements with the test pilot equipment ON								
Measurement	Electrical Field Reference Value (V/m)	Total Measured Value (V/m)	Relation between reference value and measured value	Value Measured in Pilot WI-FI 5GHz CH36 (V/m)	Relation between reference value and CH36 band value measured	Value Measured in Pilot WI-FI 5GHz CH40 (V/m)	Relation between reference value and CH36 band value measured	¿Sensitive Space?
M1	61	0.8563	71	0.03262	1870	0.0207	2947	No
M2	61	0.967	63	0.02894	2108	0.01901	3209	No
M3	61	0.9366	65	0.02284	2671	0.02038	2993	No
M4	61	0.7868	78	0.02276	2680	0.01913	3189	No
M5	61	0.8455	72	0.02594	2352	0.0207	2947	No

In the measurements carried out around point WI-FI 5GHz “SANA144”, with all of the WI-FI 5GHz stations switched on, the measured value with respect to the reference value allowed is at least **63** times lower.

The measured value that the pilot test brings to the total is, at least **1870** times lower than the permitted reference value in channel 36, and **2947** times in channel 40.

14.8.6 Measurements taken at point WI-FI 5GHz ROCBSANA

Measurements with the test pilot equipment OFF						
Measurement	Electrical Field Reference Value (V/m)	Total Measured Value (V/m)	Relation between reference value and measured value	Pre-existing Band Value Pilot WI-FI 5GHz CH36 (V/m)	Pre-existing Band Value Pilot WI-FI 5GHz CH40 (V/m)	¿Sensitive Space?
M1	61	1.255	49	0.02165	0.02145	No
M2	61	1.14	54	0.01957	0.01924	No
M3	61	1.119	55	0.0215	0.02145	No
M4	61	1.109	55	0.01942	0.02003	No
M5	61	1.119	55	0.02187	0.02136	No
M6	61	0.794	77	0.0193	0.01923	Sí
M7	61	1.112	55	0.01756	0.01754	Sí

In the measurements carried out around point WI-FI 5GHz "ROCBSANA", with all of the WI-FI 5GHz stations switched off, the measured value with respect to the reference value allowed is at least **49** times lower.

Measurements with the test pilot equipment ON								
Measurement	Electrical Field Reference Value (V/m)	Total Measured Value (V/m)	Relation between reference value and measured value	Value Measured in Pilot WI-FI 5GHz CH36 (V/m)	Relation between reference value CH36 and band value measured	Value Measured in Pilot WI-FI 5GHz CH40 (V/m)	Relation between reference value CH36 and band value measured	¿Sensitive Space?
M1	61	1.345	45	0.02284	2671	0.01899	3212	No
M2	61	1.253	49	0.02239	2724	0.02105	2898	No
M3	61	1.105	55	0.02516	2424	0.02341	2606	No
M4	61	1.057	58	0.02326	2623	0.02083	2928	No
M5	61	1.273	48	0.02345	2601	0.01932	3157	No
M6	61	0.7859	78	0.022	2773	0.02163	2820	Sí
M7	61	1.27	48	0.02382	2561	0.02414	2527	Sí

In the measurements carried out around point WI-FI 5GHz "ROCBSANA", with all of the WI-FI 5GHz stations switched on, the measured value with respect to the reference value allowed is at least **45** times lower.

The measured value that the pilot test brings to the total is, at least **2454** times lower than the permitted reference value in channel 36, and **2527** times in channel 40.

14.8.7 Measurements taken at point WI-FI 5GHz ROCB132

Measurements with the test pilot equipment OFF						
Measurement	Electrical Field Reference Value (V/m)	Total Measured Value (V/m)	Relation between reference value and measured value	Pre-existing Band Value Pilot WI-FI 5GHz CH36 (V/m)	Pre-existing Band Value Pilot WI-FI 5GHz CH40 (V/m)	¿Sensitive Space?
M1	61	0.4562	134	0.01601	0.0163	No
M2	61	0.4699	130	0.01459	0.0142	No
M3	61	0.4891	125	0.01595	0.01609	No
M4	61	0.4466	137	0.01769	0.01746	No
M5	61	0.4733	129	0.01626	0.0163	No

In the measurements carried out around point WI-FI 5GHz "ROCB132", with all of the WI-FI 5GHz stations switched off, the measured value with respect to the reference value allowed is at least **125** times lower.

Measurements with the test pilot equipment ON								
Measurement	Electrical Field Reference Value (V/m)	Total Measured Value (V/m)	Relation between reference value and measured value	Value Measured in Pilot WI-FI 5GHz CH36 (V/m)	Relation between reference value and CH36 band value measured	Value Measured in Pilot WI-FI 5GHz CH40 (V/m)	Relation between reference value and CH36 band value measured	¿Sensitive Space?
M1	61	0.4436	138	0.01423	4287	0.01397	4366	No
M2	61	0.4887	125	0.01744	3498	0.0157	3885	No
M3	61	0.4439	137	0.01427	4275	0.0143	4266	No
M4	61	0.4125	148	0.01662	3670	0.0157	3885	No
M5	61	0.4796	127	0.02403	2538	0.01624	3756	No

In the measurements carried out around point WI-FI 5GHz “ROCB132”, with all of the WI-FI 5GHz stations switched on, the measured value with respect to the reference value allowed is at least **125** times lower.

The measured value that the pilot test brings to the total is, at least **2538** times lower than the permitted reference value in channel 36, and **3756** times in channel 40.

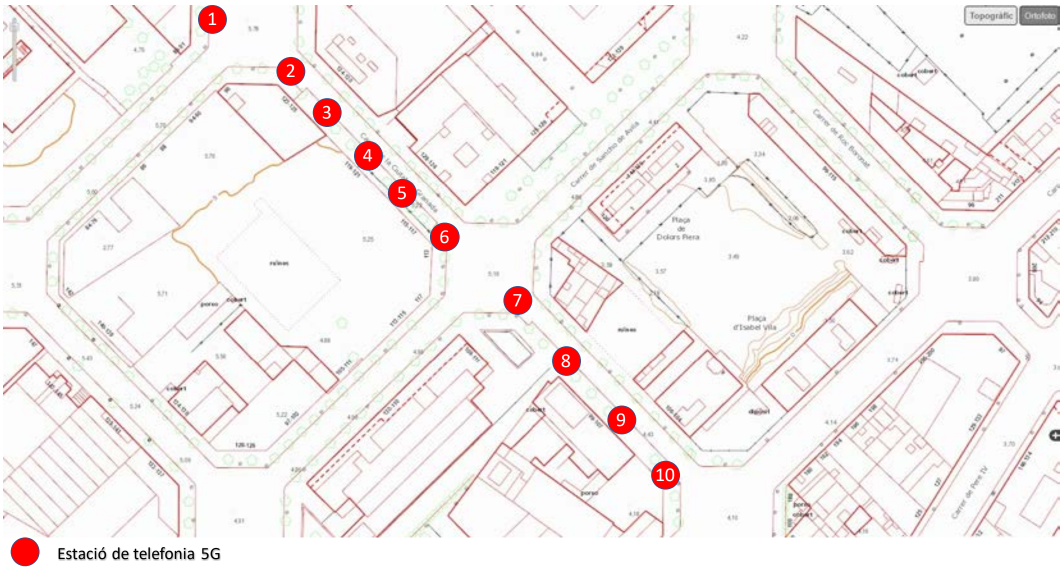
14.8.8 Estimated levels in a hypothetical extension of the pilot test

Once the results of the measurements have been seen, an estimate can be made of what would happen if the pilot test was extended, increasing the number of stations.

14.8.9 Pilot test with more 5G phone stations

As mentioned in point 2, one of the objectives of this study is to estimate what the levels of electric field intensity would be if, for example, instead of having three phone stations 5G in Ciutat de Granada Street, there were ten.

. Figure 14.4 Map of 10 hypothetical 5G phone stations



Source: ADTEL

In the measurements, with three 5G phone stations, a maximum value of 0.313 V/m was measured in the frequency band of the 5G pilot test, and the average value of all measurements made in this band is 0.122 V/m.

So, in the worst-case scenario, if each of the ten hypothetical stations brings a value of 0.313 V/m to any measured point, the value will be approximately this:

$Estimated\ Value\ 5G \approx \sqrt{10 * (0.313^2)}$=**1.29 V/m**

This estimated value of 1.29 V/m with respect to the permitted reference value is 47 times lower.

So, if this value is combined with the maximum measured value with the 5G equipment off, we will have the worst possible combination, that which would yield a higher estimated value:

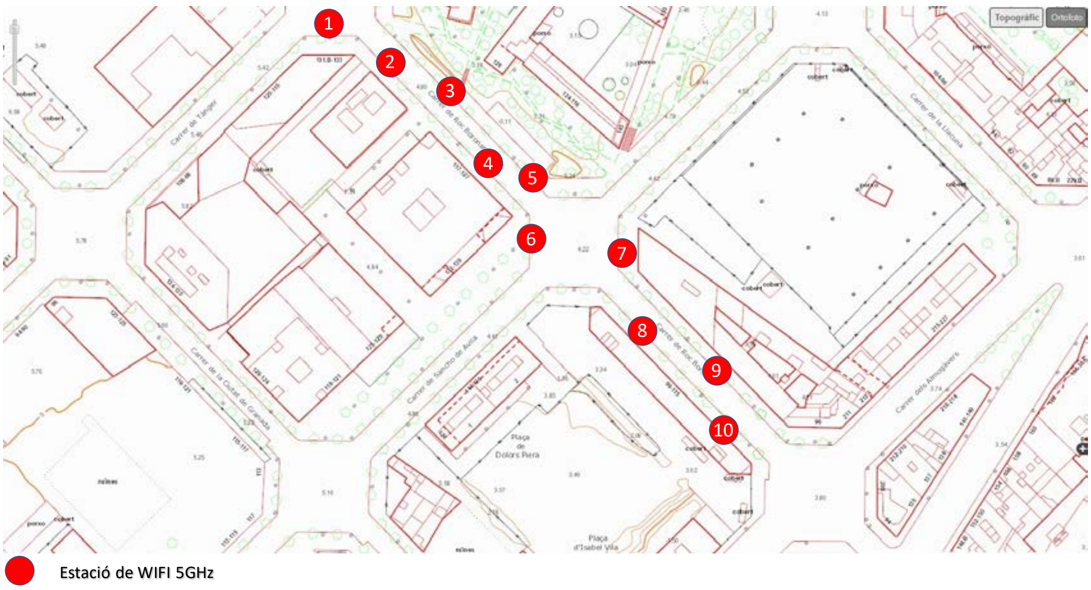
$Estimated\ Value\ \mathrm{total} \approx \sqrt{1.29^2 + 0.9594^2}$=**1,6 V/m**

This estimated value of 1.6 V / m with respect to the reference value allowed is 38 times lower.

14.8.10 Pilot test with more 5GHz WI-FI stations

Since, as seen in sections 8.5, 8.6 and 8.7, the electrical field intensity measurements provided by the WI-FI 5GHz pilot test equipment are very low, it can be ensured that with the inclusion of 7 more WI-FI stations in the same area, the permitted reference value would not be exceeded

. Figure 14.5 Map of 10 hypothetical 5GHz WI-FI stations



Source: ADTEL

In the measurements, with three WFI 5GHz stations switched on, the maximum values for CH36 are 0.03262 V/m and 0.02414 V/m for CH40, and the average value of all measurements made in this band is 0.02251 V/m for CH36 and 0.01913 V/m for CH40.

So, in the worst-case scenario, if each of the ten hypothetical stations at any point measured this maximum value, we would approximately have the following:

$Estimated\ Value$ WI − FI $5GHz \approx \sqrt{10 * (0.03262^2) + 10 * (0.02414^2)}$=**0.1283 V/m**

This estimated value of 0.1283 V/m with respect to the permitted reference value is 475 times lower.

So, if this value is combined with the maximum value measured with the 5GHz WI-FI stations off, it would have the worst combination possible which would give the highest estimated value:

$Estimated\ Value$ total $= \sqrt{0.1283^2 + 1.255^2}$=**1,26 V/m**

This estimated value of 1.26 V/m with respect to the allowed reference value is 48 times lower.

14.9 **Conclusions**

Based on the measurements and checks carried out, it can be concluded that, in the pilot test of 5G and WI-FI 5GHz stations de la Superilla del Poblenou:

- All electric field intensity measurements comply with the requirements of Real Decreto 1066/2001 (aimed at public radio protection).
- The maximum level of total electric field intensity measured is 45 times lower than the maximum reference exposure level allowed in Real Decreto 1066/2001
- The maximum level of electric field intensity relative to emissions in the 5G telephone band measured is 195 times lower than the maximum reference exposure level allowed in Real Decreto 1066/2001.
- The maximum level of electrical field intensity relative to emissions in the WI-FI 5GHz band measured is approximately 1870 times lower than the maximum reference exposure level allowed in Real Decreto 1066/2001 in Channel 36, and 2527 times lower in Channel 40-
- It can be seen that in all measurements, the highest contributions of electric field intensity to the total measured levels come from mobile phone bands of 800, 900, 2100 and 2600 MHz, due to a nearby emitter center in the area of the measurements
- If the pilot test were increased to 10 5G mobile telephone stations, it is estimated that the total measured value would be 38 times lower than the maximum reference exposure level allowed in Real Decreto 1066/2001
- If the pilot test were increased to 10 of WI-FI 5GHz stations, it is estimated that the total measured value would be 48 times lower than the maximum reference exposure level allowed in Real Decreto 1066/2001.

15. APPENDIX C – Urban Guidelines for ICT Superblocks model

The world is facing relevant societal challenges especially regarding to global economy, climate change and especially warrantee a fair access to resources. We are at a critical point, were decisions around these topics will take a relevant impact on the next decades. Innovation should provide the tools and skills to support policy making and strategically visions for the future in Europe and the rest of the world. Last year, it was published the European Digitalisation Strategy (Nov 2018), which establishes a vision and principles to follow by the EU Members. It highlights the role of data and its management as a key aspect for economic, social and environmental affairs. The document also states that it is necessary to consider new and innovative digital solutions which consider the following factors: legal obligations, new user requirements, heightened security concerns and a corporate approach to information management, emphasizing the sharing and reuse of data. The major IT challenges pointed by the Commission are: (i) the design, development and deployment of the next generation of mission-critical digital solutions, and (ii) the modernization of its legacy systems.

The present Report forms part for the 5GCity EU Project Funded (Horizon 2020) and focuses on the analysis of IT infrastructure requirements in urban contexts. This analysis takes the Superblock urban model developed in Barcelona City as a starting point. The aim of this report is to provide some urban considerations about the deployment of the technological parts, which are needed for 5G, in urban areas, and also considering the radiation of 5G while implementing them in the public space, therefore it is very important to consider the matching point with urban design and health.

The structure of the document is set in six parts. The first part gives the background about IT and 5G technologies state of art. The second part describes the Information and Communications Technologies ICT Superblock model and the main urban elements required. Then the third part it is dedicated to the ICT Superblock deployment methodology, were four cases of analysis in Barcelona City are included. The fourth part of the report explains the radiation measurements realized in one of the pilot areas. Then conclusions and annexes are included at the final part of the document.

15.1 Background

1G brought the very first cell phones, 2G text messages, 3G online access, 4G today mobile devices (1GB/s). If more users or a rising number of devices (IoT and others) need a higher amount of data, 4G is on the limit of its capacity. 5G (20GB/s in the Plan until 2020). 5G will be the foundation for autonomous driving, virtual reality, the internet of things, new modes of production (industry 4.0) and a lot of more developments and urban services that will shape the future city.

High-speed internet connectivity is not a luxury but could become a right for all citizens; especially those who are more isolated in remote areas. In cities, there is a wide possibility of services for waste management, renewable energy microgrids, social assistance, urban monitoring, etc. driving into a more ecological use of resources in urban areas. An essential difference to the actual network is edge computing, which means that the network will be placed more decentralized in the city than it is today. The small cells and the other belonging technical items have to be deployed in the urban areas. In contrast to the current network of 4G there have to be deployed much more technical items in the public space than before.

15.2 5G technologies

To understand which technologies have to be implemented in the future the following part gives a brief overview of the most important ones. The challenge is to understand how they work together and how to implement them according to different **urban morphologies, population density, urban and economic activities,** and most important to **secure health** as well the integration of the network in the whole urban ecosystem.

The fifth-generation (5G) of mobile data transmitting is not just one single new technology it is a set based on different elements. At the moment, not all of the elements work together and even others will follow, so for the implementation of 5G will succeed in different stages/levels.

15.2.1 Millimeter waves Level 1 (in realization)

More people and devices are consuming more data than ever before, but it remains on the same bands of the radio-frequency spectrum that mobile providers used since ever. The result is less bandwidth for everyone, which causes slower service and more dropped connections.

A solution is to transmit signals on a whole new of the spectrum, one that's never been used for mobile service before. That's why providers are experimenting with broadcasting on millimeter waves, which use higher frequencies than the radio waves that have long been used for mobile phones. **Millimeter waves are broadcast at frequencies between 25-60 GHz**, compared to the bands below 6 GHz that were used for mobile devices in the past. They are called millimeter waves because they vary in length from 1 to 10 mm, compared to the radio waves that serve today's smartphones, which measure tens of centimeters in length.

But there is a hitch to millimeter waves, they can't travel through buildings or obstacles, and they can be absorbed by plants and rain. That's why 5G networks will likely augment traditional cellular towers with another new technology, called small cells.

15.2.2 Small Cells (Transmitters) Level 1 (in realization)

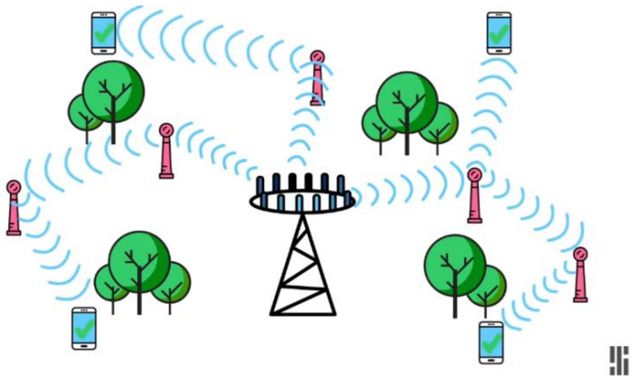


Figure C.1 Small Cell; Spectrum

Small cells are miniature base stations and transmitters. To prevent signals from being dropped, streets could install thousands of these stations in a city to form a dense network that acts like a relay team, receiving signals from other base stations and sending data to users at any location. While traditional cell networks have also come to rely on an increasing number of base stations, achieving 5G performance will require an even greater infrastructure. Antennas on small cells can be much smaller than traditional antennas if they are transmitting tiny millimeter waves. This size difference makes it even easier to stick cells on light poles and buildings.

This radically different network structure should provide more targeted and efficient use of spectrum. Having more stations means the frequencies that one station uses to connect with devices in one area can be reused by another station in a different area to serve another customer. This enables new services that rely on close proximity to the user and/or other location and presence information. In addition to broadcasting over millimeter waves, 5G base stations will also have many more antennas than the base stations of today's cellular networks—to take advantage of another new technology: massive MIMO.

15.2.3 Massive MIMO Level 2

5G base stations will support about a hundred ports, which means many more antennas can fit on a single array. That capability means a base station could send and receive signals from many more users at once, increasing the capacity of mobile networks by a factor of 22 or greater. This technology is called massive MIMO. MIMO, which stands for multiple-input multiple-output. Massive MIMO looks very promising for the future of 5G. However, installing so many more antennas to handle cellular traffic also causes more interference if those signals cross. That's why the MIMO has to incorporate beamforming.

15.2.4 Beamforming Level 3

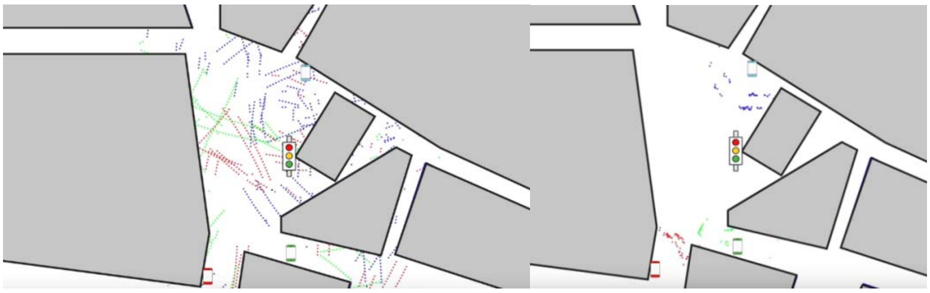


Figure C.2: Beamforming; Spectrum

Beamforming is a traffic-signaling system for cellular base stations that identifies the most efficient data-delivery route to a particular user, and it reduces interference for nearby users in the process. The primary challenge for MIMO is to reduce interference while transmitting more information from many more antennas at once. At MIMO base stations, signal-processing algorithms plot the best transmission route through the air to each user. Then they can send individual data packets in many different directions, bouncing them off buildings and other objects in a precisely coordinated pattern. For millimeter waves, beamforming is primarily used to address a different set of problems: Cellular signals are easily blocked by objects and tend to weaken over long distances. In this case, beamforming can help by focusing a signal in a concentrated beam that points in the direction of a user, rather than broadcasting in many directions at once. This approach can strengthen the signal's chances of arriving intact and reduce interference for everyone else.

15.2.5 Full Duplex Level 4

Today's base stations and cell phones rely on transceivers that must take turns if transmitting and receiving information over the same frequency, or operate on different frequencies if a user wishes to transmit and receive information at the same time. With full level 5G, a transceiver will be able to transmit and receive data at the same time, on the same frequency. Additional to these technologies, today mostly small cells, it requires urban infrastructure like cabinets and conduits to implement the network.

15.3 Urban application cases

The lack of reliable information on the characteristics of the 5G network creates some difficulties in the conception and planning of scenarios for the city. In this chapter we analyse new uses that only with the advent of the 5G infrastructure can be developed, but also improvements for those technologies already available on the market and using the 4G network. The series has been divided into two topics, **public space and mobility**: each of them contains cases of citizens' uses, security, environmental quality, tourism and networks fluxes. The selection, moreover, was carried out thinking of the reference scenario, the superblock. For a better classification of the cases it was necessary to use the triangle "Usage scenarios of IMT for 2020 and beyond" contained in the Recommendation ITU-R M.2083-0 (2015): the position of the point in the triangle indicates the greater or lesser importance of enhanced mobile broadband, massive machine-type communications or ultra-reliable, and low latency communications.

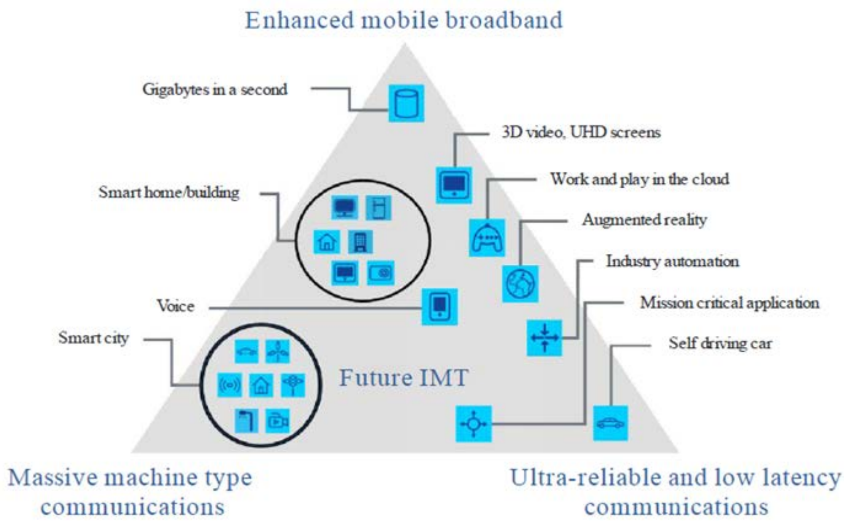


Figure C.3: "Usage scenarios of IMT for 2020 and beyond"; ITU

Main uses and digital requirements by urban unit (future scenario)

Improved with 5G	**Developed only with 5G**
● Public space - Smart lighting system - Smart waste - IoT network - Green city solution - ShotSpotter system - Structure monitoring	● Public space - Kiosk - Massive MIMO - Smart tourism
● Mobility - Smartest intersection - Starling crossing - Smart parking	● Mobility - MaaS - Parcel delivery - Connectivity node - e-Palette vehicle

15.4 Data demand estimation

The following sections document different use cases for the installation and deployment of the 5G infrastructure in the urban fabrics. In this case a spatial analysis is done with GIS. With the data generated maps were created to support the analysis of the different character of urban data and fabrics. The main part of the spatial analysis is structured in three possibilities

A. **Demand** through population density, mobility, etc.
B. the possible **distribution** shaped by the physical structure of the city.
C. the data about **sensitive places** detected to ensure health and wellbeing

In a further step there could be made 4 different scenarios, but in this work the main focus is on scenario 1, future research should also take the other scenarios into account. So not all the following factors were taken into account for the analyse, but the build a foundation for the analysis of urban data demand pattern.

1. **the first depicts the actual case as a base for the initial implementation;**
2. the second could describe a soon and realistic future without urban development management, that means mostly a market-driven installation of 5G (for example the number of cars remain, but they are autonomous, augmented reality, etc.)
3. the third is a goal for a soon future but managed urban development with incentives for examples (car-less areas, improved public transportation, and other services)
4. the fourth an ultimate future scenario of an automated and digitized urban area, automated traffic, urban services, etc.

15.4.1 Demand variables and conditioning factors

The Installation of 5G in different urban areas accords to the demand of data in the specific area. For this reason, it is important to understand the different types of public spaces. A residential area has another demand then a business district or a pedestrian area. It is important to know the average demand for transmission per user and the number of people or devices who use the internet or data on the street. In both cases, it will depend on the type of activity in that specific urban environment, although an approximation to the average can be the first data. Also, the data demand will rise in the next few years for this reason the implementation could follow at different levels. It is also to consider that the installation of a 5G network in an urban area could catalyse urban development (also gentrification) in this specific area. During the timeline, the demand will rise, but the following factors are a valid base for a ground analysis of data demand according to the urban constellation.

15.4.1.1 Population

The hypothesis that the **density of the population** in the urban area is forming the **density of people in public spaces** is not always valid. Usually, there is a correlation between inhabitant density and density of people in the streets, but it is very important to consider that the inhabitant density and the density of people in public spaces can vary greatly. There are differences between the function of public spaces (for example commercial or residential area), some are attracting more people than others and also differences between changing times of the day, or even during the seasons of the year. The measurement of people using public space must be more precise than just population density. If we speak from smartphone usage (not IoT, etc.) some places tend to make individuals use more or fewer data.

- the density of population (inhabitants/ha)
- density of people in public space (inhabitants/ha)

15.4.1.2 Economical activities

The density and cluster of economic activities in the urban areas are interconnected with the public spaces which surround them, it is important to analyse the patterns and density of economic activities to analyse different demand and usage patterns. The economic activities can also give information about the kind of usage during different times of the day, week and year. Significant is the consideration of logistics intense businesses or industry 4.0 such as the usage of public space for craft or gastronomy, or any data-intensive type of business model. **The Density of economic activities and density of specific activities or clusters should be the decisive factors measured in ha or m2 according to the public space (street).**

- business
- industry (4.0)
- logistics
- retail
- craft
- gastronomy
- tourism
- health
- education
- sport
- markets
- entertainment
- etc.

15.4.1.3 The function of public space

The functions of the urban areas like a residential area, a mixed urban area or for example a commercial or touristic area shape the usage and the challenges according to the public space, also the functions of the public space itself are influencing the behaviour and in the end the demand of data. **For the typology, the according to factor will be the functions of the area in m^2.**

- leisure
- wait
- long-stay
- communication / assembly / interaction
- transit
- play/sport
- education
- etc.

15.4.1.4 Mobility

A main factor in public spaces is the urban mobility that takes place in them. It is crucial which kind of mobility takes place and how automated, digitized, or for example pedestrianized, individualized or common it is. 5G promises to set the base for automated driving in the city, which would take the data usage to another level, even now a lot of shared mobility services like electric scooters or shared bikes and other mobility services have a stable data connection. **The factors for the typology should be the m^2 of public space usage for the specific kind of mobility, and also the speed limit, there could be some cross-hatched areas and also single-use cases, for example in rush streets or pedestrian areas. Another factor could be the number of pedestrians crossing or the amount of traffic.**

- individual traffic
  - active mobility
    - cycling
    - walking
  - motorized mobility
    - e mobility
    - conventional car or motorcycle
- public transport
  - electric, hybrid or conventional motor
- shared mobility
  - shared mobility points (biking)
- logistics
  - consider different possibilities of loading zones
- stationary traffic (parking)
- connectivity of streets

15.4.1.5 Urban infrastructure services

5G is advertising to improve the urban services through measurements, regulation and optimized use of resources. The implemented services are central to the demanded data in public spaces. These services will arrive slowly in the city, so for that reason, we can consider implementing the 5G at different levels.

- waste management and circular city
- energy production
- climate regulation
- environmental data collection
- light
- participation
- etc.

15.4.2 Average demand

Some data related to global demand and individual demand can be reviewed. In the first case we will obtain information on patterns of distribution of the demand as a whole. In the second case, we will be marked by trends in increased demand, considering that the population would be more or less stable and the increase in demand would come from the evolution of individual needs.

15.4.2.1 Total demand distribution

A look at the distribution throughout the day of the use of the smartphones shows a constant demand outside the night time. This graph depicts the personal usage of data for different activities or in free time. The Internet of Things and other use cases which are not connected with a personal demand are not taken into account here. For a further research the data demand of server centers in the city would be interesting.

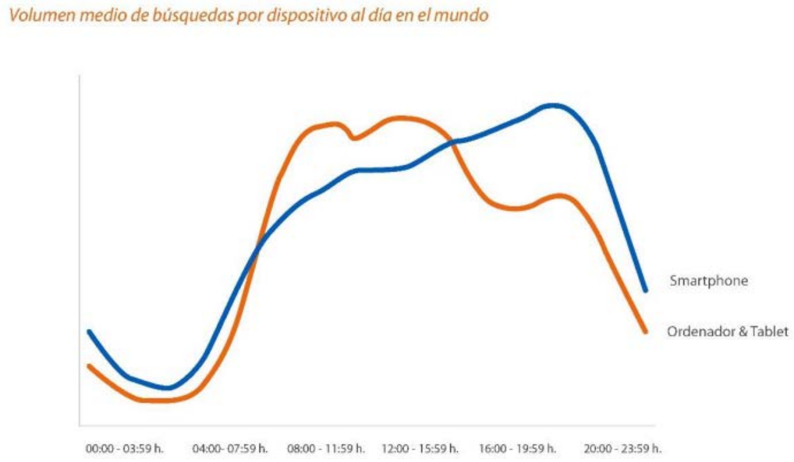


Figure C.4: Vodafone Ditrendia Mobile Report 2017[14] graphic of world consumption diary distribution

The trend is like a similar concentration equal all day since wake-up hours to the night. In Spain, probably the late hour will be later than in other countries but we are interested in global numbers. It could be interesting to check the time that people stay on public space. One of the possibilities is to obtain data about the time use in mobility. But it must be completed with other activities like leisure time and other outdoor activities like sports.

15.4.2.2 Displacements

It could be interesting to study the behaviour patterns of people and the use of public space to know the supply capacities that should be covered with a public communications network for the same public space.

One of these behavioural parameters may be the time spent on mobility and especially active mobility, that is, the time that people use to move around the street and during which they may need to be connected.

A study of displacement time may come from mobility surveys. Considering the Barcelona mobility survey, some interesting data can be obtained:

- The average daily number of displacements on a labor day is 3,9 (⅓ laboral, ⅔ personal; 6 million walking 43%, 3 mio in public transport, 5mio in private transport; only 8,4% of all displacements are multimodal).
- The distribution of these paths over time can be observed in the following graphs:

[14] Vodafone Ditrendia Mobile Report 2017

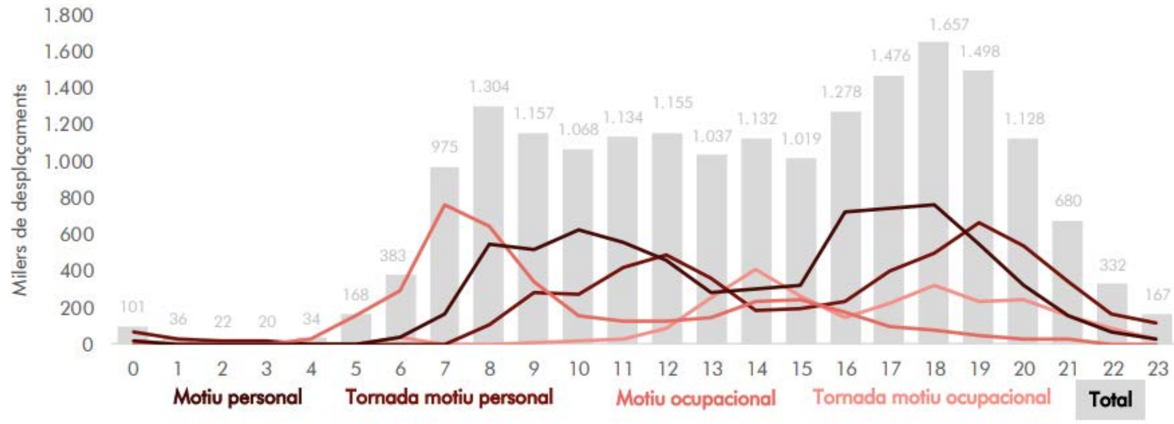


Figure C.5: Mobility Survey on labour day 2018[15]. Executive summary: The time of mobility. Time distribution due to displacement.

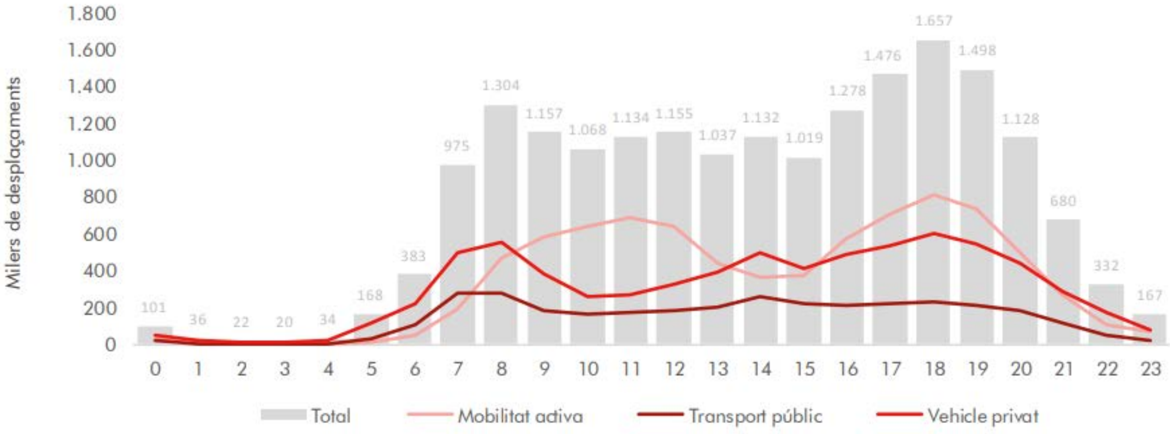


Figure C.6: Mobility Survey on labour day 2018[16]. Executive summary: The time of mobility. Time distribution by displacement mode.

In this case, we observe that the distribution of displacements is almost uniform at the time of day. Therefore, it is not possible to consider a differentiated behaviour, in a first approximation, at certain times of the day.

- Regarding the active displacement, practically the one that is done walking, we can obtain from the same previous source data on the average times that are used:

[15] Survey of Mobility Barcelona 2018

[16] Survey of Mobility Barcelona 2018

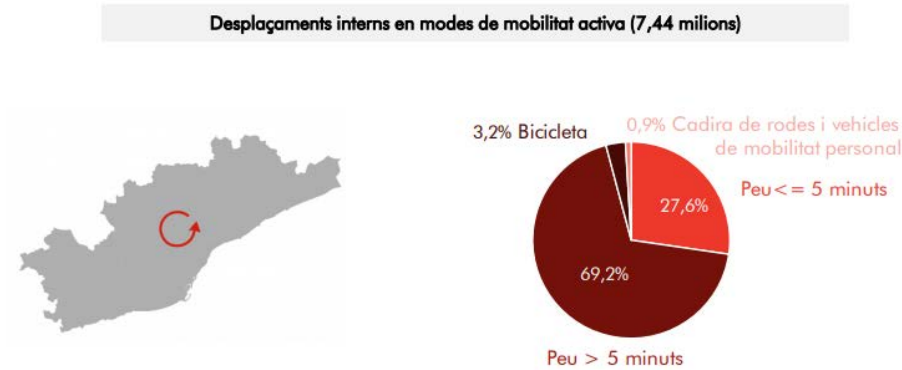


Figure C.7: Mobility Survey on labour day 2018[17]. Executive summary: Type of flow according to mode of transport. Active mobility mode.

Tipus de desplaçament	Mode de transport	Durada mitjana (minuts)
Intramunicipal	Mobilitat activa	14,8
	Transport públic	27,1
	Vehicle privat	11,9
	Total	**15,9**
Intermunicipal	Mobilitat activa	21,7
	Transport públic	51,9
	Vehicle privat	27,0
	Total	**32,6**

Figure C.8: Mobility Survey on labour day 2018[18]. Executive summary: Average time perceived as displacement.

This information is used to calculate the number of travels walking daily: 3,9 travels daily*043% walking= 1,677 travels day walking. For the time on street walking it's possible use 14,8 minutes per day and per travel walking (Active mobility inside municipality, average time)

The average time in the street is 23,8 minutes. (Between 7AM and 21 PM is distributed the most of the displacement daily). These 23,8 minutes is only the time for displacement, but we must add time on the street for other activities to have the exact time a person spends in public space within a day. It's not possible to get accurate data. A good approach will be a time around 25-30 minutes on an average labour day in the street but it doesn't count the time in buses or private vehicles.

It's also necessary to add transport by bus. In buses, the activity and demand of data is considered to be higher than the use of data of a person that is walking. The bus allows a more intensive type of activity and network use such as watching videos in the internet.

Next to the time for displacement to work or for personal reasons there has to be added the time on the street for outdoor activities like doing sports, playing, having a leisure stroll or sitting on a square. Each country has a different culture and climate conditions and that is why people can distribute this time in

17 Survey of Mobility Barcelona 2018
18 Survey of Mobility Barcelona 2018

different ways. For the type of distribution study that is related to this project just the activity peaks will be considered. It was calculated the demand in the periods of high activity. Another problem is to transfer these activities to the type of communication demand. Once again, we find cultural differences and habits of each country.

In Barcelona, a Mediterranean country with a climate and culture that allow multiple outside activities people spend time in the public space till night time. The days seem longer than in northern Europe because the are taking more activities place outside the private space. Activities or places like meeting points have a big demand of people and will lead to a high need of data demand.

In Barcelona, the number of bars and restaurants with terraces and tables on the street has another important focus of demand. This information could be implicit in the typology of the street or area. Once again important is to calculate the demand in peak time. (And have a security number for special times).

Activity surveys for Catalonia establish that 58.6% of people perform leisure and fun activities, between 1,46 hours on weekdays and 2,26 hours on average on weekends. Not all of this activity occurs outdoors but can be considered an important (valuable) part in summer.

Activities directly related to the outdoors (which would include out-of-town activities) or sports (which does not always include outside activity) are 2.00 hours on weekdays and 2.14 on weekends and include 38.4% of the population[19].

To sum up, a calculation of the time on the street and public space with the time of use of the smartphone or other devices using communications is difficult to approximate. Further studies for according to the usage of data in public space are needed.

15.4.2.3 Individual demand

Below you can review some interesting facts about the behaviour and trends of the demand and network activity of people in a more individualized way:

Regarding the activity by age we can observe the following distribution:

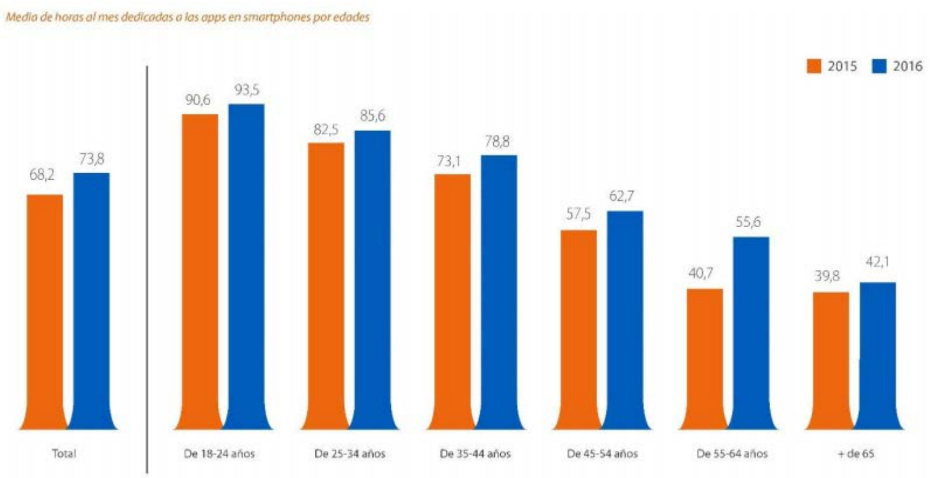


Figure C.9:Vodafone Ditrendia Mobile Report 2017[20], Average hours per month devoted to mobile apps by age

[19] INI time use survey, 2003
[20] Vodafone Ditrendia Mobile Report 2017

In this graphic show us than the most of the time in use will be for apps (social media, stores, banks… the most popular today WhatsApp): practically 148 minutes/day of 170 will be for social media.

In a more extensive study, we could compare these data with the evolution of the population pyramid. However, in this study we will make a first approximation.

Another data is that the +65 is only half average time than younger. It might be interesting to see if these trends remain or evolve.

15.4.2.4 Typology of the services, individual consumptions and projections

Next, the data on demand needs will be dissected according to the main activities carried out on smart phone by users:

Normal activities with big demand:

Navigation	2,5Mb/minute	41,6 Kbps
GPS	1Mb/20km	Very low for a city average speed 12Km/h.
Games online	1,5Mb/minute	25 Kbps
App social media (facebook example)	2,5Mb/minute	41,6 Kbps
Music	1,5Mb/minute	25 Kbps
Youtube	6Mb/minute	100 Kbps
Netflix movie online	60Mb/minute (1Mbps)	1000 Kbps
VoiceIP	1MB/minute	16,6 Kbps

Most of the activities have a demand between 1-3Mb/minute. Only videos and movies have a high demand. 4K or 5K could be 20-50Mbps.

From here we can make demand approximations for maximum capacity considering full streets and different demand cases.

For 5000 persons (full capacity) for a capacity of 350 Mbps in a small cell permit a 70 Kbps for each without deteriorated signal.

For most of the activities in a full capacity, it will be under the maxima capacity.

Depend on the type of activities the demand can spill the possibilities. These cases could be possible in case of a high video demands and a high video transmission demand.

Tables and approximation data on different situations can be found below, in the section Data traffic demand in urban space, in the Annexes.

It has been considered a projection of the future multiplying the current demand by five, although in this context of constant technological changes it is difficult to know exactly these data. In any other case, the maximum hypothesis used refers to the fact that the total connections are made in the street although we know that the time in the street is relatively small and that proportionality can be made in the times of use of connection with the times in the Street.

Conclusions:

Although in some cases we can find ourselves nearby, none of them exceeds the capacities of the type cells considered. Obviously, all calculations are based on approximations with the hypotheses contemplated and can be revisable. More dedicated studies on behaviour and demand may be necessary.

15.5 ICT Superblock model

Our society faces a constant adaptation of habits and behaviour to new technologies and so does our environment. Cities will also need to prepare their physical structure for the upcoming technology advances. The challenge relies not only on the access of population but also in the efficient use of resources. For the implementation of new strategies, most of the new applications will require adequate integration to current urban furniture and be coherent to the services provided to citizens.

In that sense, the Urban Ecology Agency of Barcelona developed an alternative urban planning tool called Superblock. The 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 represents the first step". The new urban management basic unit works as a guideline for the energy transition, zero waste and social strategies in cities, providing the facilities and adequate infrastructure to achieve a more sustainable city.

5GCity Project Barcelona's Pilot case is located in a recent implemented Superblock in the neighbourhood of Poblenou. This area began the urban transformation since 2016. One of the most relevant characteristics of the area is the increment of public space designated to citizens' uses. This pilot area has become a living lab for several projects, such as 5GCity because it facilitates the installation of new services and urban configurations to prove.

15.5.1 Scheme for infrastructures in a superblock area:

The superblocks in Barcelona vary in size, shape and structure of the street network but mainly they have a size of 400m by 400 m. In search of a scheme for the deployment of the 5G- technology in the city there has to be taken into account all technical elements.

For the installation of the 5G Network are also needed technical rooms, which contains elements of traffic control, servers and more and is of considerable size per each superblock unit. This space will be used to manage all traffic in the distribution of a superblock, although one may not be necessary for each block in case of low demand so that the management of a technical room could cover several superblocks at once. However, it would be important to have a space prepared in each of them.

In a typical Superblock of 400 m x 400 m the 5G network could follow a scheme like this. There are placed at the outer edges of the Superblock the neutral nodes (technical rooms) which connect the superblocks each other through primary network and send the data packages to the inner infrastructure of the superblock.

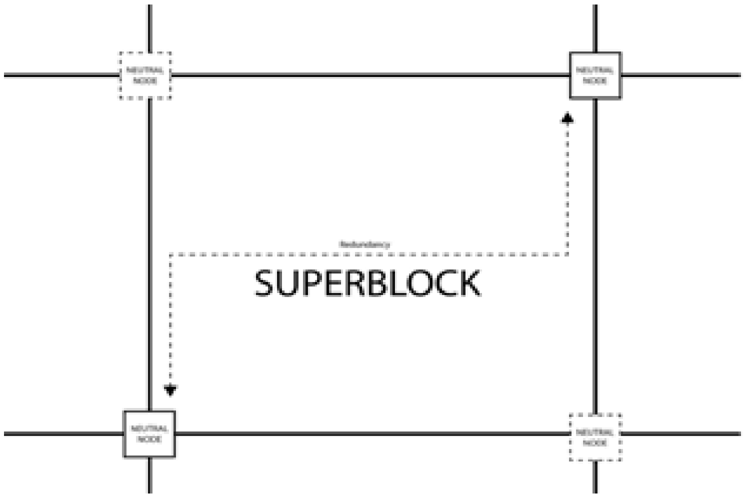


Figure C.14: This diagram illustrates the structure of the main network and how they connect to the 'Neutral Nodes' with the Superblock structure. The locations are conceptual, not accurate; BCNecologia

Another important element of the new technology are the **underground pipes.** The pipes to carry the wiring from the trunk and/ or the distribution networks to the microcells, have been planned in a simple model as well as the distribution cabinets. They should be placed next to the sidewalk boundary at the inner crossroads of the Superblock. This is due to the easier maintenance and shorter channel distance connecting to the micro-cell. For a superblock in an orthogonal structure the number of microcells per cabinet could be less than ten. The channelling will follow the local and European regulations regarding the pipelines, distances to the ground, relationship with other types of pipelines, signalling, connection chambers and interconnection. A possible scheme for a deployment of pipelines could be as follow:

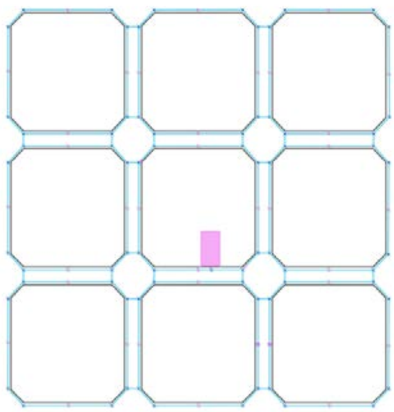


Figure C.15: 5G Communication pipelines in blue. In pink a technical room.In the interior crossings the possible locations of the cabinets; BCNecologia

15.5.2 Application

For the "typical" Superblock there have been developed three different approaches to apply the small cells in a typical grid structure of Barcelona's Eixample. The placement of the small cells in different schemes shows that a logical distribution of cells can reduce the number of cells needed significantly. In the third case the data demand has been taken into account as another parameter for the deployment.

The coverage area of a microcell in the Barcelona case

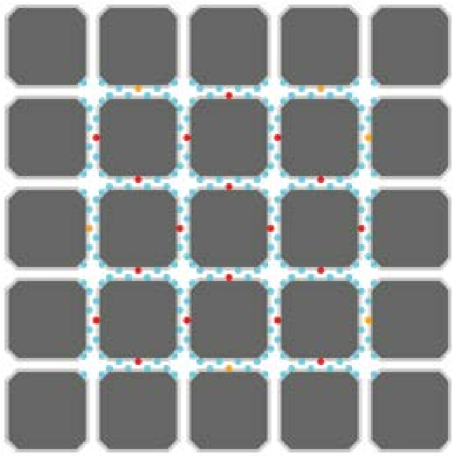
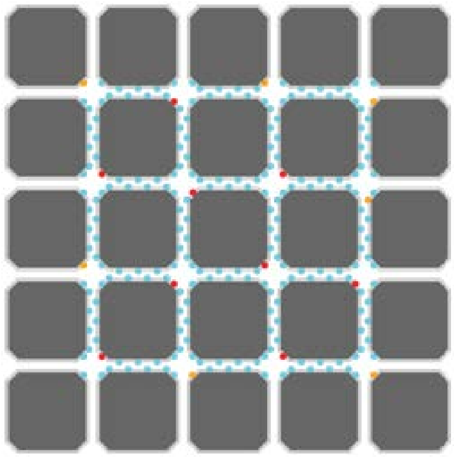
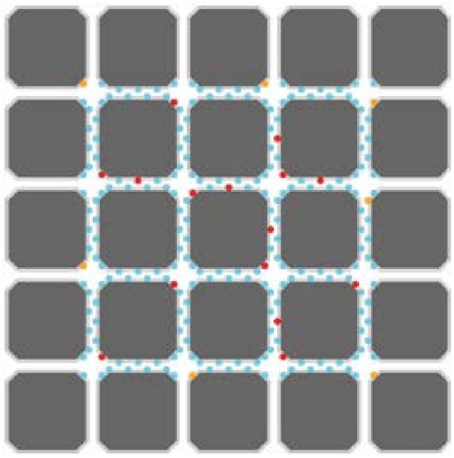
	**1** In application case 1 of the Superblock-layout the microcells is shown a superblock (3x3 blocks): In red devices owned to the superblock, in orange, those belonging to adjacent superblock. In blue, lamppost. Radius 70 meters. The distribution using places in the middle of the street sections for covering: **18 small cells**. (The number is superior to a distribution in the crosses)
	**2** Distribution in crosses uses half of the devices as the previous distribution: **9 small cells**. Differences between 1 and 2 distribution: 2 uses less number of cells, but achieves double capacity.
	**3** A mixed distribution: Using a combination of distribution 1 and 2 in some streets with high demand lead to a total amount of **14 small cells** per superblock.

Figure C.s 23-25: Typical Superblock; BCNecologia

15.5.3 ICT Infrastructure

For the deployment of the new technology in the public space as new public service, a previous definition of its necessary elements, their technical and physical characteristics, the standards to which they must adhere and given interaction with other elements that have to be respected. The overview given in this chapter creates the basis for further consideration of installation in different urban contexts

The 5G technology bases most important today on the small cells as transmitters, but needs also pipes and a wiring network that provide cells with energy and fiber wire and create an underground connection to the local power net, the telephone network via and also connect the cabinets to the transmitters. Technical rooms and cabinets in the streets are two new elements to consider as part of the telephone network.

As the 5G network use contemplates the use of higher frequencies for its installation, which means a bigger density of additional technical elements of urban infrastructure, these elements must uphold the contemplated normative in the public space. They should consider the regulation of urban use and regulation of environmental impact for the whole network applies:

- Every element tries to use existing infrastructure and tries to be least optical invasive
- It is necessary to understand the space needs of the infrastructure with all the mobile parts, such as doors and accesses, open and deployed, calculating the additional space necessary for maintenance and replacement tasks and any other ordinary or extraordinary task possible.
- It is necessary to adapt the infrastructures within the immediate urban space, avoiding obstructing other uses and basic infrastructures, for example the visualization of traffic signs, reduction of the effects of night light, hinder the passage of pedestrians or vehicles, etc. In this sense, it is recommended to avoid the deployment of a new network of specific posts for small cells, which would have a difficult development in a densely occupied urban space, with elements such as street lamps, benches, wastebaskets, mailboxes, fountains, traffic lights, bus stop, trash bins, trees, green, kiosks, parking meters, and other microarchitecture elements. In any case, the possibility of carrying out specific infrastructures cannot be excluded in cases in when there is no possibility of using a standardized option of existing street furniture.
- The necessary infrastructures must be incorporated following the regulations established in the local infrastructure plans if they exist. In any case, safety regulations must be followed with respect to other nearby infrastructures. For example, with the pipelines of gas, electricity, water, sewers, etc.
- The existence or possibility of common infrastructure managers should be considered in order to organize the deployment in a rational manner considering the rest of the existing infrastructure. Related to that, it is recommended to concentrate the deployment of the small cell network using a single existing infrastructure typology, thus facilitating operation and maintenance. In this context, the city's public lighting network seems to be the most suitable for this purpose, due to:

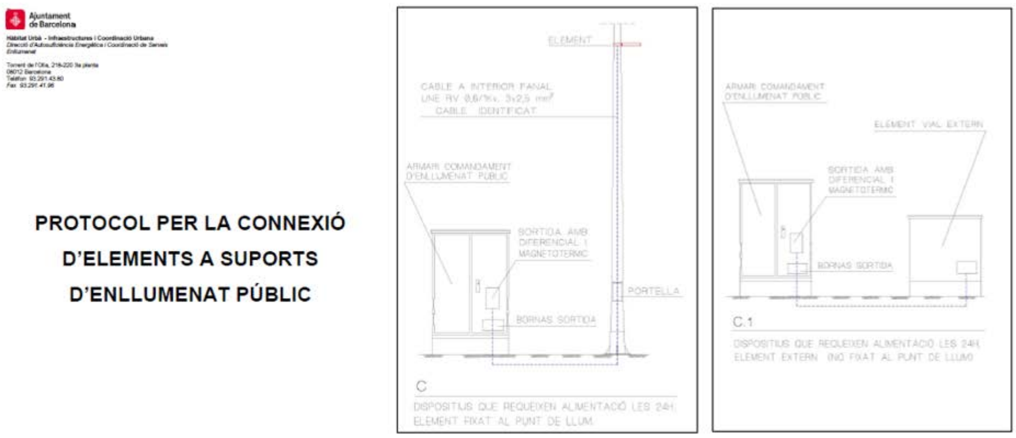
  - High number of lampposts distributed throughout all the streets and neighbourhoods of the city

  - Possibility of installing small cells at different heights (depending on the type and characteristics of lamppost)

  - Easily manage for the installation of optical fiber and electricity conduits (inside the posts)

  - Possibility of synergies in the maintenance of public lighting and small cell network.

- A protocol must be complied in order to clearly specify the way in which small cell elements must be installed in the lampposts, specifying the anchoring systems and also the conditions in which the connection to the electrical lighting grid is made. In the future, this protocol should be integrated into municipal regulations such as ordinances, urban landscape regulation, etc.



- In any case, the new elements deployed in the new 5G network must consider the aesthetic urban requirements, that are particularly important in the city of Barcelona, in which aesthetics is an essential factor in the conception of the city urban landscape. It is important to use camouflage elements that allow small cells to be better integrated into lamp posts. It should also be taken into account that some street lamps post will not be usable due to their ornamental character.

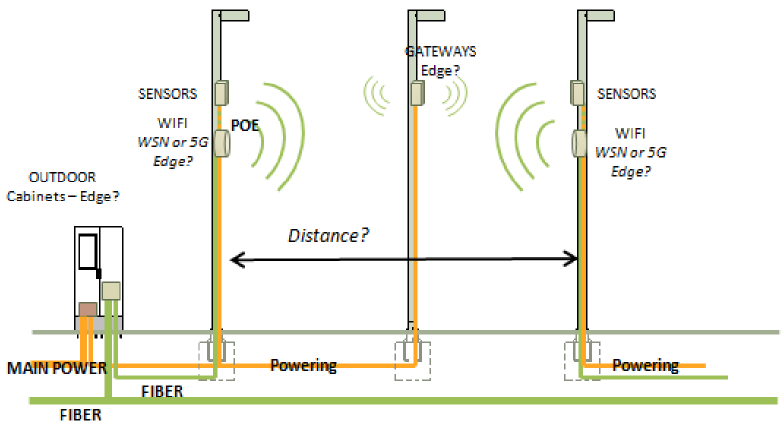


Figure C.59: Scheme of the street infrastructure for the deployment of the smallcells, using existing street lamp posts

- The correct operations for maintenance of small cells must be taken into account. In this sense, access to small cell with wheeled articulated lifts must be ensured. A maintenance plan will be developed according to the specifications of each of the device manufacturers. This maintenance plan must be agreed and coordinated with the lighting maintenance plan in order to create the less disruptions in the urban space.

15.5.4 Deployment of data transmitters and technical infrastructure

As the second part of typology the urban public areas, it is important to identify and analyse the urban areas and fabrics. This report is advised to build three exemplary types of urban typologies that could be analysed and the cases multiplied. In the first step, this chapter collects the factors for building the patterns for the 5G deployment. In a later chapter there will be a description of the 5G deployment in case studies of Barcelona.

The distribution of the data through an implementation of the 5G network in public spaces and the necessary infrastructure for it need to be given careful consideration and take into account the following factors:

- **surface and shape of public spaces**

- wide street
- narrow street
- crossing
- square
- park

- **physical density (urban morphology and open spaces)**
  The factor for characterizing the streets and public spaces should be the ratio between free and built space. Measured in ha or m2.

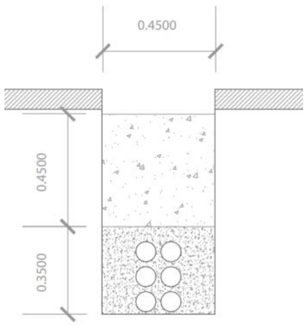
  - type and degree of building and land use
    - site occupancy index
    - floor-space index
    - cubic index
    - space index

- **urban furniture**
  - lamps (typology and number to surface lamps per ha and minimum and maximum distance of them)
  - traffic lights (number to surface)
  - seats (number to surface)
  - shade providers like textiles or wooden structures
  - kids playground
- **street trees and green**
  - green building facade (number)
  - level of street trees (number in volume, height)
  - street green (bushes, etc)
- **urban infrastructure**
  - Cabinets (number in volume and distance)
  - Bus stop, tram station, subway station (number in volume and used space)
  - Trash bins
  - Canalizations
  - High Voltage Places

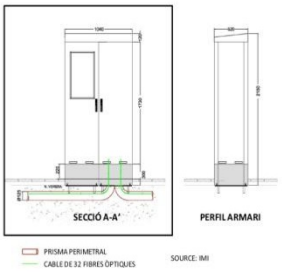
THE CAMOUFLAGING SMALL CELLS		
General Features		The camouflaging small cells is a modular solution to integrate in the urban landscape, devices such as small cells, Wi-Fi nodes or sensors, installed on lampposts or other places of the public space.

Reference/ Example drawing		 
Size		Metal structure with polycarbonate cylinder. Approx 1000x410x365mm
Place of deployment (depth, height)		Lampposts
Way of deployment		To lampposts or traffic lights, best in a central position for effective coverage. It depends on each device installed. Fixed by 10 screws to lamppost.
Interconnectivity and relation with urban furniture		Depending on the different types of devices installed. The design mimics these devices in streets.
Impact (environmental, in cityscape)		The visual impact is very slight and it’s transparent in terms of radiofrequency. It could include corporate logos in the polycarbonate cylinder. Heat emission: The high frequency with health impact should also take into account sensible spaces
Recommendations		Depending on the power supply, the camouflaging Small Cells may include overload and short circuit protections. Also, It may include modular secure power supply throw lithium batteries and charger module as well.

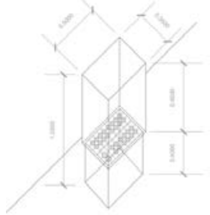
THE PIPES		
General Features		It needs to be distinguished, at least in the electric networks between, electric supply wiring (communication network): from the general network until the distribution cabinets and the distribution wiring: from the cabinets to the transmitters

Reference/ Example drawing		
Size		mind. ∅ 110 mm (recommended depending local regulation)
Place of deployment (depth, height)		0,40 m below street level (recommended depending local regulation)
Way of deployment		In the subsoil, together with pipes of energy, gas, etc wiring to small cells via the inside of light posts
Interconnectivity and relation with urban furniture		For communications it's necessary to check the local infrastructure plans to addap the deployment to them. It's possible to use service galleries that cross beneath the conduits. In intersections use chambers as well as in the connections with other elements of the network. It's recommended for each block and superblock a double connection for security telecommunication issues. For power supply it's possible to use the pipelines from other networks like traffic lights or lighting (in Barcelona the power networks for traffic lights and lighting are separated but it's possible that in other cities not) Electric canalizing must be consider distances with other conduits. (Recommended to follow local regulations)
Impact (environmental, in cityscape)		As the implementation requires considerable construction work and interventions in the urban structure the wiring should take further development into consideration and in some areas provide extra wiring for additional cells
Recommendations		It is to consider that during the day with the highest demand, street lighting do not need power. For the communication wiring, the positions and network of the communication channels in the urban network must be taken into account.

THE CABINETS

General Features		A technical element that has to be connected to the closest microcells. One cabinet can process approximately eight small cells regarding the data volume
Reference/ Example drawing		
Size		Approx. 1,73m* 1,04m* 0,52m
Place of deployment (depth, height)		On ground level with underground wiring for power supply
Way of deployment		The cabinet should be placed in the position that is most accessible along the sidewalk boundary or at the interior crossings, and if possible, near the lamp where the microcell of this crossover will be placed. This allows a shorter distance of fiber channeling. Consider attention with conditions of humidity, temperature. Special care with soils below freatic layers.
Interconnectivity and relation with urban furniture		The deployment has to take in consideration trees, green spaces, garage entrances, existing headlights, doors with loading and unloading areas, waste containers and other elements of a semi-mobile nature that may lead to distortion or obstacle in the distribution of the cabinets
Impact (environmental, in cityscape)		For maintenance and other services is recommended to provide easy access and ensure short channel distance in connection to the microcell.
Recommendations		In the case of electric supply, a prediction of the demand should be made. The cabinets can share electric and communication facilities or they can be exclusive for each of them.

THE TECHNICAL ROOMS		
General Features		The technical room or neutral node is a large structure that must be used to accommodate the hardware infrastructure necessary for the management of fiber optic signals and to accommodate other needs. This space will be used to manage all traffic, servers and other elements of networks in the distribution area, including the local storage capacity

Reference/ Example drawing		
Size		Approx. 15m²
Place of deployment (depth, height)		Ground floor or in the cellar
Way of deployment		Best installed inside public buildings and not in public space. Consider attention with conditions of humidity, temperature. Special care with soils below ground water table layers.
Interconnectivity and relation with urban furniture		Make the connections between the communication trunk networks and distribution networks at the urban cell level.
Recommendations		The number of technical rooms for managing all traffic in a neighbourhood/ blocks is depending on the data traffic demand.

15.5.5 Data Sensitive Places (less radiation areas)

The development of the 5G in the urban infrastructure will result in an increase in exposure to wireless radiotin for everyone living in the city. The electromagnetic radiation produced by mobile phones and phone masts present higher levels with health effects on humans, due to the increasing human body temperature. The current safety guidelines are based on the hypothesis that heating in the only harmful effect for humans and so says the Spanish normative (RD 1066/2001 of 25 September indicate in his Article 8, point 7.d) that: *"In particular, the location, characteristics and operating conditions of radio stations should minimize, to the greatest extent possible, the emission levels over sensitive spaces, such as schools, health centers, hospitals or public parks."*

For this project it means that first of all the sensitive spaces have to be identified and indicated. In the next step while thinking of a possible deployment method these spaces have to be considered with no or low radiation. Therefore, the transmitters should not be placed next to the data sensitive places. In the case of public parks, which are places of high demand, because people spend a long time there, and at the same time are considered sensitive places, a middle way has to be found.

15.6ICT Superblock deployment

15.6.1 Methodology

The methodology to implement a 5G Network which covers the urban fabric of the supposed model type superblocks, should follow some rules to replicate the methodology in similar urban fabrics. As every deployment area has its own characteristics, a comprehensive site analysis has to be done with a further appropriation of the method to this particular case. Like in the introduction of this report mentioned, the small cells can't transmit data through walls and have a limited radius, for this reason the urban fabric shapes the way of implementation and deployment of the 5G Transmitters. For a full coverage of 5G Network, the most reasonable points for the implementation have to be chosen.

Installing an undetermined (but not low amount) cells which are necessary to cover the need for a full coverage of each urban section without a further analysis could lead to a higher number of cells, to a heavier load of radiation and not efficient use of the small cells as well as other related resources. In this case, the urban morphology and the density of the network implies the necessary number of small cells.

For an efficient use and a conceptual installation and deployment of the small cells which follow a replicable methodology for the urban fabrics is to analyse the network and prioritize according to optimizing the expending resources each and weight the points of a possible deployment, according to demand and or ability of coverage. In this second case, it could be able to choose between different criteria and transform the methodology according to the urban patterns.

The best base for an analysis is the data of the flow of people and communications demands as well as a study of the peaks, the influx of people also uses of communications throughout the framework of the considered area. To reach this, especially at the local level and in detail by sections, is certainly not easy to obtain. In this study the focus is on certain criteria to analyse the city structures and possible data demand and a methodology is developed in 3 Steps.

A Context analysis: points of interest, sensible points

B Urban typology: urban morphology, connectivity, critical mass

C Customization: logical distribution based on context analysis

15.6.1.1 A Context analysis

The context analysis takes into account the "soft" factors of the city. The people living in the neighbourhood, the business and public activities that take place there and attracting points, spaces and infrastructure are shaping the form how digital devices are used in the city. In this context analysis the data and places which has to be part of the method are summarized and described how to collect them.

15.6.1.1.1 Points of Interest

- **Buildings or infrastructures with large influx**

Open access areas like historic buildings, basilicas, cathedrals, zoo, main railway stations or metro stations and renowned museums

These buildings or infrastructures attract a lot of people and influence of digital devices. Therefore, it is necessary to analyse the main accesses and the waiting zones of these areas. The possible functions of the area, for example waiting, working, tourism has an influence on the data usage of people.

For the purpose of covering these areas, the positioning limitations of the cells must be considered (they cannot be hung in historic buildings for example), and the points around the open spaces that will be connected between them. Therefore, a square or an open space will be considered as areas with more mesh hatching nodes for connection possibilities.

15.6.1.1.2 Special Points

- **Parks and squares:**

Parks and squares can be identified as special points. Both can be treated similar in the mesh network because they show the same characteristics. But it is considered that a (wooden) park, can create obstruction of the signals. In both cases, the small cells must have the capacity to cover the whole area.

In a square or open space, direct connectivity with the rest of the square should be given even if the other points do not follow the usual orthogonal network and have to be arranged in a way to cover the opposite site.

In a park with many trees the distances between the microcells have to be smaller because the trees will work as a barrier of coverage. If for example the width of a park is considered 100 meters, the coverage from one end to the other could be considered the middle of it and it would be necessary to cover it by the other extreme with an additional cell

15.6.1.1.3 Sensible Points:

- **Playgrounds, facilities for children and elderly and medical institutions**

Parks or Squares may have playgrounds and other facilities for children, which mean they have to be considered as data sensitive or semi-sensitive area. Therefore, if the park should be covered, you should consider doing so by moving the cells away from these areas as far as possible by still guaranteeing 5G-coverage in this area.

Facilities for children education, like kindergartens or schools should be considered as data sensitive places. Also, facilities for elderly persons and medical institutions like hospitals should be considered as data sensitive areas.

15.6.1.1.4 Population Density

The number of people living in the buildings belonging to the street section is a factor which has to be taken into account.

Number of Population in street section / Length of the Street = Density of Population

15.6.1.1.5 Activities Density:

The number of business or public activities in the buildings belonging to a street should be counted, in a first step which happened here, unspecific to their sector. To avoid that longer street sections have a higher priority the density of the activities have to be calculated.

Number of Activities in street section / Length of the Street = Density of Activities

15.6.1.2 B Urban typology analysis: urban morphology, connectivity, critical mass

As an additional step of the analysis the urban typology of a city has to be classified and analysed. In this case, two typical urban patterns of Barcelona have been analysed. One is related to a regular grid structure (Eixample) and on the other represents an historical urban structure (Gracia).

This urban morphology refers in this study to the relationship between built space and open space but does not take into account the vertical variable. Focusing on the urban morphology means here an analysis of the width of the streets, the length of street sections, dimensions of public spaces, the type of street corners and nodes.

The urban morphology was analysed by creating figure ground plans of the city and conspicuous features were highlighted. As every site study was chosen because of their special characteristics in this analysis is where the differences were seen very clear. With the analysis of the street width and structure and review with Google Maps Satellite and Google Maps Street View streets with a high and low traffic volume, as well as streets for pedestrians were differentiated.

As another factor that characterizes the urban typology connectivity was chosen as an important parameter. Therefore, there was used the basic map and data created in GIS and an additional program called depthMapX to run a Space Synthax Analysis

Therefore, a simple street network of the site study was used and the program depthMapX run a Network Analysis

nodes and also the visibility

three parameters, streets, number of changes (visibility), number of nodes

number of connections for a cross

Connectivity (degree) measures the number of immediate neighbours that are directly connected to a space.

Connectivity is a local property: it tells you how many elements (e.g. convex spaces) are directly connected with one certain element.

Explain what and how the analyse is working

what is connectivity, how to characterize the urban morphology

15.6.1.3 C Customization: logical distribution based on context analysis

Once the urban morphology had been analysed, the methodology proceeds to review the smart cells coverage in terms of distribution according to minimal distance and provision according to a potential demand.

15.6.1.3.1 Coverage by distribution

The coverage basic parameters are maintaining a maximum distance between the smart cells value between 70 and 120 meters. The distribution of cells must be checked and see if there are possible location points to add or adjust from the previous step. A minimum desirable distance between devices will also be determined (which will be determined among other conditions by the height at which small cells are installed in each lamppost), in order to achieve a flat coverage with minimum variations of SNR. Also, it is necessary to follow to different methods for this reallocation according to homogenous and irregular urban fabrics. The irregular morphologies it is recommended to follow heuristic methods of allocation, and intermediate methods for some exceptional cases (see Av. Diagonal Case). The final result will give the exact number of smart cells required.

15.6.1.3.2 Coverage by provision

The coverage by provision refers beyond the morphology aspects of each case of application, it is necessary to consider the total number of smart cells required according to the potential demand regarding to critical mass (population + economic activities). The coverage by distribution may be sufficient in most of the cases, meanwhile the coverage by provision could be insufficient according to the potential number of users. In these last cases, it is necessary to identify the limiting factors to achieve this potential coverage.

As an example, the following figure shows the number of persons who can potentially use, at the same time, a street segment of the Eixample area. Different scenarios of public space occupation are presented both for pedestrians and for vehicle users. It will be necessary to find a balance between the scope of the deployment of the new infrastructure and the maximum capacity offered to the user.

Total area: 2670 m2
Pedestrians area: 1150 m2
Area for vehicles: 1520 m2

Pedestrians area				Vehicles area					
Area	persons/ m2	Total persons		Area	vehicles	pers/vehic	Total persons		Total persons
1150	0,1	115		1520	20	2	40		155
1150	0,2	230		1520	30	2	60		290
1150	0,5	575		1520	60	2	120		695
2670	3	8010		1520	72	2	144		8154

The main limiting factors for coverage by provision are interference and radiation limitations. This analysis and methodology of deployment it is based on the measurements realized in the Pilot Area of Barcelona (Poblenou) with frequencies of 3,5 – 5 GHz. In the case of increasing these frequencies, the limiting factor will be more restrictive in order to avoid impact on health.

15.6.2 Superblock cases of analysis

As the 5GCity project use the public space of Barcelona as a pilot area from an urban designer perspective there was taken into account design integration and inclusiveness. As we see this project as a possible representation of the future city it is important to propose new technologies like 5G, in a non-invasive way.

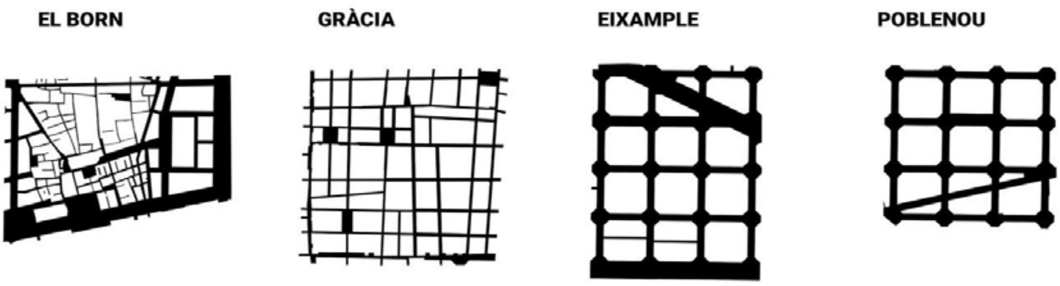


Figure C.11: BCN 5G Superblocks; BCNecologia

The implementation aims to promote the evolution, balance, and well-being in the daily life of the public space. Like explained in detail in the first report, for implementing the new technology into urban space in Barcelona, different design guides for the city itself were taken into account. The new urban furniture tries to fit and cohabit in the best way and as the 5G proposes an unlimited capacity for disruption in the public space it is especially important to take into account sensible spaces and groups of people.

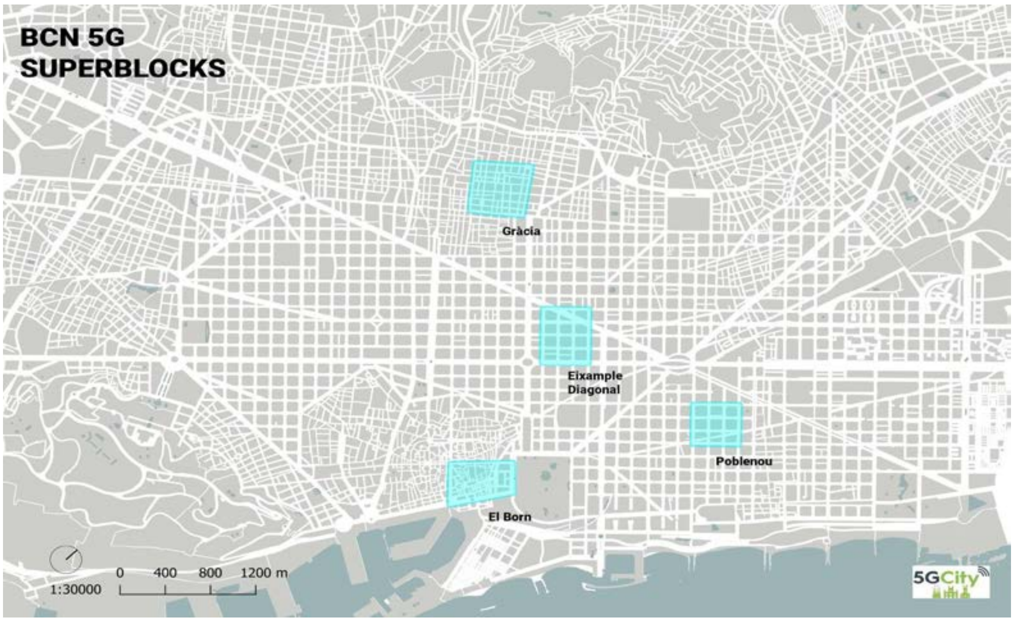


Figure C.12: BCN Superblocks - Overview; BCNecologia

15.6.2.1 GROUP OF CASES 1: URBAN FABRIC EIXAMPLE

Barcelona's Eixample is characterized by an orthogonal street layout, with streets that have a width between 20 meters and 50 meters. Another particular characteristic in the Eixample's urban fabric are the octagonal blocks, chamfered in the corners, which all have the same size around 133 meters. There are just a few streets in Eixample that are not following the orthogonal grid but split the city diagonally. Most of the streets are straight and continuous which means the coverage is relatively easy to achieve. The urban infrastructure like light posts, cabinets and trees are to be found in every street and equally distributed. Here it will be easily accessible for pipelines and interactions with other services. Apart from the physical structure the Eixample shows a highly dense population and concentration of activities, a few green areas and staying space per inhabitant.

Because of its symmetry and repetitive urban structure creating a methodology for Eixample has to follow some basic rules and has a high transferability.

15.6.2.1.1 Case 1: Poblenou

CHARACTERISTICS

The case study is located in the Superblock of Poblenou neighbourhood, has a particularity that the traffic flow is routed around and inside of the Superblocks lie streets with low traffic volume or pacified streets.

Figure C.26: The Poblenou superblock seen in the urban context; BCNecologia

The Superblock of Poblenou is a part of the Eixample' s urban fabric. Even if the pilot area of Poblenou has it's slightly different characteristics, then the "model type" superblock because it does not show a high population density, in this 5GCity pilot project this urban structure was analysed as a potential replicable area for the result and recommendation. The Superblock model is based on the fact of being a replicable urban cell. The reason is to configure the deployment of a network of microcells transmission-reception with the possibility of replicating the distribution or using it as a basis for a general model considering other intervention parameters. In addition, the infrastructure implicit in such deployment and its relationship with the urban environment must be considered. The theoretical basis for deployment must then be adapted to the specific characteristics of the deployment points

The Superblock of Poblenou has a total surface of 203.287 m2, and is the smallest of this study, it is the standard shape of the eixample model case superblock which was part of the study, there also took place the case study with the real implementation of 5G. The public space in the superblock has 80.590 m2, The Superblock is crossed by a street, not belonging to the grid which is with the 20m wide streets and the middle part corner squares quite representative for the overall Eixample city structure. The Building structure is not very dense in the comparison of overall barcelona. For these reasons the space index, also the comparison between public space and total surface is 0,40.

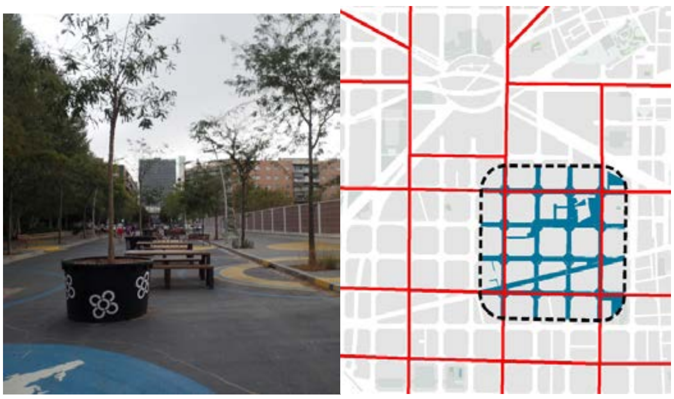


Figure C.27: The generous public space in the Superblock in Poblenou; BCNecologia

In the Superblock case study, Poblenou can be seen as a special superblock with a large amount of public space and a regular grid structure, with one diagonal street crossing the Superblock as an exception. As in this case there is a low density of residential activity and commercial activities, because there are mainly big enterprises that have their offices there, a museum, a large university complex in the analysis concentrated us on the physical layout of the streets as a parameter for the small- cell deployment.

ANALYSIS

Points of great interest:

- The museum Fundacio Can Framis

List of sensitive points:

- Flor de Maig school
- Kid & Us (Kindergarten)
- Corporació Fisiogestió (Health center)
- Playgrounds

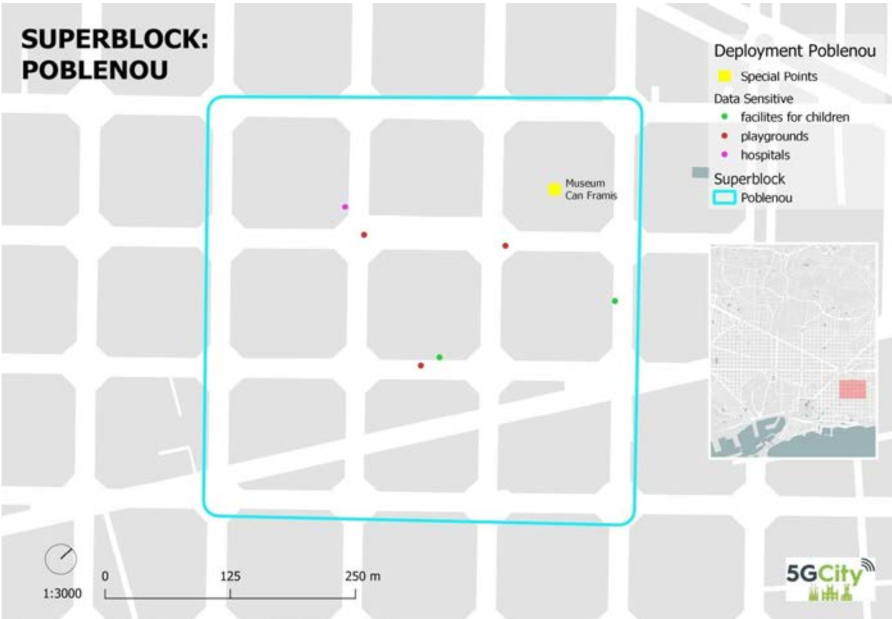


Figure C.28: Poblenou: sensitive and interesting points; BCNecologia

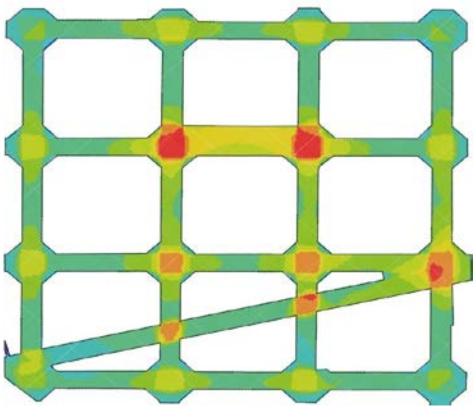


Figure C.29: The high connectivity of the inner sections of the superblock in Poblenou; BCNecologia

RESULT

It will be used for the proposal in this area the methodology for a typical superblock area introducing a solution for the exceptional diagonal crossing street and avoiding exceptional sensitive points in crosses.

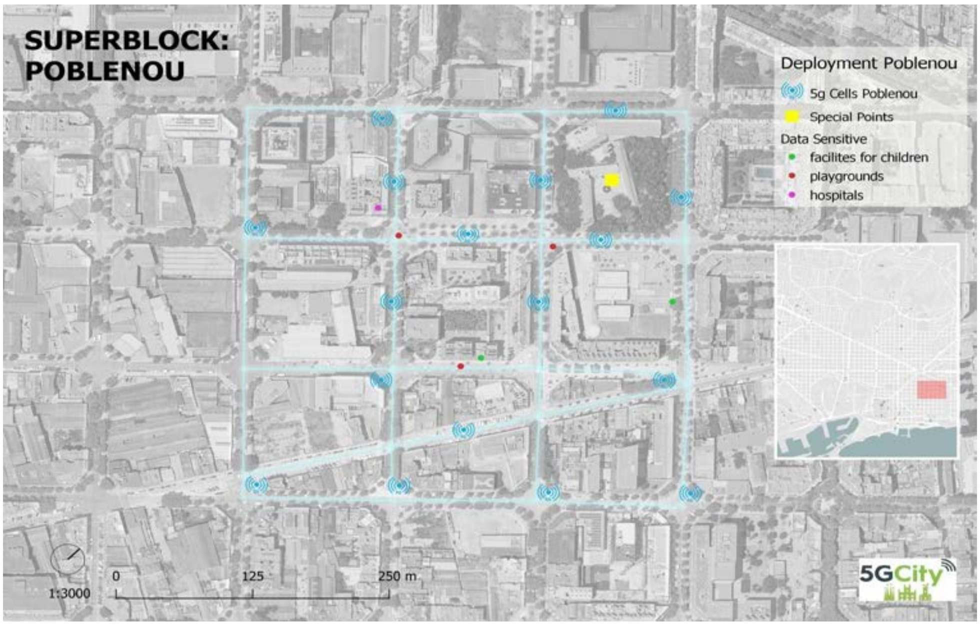


Figure C.30: Distribution solution for the Superblock in Poblenou; BCNecologia

The result is a proposal with 17 cells. No all the crosses in bounding are covered and perhaps some of the bounding cells in the proposal owned to the same superblock. In a first scheme the number of cells would be equivalent to the number of crosses adding one for a good covering of central section of diagonal street with 17 cells. Moving these cells, it's able to avoid the crosses with sensitive points. The total number of small cells for a full coverage of the area is 17 with small cells the lowest number between the others. In Average a small Cell in the Superblock Poblenou can cover a public space area of around 4740 m^2 (0,47 ha) and total surface of ca. 11.960 m^2 (1,20 ha), in comparison with the others the small cells have the highest covering rate in Poblenou.

POSSIBLE FUTURE DEPLOYMENT

For the Superblock Poblenou there have been developed three different methodologies to apply the small cells in a typical grid structure of Barcelona's Eixample. The placement of the small cells in different schemes shows that a logical distribution of cells can reduce the number of cells needed significantly. In the third case the data demand has been taken into account as another parameter for the deployment.

Figure C.31: A small cell already installed on the Poblenou superblock

The Streetlights in the Superblock Poblenou are deployed equally around the block. They are all free standing on the sidewalks like seen in Figure C.32. It delays also that on every corner there is one light post placed in the center which makes it possible to apply the distribution solution developed with the existing furniture.

Figure C.32: Layout of free standing streetlights (blue) in the Superblock Poblenou. Source:URBIS

15.6.2.1.2 Case 2: Eixample Diagonal

CHARACTERISTICS

This Superblock in the Eixample area is characterized by the representative grid structure of Barcelona. It was chosen because this area is limited by two main streets in Barcelona, above Diagonal street and at the bottom, bounding the area, Gran Via.

A special treatment deserves the large urban roads where the width and obstacles may be sufficient to perform a special treatment. In the area studied in this case, is seen the concentration of several wide roads in a small space. Diagonal Avenue (above) or Gran Vía Avenue (bottom), are fifty meters wide in these areas. Given the special diagonal geometry of the layout in some cases, the distances between opposite corners can exceed one hundred meters. In addition, there have to be taken into account the existence of trees. These are higher than the trees of the rest of the mesh.

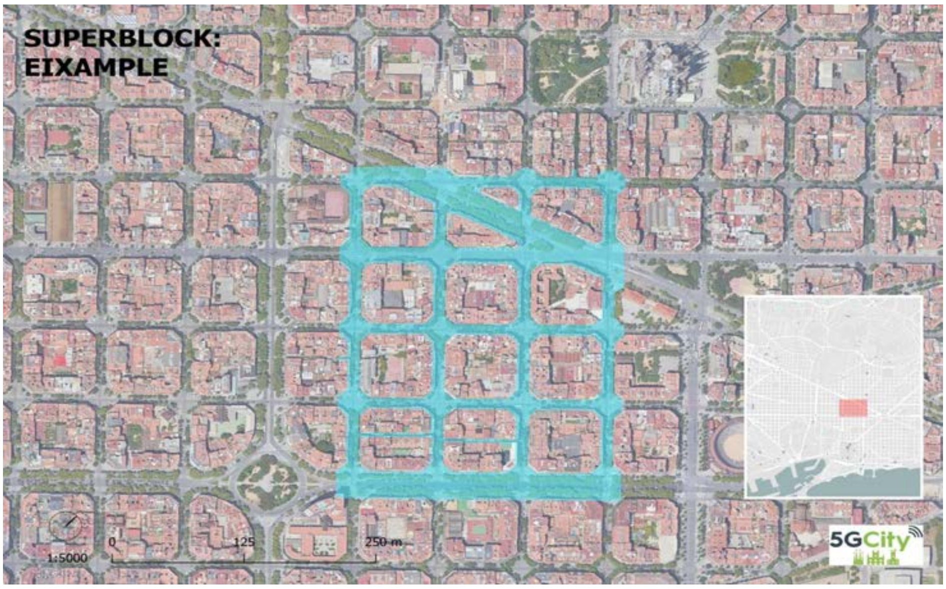


Figure C.33: a representative area in the Eixample area; BCNecologia

One of the treatment solutions in this area, although not the only one, is to consider the treatment on both sides of the wide avenues as differentiated, with an alternation between the two:

The area can be characterised by wide street space with a large width of up to 50 meters. In this area a high volume of traffic is concentrated. The width of the streets creates an open structure of the city, with a lot of space for trees in the middle lanes. On the wide Avenues there is also an increase in size for walkways and for car roads. Diagonal street and Gran Via in this area have 45 meters wide but in other areas, it is possible to increase the width until 60 meters or more. The Superblock of Eixample-Diagonal has a total surface of 272.188 m2, it is the second largest superblock which is taken in this deployment study. The public space in the superblock has 120.981 m2 and thus is the largest, The Superblock has two big roads and also the typical shape of the eixample fabric, but also a dense building structure. For these reasons the space index, also the comparison between public space and total surface is the second highest with 0,44.

In this proposal, its chosen a typical street layout within the Eixample area of Barcelona with the particularity of three main traffic streets of Barcelona: Avenida Diagonal, Gran Via and Calle Aragón. As the streets in Eixample are usually 20 meters wide the Avenida Diagonal and Gran Via measure 50 meters and point out a new challenge in implementing the 5G- cells. As the Eixample is an area of a great mix of residential living, activities and commercial purposes the layout of the 5G- cells has just been oriented with respect to the urban structure and data sensible urban infrastructure. On the wide avenues with a lot of trees the smallcells are to be placed in a shorter distance crosswise along the street to achieve a good coverage. To cover the streets, that are dividing a block, two additional points can be considered, depending on the demand expected and the resources of the project.

ANALYSIS

Special points:

There are no points of special interest

Sensible points:

- Children's hospital
- CAP health center
- Children's playground
- two residencies for elderly
- two day center for elderly

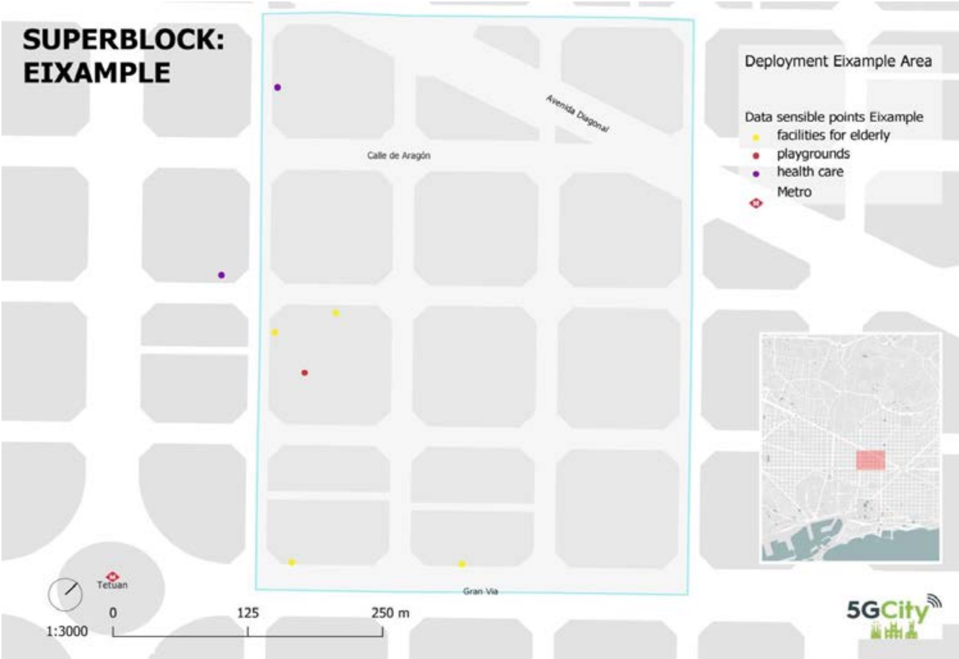


Figure C.34: Analyse Eixample Diagonal; BCNecologia

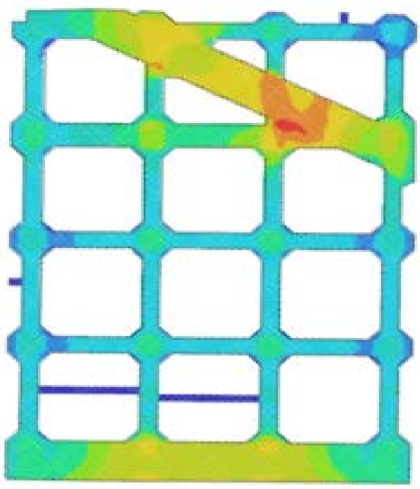


Figure C.35: Eixample-Diagonal: High concentration of wide Avenues; BCNecologia

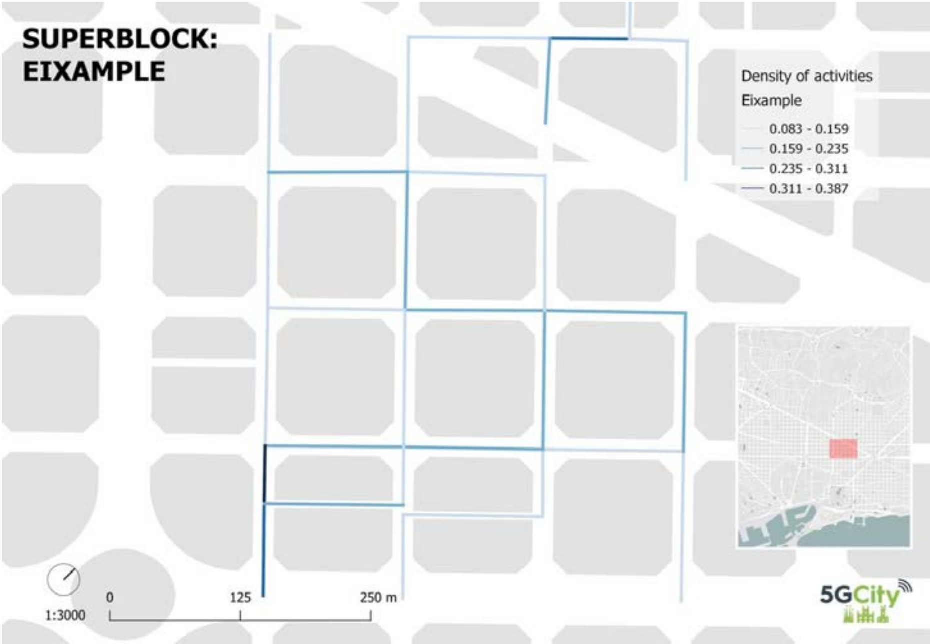


Figure C.36: The indifference of density of activities in the Eixample area; BCNecologia

RESULT

In the case of Diagonal points crossing the Avenue with the orthogonal network can be unfolded in two. In the case of Gran Vía (bottom avenue), the solution reinforces the covertures adding three points, one for each section, in transversal way avoiding sensible points. The total number of small cells for a full coverage of the area is 27 with small cells in the middle between the others. In Average a Small Cell in the district of Eixample Diagonal can cover a public space area of around 4481 m2 (0,45 ha) and total surface of ca. 10.081 m2 (1,01 ha).

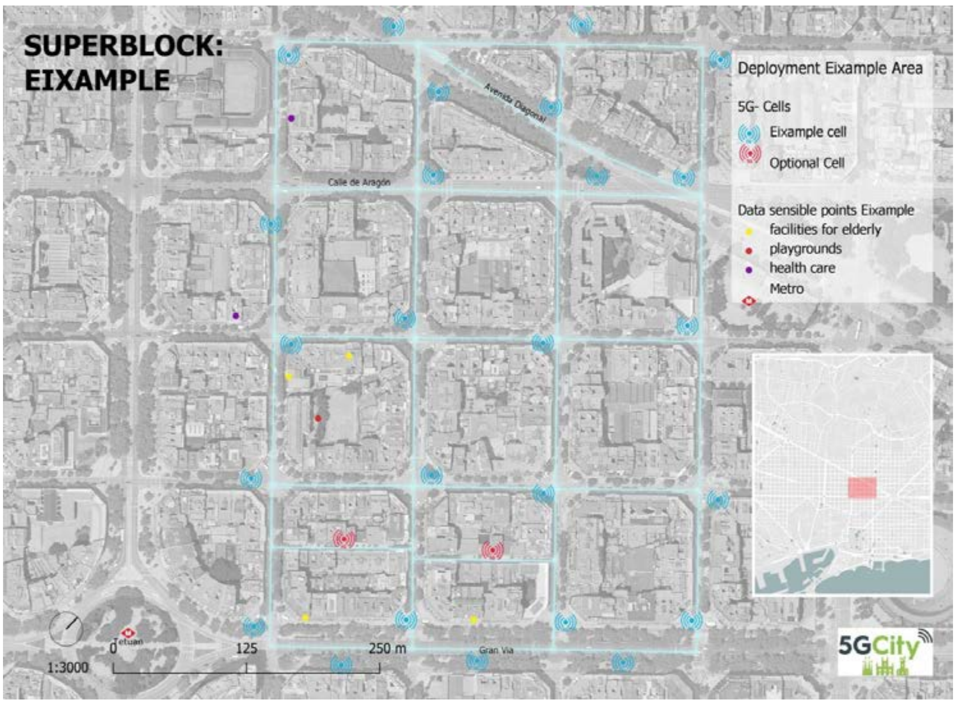


Figure C.37: Distribution solution for Eixample area; BCNecologia

A calculation with this type of large avenues would indicate adding one more cell to the basic scheme for each of the sections that cross our area. The existence of two alleys in the area adds to the solution two additional cells (marked in red). The final solution covertures with 27 cells with an aim end solution for both great avenues in the area.

Figure C.38: Possible positioning for small cells on a corner in the Eixample area; Google Streetview

In the dense Eixample fabric the lamp posts of the streetlights are the same like in the Superblock Poblenou deployed equally and are all free standing on the sidewalk. As to be seen in Figure C.39 there are always seventeen - eigthteen streetlights around one block and four streetlights cover the corner section, centrally positioned to illuminate the whole street.

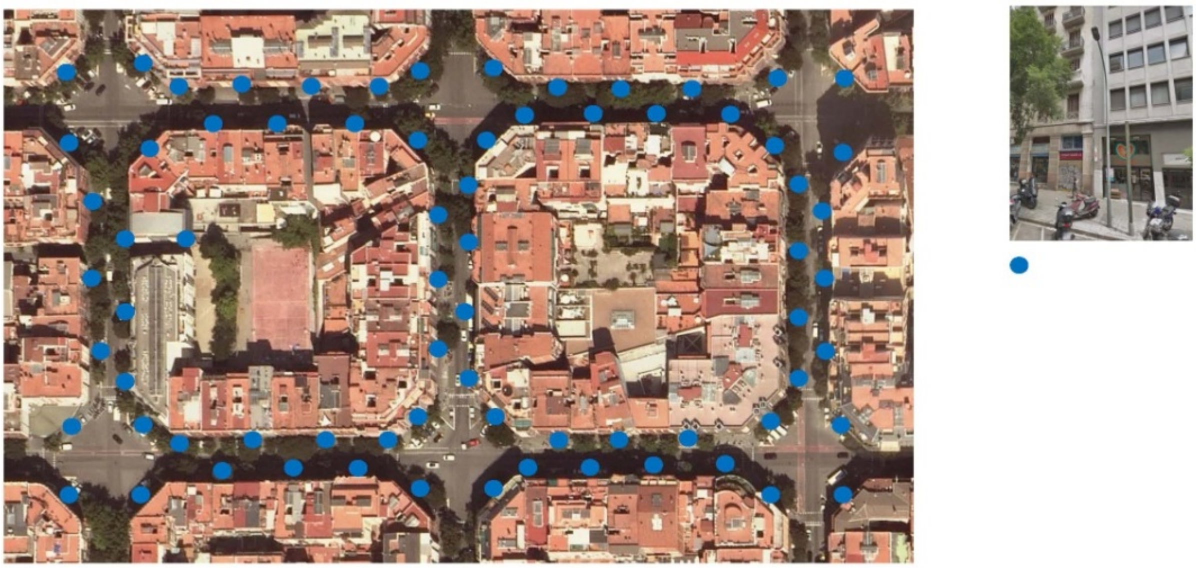


Figure C.39: Layout of free standing streetlights (blue) in the Eixample Area. Source:URBIS

15.6.2.2 Group of Cases: HISTORICAL CENTERS

In historical areas of the cities, the morphology of the urban mesh network contains its own characteristics that can be a challenge in the deployment of a modern communications network based on cells.

Two examples of the framework of Barcelona in historical areas are presented with some of its own characteristics. Both areas have been chosen because they have been part of other pacification processes within the superblock development schemes with areas restricted to indoor traffic and emphasis on pacified areas. Main characteristics of this kind or urban fabric are:

- Narrow and not straight streets: it means low coverage area and difficulties for direct signal coverage from a single point.

- Complex and dense network: sections and crossings between streets are presented in greater density. The sections are shorter and for the same area, the number of crossings and sections of streets is much greater.
- The routes between points of interest can be complex with different levels of use, not always depending on the size, width or other characteristics.
- Absence of posts for cell placement. Small spaces for the placement of cabinets.
- Interaction with unique buildings of special protection.
- Complications in interventions, difficult for pipelines and interactions with other services.
- Others: tourist concentration, leisure areas…

The main point for the coverage of an area of these characteristics should consider the increase of a number of sections, nodes, and streets with respect to a widening-type network with greater density of crossings and streets, which makes the difficulties for the coverage of a given area.

15.6.2.2.1 Historical Center: El Born

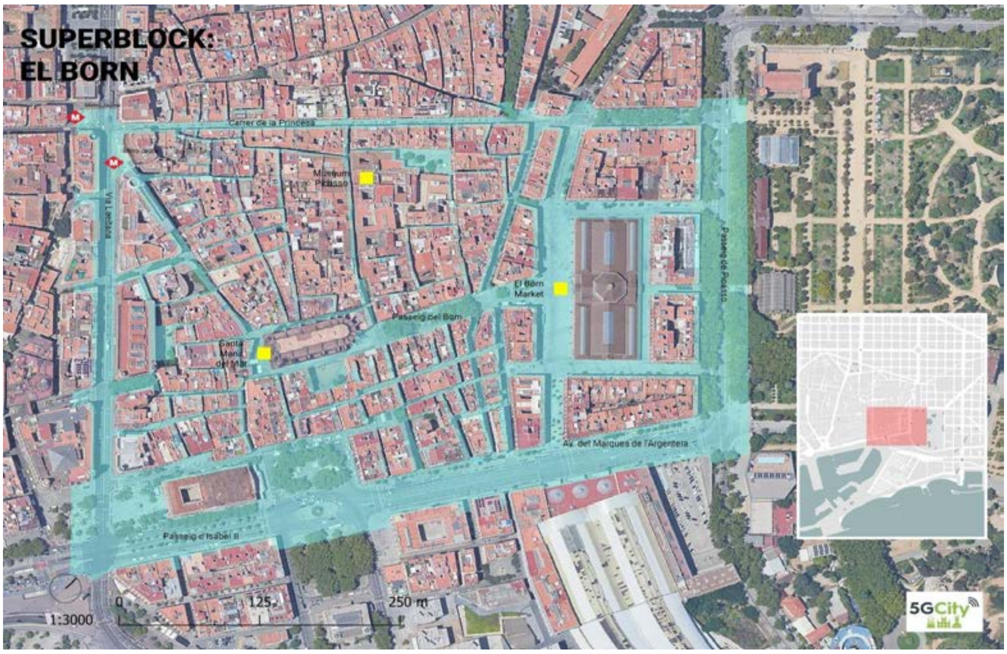


Figure C.40: El Born; BCNecolgia; Background Map:Google Maps

<u>CHARACTERISTICS</u>

Historical center: tourist, pedestrian streets, monuments, great commercial activity, narrow, pedestrian, small retail on the ground floor, residential, tourists, square, long- and short term stay in public space. The Superblock of El Born (Rivera) has a total surface of 245.812 m2, it is the third largest superblock which is taken in this deployment study. The public space in the superblock has 109.776 m2, the Superblock is surrounded by quite large streets and also has some big squares. For these reasons the space index, also the comparison between public space and total surface is the highest allo over the 4 investigated superblocks. The inner structure is very dense, with many small and winding streets.

<u>ANALYSIS</u>

Points of interest or greater influx:

- Jaume I subway exit
- Santa María del Mar (Church of very high tourist interest surrounded by recreational and commercial areas).
- Mercat del Born. (Play area with tourist facility of high interest).
- Picasso Museum (Very high tourist attraction area with narrow access).
- Other points of interest. Passeig del Born. Jacint Reventós Square, La Olla Square, Comerç Street…

Sensible points:

Schools: CEIP Àngel Baixeres (Via Laietana, bounding street), Childcare and Teeneger Team of Ciutat Vella-Gothic-Barceloneta and Casal Gent Gran Comerç

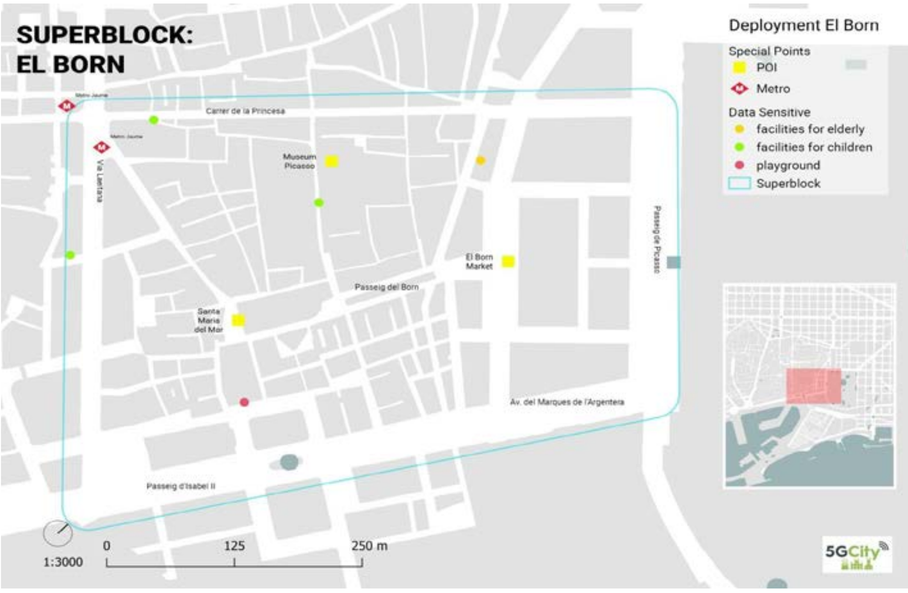


Figure C.41: El Born: special and sensitive points; BCNecologia

Connectivity and activity analysis

Figure C.42: El Born Connectivity: In this case, we see areas of great influx or better connected with the rest of the framework, but above all, we see areas with very poor connectivity; BCNecologia

a) Choose parameters: in this area, the main parameter is the activity. It's an attractive pole for tourists and locals, with commercial and gastronomic activity. Then activities like a commercial database, and connectivity like a morphologic analysis of the network, will be the main parameters to define the main network.

Figure C.43: First analysis: activities by sections; BCNecologia

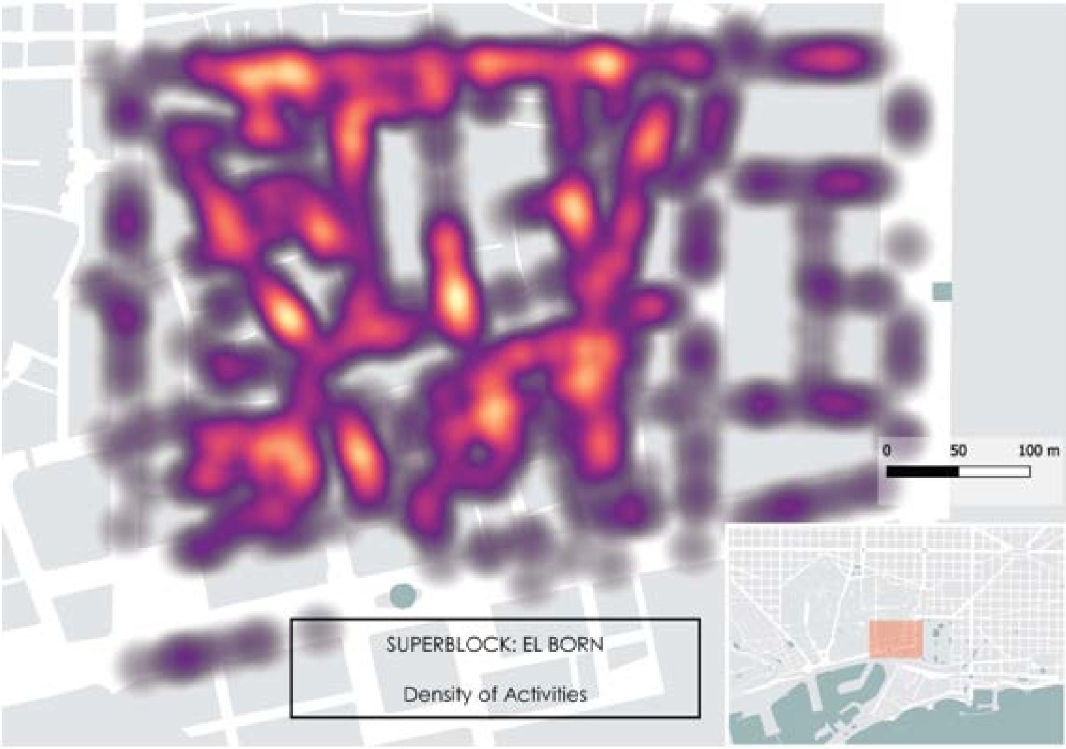


Figure C.44: Activities heat map. It can be seen in areas without activities; BCNecologia

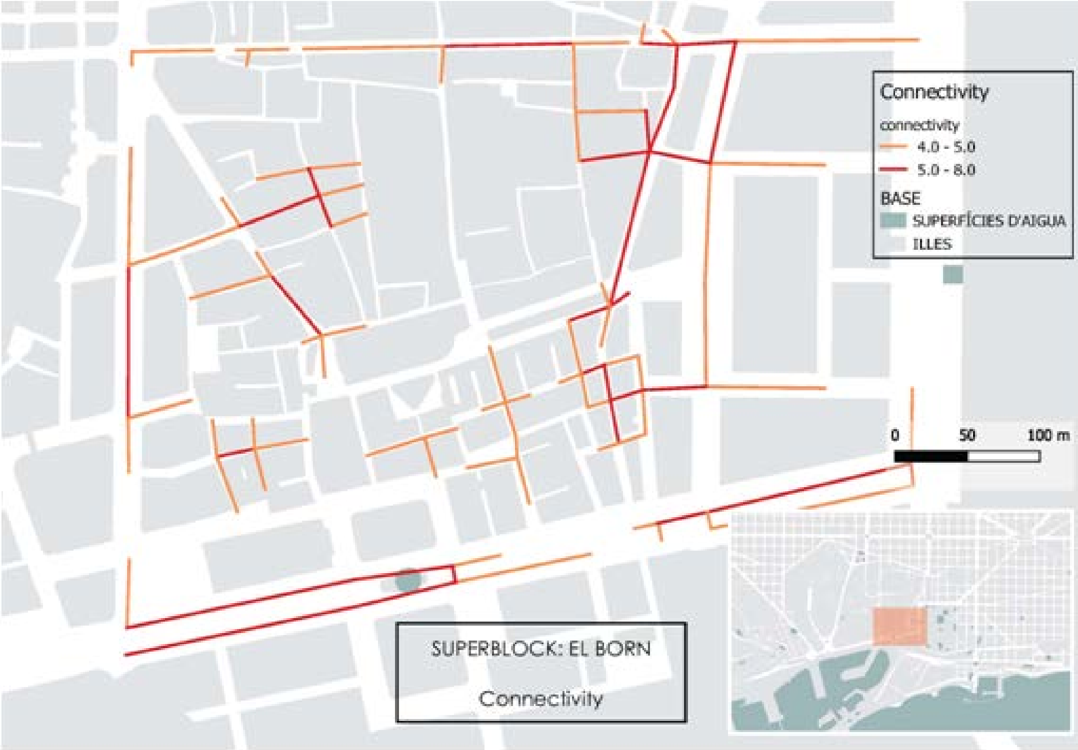


Figure C.45: Connectivity. BCNecologia

b) Simplified urban network: In this area, the complexity of the network does it necessary to study the main sections. The objective will be the coverage of these sections and the connections of the most important routes in the interior area. We can add some sections in the simplified area to have a connected network at least in the most interesting areas.

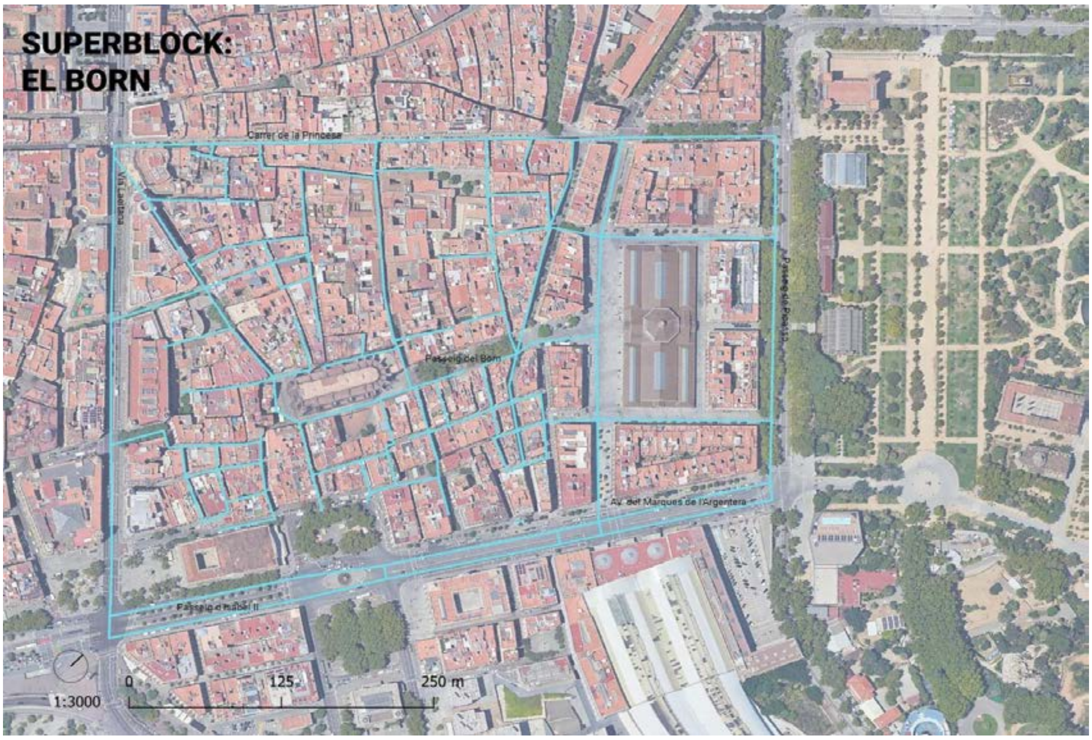


Figure C.46: Marked in blue the simplified network. BCNecologia

After this first analysis, some sections of streets will not be taken into account for the rest of the analysis, so we consider areas without interest and without coverage unless we want to use sufficient resources to cover the entire area.

For this analysis it is better to use a smaller number of nodes and sections to apply the subsequent steps and a sample of how the methodology used can work.

The result is a more simplified mesh to focus on covering the areas of greatest interest. We can complete this simplification if we have disconnected zones or zones that we can consider for other reasons.

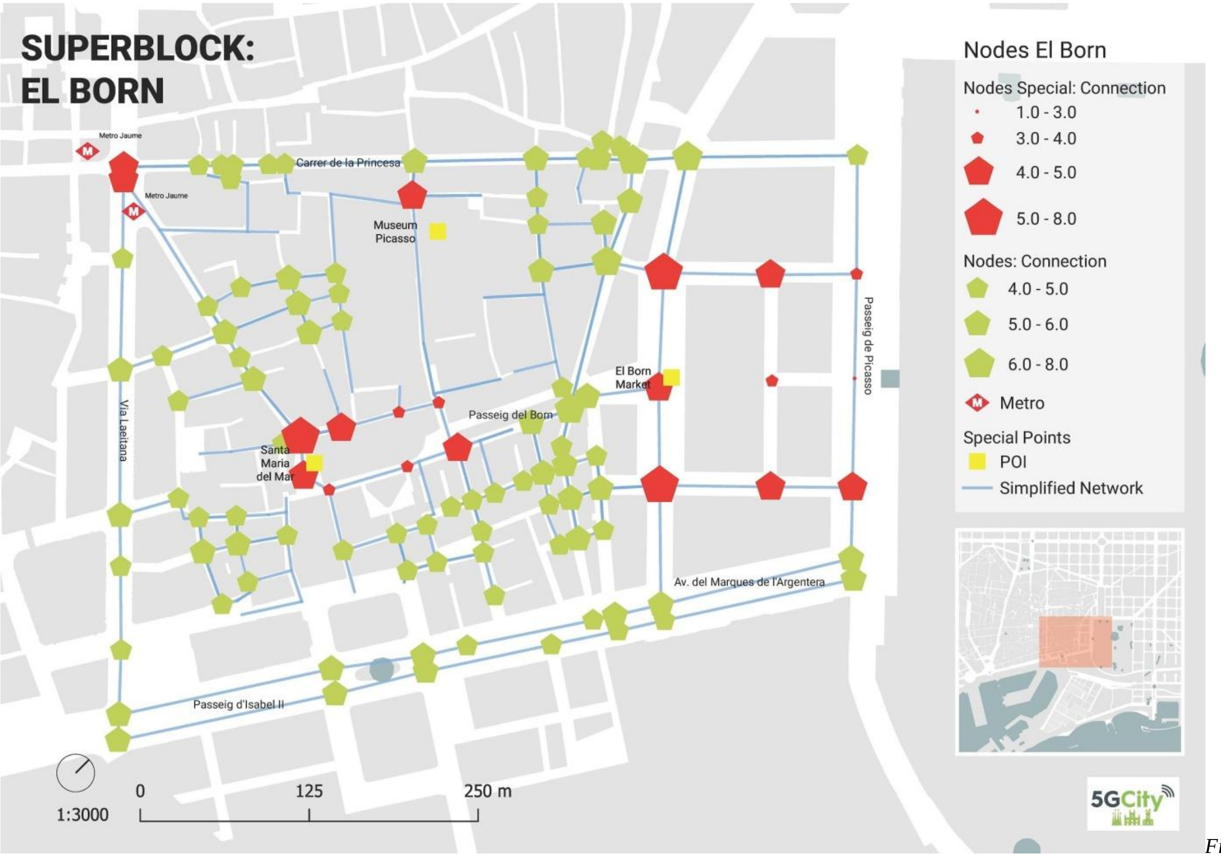


Figure C.47: A simplified scheme of nodes (crosses) by importance; BCNecologia

c) Choose the crosses how the most interesting points for location cells. There are no infrastructures like lamp posts or others to use as support. Then there are no other limitations to consider.

d) To use the algorithm to calculate an initial base. Prepare a few numbers of cells for additional supplements. (No more than 20% of the total).

e) Balance the resources (number of cells) with a reasonable covering of the area. (The number of sections, crosses, streets and their complexity are high enough to consider not total covering).

RESULTS

The first result with the application of the algorithm has not considered the sensitive points. This could have been avoided by adding a negative weight to the nodes near the sensitive points. In our case we can choose to move the cells in the beside area to achieve a similar level of coverage preventing the cells from being too close to the sensitive points. (These moved cells are marked in green in the final result).

In addition, we will add some more cells (marked in red) if once we see the result we detect any more possibility of complementing the coverage.

The final results will be:

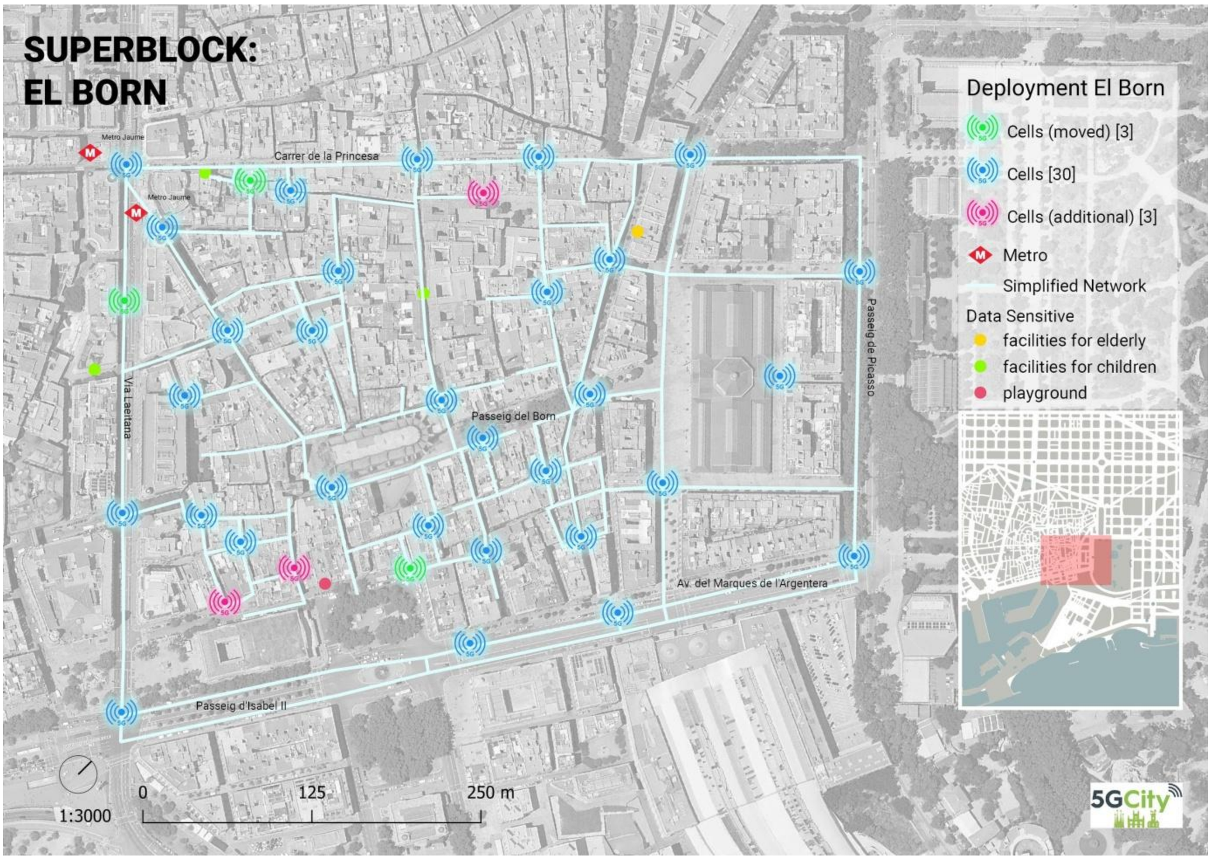


Figure C.48: Distribution solution for El Born; BCNecologia

We have moved three cells close to schools and added another four to complete coverage in streets or sections of streets. Three of them we have considered in the lowest priorities obtained by the algorithm, the last one has been considered for the movement of other.

The final result is 36 cells with which a total coverage of all the streets and alleys is not achieved but of the most important routes and points and a good part of the others. The fact that some of the streets are not straight and most are narrow, advise keeping some more cells in case the coverage radios are not as expected.

The total number of small cells for a full coverage of the area is with 36 small cells the highest between the others. In Average a Small Cell in the district of El Born (Ribera) can cover a public space area of around 3050 m2 (0,3 ha) and total surface of ca. 6830m2 (0,7ha).

NOTE: This is only a distribution analysis. We must consider the deployment of pipelines and the position of cabinets. Then it's preferable points near wide streets and open areas connected easily by main lines. The borders of the area must be considered as primary communication and supply networks.

POSSIBLE FUTURE DEPLOYMENT

Figure C.49: Possible positioning for small cells in the old street structure of the Born area; GoogleStreetview

The Born Superblock has mainly the possibility of deployment to lampposts and other facilities attached on the façade of buildings as there is almost no space for free standing lampposts. The few free-standing lampposts as seen in Figure C.50 are to be found in open spaces like the small plaza in front of the church Santa Maria del Mar and on the Passeig de Born.

Figure C.50: Layout of attached (red) and free standing streetlights (blue) close by the church Santa Maria del Mar. Source:URBIS

CHARACTERISTICS

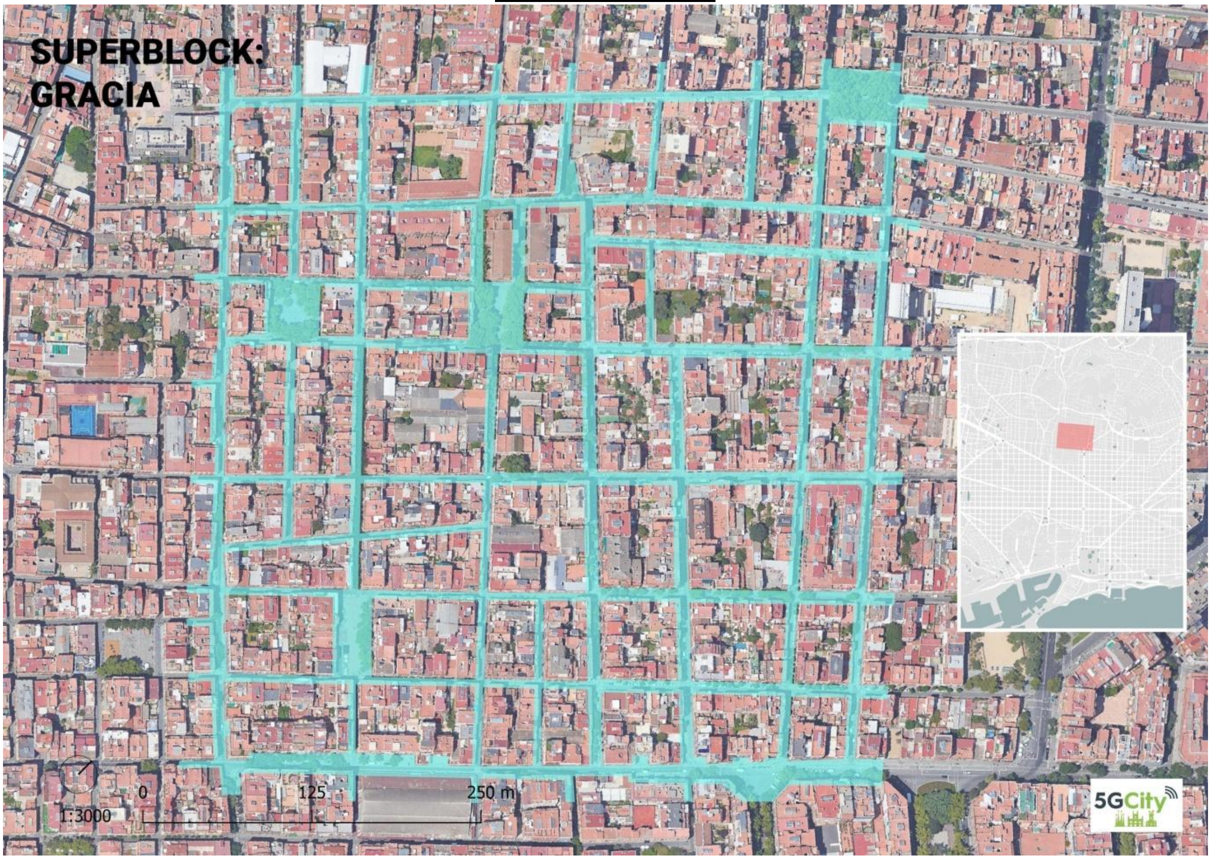


Figure C.51: Gracia Overview; BCNecologia; Background Map: Google Maps

The Gràcia neighbourhood area is characterized by deriving from a peripheral historical village of the city of Barcelona. Without the degree of tourist attraction like the area of El Born, this area is an important recreational attraction for the inhabitants of the city characterized by the existence of commercial activities, restaurants, leisure areas. The complexity is not as high as the case of El Born in terms of frames and street morphology but some characteristics are common: narrow streets, high pedestrianization, and especially non-continuous streets.

The Superblock of Gracia has a total surface of 287.970 m2, it is the largest superblock which is taken in this deployment study. The public space in the superblock has 73.699m2, the Superblock has a very dense building structure and very narrow streets, this is the superblock, in comparison, with the least public space. For these reasons the space index, also the comparison between public space and total surface is the lowest all over the 4 investigated superblocks. The inner structure is very dense, with many small streets and some squares.

ANALYSIS

Areas of interest:

- Revolució Square
- Diamant Square
- La Virreina Square

Sensible points:

- KMO School
- Virreina nursing

- Providence' Religious school
- Musical theatre school Youkali
- Children School Pam i Pipa
- Children School Trencapins
- Villa Mena nursing

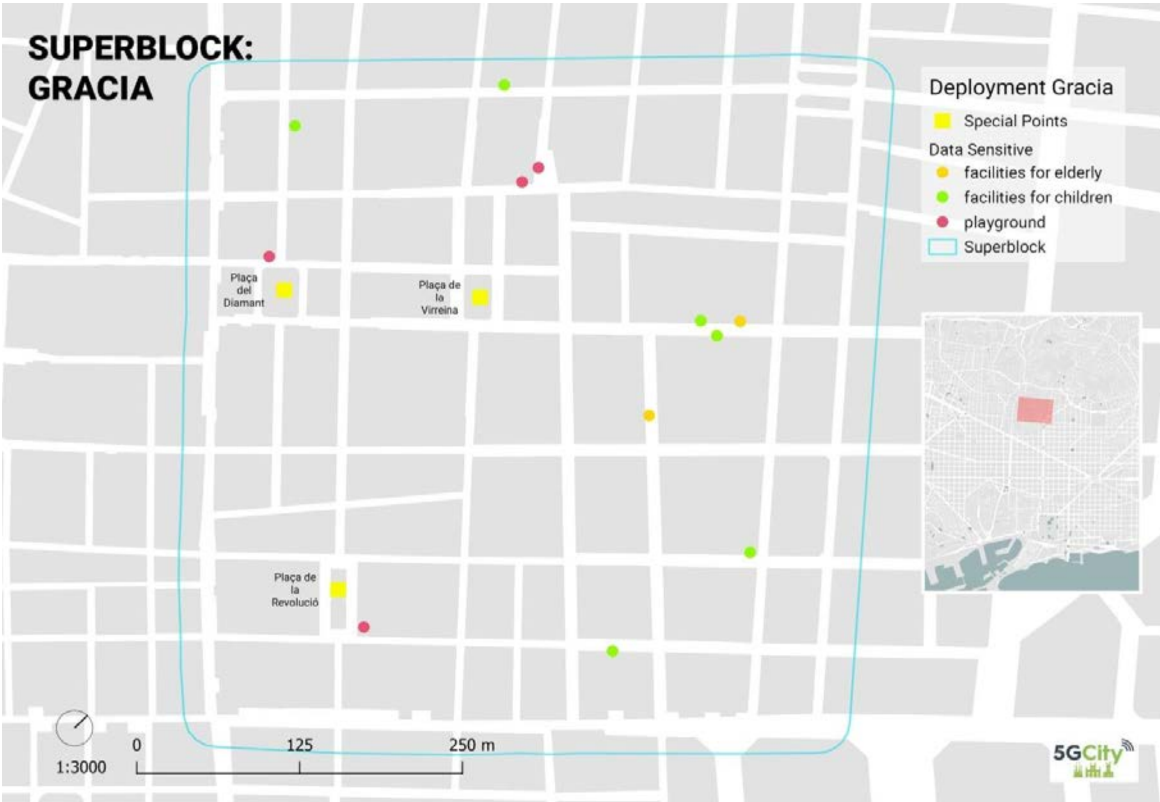


Figure C.52: Gràcia: sensitive and special points; BCNecologia

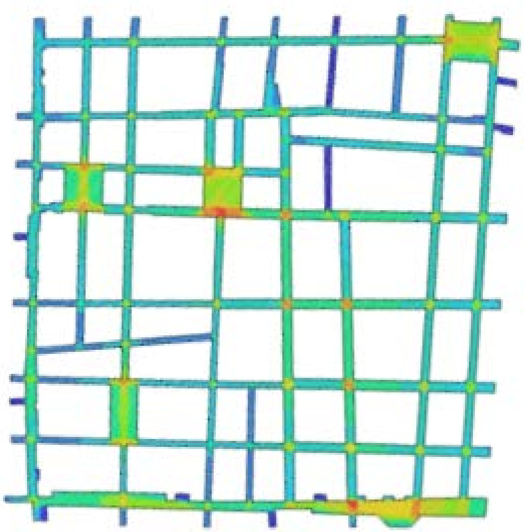


Figure C.53: Gràcia connectivity. Graduation from red to blue: Red high connectivity, blue low connectivity.

Steps for the analysis:

a) Choose parameters: In this case, we add the population like another parameter. Define weights of streets and sections like a sum of connectivity, activities and residential. The priorities of the cresses depend on the sections that join.

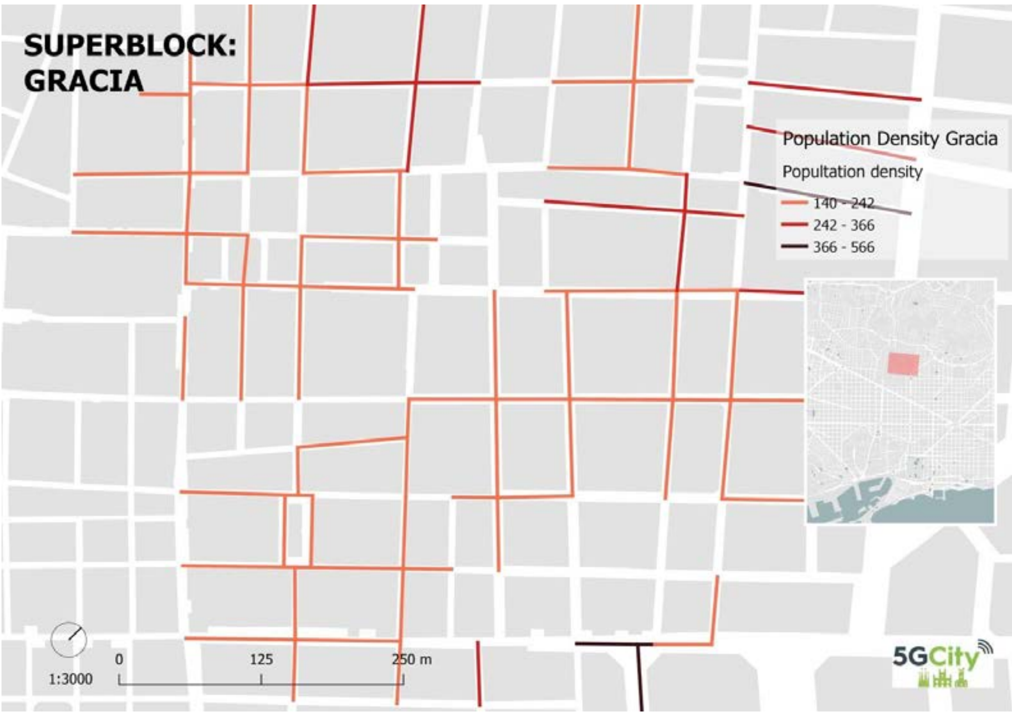


Figure C.54: Gràcia Population Density; BCNecologia

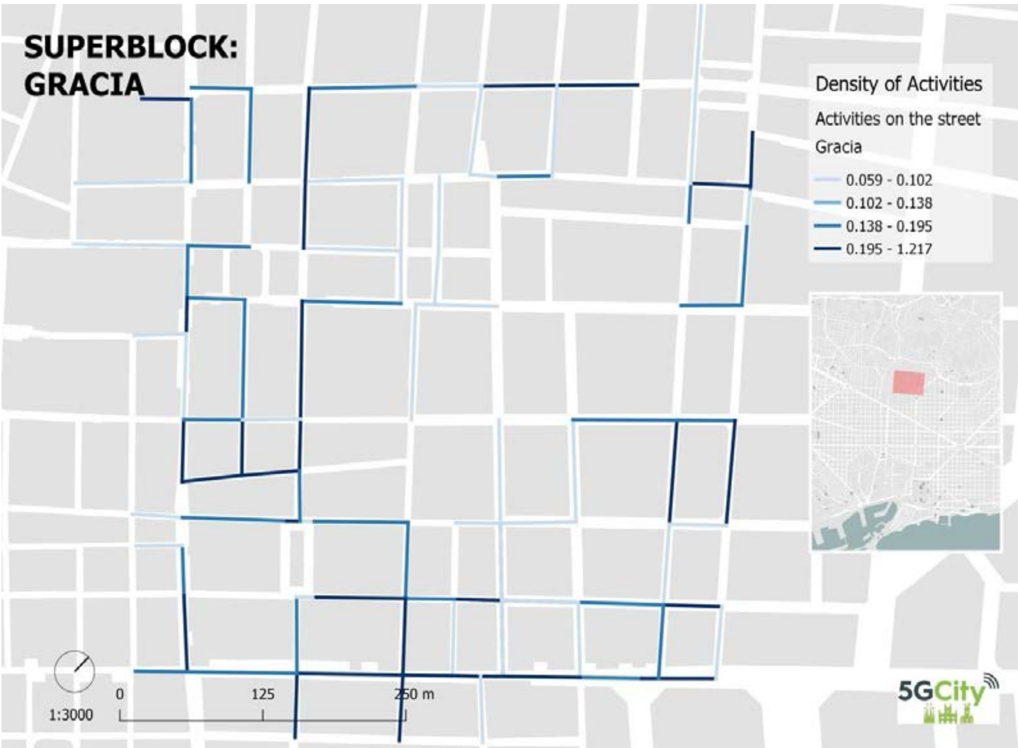


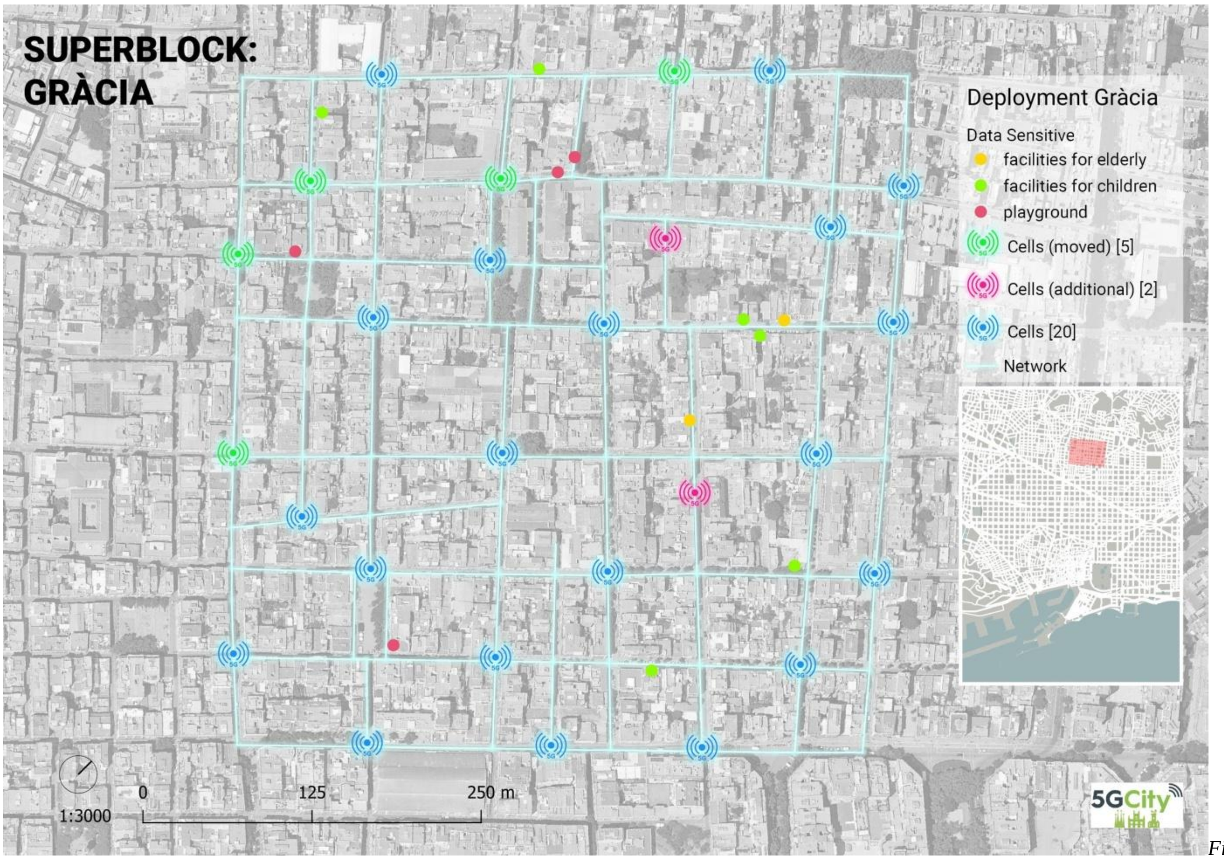
Figure C.55: Gràcia Activity Density; BCNecologia

b) Simplified urban network. The urban mesh network is more regular than in El Born. A A simplification of the network is not necessary. In this case, only little short and narrow streets have been taken out for the analysis.
c) The crosses will be the most important applicant points for cells.
d) Use the algorithm
e) With the number of cells chosen it could be enough for almost a total coverage of the Gracia area.

RESULT

The simplification of the network in this case only left out several sections of streets. The final result leaves only two sections of streets uncovered. We can choose to use two other cells for full coverage or consider whether our analysis makes it unnecessary to do so.

We have indicated two cells in red due to the low priority that the algorithm marked us. In case of scarce resources, these red dots would be the least priority. For these cases, the cells will be located in the middle of the sections and not in crosses.



Figure

Figure C.56: Distribution solution for Gràcia area; BCNecologia

The total number of small cells for a full coverage of the area is with 27 small cells in the middle between the others. In Average a Small Cell in the district of Gràcia can cover a public space area of around 2730 m2 (0,3 ha) and total surface of ca. 10.670 m2 (1,07 ha).

Figure C.57: Possible positioning for small cells in the Gràcia superblock

In the streetlayout of Gracia there are to find both types of streetlights: Free standing lampposts on the sidewalk and lamps attached to a building. Depending on the width and amount of trees in the streets there were used one or the other type of lights.

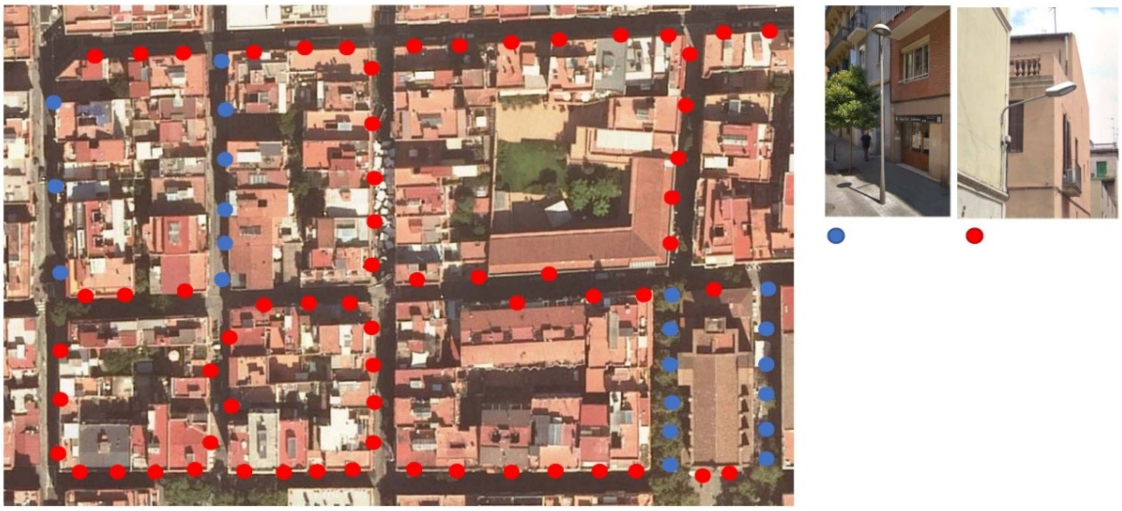


Figure C.58: Layout of attached (red) and free standing streetlights (blue in the neighbourhood of Gràcia Source:URBIS)

15.6.2.3 Summary of results

Summary of analysis.	**BORN**	**GRACIA**	**EIXAMPLE**	**POBLENOU**
Total surface (m^2)	245.812	287.970	272.188	203.287
Public space (m^2)	109.776	73.699	120.981	80.590
Space index	0,45	0,26	0,44	0,4
Minimum provision of smart cells (method)	36	27	27	17
Maximum provision of lampposts	389	384	259	180
Maximum number of wall lampposts	277	310	0	0
Public space/smart cells (m^2)	**3.049**	**2.730**	**4.481**	**4.741**
Public space/lampposts (m^2)	**282**	**192**	**467**	**448**

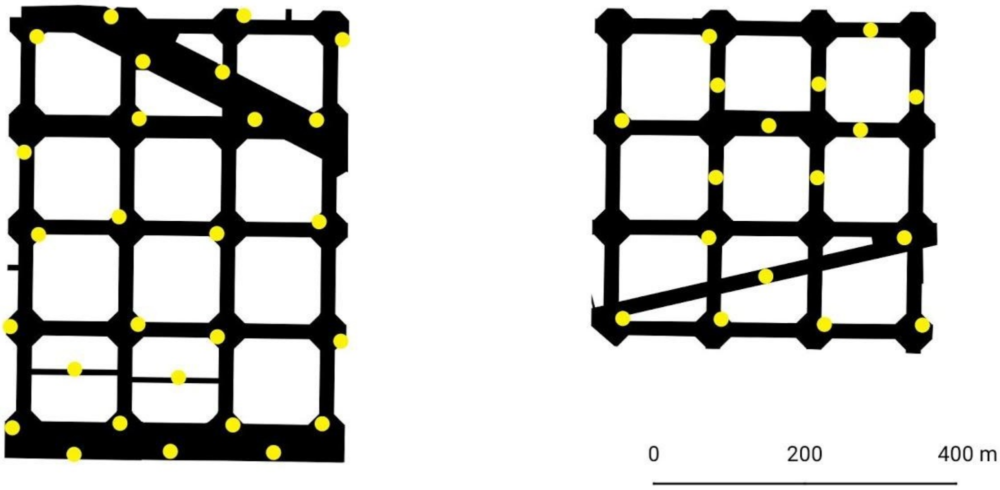


Figure C.59: Possible positioning for smallcells in the Eixample Urban fabric

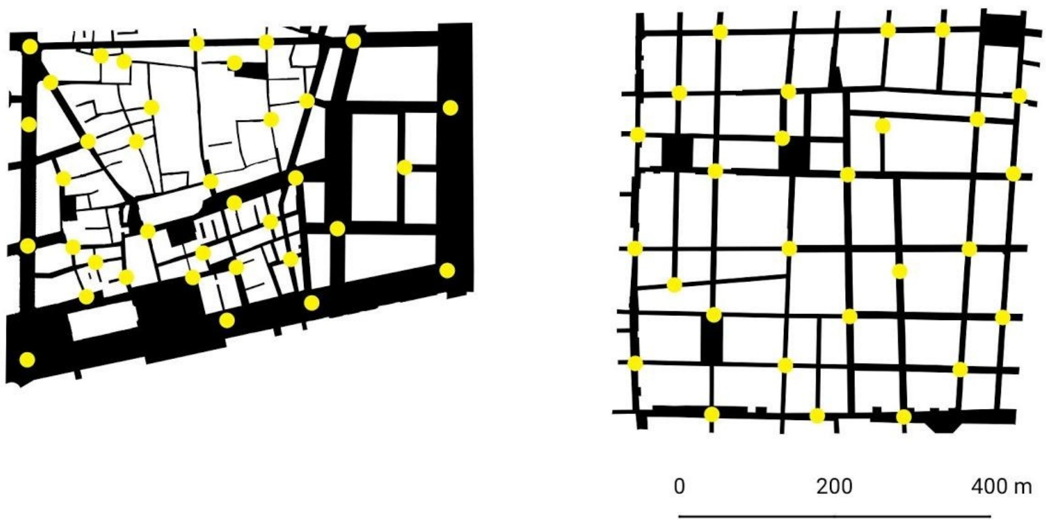


Figure C.60: Deployment Old Town urban fabric: Born and Gracia cases; BCNecologia

Eixample-Diagonal: The Superblock of Eixample-Diagonal has a total surface of 272.188 m2, it it is the second superblock which is taken in this deployment study. The public space in the superblock has 120.981 m2 and thus is the largest, The Superblock has two big roads and also the typical shape of the Eixample fabric, but also a dense building structure. For this reasons the space index, also the comparison between public space and total surface is the second highest with 0,44. The total number of small cells for a full coverage of the area is 27 with small cells in the middle between the others. In Average a Small Cell in the district of Eixample Diagonal can cover a public space area of around 4481 m2 (0,45 ha) and total surface of ca. 10.081 m2 (1,01 ha).

Poblenou: The Superblock of Poblenou has a total surface of 203.287 m2, the smallest case in this study, so it is the standard shape of the Eixample model case superblock which was part of the study, there also took place the case study with the real implementation of 5G. The public space in the superblock has 80.590, The Superblock is crossed by another street, not belonging to the grid which is with the 20m wide streets and the middle part corner squares quite representative for the overall Eixample city structure. The Building structure is not very dense in the comparison of overall Barcelona. For this reasons the space index, also the comparison between public space and total surface is 0,40. The total number of small cells for a full coverage of the area is 17 with small cells the lowest number between the others. In Average a Small Cell in the Superblock Poblenou can cover a public space area of around 4740 m2 (0,47 ha) and total surface of ca. 11.960 m2 (1,20 ha), in comparison with the others the small cells have the highest covering rate in Poblenou.

El Born: The Superblock of El Born (Rivera) has a total surface of 245.812 m2, it it is the third largest superblock which is taken in this deployment study. The public space in the superblock has 109.776 m2, the Superblock is surrounded by quite large streets and also has some big squares. For this reason, the space index, also the comparison between public space and total surface is the highest allo over the 4 investigated superblocks. The inner structure is very dense, with many small and winding streets. For this reason, the total number of small cells for a full coverage of the area is with 36 small cells the highest between the others. In Average a Small Cell in the district of El Born (Ribera) can cover a public space area of around 3050 m2 (0,3 ha) and total surface of ca. 6830m2 (0,7ha).

Gracia: The Superblock of Gracia has a total surface of 287.970 m2, it is the largest superblock which is taken in this deployment study. The public space in the superblock has 73.699m2, the Superblock has a very dense building structure and very narrow streets, this is the superblock, in comparison, with the least public space. For these reasons the space index, also the comparison between public space and total surface is the lowest all over the 4 investigated superblocks. The inner structure is very dense, with many small streets and some squares. The total number of small cells for a full coverage of the area is with 27 small cells in the middle between the others. In Average a Small Cell in the district of Gracia can cover a public space area of around 2730 m2 (0,3 ha) and total surface of ca. 10.670 m2 (1,07 ha).

Old town: Similarities and differences: In both cases, we have a dense street structure. In the case of El Born, the frames can be discontinuous (dead ends or with 90º turns), 'twisted', not perpendicular. Gràcia's map is somewhat more regular but still maintains a high density of frames per surface. In El Born, we have a large tourist influx. Less in Gràcia but the influx is high too. The area of El Born is much more restricted to road traffic. In Gràcia, although pedestrian priority is maintained, the circulation of vehicles is not restricted except on the outside roads.

15.7 **Electromagnetic Measurements**

15.7.1 Concepts

- Non-ionizing radiation: Those of the electromagnetic spectrum that do not have enough energy to ionize matter
- Intensity of the electric field: Magnitude of the electric field vector measured in V / m. From a frequency of 2000 MHz, the maximum allowed according to ICNIRP is 61 V / m. The reference power density is 10 W / m^2. This value is reflected in the regulations of the different countries.
- Magnetic field strength: Magnitude of the magnetic field vector measured in A / m
- Power density: power per unit area perpendicular to the direction of propagation expressed in mW / cm2 or W / m^2
- Emission: radiation produced by an electromagnetic source
- Emission: radiation resulting from the contribution of all radio frequency sources whose fields reach the reference point or zone.
- Exposure: Situation in which a person is subjected to electromagnetic, electrical, magnetic fields, or induced currents associated with radiofrequency electromagnetic fields.

- Population or uncontrolled exposure: When exposed persons have not been warned and cannot control the exposure.
- PIRE: antenna power. W measurement.

15.7.2 Context

Once the small cells have been deployed and in normal operation, it is wanted to find out the level of their contribution to the electromagnetic radiation levels in the area. For this, tests will be carried out with the system and facilities in perfect use and with the systems and installations turned off comparing both results in order to know:

a. The level of electromagnetic input by the system (all the small cells).

b. Ensure that global radiation does not exceed the limits established by regulations.

Being the first test with the installation in full operation, said test will serve as the electromagnetic certification in project, necessary for any new installation, as an annual compliance measurement.

In an urban environment with multiple sources of emission, the prediction methods by calculation of population exposure may not be simple, so a direct measurement model is made comparing the exposure of the rest of the sources (target source of measurement off), comparing with the total sources including the source object of measurement.

There are six stations of emission or small cells as part of the **5GCity** project concentrated in a limited space of the urban environment in an area less than 150 meters radius.

The codes used for each of these stations in the reports are:

CGRA125 (5G)

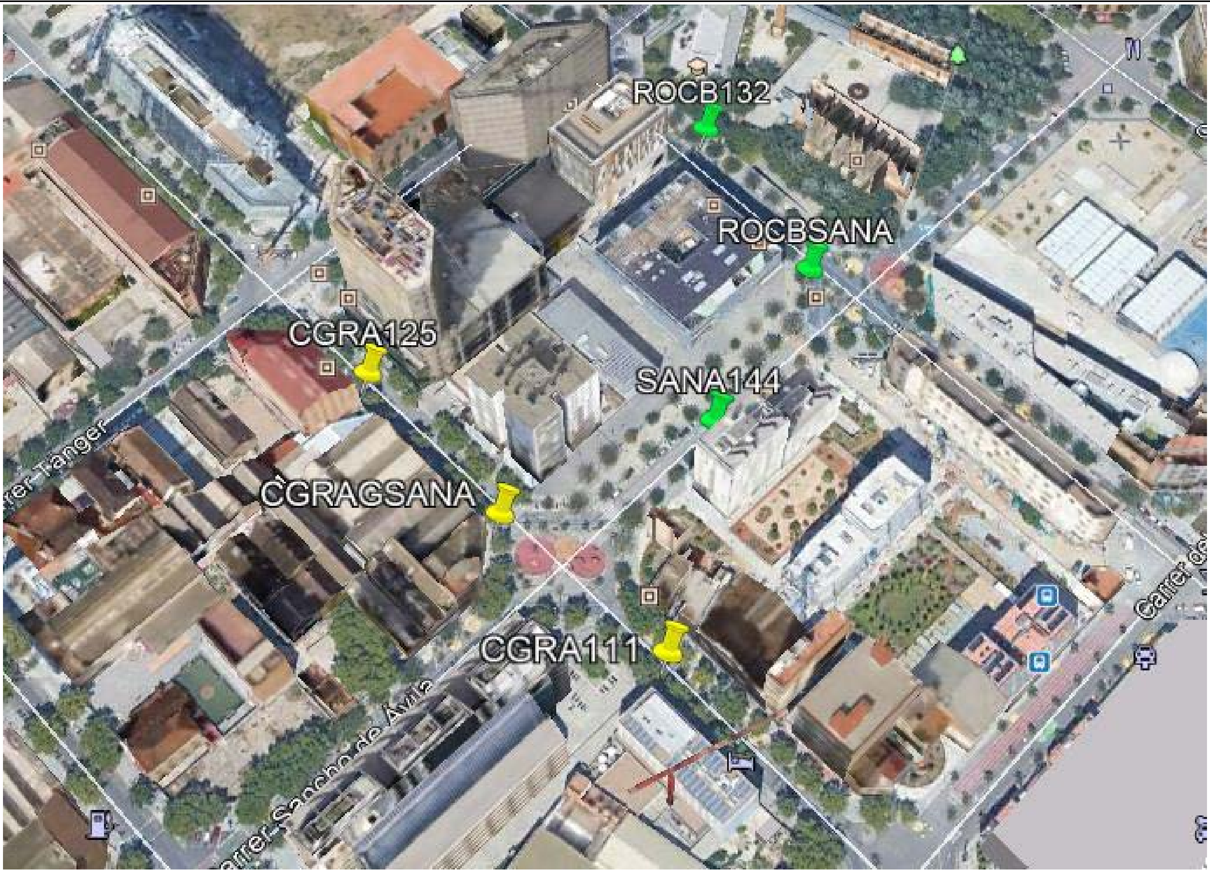
CGRASANA (5G)

CGRA111 (5G)

SANA111 (Wi-Fi5G)

ROCBSANA (Wi-Fi5G)

ROCB132 (Wi-Fi5G)



Three of the small cells emit at frequencies of 5G at frequencies close to 3,4GHz. While the other threes emit Wi-Fi in the band near 5,2GHz.

The sensitive points close to each of these emitting stations should be considered.

Six points have been detected, close to three of the six small cells:

- Early Childhood Education Center: CGRA125
- Early Childhood Education Center: CGRASANA
- Public park: CGRASANA
- Health Center: CGRASANA
- Public park: ROCBSANA
- Early Childhood Education Center: ROCBSANA

In these six sensitive points, part of the measurement points will be used to assess their level of exposure.

15.7.3 Methods

Measurements have been made around each of the small cells with six measurements around each of them in two batches, one with the small cells emitting and the other without emission (system off). The total is 72 measurements measuring at 36 different points with the system turned off and the system running.

The measurements are made by taking values for six minutes. The average measurement being used during these six minutes although maximum values are also taken during these six minutes.

3,46-3,48 GHz bands have been used for the measurement of 5G and 5,17-5,19 GHz and 5,19-5,21 GHz for 5G Wi-Fi. (In the latter case they have been divided into two bands because two different channels are being used within the band 5,17-5,21 GHz.

In the case of the 3,46-3,48 GHz band, it is a private and exclusive band, so that the system's on / off measurements will give us realistic values of small cell contribution to total emissions.

In the case of Wi-Fi 5G, the channels used are not exclusive and therefore there may be distortions in the contributions. It is not clear that with the system turned off the results are lower than with the system on.

As previously mentioned, five of the six points used for the measurement of small cells will be used for the next measurement in different directions of each small cells. Leaving the remaining ones to observe the radiation at points of interest including the next sensitive points.

15.7.4 Results

We can consider that the measurements are well below the maximum allowed reference level (61 V / m).

In the measurements corresponding to the 5G cells, the direct increase ratio between the switched off and on systems is consistent with the expected averages. The maximum increase detected is 0,313 V / m and the minimum (for nearby points) is 0,05 V / m.

For the different stations we compare the intensity of the electric field for the different measuring points around the station with the system turned off and running. In the case of the on system, we will consider the station's emission band and the entire spectrum.

What is of interest is to verify that the total emissions are below the maximum allowed reference (61 V / m).

For 5G cells:

15.7.4.1 Cell 5G CGRA124:

Puntos	**V/m total off system**	**V/m on system-5G band**	**V/m on system total spectrum**	**Ratio value on system/reference value (61)**
M1	0,5515	0,2363	0,5739	106
M2	0,4511	0,1308	0,4771	128
M3	0,485	0,0868	0,4525	135
M4	0,5246	0,1244	0,4961	123
M5	0,4642	0,1657	0,4898	125
M6	0,5288	0,04589	0,6958	**88**

15.7.4.2 Cell 5G CGRASANA

Puntos	V/m total off system	V/m on system-5G band	V/m on system total spectrum	Ratio value on system/reference value (61)
M1	0,8845	0,1203	0,7331	83
M2	0,7843	0,1158	0,7843	78
M3	0,8946	0,05858	**1,016**	**60**
M4	0,8972	0,1111	0,8942	68
M5	0,8078	0,1555	0,8082	75
M6	0,8816	0,0536	0,8263	74
M7	0,9404	0,1106	1,011	**60**
M8	0,6152	0,09101	0,6571	93

15.7.4.3 Cell 5G CGRA111

Puntos	V/m total off system	V/m on system-5G band	V/m on system total spectrum	Ratio value on system/reference value (61)
M1	0,5259	**0,313**	0,9708	**63**
M2	0,4563	0,1575	0,9009	68
M3	0,2647	0,1026	0,9361	65
M4	0,2167	0,05638	0,9615	**63**
M5	0,9594	0,0835	0,9036	68

15.7.5 Conclusions on 5G stations

The maximum value provided by the station in the measurements is **0,313 V / m**

The maximum measured value of total emissions is 1,016 V / m. It is a value **60 times lower than the maximum allowed reference.** It can be seen that there are stations with more constant values or lower values, depending on the location and noise from other emissions and their variation in operation. In any case, the incorporation of the cells in a street at distances of around 60 meters from each other does not imply a significant increase in emissions in the urban setting.

For WI-FI 5G: we perform the same analysis for the three stations located:

15.7.5.1 Cell SANA144

Puntos	**V/m total off system**	**V/m on system-Wi-Fi36 band**	**V/m on system-Wi-Fi40 band**	**V/m on system total spectrum**	**Ratio value on system/reference value (61)**
M1	0.9981	**0.03262**	**0.0207**	0.8563	71
M2	0.9779	0.02894	0.01901	0.967	63
M3	0.879	0.02284	0.02038	0.9366	65
M4	0.8559	0.02276	0.01913	0.7868	78
M5	0.8494	0.02594	0.0207	0.8455	72

15.7.5.2 Cell ROCBSANA

Puntos	**V/m total off system**	**V/m on system-Wi-Fi36 band**	**V/m on system-Wi-Fi40 band**	**V/m on system total spectrum**	**Ratio value on system/reference value (61)**
M1	1,255	0,02284	0,01899	**1,345**	**45**
M2	1,14	0,02239	0,02105	1,253	49
M3	1,119	0,02516	0,02341	1,105	55
M4	1,109	0,02326	0,02083	1,057	58
M5	1,119	0,02345	0,01932	1,273	48
M6	0,794	0,022	0,02163	0,7859	78
M7	1,112	0,02382	0,02414	1,27	48

15.7.5.3 Cell ROCB132

Puntos	V/m total off system	V/m on system-Wi-Fi36 band	V/m on system-Wi-Fi40 band	V/m on system total spectrum	Ratio value on system/reference value (61)
M1	0,4562	0,01423	0,01397	0,4436	138
M2	0,4699	0,01744	0,0157	0,4887	125
M3	0,4891	0,01427	0,0143	0,4439	137
M4	0,4466	0,01662	0,0157	0,4125	148
M5	0,4733	0,02403	0,01624	0,4796	127

The increase for the three Wi-Fi points is not as clear.

The contribution to the electric field in the stations of maximum Wi-Fi is of the order of **0,052 V / m** in the sum of the two channels used. The contribution may contain other sources, so the net contribution would be lower, a relatively low value. The maximum in the broadcast stations for the entire spectrum is **1,345 V / m (45 times lower than the maximum reference value)**. We can see that there are locations with greater volume of fund emissions. In any case, they are far from the maximum recommended levels.

Projection from the study:

Calculations have been made to consider, based on the results obtained, an assessment of placing a greater number of cells emitting in 5G on the same street, taking advantage of the fact that the emitting cells in 5G for frequencies around 3,4GHz are in the same distance of street. A calculation for the use of ten cells in the 265 meter in length along two street sections considering that all contribute the maximum found would give us an approximate value of:

Value with 10 microcells: 5G≈√10*(0,3132)=1,29 V/m

Adding an average of the background electric fields found:

Value total spectrum≈√1,292+0,95942=1,6 V/m

It is a value 35 times lower than the maximum reference allowed, which, in principle, complementing it with a greater number of cells (every 25-30 meters) would not give problems in this aspect, so the limitation would come from interference problems between the cells themselves.

If it’s calculated for WI-FI 5G:

Value with 10 microcells WI-FI 5GHz≈√10*(0,032622)+10*(0,024142)=0,1283 V/m

Adding the rest of the spectrum:

Value total=√0.12832+1.2552=1,26 V/m

It is a value 48 times lower than the maximum reference allowed.

15.8 Conclusions

15.8.1 Criteria to consider in the deployment

15.8.1.1 Territory and city:

In cities the criteria look like it is going to be using the less possible sites and densifying the network in high demand zones by adding small cells alongside the current macro cells. So, minimizing the deployment of new 5G components and sharing infrastructures is the key. Developers and the administration should aim for connectivity as a reality serving the digital society and improving public services. Also, the administration should keep fostering the investments because this technology will give more competitiveness to the territory and its business. It is of critical importance for the administration to develop a deployment strategy and give awareness to the companies and population of this technology and its services. Also, they should maximise the efficiency of these infrastructures and try to ensure the continuous connectivity throughout all the territory.[21]

Ensure a way of deployment of the new infrastructure in the urban space that causes as far as possible no negative visual impact, can't become target of wilful destruction

15.8.1.2 Technology and services:

5G technology is expected to achieve its maturity in 2021 and rollout planning should be done by private companies and also by public administration to boost the technology deployment. The population needs to perceive the relevance of this technology.[22]

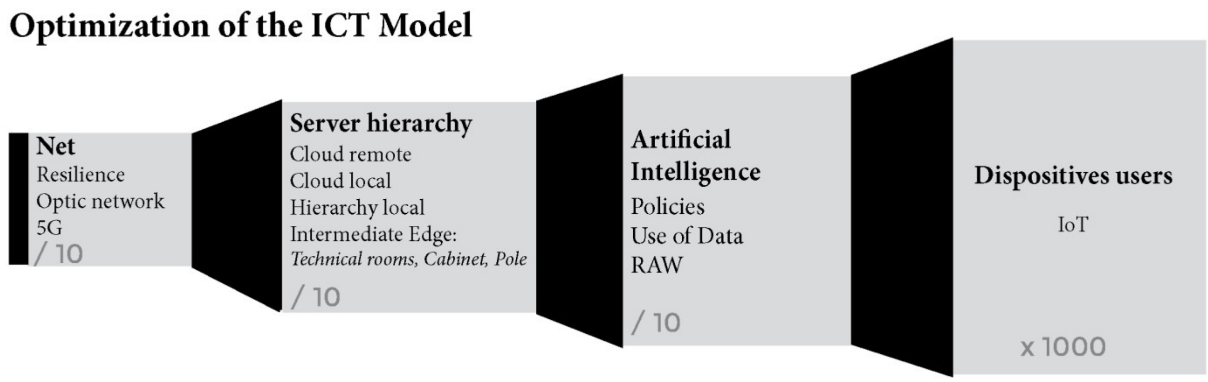
It is important for the implantation of the 5G technology to reach as much population as possible, avoiding the creation of technology gaps in any area of the territory. Another important point is assuring the data and user's privacy.[23]

15.8.1.3 Optimization of the ICT Architecture

One of the aspects that the ICT Superblock model brings is the possibility of optimizes the ICT architecture basically by two main variables: Artificial Intelligence and a new Server hierarchy. Even the number of dispositive (users) increases in the area, and proportionally their demand of ICT infrastructure, the use of AI

[21] https://www.5gcity.eu/2019/07/30/best-practices-and-rationalisation-in-the-5g-mobile-networks-deployment/
[22] https://www.5gcity.eu/2019/07/30/best-practices-and-rationalisation-in-the-5g-mobile-networks-deployment/
[23] https://www.5gcity.eu/2019/07/30/best-practices-and-rationalisation-in-the-5g-mobile-networks-deployment/

and setting a new hierarchy will allow to decrease the number of cells, due to their continue interaction. The challenge is then in the legal aspects around data use and data protection.



15.8.1.4 Management of the networks.

If an operator would like have his own network and controlled it, then the city could be full of small cells with several problems: interference between cells and a lot of infrastructures unnecessary mainly. However, the competition between operators could share the market demand. With three or four operators with independent networks, the demand for every mesh will be a third or a quarter of the total demand, but it's necessary a lot of cell for a good covering of the territory. That is when the problem appears, since the minimum to cover the territory can be superior to the theoretician to cover the demand.

That's possible in some morphological areas with low density of streets. But when the morphology of the area is more complex with narrow streets, short no continuous streets, no straight streets like historic centers, it's possible to find problems of saturation of cells. Adding other problems to it about the scarce and insufficient space for the deployment of the infrastructures like pipelines, ducts (for power and communication), space for location cabinets…

The problems about the radiation exposure are not the main problem, at least technically and theoretically, if the frequencies are not exceeding the 5Hz. By the other hand, it is recommended to avoid an over covering in low demand areas or complex areas by a group of independent operators with an efficient use of resources could be more challenged issue.

<END OF DOCUMENT>