5G CITY

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

D5.1: 5GCity Infrastructure Design and Definition

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:	Document version: **V1.0**

Work package: **WP 5**

Deliverable title: 5GCity Infrastructure Design and Definition

Start date of the project: 01/06/2017 (duration 30 months)	Contractual delivery date: 12 Month	Actual delivery date: Date of submission to Coordinator

Editor name: Carlos Colman Meixner (UNIVBRIS)

List of Contributors

Participant	Short Name	Contributor
University of Bristol	UNIVBRIS	Carlos Colman Meixner, Dimitra Simeonidou
Fundacio I2CAT	I2CAT	Sergi Figuerola, Shuaib Siddiqui, August Betzler
Nextworks s.r.l.	NXW	Nicola Ciulli, Paolo Cruschelli
Retevision (Cellnex Telecom)	Cellnex	David Pujals, Luis Moreno
Italtel	ITL	Antonino Albanese, Viscardo Costa
WINTREE	WindTre	Maria Rita Spada
Institut Municipa d'Informatica Ajuntamiento de Barcelona	IMI	Gonzalo Cabezas, Mariano Lamarca, Raul Pertierra
Municipality of Lucca	LUCCA	Mauro Di Bugno, Luca Falsiroli, Sfefan Guerra
RAI TV	RAI	Luca Vignaroli
MOG Technology	MOG	Pedro Santos
VOSYS	VOSYS	Michel Paolino, Teodora
ADLINK	ADLINK	Gabriele Baldoni
Barcelona TV	BTV	Jordi Colom
Ubiwhere	UBI	Pedro Diogo
Accelleran	XLR	Simon Pryor, Antonio Garcia

List of Reviewers

Participant	Short Name	Contributor
Fundacio i2CAT	I2CAT	Sergi Figuerola, Shuaib Siddiqui, August Betzler
Nextworks s.r.l.	NXW	Paolo Cruschelli

Change History

Version	Date	Partners	Description/Comments
0.1	01/05/2018	UNIVBRIS	First Draft
0.5	10/05/2018	I2CAT	City of Barcelona Infrastructure V1
0.6	15/05/2018	RTV	New Infrastructure for the City of Barcelona
0.7	26/05/2018	UNIVBRIS	New Infrastructure for the City of Bristol.
0.8	15/06/2018	LUCCA/UBI/ RAI/XLR/	Infrastructure of Lucca, Use Cases Sections
0.9	27/06/2018	NXW/I2CAT /RTV/UNIV BRIS	Final Version of Infrastructure for each city.
1.0	30/06/2018	UNIVBRIS/I 2CAT	FINAL VERSION

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

This document is focused on the definition and/or design of the 5GCity Infrastructure on each one of the cities involved in 5GCity to support the different Use cases to be deployed in each one of them. To do so, this deliverable provide the needed level of detail (technical and deployment) to achieve the demonstration goals the project has within its timeframe. In fact, this deployment is very challenging, considering that new infrastructures in cities are particularly complex and sometimes subjected under non-expected circumstances that do not happen in the labs.

This deliverable is the first outcome of the on-going Task 5.1, and provides the following outcomes:

- It matches the use cases requirements defined in D2.1 with the logical 5GCity infrastructure and vision.
- It matches the 5GCity architecture and platform defined in D2.1, D3,1, and D4.1 with the 5GCity infrastructure.
- A definition, design and/or assessment of the current physical infrastructure of each city based on the deployment and/or implementation of the use cases.
- The identification of the physical layout and location for 5GCIty trials in each city.
- A project plan of the infrastructure deployment of the 5GCity infrastructure on each city.
- A list the most important element of each one of the projected infrastructures with their associated use cases.

In addition, the deliverable presents a concrete example of each use cases on the projected infrastructure, and a description of city wide infrastructure deployments completed or to be completed for the project.

All involved stakeholders/actors and their interests are identified within the context of 5GCity.

1. Introduction

5GCity aims to deploy and test a 5G neutral and sliceable architecture in three cities to demonstrate the benefits of multi-tenancy and flexibility of 5G networks . The lessons learnt can be different in each city and the overall project contribution paves the way for 5G deployment in European cities. Additionally, since the project is not constrained to any specific vendor, having three different testbeds can also mean that a diversity of hardware and software can be tested resulting to better conclusions about industrial level 5G applications.

This deliverable presents the work done on infrastructure definition, design for 5GCity deployments in the three cities within the project's first year. The goal is to ensure that each city infrastructure can accommodate and facilitate all requirements of different 5GCity use cases. Therefore, this document is focused on the infrastructure definition and design in each of the cities, in such way that the deployments will be able to execute the use cases. The deliverable also aims to present the mapping between 5GCity logical architecture and the building blocks in each city that form the infrastructure.

This document comprises five main sections. Section one introduces the deliverable along with a high-level description of the use cases, an introduction to the project infrastructure and how the latter maps to the architecture. The second section presents the technical requirements of the use cases concerning the infrastructure. More precisely, section two is focused on what each use case requires in terms of hardware and software and how the infrastructure will meet those requirements. The section three is the main section of this document, it describes in detail what is the deployment status and capabilities in each of the cities. Also, section three is focused on all the hardware that is deployed. Wireless, metro, edge, data-centre hardware and fibre infrastructure functionalities are described for each of the cities. Section four illustrates how the use cases will be deployed in each of the cities. Finally, section five concludes the document and the annex describe the new dark fibre in City of Barcelona to be available for 5GCIty.

1.1. 5GCity Use Cases Scenarios

The 5GCity architecture is designed to be casted over project use cases to a wide range of use cases according to the difference requirements, especially in terms of latency, resilience, coverage, and bandwidth. One of the challenge is to provide end-to-end network and cloud infrastructure slices over the same physical infrastructure to fulfil vertical-specific requirements as well as mobile broadband services in parallel. As described in [1][2] 5GCity has identified three main scenarios which classifies the project Use Cases (UCs), namely the Neutral Host, Industry vertical (Media and Entertainment) and city services.

In the first scenario (Neutral Host), 5GCity leverages its virtualization platform to enable the cities (or any infrastructure provider) to create dynamic end-to-end slices containing both virtualized edge and network resources and lease it to third-party operators or verticals. The scenario consists of managing the underlying physical infrastructure to offer a set of virtual resources to an operator, who builds, on top, its own services ready for end-user consumption. It is expected the neutral host scenario combined with 5G networks will improve the telecom market [4].

The second scenario (Industry vertical) is strictly related to different aspects of the media and entertainment industry, which are strictly integrated into 5GCity project, and encompass all the Use Cases pivoting around video acquisition, editing and delivery [5].

The third scenario is related Smart City which is tailored to the specific needs of a city (in our case, Lucca); this scenario exploits the cities' surveillance cameras by deploying a virtualized monitoring service that can process video streams near cameras automatically to identify illegal dumping. And for autonomous mobility in the city to enhance public transportation.

The three Use Cases scenarios and city where the use-cases will be deployed are summarized in Table 1 .

ID	Use Case Name	City			Scenarios
		Barcelona	Bristol	Lucca	
UC1	Unauthorized Waste Dumping Prevention	No	No	Yes	Smart City
UC2	Neutral Host	Yes	Yes	Yes	Neutral Host
UC3	Video Acquisition and Production Community media engagement in live events	Yes	Yes	No	Media
UC4	UHD Video Distribution Immersive Services	No	Yes	Yes	Media
UC5	Mobile Backpack Unit for Real-time Transmission	Yes	No	No	Media
UC6	Cooperative, Connected and Automated Mobility (CCAM)	Yes	No	No	Smart City

Table 1 - 5GCity Use Cases.

1.2. 5GCIty Infrastructure

5GCity Infrastructure will adapt distributed cloud technologies within 5G dense deployments in city-based environments by building a three-tier based edge and network to provide a multi-tenant, cost-effective platform for virtualized heterogeneous services for access networks.

The proposed three-tiers 5GCity infrastructure to be used in the project consists in:

- **Tier 1 - 5GCity Small Cells and 5GCity Wi-Fi Nodes**: multi-vendor and multi- band sliceable radio for neutral host model in lamppost or in street towers, e.g.., Wi-Fi, LTE-A, 5GNR etc.
- **Tier 2 - 5GCity Edge/Multi-Access Edge Computing (MEC) Node**: compute and storage at the edge for multi-tenant radio functions and or multiple edge applications placed in between the 5GCity Metro/Edge Node and the radio or tier 1 devices.
- **Tier 3 - 5GCity Metro/Edge Node:** set of computing and storage element used from a metropolitan datacenter to run the 5GCity platform and compute. Because a metropolitan datacenter can be shared by more than one institution we define the concept of "node", i.e., 5GCity Metro/Edge Node that is hosted or housed in a public datacenter serving the neutral host provider or infrastructure provider running the 5GCity platform.

Figure 1 introduces the defined three-tiers 5GCity infrastructure to be deployed and tested by the project in the physical infrastructure of the three cities. The tier 1 also includes the Radio Access Network (RAN) cabinet that might be used as extreme edge to place an experimental MEC Node and radio functions.

In our deployment the edge network will basically interconnect one or two RAN cabinets with one or two Edge/MEC nodes and the core metro network will interconnect the two levels of edge nodes. The RAN cabinets also will connect at least one lamppost or street tower hosting 5GCIty Small Cells and/or 5GCity Wi-Fi nodes. The tenants or verticals requesting a slice from the three-tier 5GCity infrastructure will connect the 5GCity software and platform.

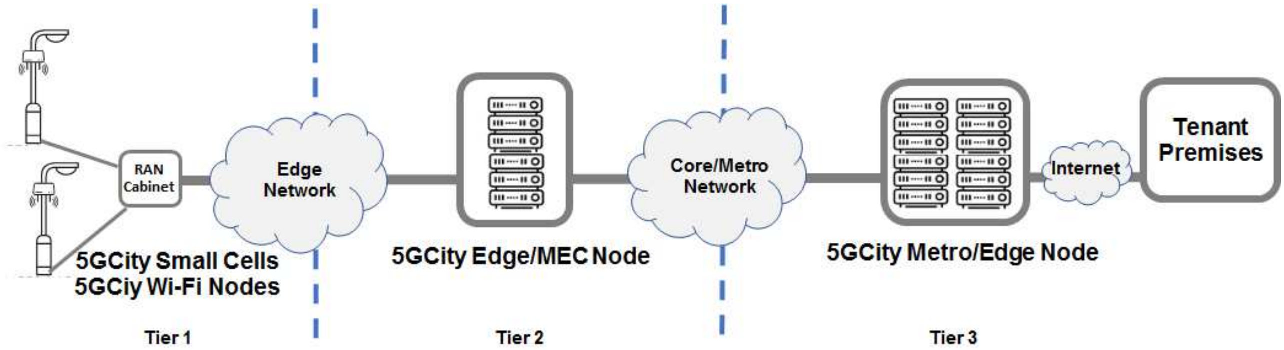


Figure 1 - Proposed three-tier 5GCity Infrastructure.

.

The proposed infrastructure model will be mapped and deployed on each city infrastructure and citywide testing environment. In some city the 5GCity Metro/Edge Node can share the metro datacenter with 5GCity Edge/MEC Node.

1.3. Architecture Mapping into 5GCity Infrastructure.

This sub-section describes how the 5GCity software architecture presented in D2.2 [3] and summarized in Figure 2 maps into the three-tier 5GCity logical infrastructure introduced on Figure 1.

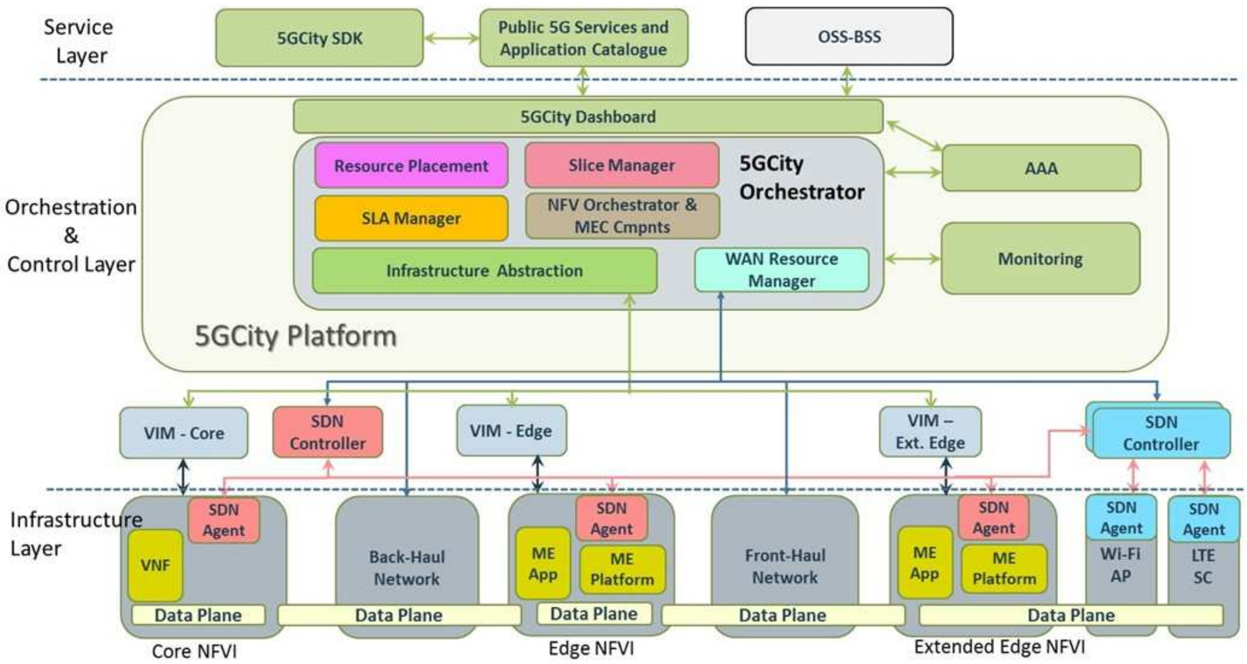


Figure 2 - 5GCity architecture introduced on D2.2 [3].

The assumption done in the remaining part of this section is that, even considering that each of the three cities (Lucca, Bristol, Barcelona) have different infrastructure characteristics, in all the three cases the main idea of 5GCity three-tier architecture (Figure 2) is respected and is organized as follows:

- **a pool of resources** (computing, storage) which assumes the role of dataenter resources. We will assume that this pool is divided in two sub-pools, DC_pool_1 and DC_pool_2, being the first dedicated to the deployment of the 5GCity control plane and the second dedicated to datacenter (DC) computing resources., e.g., 5GCity Edge/Metro Node.
- **a pool of resources (computing, storage)** which assumes the role of edge resources e.g., 5GCity Edge/MEC Node.
- **a pool of resources (radio)** which assumes the role of radio access network devices e.g., 5GCity Small Cells and 5GCity Wi-Fi Nodes.
- **a communication network which** enable communication among the three pools of resources

Table 2 provides the identification of the functional blocks which composes 5GCity architecture, coupled with an indication of which resources are deployable as virtual resources.

Functional block	Deployed as Virtual Resource
5GCity Dashboard	Yes
5GCity Orchestrator	Yes
5GCity Core VIM	Yes
5GCity Core NFVI	No
5GCity Edge VIM	Yes
5GCity Edge NFVI	No
SDN controllers	Yes
Wi-Fi Access Points	No
LTE Small Cells	No

Table 2- 5GCity architecture functional blocks.

The mapping model of 5GCity architecture to the city infrastructure is done according the following assumptions:

- **5GCity Dashboard and Orchestrator** will be running in a virtual machine (VM) each including the resource manager, the slice manager, the SLA manager, the WAN resource manager, NFVO, VNFM, infrastructure abstraction module, authentication module (i.e., AAA module), and monitoring module. Optionally, all these modules could run on separate VMs in case of some performance or storage issues encounter in the deployment.
- **5GCity Core VIM** will be deployed on a VM on the core DC.
- **5GCity Edge VIM** will be deployed on a VM on the edge DCs.
- **5GCity NFVI** will be deployed across a group of physical resources running on physical server in the core DC.
- **5GCity Edge NFVI** will be deployed across a group of physical resources running on physical server in the core DC.
- **5GCIty SDN Controllers** will be deployed in wo different places based on their role in the architecture
    - **Core SDN** will be deployed in a VM placed in the core resources to control the communication between the core DC and edge DCs.
    - **Edge SDN** will be deployed one or more VMs placed in edge resources to control the communication from wireless or radio (i.e., Wi-Fi access points and LTE small cells) to the edge and core.
- **5GCity Small Cells (LTE-A)** will be running on physical machines located on lampposts on the street.
- **5GCity Wi-Fi Nodes or Access Points (AP)** will be running on physical machines, located on lampposts on the street.

- **The networking between NFVI PoPs** (Core NFVI and Edge NFVI) and between Edge NFVI and RAN is formed by SDN enabled switches and will be handled by the deployment of L2/L3 tunnelling mechanism. VLAN, VXLAN or GRE Tunnels will be used for this purpose. This will include both data plane and control plane networks.

Given the above list of initial assumptions a solution which maps 5GCity architecture to the city infrastructure is provided in Table 4. We also assume that each pool of resources can be allocated into a 5GCity Edge/Metro Node housed or hosted in a Metro/Core Datacenter (DC) and/or in a 5GCity Edge/MEC Node housed in edge DCs or edge servers. In addition, any of the nodes has at least one physical server available.

Server Pool	Virtual Machine	Functionality and Role
DC_pool_1	VM 1	5GCity Orchestrator 1. Resource manager 2. Slice manager 3. SLA manager 4. Infrastructure abstraction 5. WAN resource manager 6. NFVO VNFM 7. Monitoring 8. AAAA
DC_pool_1	VM 2	5GCity Dashboard
DC_pool_1	VM 3	5GCity Core VIM
DC_pool_1	VM 4	5GCity Edge VIM
DC_pool_1	VM 5	5GCity Core SDN Controller
DC_pool_2	Physical resources	5GCity Core NFVI
Edge_pool	Physical resources	5GCity Edge NFVI
Edge_pool	VM 6	5GCity Edge SDN Controller
Radio	Physical resources	Wi-Fi AP Controller
Radio	Physical resources	LTE Small Cell

Table 4 - mapping of 5GCITY architecture to city infrastructure.

We do not recommend deploying NFVI infrastructure as a VM nor in the datacentre neither in the edge part. This deployment model, even if theoretical possible, would lead to a certain number of performance issue and impose severe limitations to the overall 5GCity architecture roll-out solution.

A potentially simplified scenario includes the possibility to have a single VIM controller, on the core/metro datacentre hosting or housing the 5GCity Metro/Edge Node, with no changes to the NFVI.

On the RAN part, each city will have physical hardware installed on lampposts or towers, able to run Wi-Fi Access Points and LTE Small Cells (where applicable). In this case, Wi-Fi Access Point control software and LTE Small Cell will be running as virtual machines into this hardware. An SDN controller, for each lamppost, will be also running to configure both LTE Small Cells and Wi-Fi Access Points.

The final mapping is also presented in Figure 3 , which provides indication of how City physical resources are grouped according the roles described in 5GCity architecture [3] and how 5GCity functional blocks are mapped back to groups of physical resources.

For the sake of completeness, we also provide indication of where VNF composing the 5GCity Network Services deployed upon the infrastructure are deployed. Different colours are used to identify VNF belonging to different Network Services.

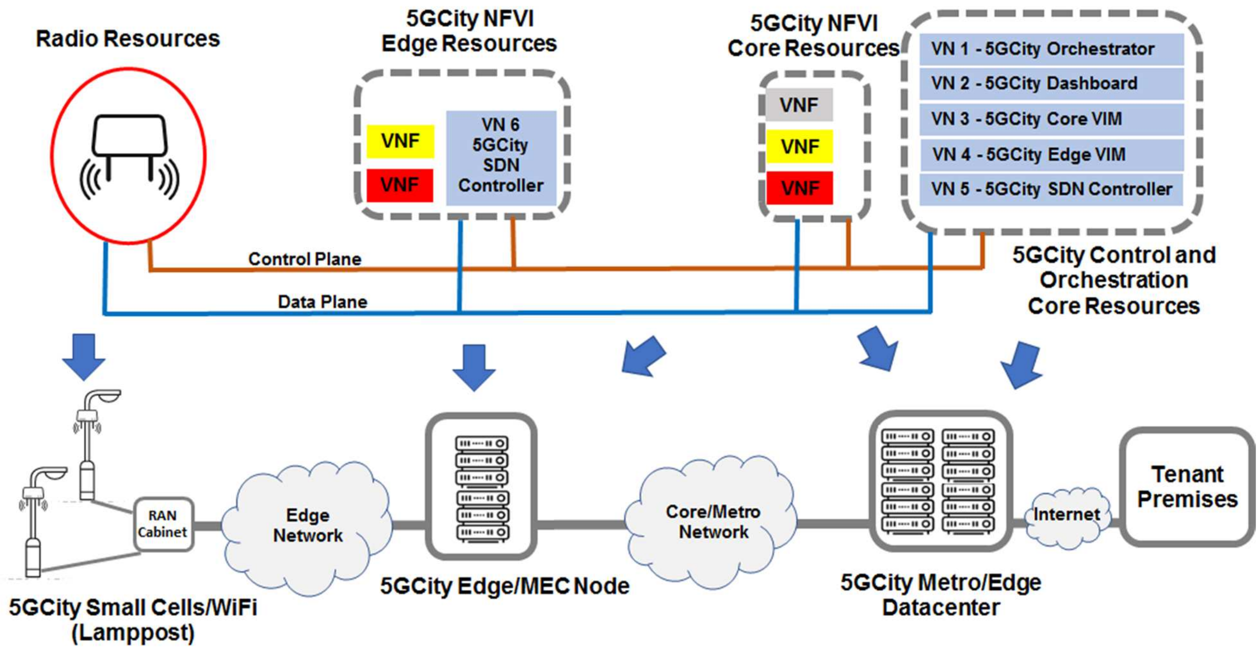


Figure 3 - Mapping of 5GCity architecture into a the three-tier 5GCity infrastructure.

The next section introduces 5GCity use cases mapping into the 5GCity infrastructure.

2. 5GCity Use Cases Infrastructure Requirements

This section summarizes and extends the 5GCity use cases scenarios and requirements of D.2.1 and match them into the three-tier 5GCity infrastructure before introducing its deployment on each city.

2.1. UC 1 - Unauthorized Waste Dumping Prevention

This use case aims to test smart and automatic system to survey violation related illegal waste dumping in the collection areas. Media content produced by the Camera is analysed and stored at the edge. In case of illegal action, an automatic alarm is triggered by software hosted at the edge resources. A selection of media content (i.e. portion of the video which demonstrate an illegal action, and photo which identifies the transgressor) is also transmitted to 5GCity terminals operated by Local Police personnel. The overall workflow is well described in Figure 4. This UCs only will be deployed in the City of Lucca.

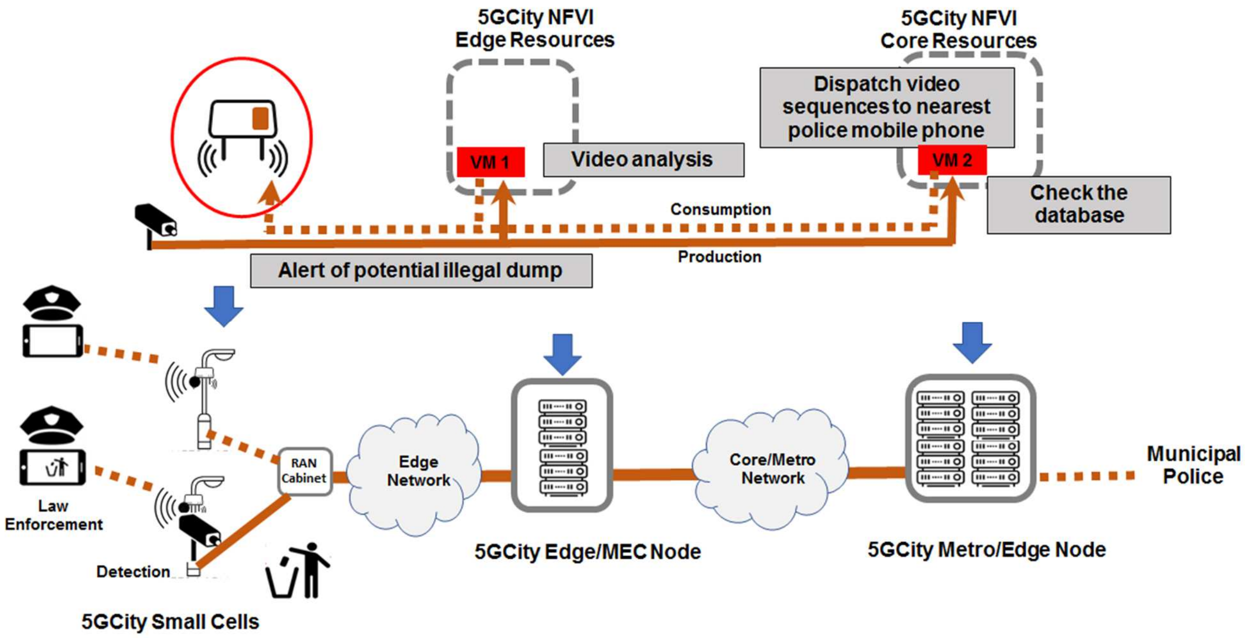


Figure 4 - **UC1 deployment in the three-tier 5GCity infrastructure.**

The role of 5GCity Edge/MEC Node is essential given the low delay requirement by this system and video analytics. The table 3 summarized the requirement of the UC1 to be virtualized and deployed in the 5GCity infrastructure.

Internet	**Metro DC**		**Backhaul Network**	**MEC**		**RAN**	
Data rate: 2 Mbps (Minimum)	VM#1	Cores: 2 vCPU RAM: 2-4 GB Storage: 20-50 GB	Data rate: 100 Mbps	VM#1	Cores: 1 vCPU RAM: 128 MB (**) Storage: 2-10 GB	LTE	UL (*) 2Mbps DL (*) 2Mbps

				VM#2	Cores: 1 vCPU RAM: 256 (**) MB Storage: 2-10 GB		

Table 3 - Hardware and software requirements – UC 1.

(*) the UL and DL data rate are intended on a per user device basis

(**) we had assumed that Virtual Machine Hosted on edge resources will be based on Unkernel Operative System and are characterized by small footprint. In case this assumption will not be verified we will fall back to a standard Virtual machine with a reference template which corresponds to t2.small according to Amazon EC2 deployment flavour style templates.

2.2. UC 2 – Neutral Host

Neutral host combines the aspect of "hosting" and the aspect of "neutrality". The hosting aspect refers to an entity that provides a set of resources that are made available for customers such as mobile network operators to allow continuous services. The "neutrality" aspect refers to the host acting as a shared platform to multiple hosted clients. Neutrality in this context does not imply strict equality between hosted clients, as the resources offered to each hosted client are subject to commercial agreement between the Neutral Host and the hosted client, and policy-based management may be applied. From a user's point of view, the system behaviour and services using the resources of a Neutral Host should be available without user intervention and, ideally, these should be seamless and identical to those provided by their hosted clients' dedicated resources. The 5GCity the distributed fixed and radio infrastructure is designed to implement a flexible network slicing allocation schemes, at defining policies to support agreed SLAs and at demonstrating scale up/down of infrastructure resources, assigned to Service Providers.

This concept has been around for some time, but it's likely that it will be within the 5G framework that its potential will be fully exploited, given the following main ideas: (i) the need for enhanced and ubiquitous connectivity in urban context coupled with increasing radio coverage and bandwidth requirements (ii) the smart cities entities cover pivotal role within 5G framework and a city municipality is the perfect candidate to cover the role of 5G Neutral Host (iii) Neutral Host is the perfect candidate to allow within the same neutral framework to fully satisfy the 5G requirements for the different use-cases (eMBB, URLLC, massive IoT). It should be noted that Neutral Host is not only a technical framework that integrate NFV and radio slicing but has an important business aspect which focuses around the creation of new SLAs categories to rule the interactions between the host and content/service provider. Figure 5 shows an example of the UC 2 operation into the 5GCity infrastructure.

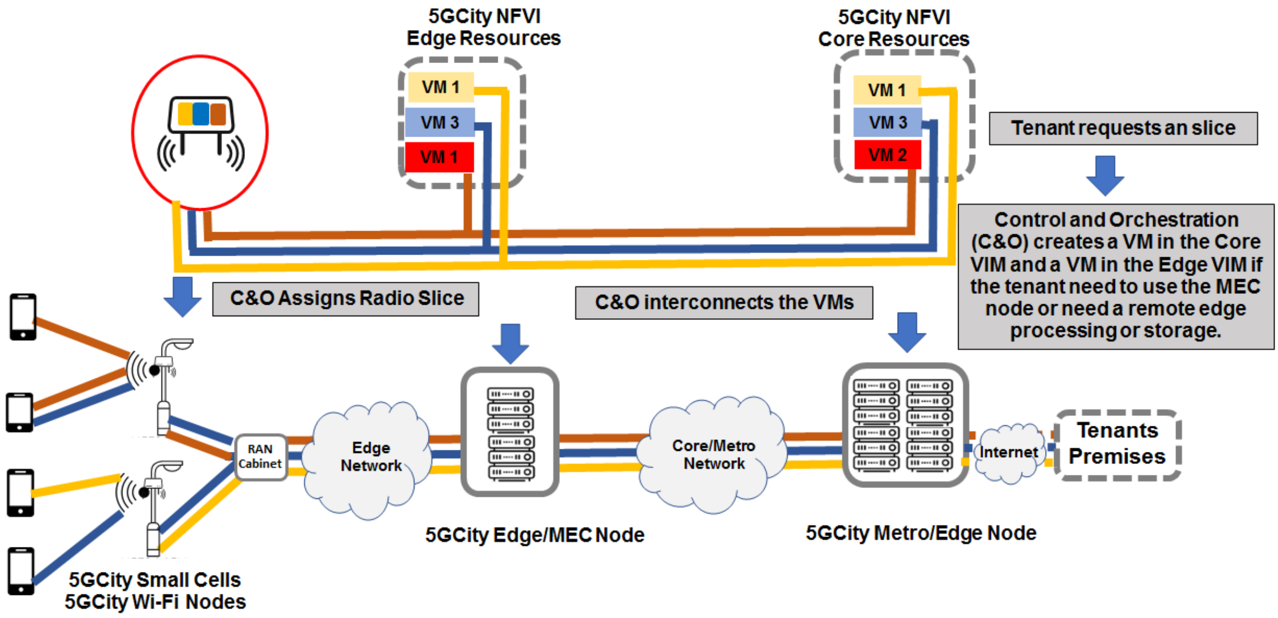


Figure 5 - UC2 deployment in the three-tier 5GCity infrastructure.

In the example of the Figure 5 the 5GCity Control and Orchestration (C&O) performs the slicing of the infrastructure by creating the VMs under the VIMs of the core and edge by assigning a slot in the radio and network (i.e., bandwidth, wavelength, frequency slot). Through 5GCity's platform (C&O), several dedicated network slices will be deployed, through NFV, offering dedicated 2-8 Mbps fronthaul links in a multi-RAT environment. With these networks, end-users will be able to connect to different Wi-Fi access points and even small cells (LTE/5G) and leverage the low-latency communication link between edge applications and those running at 5GCity's core network. Key technical requirements of the system to achieve the Neutral Host goals are bandwidth, latency, and coverage. The deployment requirement for UC2 is summarized on table 4.

Internet	Metro DC		Backhaul Network	MEC		RAN	
Data rate	VM# x	Cores: 1 RAM: 100MB Storage: >5GB	Data rate:	VM# x	Cores: 1 RAM: 100MB Storage: >5GB	LTE	UL 10 Mbps DL 50 Mbps
100 Mbps	Linux OS		10 Gbps	Linux OS		Wi-Fi	UL 30 Mbps DL 150Mbps

Table 4 - Hardware and software requirements – UC 2

2.3. UC 3 - Real-Time Video Acquisition and Production in the Edge/Cloud

The use case is organized n five steps, from the media creation to the media consumption. The crowd with their own smartphones makes the first step (Figure 6), enjoying the show and recording it. Because exists a lot of different devices in the market, each brand or model, have different types of video recording capabilities. These differences are in the framerate, codecs applied on the video and on the audio, etc. The differences create the necessity of the second step, the video and audio normalization. This step ensures all the streams have equal characteristics. The second step can be made on the MEC or Metro DC, or in both, the only requirement is processing power. The third step is to create a new feed based on the normalized crowd feeds and deliver it to the TV production centre. The fourth step is deliver the final content to the end user from the TV Production Centre to the Venue. The last step is the consumption of the feed by a user in the venue or nearby area. The figure 6 shows where each step is made on the live cycle.

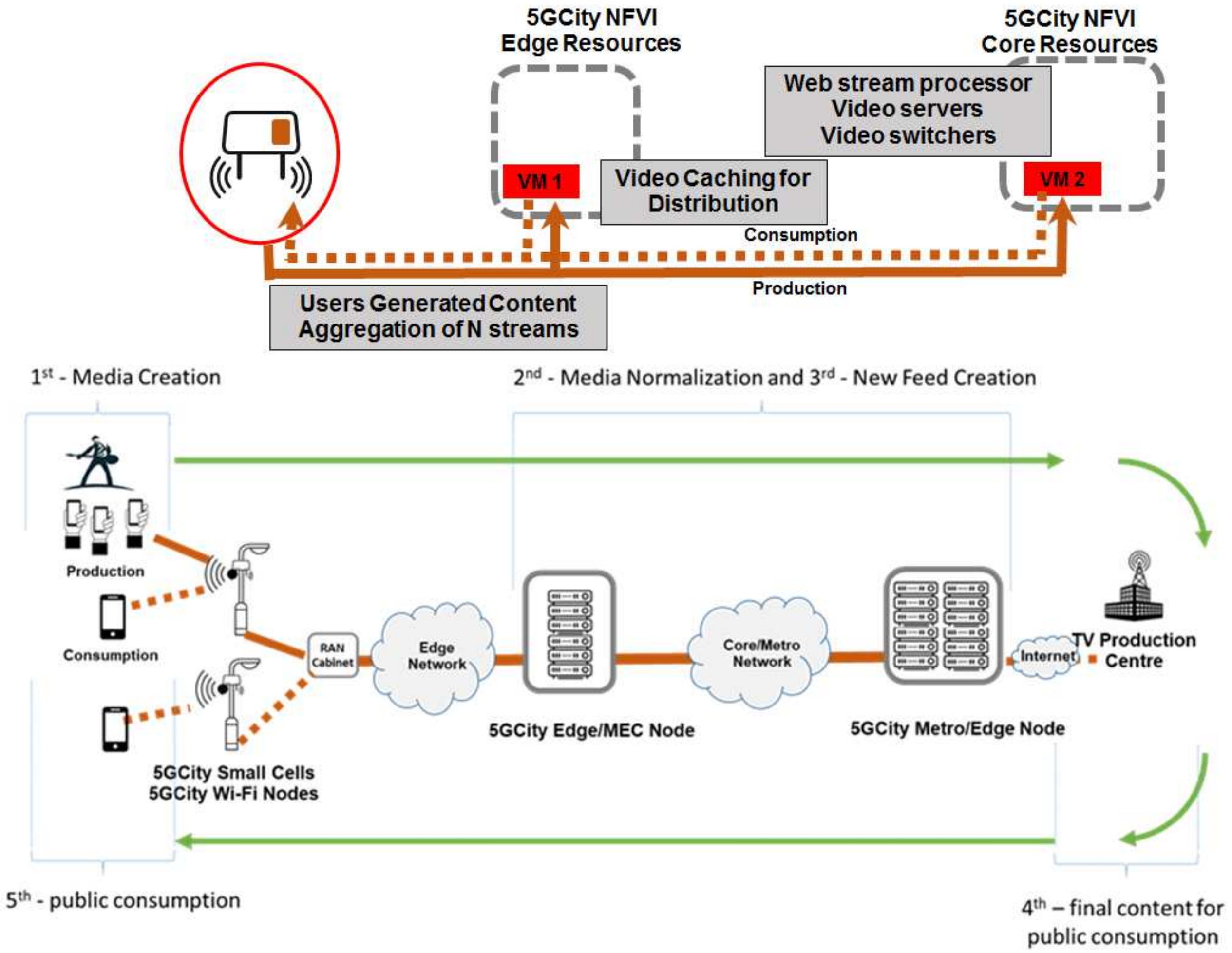


Figure 6 - UC3 deployment in the three-tier 5GCity infrastructure.

To deploy UC3 in 5GCity infrastructure some minimal requirements need to be met [4]. Table 5 summarizes the most important requirements. We assume that this requirement can be meet by placing the 5GCity MEC/Edge Node in the appropriated edge DC*.

Internet	Metro DC		Backhaul Network	MEC		RAN	
Data rate:≈50 Mbps	VM# 1	**Cores:** 16 **RAM:**16GB **Storage:**480GB SSD	**Data rate:** 900MBps	VM# 1	**Cores:** 16 **RAM:** 16GB **Storage:**480GB SSD*	LTE	**UL:** 8 Mbps **DL:** 4 Mbps
						Wi-Fi	**UL:** 8 Mbps **DL:** 4 Mbps

	Metro DC	Edge	End-user
Physical HW	➢ >= 16GB of RAM ➢ >=12 Cores Intel XEON processor ➢ >=10Gbps	➢ Traffic routing capabilities (routers and/or switchs). ➢ Wi-Fi access points	➢ Smartphone with HTML5 and WebRTC support
Connectivity	Fiber Optic between Metro DC and Street Cabinet • Latency < 10 ms • >= 10 Gbps	Fiber Optic between Lamppost and Street Cabinet ➢ Latency < 10 ms ➢ >= 1 Gbps	Wi-Fi between Small Cell and UE ➢ Latency <= 5 ms ➢ <= 1 Gbps

Table 5 - Hardware and software requirements – UC 3.

2.4. UC 4 – Ultra High Definition Video Distribution and Immersive Services

The immersive part of the project is designed 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 VR/AR/MR-like devices [4]. Also, with the production of video 360° to improve the immersion of the user experience. At the same time the visual search allows matching images or videos captured by the user, such as buildings, statues, paintings, with contents present in databases thanks to visual similarities. Additional content could be automatically retrieved, for example from television archives, in form of 2D video, panoramic video and 3D models that will augment the reality in which the user is immersed. New UHD/4K contents will be available for the users, just to create “digital pills” in a hypothetical journey that include more information and A/V. This use case requires ultra-high bandwidth, to carry high quality UHD/4K video signals and a very low system latency, which should enable to implement effective interactive applications. 5GCity architecture facilitates both with its distributed cloud & edge and radio 5G-platform (i.e., MEC node).

The video 360 material is produced with specific camera systems which have a minimum of two sensors, and two lenses, to have a field of view (FoV) as large as the whole spherical horizon around the camera. The different video contributions needed to be processed in suitable applications where the stitching of the different images, the color correction, the projection – usually in the equirectangular format – and the coding were performed. These systems lacked in synchronization among the cameras, which caused artefacts with moving objects. More recent products consist in a single system equipped with several sensors hardware synchronized. Some examples are: the Nikon Key Mission 360 with two sensors, the Orah 4i with four and the Nokia Ozo with eight sensors.

To generate video 360 material to be used as VoD, the Nikon system will be used both because of it easiness of handling and primarily because, being an “action cam” system, it is suitable for outdoor use. It records on an on-board micro-card from which the sequences can be transferred to an editing/processing machine for “makeup” and finally loaded on the video repository. To generate streaming material, the Orah 4i system will be used because it has an embedded streaming server capable to provide “live” video. This system requires electric power supply and must be used indoor. Both systems generate 4K sequences at 24/30 Hz with equirectangular projection which are undistinguishable from traditional UHDTV signals. For 360° video streaming, the distribution of live or VOD 360° video services over IP can follow two possible approaches [4]:

1.“Viewport-Independent” approach.

2.“Viewport-Dependent” approach with tiled encoding.

In both cases, it is assumed that an equirectangular projection is used for conversion of the 360° video into a two-dimensional rectangular video before the encoding stage.

From a more technical point of view, the Neutral Host model allows the building of end-to-end segmented slices, which encompass a wide variety of resources (network storage, computing). Those slices are leased to Service/Content Providers, which in turns can operate the virtual resources they have been assigned, by mapping their services to the set of slices that have been assigned.

Augmented reality provides an efficient and intuitive way to display computer-generated information overlaid and aligned with objects in the real environment. For this reason, AR solutions have been used to increase user experience in the context of cultural tourism. For example, many museums provide AR applications that, using markers, recognize the location and orientation of the user and overlap computer generated assets on the artwork the user is interested in. On the other hand, there are several challenges for outdoor solutions: first, the user tracking is not easy: there are GPS solutions, but they do not accurately provide position and orientation of the user. Moreover, there are places, such as urban canyons, where GPS does not work. The second issue is related with problems with the positioning of markers or target images in outdoor environment and problems with lighting control.

There are several prefixes added to the term Reality: Virtual Reality (VR), Augmented Reality (AR) and Mixed Reality(MR). The term VR includes video 360 where a view is recorded in each direction at the same time thanks to omnidirectional camera or collections of aligned and calibrated camera. VR is further subdivided into:

- 360 videos when the content is mostly based on video.
- CG VR (Computed Generated VR), when the content is mostly rendered by 3D models, in real time in the user's device.
- 360/VR when both 360 video and CG content are present at the same time.

The difference between the terms AR and MR is as follows:

- AR: is an overlay of content on the real world but such content is not anchored with it or part of it. Real-world content and CG content do not interact with each other.
- MR is an overlay of synthetic content that is anchored on the real world and interacts with it. For example, a virtual character who is placed on the table of the real world and walks on it. The key feature of MR is that virtual and real content interact with each other.

Both VR and MR provide different degrees of immersion, i.e. the perception of being physically present in a real or imaginary world. To achieve this, realistic audio (e.g. binaural or 3D audio), high-resolution images and support for natural user interaction are necessary. Such interaction with the world of VR/MR must be as close as possible to the one experienced by the user in real life, such as looking around from a fixed point: 3DOF, (Degree of Freedom) or moving freely in the real world and looking around objects: 6DOF. The latest technological advances in the field of multimedia, sensors and displays have made VR/MR possible thanks to Head Mounted Displays (HDM):

- **un-tethered**: for example, smartphones inserted into a headset (Google Cardboard (Figure 7(a)), Samsung Gear VR (Figure 7(b)). They provide only a 3DOF.
- **tethered** (wired or wireless): connected to a personal computer or console game (e. g. Oculus (Figure 7(c), HTC Vive (Figure 7(d)), Sony PlayStation (Figure 7(e)), Samsung Odyssey (Figure 7(f))).
- **self-contained:** HoloLens and Magic Leaps (the latter is still in development), they have a pc on board and are autonomous.

Figure 7 - VR Devices; a) Google Cardboard, b) Samsung Gear VR, c) Oculus, d) HTC Vive, e) Sony PlayStation VR, and f) Samsung Odyssey HMD.

One of the aim of use case 4 is 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 system will provide semantic information and additional content on monuments and sculptures to tourists visiting the involved cities. The main features of the use case are as follows:

- recognition of monuments and sculptures.
- showing information and history.
- possibility of viewing additional content.
- virtual reconstruction of monuments
- production and distribution in real time.

The visual search allows matching images or videos captured by the user, such as buildings, statues, paintings, with contents present in databases thanks to visual similarities, without the need for manual query input. These visual search algorithms are based on extracting key points from the image and creating descriptors representative of the image. One of the basic algorithms is the Scale Invariant Feature Transform (SIFT). The Moving Picture Expert Group (MPEG) in 2010 started a standardization called Compact Descriptor for Visual Search (CDVS) that offers a robust and interoperable technology to create visual search applications in image or video databases. The main blocks of the CDVS consists in extractors and compressors of local and global descriptors based on SIFT features.

As a first step, the CDVS database is filled with the descriptors of the reference images; then, in retrieval mode, a query image is compared with the database entry and a list of images based on a score is provided. One of the fields in which the 5G network will have a greater impact is visual search, thanks to the ability to offer Edge computing to speed up data analysis, low latency and the ability to transport more information. To provide an immersive experience, it was considered necessary to use a Head Mounted Display and the Microsoft HoloLens device was selected for the mixed reality application.

In 5GCity we will use Microsoft HoloLens: this device combines several technologies into a single, autonomous and portable device.

Figure 8 - Microsoft HoloLens and components.

The device is equipped with sensors that scan the real surrounding of the wearer and creates a map of its surrounding and at the same time orients itself properly within this map in real time. In relation to the real environment, three-dimensional or flat holograms can be placed and once a hologram is placed in the environment, the viewer can walk around it. Holograms can be any virtual 3D or 2D object. The HoloLens can be divided into several parts (Figure 8):

HoloLens are equipped with several sensors such as:

- four environment understanding cameras.
- one depth camera.
- 1 2MP photo/HD video camera (video a 30 FPS a 1,1 mega pixel (1408x792).
- 4 microphones.
- 1 ambient light sensor.

The HoloLens has some limits:

- Battery - The built-in battery of the HoloLens allows the user to move freely through the environment he is in. Using the HL continuously allows for about 2-3 hours of use.
- Weight - Another point that has to do with maximum time of usage, is the weight of the product.
- Resolution models - The HoloLens can process a maximum of 150.000 vertices safely. This is the total of all visible holograms. Only using visually simple objects, this is not a problem, however, the number of vertices grows exponentially when using more detailed objects.
- Limited field of view -it is quite noticeable that the field of vision is quite small compared to the total human vision. Holograms that are too big to fit on the holographic lenses, are cut off visibly.
- Surrounding - HoloLens uses spatial mapping to create a virtual representation of the real world to place holograms in. This does ask for a surrounding that can be mapped. If the user sits in a location that constantly changes, for example due to large streams of people passing by, or moving machines, the HoloLens will not be able to properly map the surrounding.

Figure 9 presents the mapping of the UC4 into the three-tier 5GCity infrastructure and summarizes the steps of the UCs in the three-tier 5GCity infrastructure.

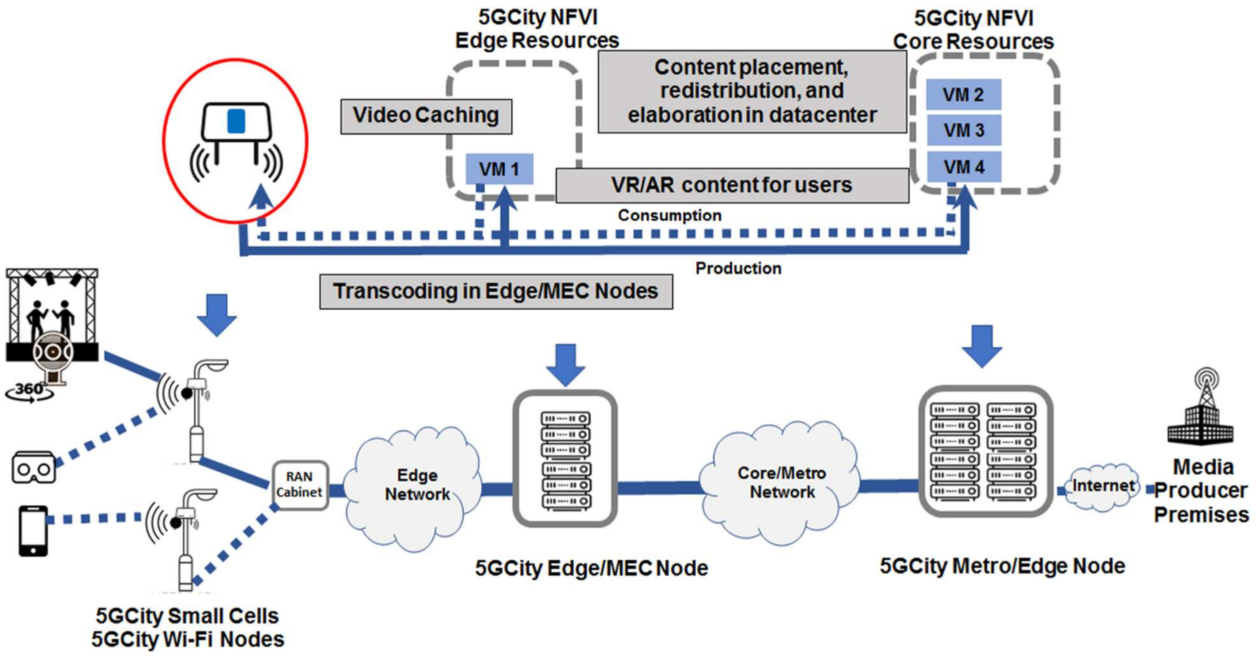


Figure 9 - UC4 deployment in the three-tier 5GCity infrastructure.

Internet	**Metro DC**		**Backhaul Network**	**MEC**		**RAN**	
A minimum 100 Mbps connection to Internet, in order to send the signal to the TV studios	VM# 1	Cores:2 RAM:16 GB Storage:128 GB	A minimum 100 Mbps connection to Internet, to send the signal to the TV studios	VM# 1	Cores:1 RAM:8 GB Storage:128 GB	LTE	UL 2 to 10 Mbps DL 5 to 20 Mbps
						Wi-Fi	UL 2 to 10 Mbps DL 5 to 20 Mbps
	VM# 2	Cores:2 RAM:32 GB Storage:1 TB				LTE	UL 2 to 10 Mbps DL

							5 to 20 Mbps
						Wi-Fi	UL DL

Table 6 - Hardware and software requirements – UC 4.

2.5. UC 5 - Mobile Real-Time Transmission

Currently almost all TV stations are using what in popular language is called “backpack unit” for video transmission in remote areas. The backpack unit bundles multiple 4G connection together to transmit the video signal back to the TV station for further processing. The mobile real-time transmission Use Case will demonstrate how the 5GCity architecture will improve the available bandwidth of live connections (real-time transmission) leveraging on the capacity of 5G network. 5GCity system will enable the increase of bandwidth used for live connections, provisioning specific slices with a guaranteed QoS, enabling edge computing processing capabilities for production of video contents at the edge. Furthermore, 5GCity architecture enables required video processing at the very edge instead of TV station, reducing the high production cost of multi-camera events [4]. Table 7 summarizes the connectivity requirements for transmission and video quality, Table 8 lists the infrastructure requirements. Finally, Table 9 presents the requirements for the deployment of UC 5 in the three-tier 5GCity infrastructure. The Figure 10 briefly describe the step followed by the UC 5 production and distribution (e.g., caching).

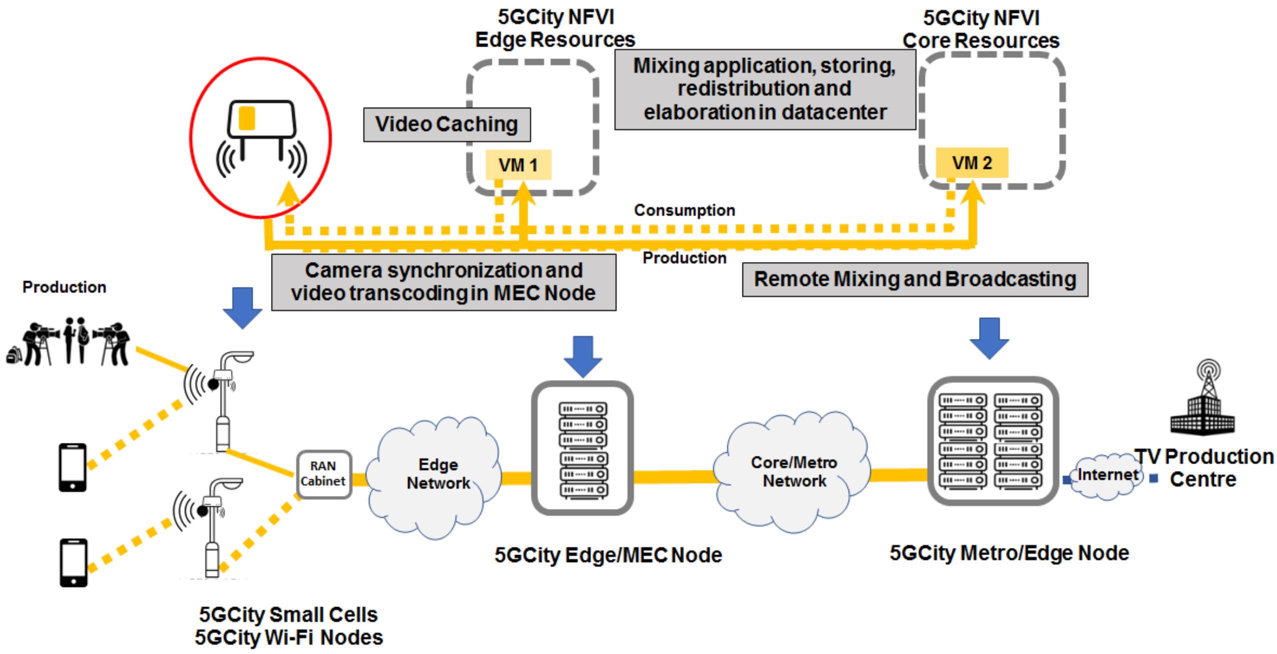


Figure 10 - UC5 deployment in the three-tier 5GCity infrastructure.

Part		Bandwidth
1	3G/4G/LTE modem or/and WiFi	SD 2-4 Mbps HD 6-10 Mbps
2	3G/4G/LTE modem or/and WiFi	SD 2-4 Mbps HD 6-10 Mbps
3	3x 3G/4G/LTE modem or 3x WiFi	From cameras to lamppost 3x SD 2-4 Mbps=12 Mbps (max) or 3x HD 6-10 Mbps= 30 Mbps (max) From Lamppost to betevé studios SD 6-8Mbps or HD 15 Mbps

Table 7 - Connectivity requirements I.

UC Part	Infrastructure requirements
1	backhaul connectivity to the TV studios using 5GCity infrastructure
2	backhaul connectivity to the TV studios using 5GCity infrastructure
3	8 Xeon CPU cores with 32 GB memory to allocate the 2 video stream servers plus de mixer server.

Table 8 - Infrastructure requirements II.

Internet	Metro DC		Backhaul Network	MEC		RAN	
Data rate	VM# x	Cores: RAM: Storage:	Data rate:10Mbps	VM# 1	Cores:8vCPU RAM:25GB Storage:	LTE	UL: 30Mbps DL: 4 Mbps
	Metro DC can also allocate the VM.					Wi-Fi	UL: 30Mbps DL:4 Mbps

Table 9 - Hardware and software requirements – UC 5.

2.6. UC 6 - Cooperative, Connected, and Automated Mobility

The goal of this use case is to demonstrate how 5G technology will be key in future Cooperative, Connected and Autonomous Driving. The use case hopes to align the EC's goals to build and deploy C-ITS (Cooperative Intelligent Transport System) and CCAM (Cooperative, Connected and Automated Mobility) across Europe's main roads as to provide specific services to involved vehicles with the goal of achieving a safer and more efficient driving experience. As such, this use case is focused on V2I (Vehicle-to-Infrastructure) and V2N (Vehicle-to-Network) communications as to demonstrate how Service Providers can leverage the distributed nature of resources found in typical cellular network deployments to provide seamless and reliable CCAM services. Having in mind future 5G deployments where a great number of small cells is expected to hit the market, the use case hopes to demonstrate how the novel Neutral Host paradigm will make way not only for efficient new 5G network deployments but also dedicated services making use of the distributed resources and the right framework to facilitate the orchestration and management of such services. From a business perspective, the use case hopes to demonstrate how these deployments are envisioned to happen in the future, with direct impact in the whole value chain and relevant 5G-actors' business model. The combination of innovative technology such as Edge/Fog Computing, Network Slicing and flexible use case driven V-RAN deployments showcases how novel 5G-based services will surface, having a specific goal in mind, backed by an agreed upon SLA, effectively making way for new MVNOs and Service Provides to enter the market, while also reducing OPEX and CAPEX costs for existing Service Providers. This efficient re-use of available resources to deploy services (dedicated applications) on top of will be facilitated with the introduction of standard frameworks such as ETSI MEC and other fog-oriented ones like fog05 and OpenFog, which is also a key component of the use case's.

Due to such low latency and reliability requirements of such scenario, the use case will rely on a dedicated slice spanned across the three tiers of 5GCity's architecture: core, edge and extended edge. Having in mind that such warnings must be communicated to the vehicle in less than 10ms after a successful connection and that the vehicle must trust this information to autonomously react to such information, the notion of trust and secure computing will not be overlook. To tackle this requirement, a dedicated Edge VIM will be used to ensure the integrity and authentication of such edge resources, by leveraging the hardware's TEE (Trusted Execution Environment) and virtualized TPM (Trusted Platform Module) to (i) securely instantiate applications in secure ARM nodes and (ii) provide a notion of trust between vehicles and these edge resources. Furthermore, for an efficient usage of resources and to make sure the lowest latency is perceived, the Edge Application instantiated at the cabinet level will be the one solely responsible to transmit any warning to any connected vehicle – any other long-running task will be allocated by such application to those resources with less computational power instantiated at the extended edge (lampposts). The goal with this distribution of data is also to ensure the data is intelligently and efficiently stored as close as possible to the end user – in future deployments where a different RAT (radio access technology), such as LTE-V2X using the PC5 interface, would be available, these extended edge resources would then be the ones responsible to announce such alerts through this dedicated V2I link (vehicle connected to an ad-hoc link provided by the lamppost, with fewer network hops and redundancy). Figure 11 summarizes the deployment of UC 6 in the three tier 5GCity infrastructure.

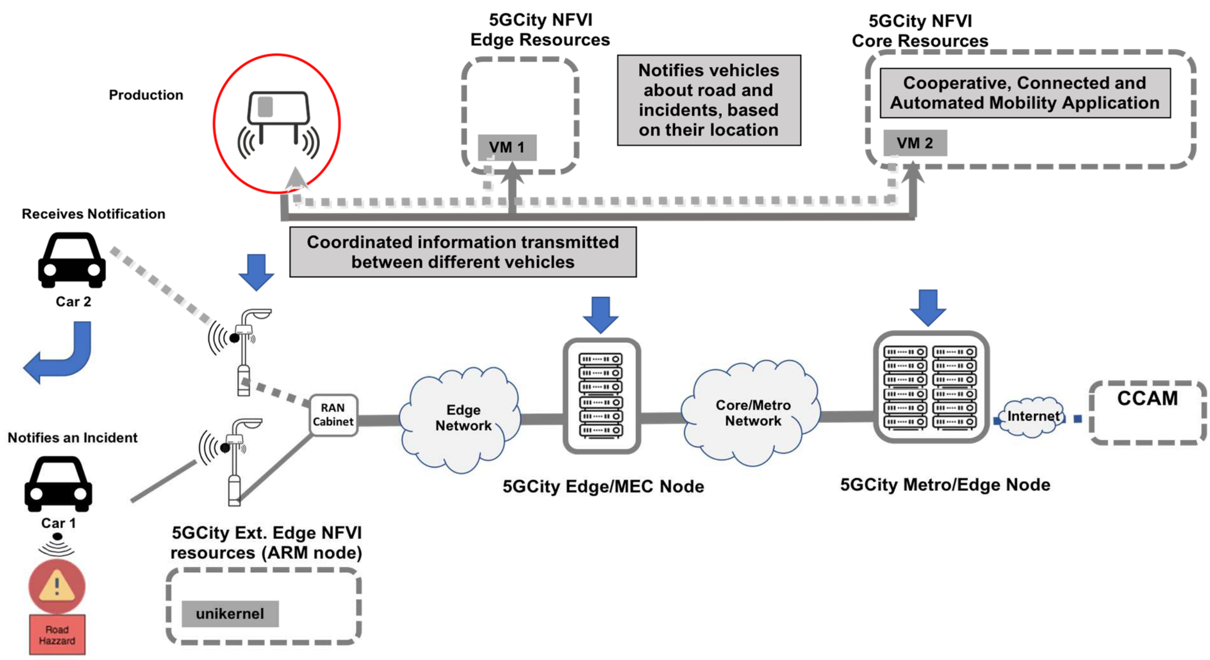


Figure 11 - UC6 deployment in the three-tier 5GCity infrastructure.

Table 10 summarizes the minimal requirements for each UC. In terms of radio (wireless) bandwidth for video uploading (UL) and/or downloading (DL). Network bandwidth to transmit the video from the radio to edge and core datacenters. And, number virtual machines (VMs) placed in edge and core datacenters. And finally, the Internet connection required for remote control. In the next section we use the given requirements to construct an illustrative example of the 5GCity UCs deployments.

	Metro DC	**Edge**	**Extended Edge**	**End-user**
Physical HW	➢ 3 x 32-96 GB RAM ➢ 6-12 Cores E5-2650v4 @ 2.2 GHz ➢ 2 TB SSD (tentative)	X10SDV-12C-TLN4F+: ➢ 12 Cores (Intel® Xeon® processor D-1557) ➢ 128 GB RAM ➢ 2 x 960GB SSD	➢ Samsung Exynos542 2 Cortex™-A15 2Ghz and Cortex™-A7 Octa core CPUs ➢ 2Gbyte LPDDR3 RAM PoP stacked ➢ 64 GByte eMMC5.0 HS400 Flash Storage	NA
Allocated HW (minimum required)	• 2 Cores • 2 GB RAM • 1 x 15 GB SSD	1 * MEC Server: • 2 Cores • 2 GB RAM • 1 x 25 GB SSD 2 * Small Cells (Accelleran's E1000 series @ 3.5 GHz)	• 2 A7 Cores • 1 GB RAM • 1 x 15 GB SSD	2 x UEs compatible with 3.5 GHz radio
Number of Applications	1	1	1	1
Virtualization (application)	Any	Edge Vim (trust, security and integrity)	Fog05	NA (Orchestration and management of such application from the platform is not envisioned)
Connectivity	Fibre Optic between Metro DC and Street Cabinet. DL and UL @ Metro:	Fibre Optic between Lamppost and Street Cabinet. DL and UL @ Edge:	Fibre Optic between Street Cabinet and Lamppost.	3.5 GHz between Small Cell (Lamppost) and UE. Perceived DL and UL

	➢ Latency <= 20 ms ➢ Bandwidth >= 1 Gbps	➢ Latency <= 3 ms ➢ Bandwidth >= 1 Gbps	DL and UL @ Lamppost: ➢ Latency <= 1 ms ➢ Bandwidth >= 1 Gbps	and UE: ➢ Latency <= 3 ms ➢ >= 500 Mbps

Table 10 - Hardware and software requirements – UC 6

2.7. Deploying the UCs

After discus the deployment requirement of each UC on the three-tier 5GCity infrastructure a summary is introduced in Table 11. The requirements are upload and download rate Radio (Wi-Fi / L TE) the network bandwidth, Edge VM, Core VM and Internet Mbps.

UC	Radio (Mbps)	Network (Gbps)	Edge (VM#)	Core (VM#)	Internet (Mbps)
#1	UL:2 DL:2	~10	1	1	**50**
#2	UL:Variable DL:Variable	~10	1	5	100
#3	UL:2-8	~2	1	1	50
#4	UL:100 DL: 20	~1	1	3	100
#5	UL:10	~0.1	1	1	50
#6	UL:500 DL:500	~0.5	1	1	50

Table 11 : Minimal requirements for UCs production.

3. 5GCity Infrastructure Deployment

This section describes the 5GCity infrastructure deployment in the City of Barcelona, in the City of Bristol, and in the City of Lucca.

3.1. 5GCity Infrastructure Deployment in the City of Barcelona

This subsection introduces 5GCity infrastructure deployment in the City of Barcelona by first defining the area for the trials, the planned deployment, and each node and components.

3.1.1. Area for The Trials in Barcelona

The area selected for the 5GCity trials in the City of Barcelona is in the 22@ area in the district Sant Marti. In this area is located the 22@ Superblock (Figure 12), an integral solution to the use of public space, uniting urban planning with mobility, and limiting the presence of private vehicles to return the public space to the citizen.

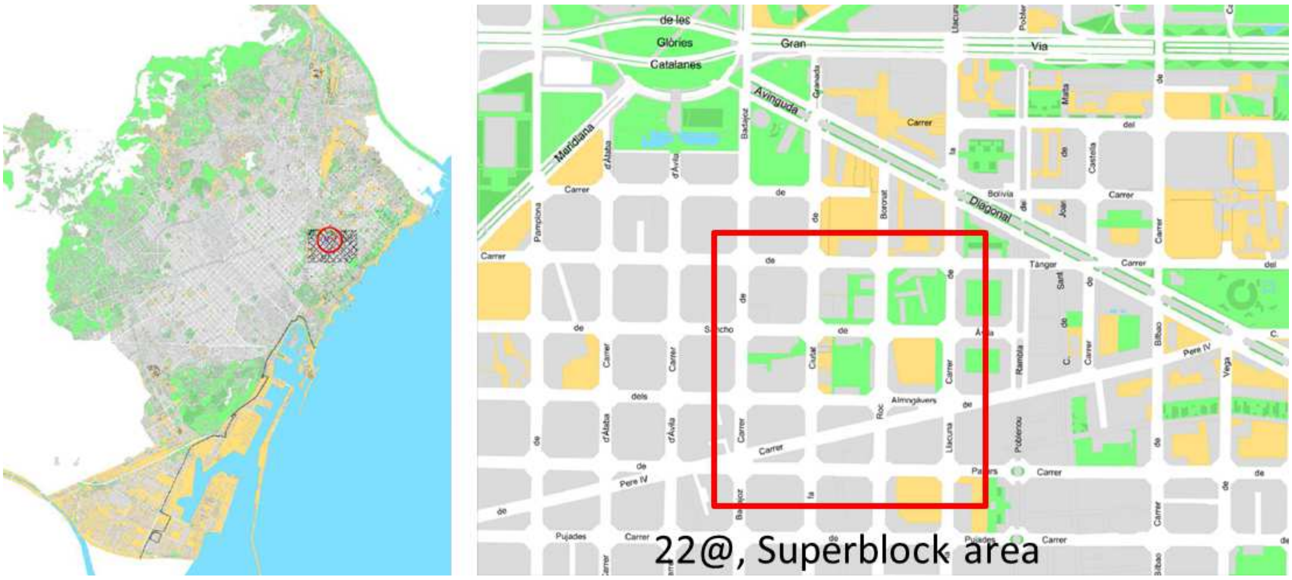


Figure 12 - Superblock (Supergrilla) area projected for 5GCity trials in the City of Barcelona.

3.1.2. Projected Deployment in Barcelona

The infrastructure projected for 5GCity deployments and trials comprises eight to nine lampposts for 5GCity Small Cells (Accelleran) and 5GCity Wi-Fi Nodes (I2CAT), connected through public fibre optics with two streets cabinets that will house 5GCity Edge/MEC Nodes (Figure 13). The two cabinets will be also connected to the 5GCity Metro/Edge Node housed in the Omega Building premises of I2CAT (OMEGA-DC) where the 5GCity platform will be hosted.

Figure 14 introduces the core network architecture of the Barcelona infrastructure. The left side of the figure illustrates the optical connectivity (passive optical network (PON)) between the OMEGA-DC housing the 5GCity Metro/Edge Node) and the IMI Glories Office, which serves as connection point to the 22@ Superblock area where the 5GCity Small-Cells and 5GCity Wi-Fi Nodes are deployed (right side of the figure).

.

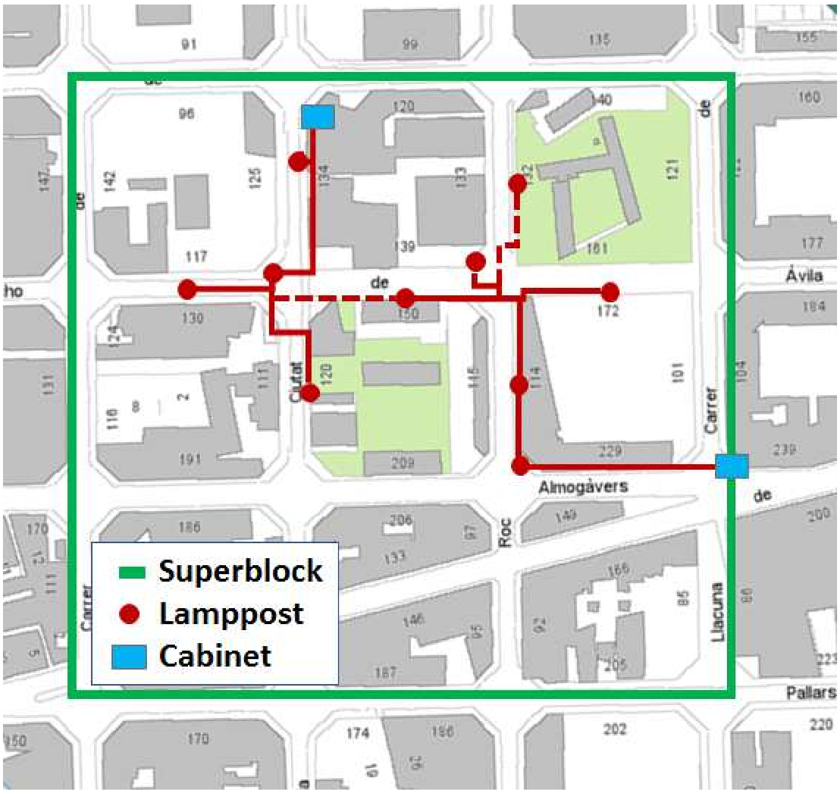


Figure 13 - Lampposts, cabinets, and main fibre connections (red lines) to be available for 5GCity deployment.

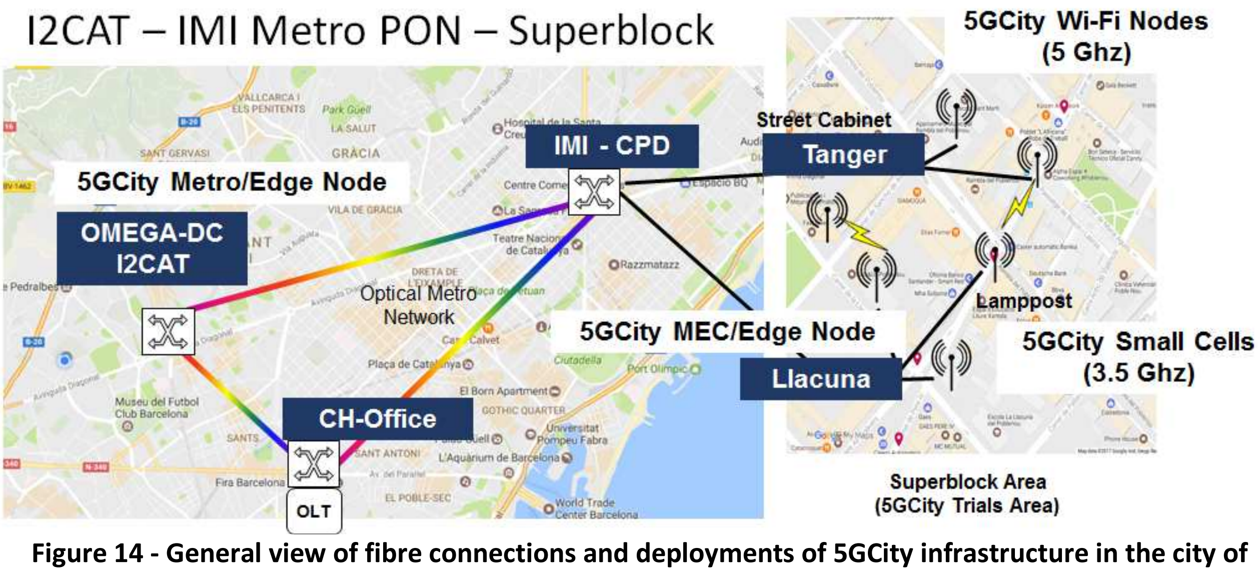


Figure 14 - General view of fibre connections and deployments of 5GCity infrastructure in the city of Barcelona.

The second important site for 5GCity deployment in the City of Barcelona is the i2CAT premises located in Zona Universitaria (CH-Office), west part of the city. This site can host the 5GCity Metro/Edge Node 2 to provides computing resources for 5GCity platform and main components of the software architecture, with computing capabilities available for slicing. The two sites (i2CAT and 22@ Superblock area) are connected using fibre cabling. Finally, the three-tier 5GCity infrastructure deployment in the City of Barcelona (Figure 15) can be summarized as:

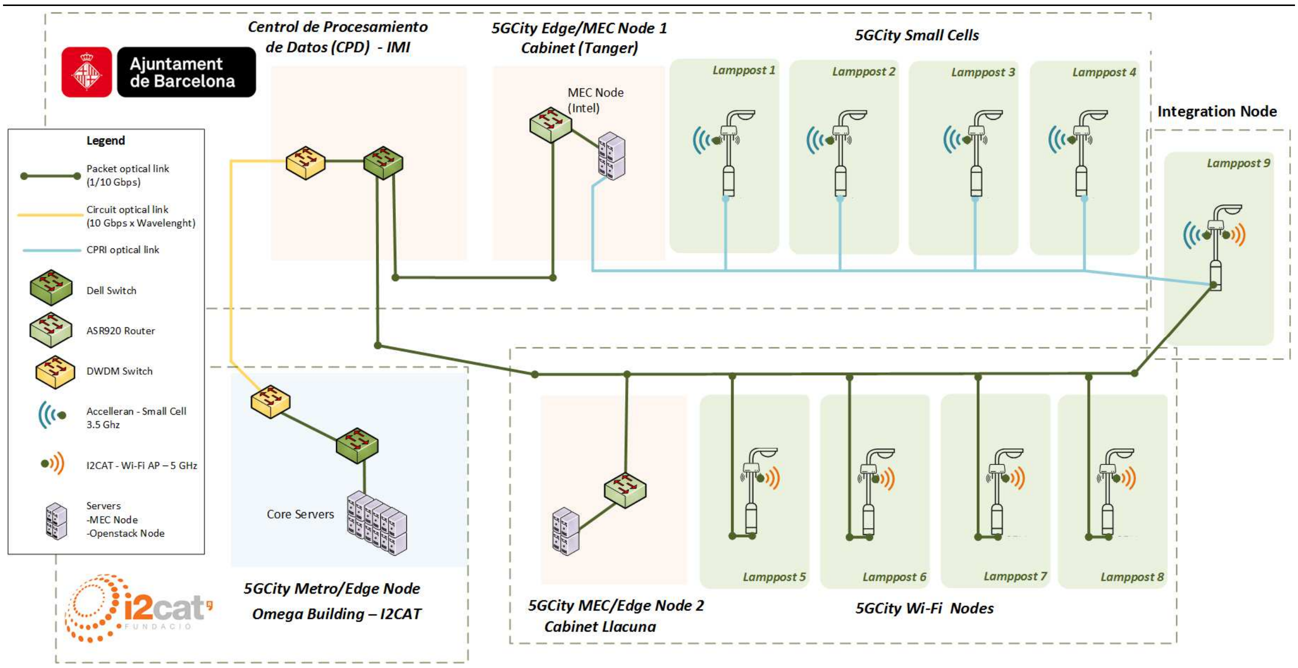


Figure 15 - Detailed logical network diagram of the Barcelona deployment

1. **5GCity Small Cells / 5GCity Wi-Fi Nodes**: Located at street level, lampposts hosting the RAN technologies, small cells and Wi-Fi, to connect end users to the 5GCity infrastructure (Figure 16).

2. **5GCity Edge/MEC Nodes**: Located between the street level and the orchestrator, the MEC nodes will host the computational power for deploying the last mile software components on demand. The MEC nodes will be located as closed as possible to lampposts (i.e., street cabinets in Llacuna and Tanger (Figure 16)). In Barcelona, two different configurations for MEC Node enable deployment will be tested:
    a. In the cabinet at street level or closer to the lamppost.
    b. In the technical room at IMI premises far from the lamppost.

3. **5GCity Metro/Edge Node:** Will be placed at i2CAT-DC premises to host and to control the operation and orchestration of the infrastructure by managing the components distributed at different levels.

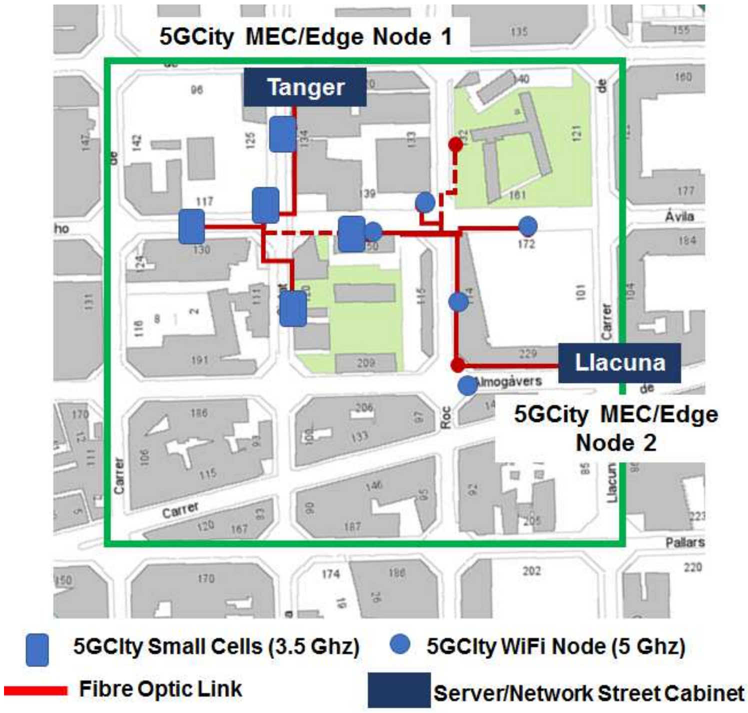


Figure 16 - Map of planned deployment of 5GCity Small Cells (provided by Accelerant), 5GCity Wi-Fi nodes (provided by I2CAT), and the 5GCity Edge/MEC nodes.

3.1.1. 5GCity Small Cells in Barcelona

The 5GCity Small Cells in the City of Barcelona will use LTE RAN access components based on Accelleran commercial technology. The LTE RAN will be implemented using commercially available outdoor small cells (Accelleran E1000) which will implement the RRU component of the 3-Layer based architecture, while the associated vRAN controller will run in the edge. The LTE Small Cells to be used in City of Barcelona will operate in the frequency band B42 (3.4 – 3.6GHz).

Figure 16 depicts a city street map of the Sant Martí district in the City of Barcelona, where the positions of the lampposts and the MEC servers are marked. The four leftmost lamp posts will be equipped with 5GCity Small Cells, whereas the rightmost four lamp posts will be equipped with 5GCity Wi-Fi nodes. The central lamp post is reserved, if possible, to be used for an integration of both RAN technologies once the LTE and Wi-Fi nodes have been tested separately. The fibre connections for the lampposts equipped with 5GCity Small Cells and the integration lamppost are aggregated at the top server location (Tànger street) in IMI premises, while the fibre for the Wi-Fi nodes is aggregated at the street cabinet in Llacuna street. For the City of Barcelona, the 3.5GHz (3GPP B42) variant of the Accelleran E1000 Small Cell Series (E1010) will be deployed with the Accelleran Small Cell Software Solutions which allow the disaggregation and virtualization of Small Cell L3 components running at 5GCity MEC/Edge Node and providing virtualized vRAN Small Cell cluster with specialized functions for control a cluster of multiple Small Cells in lampposts.

3.1.1.1.. ACCELLERAN E1000 Small Cell

The B42 variant of the Accelleran E1000 Small Cell Series (E1010) (Figure 17). The characteristics of the 3.5GHz E1010 Small Cells are the following:

- 2 x 2 MIMO.
- Local area basestation class.
- 24dBm/250mW RF power per antenna port.
- 1 transceiver per unit (single cell)
- 1 GBE (PoE+) port.

- Embedded GNSS (GPS, GLONASS, BDS).
- 2 x N-Type female external LTE antenna ports.
- 1 x N-Type female external GNSS antenna port.
- 56V PoE270 x 200 x 65 mm (3.5 litres exc. antennas).
- IP67.
- 2.8 Kgs.
- -40ºC to +50ºC operating temperature.

Figure 17 - Accelleran E1000 LTE Small Cell.

Accelleran E1010 Small Cells are delivered with a universal pole mounting kit (Figure 27). However in the case of City of Barcelona and as part of 5GCity project, an special mounting kit has been developed to attach the E1010 into the standard Barcelona radome fixtures and permit orientation on a different plane from other equipment that might be mounted on the same lamppost (ex. 5GCity WiFi Nodes).

Figure 18 - Accelleran E1000 integrated for Barcelona.

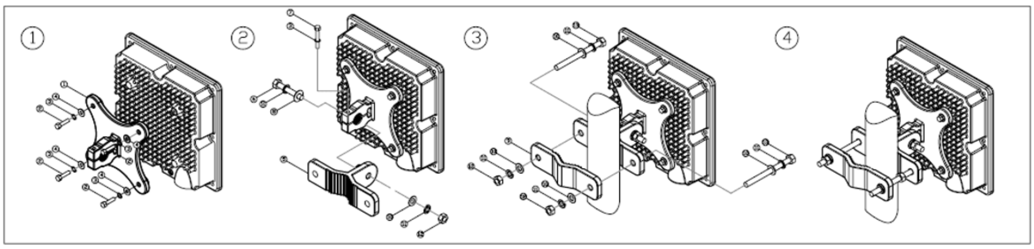


Figure 19 - Standard pole mounting bracket.

Electrical grounding of the E1010 / E1013 is provided through an external grounding connection. The E1010 is delivered with a separate PoE+ injector but is compatible with compliant PoE+ power supplies. In the case of the City of Barcelona, for example, a PoE+ compatible power supply will be provided as defined in standard deployments for ICT in the City of Barcelona lamppost deployments. This will use the current available power supply design and provide the possibility to have optional uninterrupted power supply components (batteries) in this existing design.

The antennas recommended for general deployment with the E1010 Small Cells are single pole vertically polarised fiberglass antennas with N-type connections that can either be directly attached onto the E1010 Small Cell or mounted separately and connected via RF feeder cables. Alternative antennas can be specified where necessary. The Radiation Patterns at 3500 MHz (H-Plane and E-Plane) are ilustrated on Figure 29

The characteristics of the recommended antenna are as follows:

- Bandwidth: 200 MHz.
- Gain: 6 dBi.
- Vertical Beamwidth: 28.
- VSWR: <= 1.5.
- Impedance: 50 Ohms.
- Polarisation: Vertical.
- Connector: N-Type female.
- Dimensions: ⏀20 mm x 300 mm.
- Weight: 180g (Without bracket).
- Pole diameter: ⏀35 mm-⏀50 mm.

Figure 20 - Recommended omnidirectional antenna.

E1010/E1013 supports an internal GNSS receiver for location and timing reference. An outdoor antenna is provided with each unit which must be fitted for normal operation to be possible. Figure 30 presents the radiation pattern of the E1010/E1013 small cells.

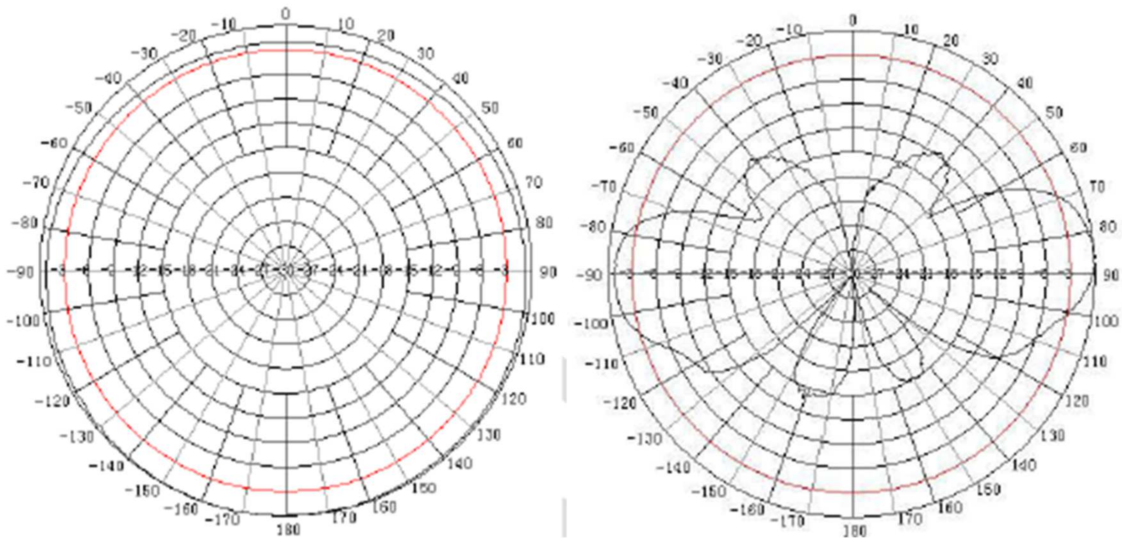


Figure 21 - Radiation patterns at 3500 Mhz.

3.1.1.2.. Virtual RAN and MEC Gateway

The E1000 small cells may be deployed as fully integrated eNB solutions providing a “classic” eNB solution. In this configuration the networking interface of the E1000 transports the following interfaces:

- S1 Control to MME.
- S1 User to SGW.
- OAM to remote EMS.

Alternatively, Accelleran supports a virtual RAN configuration where the disaggregated control plane functions of the eNB execute on the edge server, freeing resources in the embedded platform and enabling cluster-level control of radio resources and mobility decision making. 5GCity deployments will make use of the vRAN configuration to support Neutral Host applications. In the vRAN configuration the networking interface between the RRU (E1000) and the BBU (edge vRAN) transports the following interfaces:

- RRC Control from vRAN BBU to RRU.
- User traffic to BBU.
- Configuration and monitoring flows from vRAN BBU to RRU.

Accelleran also supports the optional instantiation of a vEPC function either on the E1000 platform itself (“Network in a Box”) or on the edge server. In 5GCity deployments, a vEPC instance can optionally be established on the edge server to provide local termination of user traffic for Multi-access Edge Computing applications. Lifecycle management of the vEPC instance and associated networking is orchestrated by the 5GCity virtual network infrastructure.

3.1.1.3.Neutral Host and Network Slicing

The Accelleran vRAN solution supports end-to-end network slicing via its software defined networking architecture. Slicing support for LTE 4G compliant systems is necessarily limited, due to the constraints of the standards which do not support slicing concepts directly. The following slicing features can be supported in 5GCity

- Mapping of User (IMSI) to slice.
- Mapping of PLMN ID (network ID) to slice.
- Mapping of S1-C instance (MME) to slice.
- Layer 2 (MAC) level resource isolation per slice.

Slice allocations and configuration is carried out dynamically through an SDN interface based on NETCONF / YANG, which is integrated into the 5GCity orchestrator.

3.1.2. 5GCity Wi-Fi Nodes in Barcelona

5GCity Wi-Fi Nodes will be important resources in the tier 1 of 5GCity infrastructure to provide flexibility and addition sliceability and throughput. In the City of Barcelona, 5GCity WiFi Nodes will be constructed and provided by I2CAT. They mainly consist in single board computers (SBC) equipped with IEEE 802.11ac interfaces and omnidirectional antennas. Each SBC with wireless interfaces is provided with a weather resistant casing that also provides a power converter to adapt to the voltage of the SBC, O/E media converter, a Ethernet switch to connect the various Ethernet port of the SBC and a battery to provide backup power in case the mains power fails. Further, an alarm module is installed that allows to check for any critical state of the components in the box and to perform remote resets of the devices inside the box. Figure 22 shows the interior of the box as seen when removing its top cover.

The SBC chosen for this project is a Gateworks (GW) Ventana 5410 board that has the following main characteristics:

- Freescale™ i.MX6 1GHz quad core ARM® Cortex™ -A9 automotive grade processor.
- 1Gbytes DDR3-1066 SDRAM memory.
- Micro SD™ flash expansion socket.
- Six High-Power Gen 2.0 Mini-PCIe sockets.
- Two GbE Ethernet ports.
- General Purpose Digital I/O and I2C expansion port.
- 8 to 60 VDC input voltage range.
- Power through ethernet or a barrel jack.
- 4W typical operating power.
- -40°C to +85°C operating temperature.

Figure 22 - Interior of the casing holding the SBC, battery, ethernet switch, power module, and an alarm module (top to bottom).

The GWs offer 6 PCI-e slots, allowing for the use of multiple Wi-Fi cards. In the 5GCity deployment, each GW will be equipped with several Wi-Fi NICs (Figure 23), operating as access points to grant access connectivity to user equipment. In 5GCity, two wireless interfaces will be used per lamp post; using different radio channels on each of the interfaces allows for an interference free, simultaneous use of the radio spectrum in one and the same area. The interfaces are Atheros 10k NICs (QCA 9888 with 2x2 MIMO), with the following technical details:

- IEEE 802.11ac/n.
- 2.4 GHz, 5 GHz.
- Up to 867 Mbit/s.
- 20/40/80/160 MHz Channels.
- 2 Spatial Streams.

Figure 23 - Interface Atheros 10K

Since the interfaces support 2x2 MIMO, each interface will be equipped with 2 antennas (Figure 24) with the following characteristics:

- Frequency range 2.4 GHz-2.5 GHz / 5.15-5.9 GHz.
- Gain @ 2.4 GHz: 5 dBi, gain @ 5 GHz: 5 dBi.
- Polarization: vertical.
- Back ratio: N/A.

Figure 24 - Antenna

.

Since every Wi-Fi node will be equipped with two wireless network interfaces, each with 2 antennas, the overall number of antennas per Wi-Fi node sums up to 4.

3.1.3. 5GCity Edge/MEC Nodes in Barcelona

Mobile/multi-access edge computing (MEC) is a network architecture concept that enables application developers and content providers cloud-computing capabilities and an IT service environment at the edge of the network. The basic idea behind MEC is that by running applications and performing related processing tasks closer to the cellular customer, network congestion is reduced, and applications perform better. MEC provides a new ecosystem and value chain. Operators can open their radio access network (RAN) edge to authorized third-parties, allowing them to flexibly and rapidly deploy innovative applications and services towards mobile subscribers, enterprises, and vertical segments. This environment is characterized by ultra-low latency and high bandwidth as-well-as real-time access to radio network information that can be leveraged by applications.

Technical standards for MEC are being developed by the european telecommunications standards Institute (ETSI), which has produced a technical white paper about the concept. MEC provides a distributed computing environment for application and service hosting. It also could store and process content near cellular subscribers, for faster response time. Applications can also be exposed to real-time radio access network (RAN) information.

The key element is the MEC application host which is integrated at the RAN element. This server provides computing resources, storage capacity, connectivity and access to RAN information. It supports a multitenancy run-time and hosting environment for applications. The virtual appliance applications are delivered as packaged operating system virtual machine (VM) images. The platform also provides a set of middleware application and infrastructure services. Application software can be provided from equipment vendors, service providers and third-parties. For more details please consult the deliverables D3.1 [6] and D4.1 [7].

MEC nodes need to provide computing, storage, and connectivity at the edge of the network in the second tier of 5GCity infrastructure. These servers should be able to onboard VMs and interconnect them also to the ones that will be deployed in the core network to provide end-to-end services. In the City of Barcelona, 5GCity will deploy and test Intel MEC node solution. *Intel MEC host* called 'Fog Computing Reference Design' will be engineered for testing in each city. The proposed Intel MEC nodes have small form factor (not standard) with low power consumption, Ethernet and 802.11ac/b/g/n network connectivity, and FPGA to offload some computation from the CPU. As storage they have an M2 SSD drive for the operating system and rooms for more hard drives as well as PCIe interface for GPU devices. As operating system the Intel MEC node uses Ubuntu Server 16.04 LTS. The Intel MEC node uses a CPU Intel Xeon E3-1275 V5 (4C,8T, 3.6 GHz), 32GB DDR4-ECC RAM, SSD M2 256GB, FPGA module Intel Cyclone V GT, the network is 1 GB Ethernet port, Wi-Fi 802.11ac/b/g/n M2 module. The dimensions are 230mm x 230mm x 105mm. The power consumption is 220W max.

Both 5GCity Edge/MEC Nodes will be deployed at Llacuna and Tànger cabinets. It mainly consists of a router ASR920 and an intel processor. Cisco ASR920 Series Aggregation Services Router provide a comprehensive and scalable set of Layer 2 and Layer 3 VPN services in a compact package. They also offer the high throughput and low power consumption ideal for mobile backhaul. The intel MEC server equipment (CAB0) serving as compute node for the Llacuna cabinet is provided by ADlink, whereas CAB1 is a server provided by i2CAT. The characteristics are given in Table 12. Note that CAB0 is intended to be deployed in the cabinet located in Llacuna street, whereas CAB1 is intended to be deployed in the technical room in Tànger street.

Name	Roles	Software	vCPU (#*GHz)	Memory (GB)	Storage (GB)	Ethernet ifaces (GbE)	PCIE
CAB0	Compute, Volumes	Ubuntu 16.04.3	4 x 3.6GHz	32	256 SSD	1	3
CAB1	Compute, Volumes	Ubuntu 16.04.3, OpenStack Ocata	12 x 1.5 – 2.10 GHz	128	1800 SSD	2	1

Table 12 - 5GCity MEC / Edge Nodes hosts/server for Barcelona

On one hand, Tànger will be connected using a 10 Gbps fibre to IMI in Glories switch. This will be filtered to I2CAT premises. On the other sides, Llacuna will be connected using 10 Gbps fibre to IMI Glories switch. This will be filtered to I2CAT premises to connect with 5GCity Metro/Edge Node. The RAN cabinets to host the 5GCity equipment will contain a dedicated area for the project only accessible by the 5GCity maintainers. Thus, incidences in other services hosted at the same cabinet will not affect the operation the 5GCity services. This division among services will be applied in both the street cabinet and the technical room at IMI's premises. Thus, the street cabinet deployed includes 4 locked doors (Figure 25) to provide differentiated locked accesses to the hardware installed.

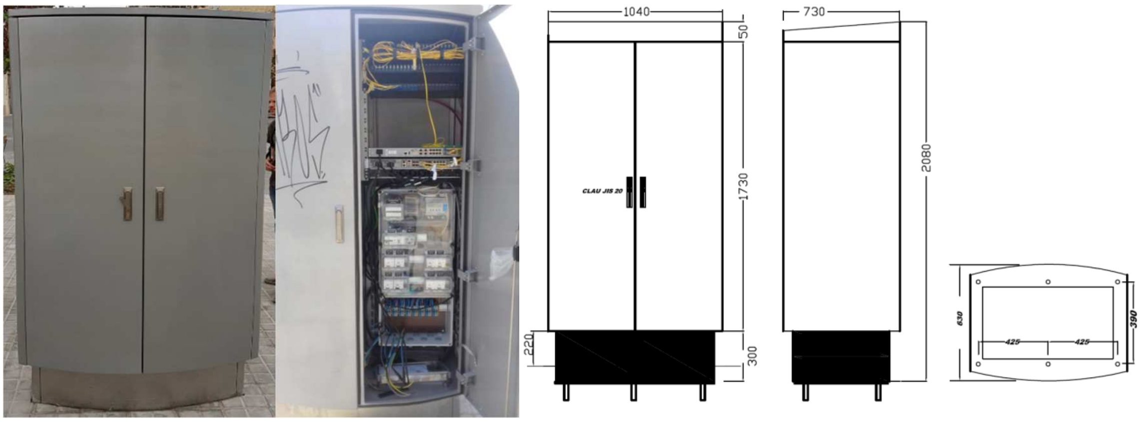


Figure 25 : Street cabinet at Llacuna street. Dimensions (right) and actual image (left).

The cabinets will include HW resources such as the 5GCity Edge/MEC server, router and power supply protections.

3.1.4. 5GCity Metro/Edge Node in Barcelona

The 5GCity Metro/Edge Node will be located at the i2CAT premises *("Omega"* building) or OMEGA-DC (Figure 14). It mainly consists of 3 servers for computing resources. These servers are embedded in a network infrastructure that connects the servers with each other, with the IMI site and to the Internet. The details of each server are given in Table 6.

The three servers have different characteristics (CPU, RAM, Storage) and play different roles within the scope of the OpenStack deployment. The servers are also connected to the Internet, serving as a connection point to external services while enabling up to 1 Gbps of Internet connectivity.

Name	Roles	Software	vCPU (#*GHz)	Memory (GB)	Storage (GB)	Ethernet ifaces (GbE)	PCIE
IAS0	Controller	Ubuntu 16.04.3, OpenStack Ocata	4 x 3GHz	32	240 SSD	4	1
IAS1	Controller, Compute, Volumes	Ubuntu 16.04.3, OpenStack Ocata	6 x 2.4GHz	96	1900 SSD	6	3
IAS2	Controller, Compute, Volumes	Ubuntu 16.04.3, OpenStack Ocata	6 x 3.5GHz	96	1900 SSD	6	3

Table 13 - 5GCity Metro/Edge Node hardware for Barcelona.

The OpenStack software services will be available in Barcelona as part of the 5GCity deployment. OpenStack components are mainly deployed in a Hyper-converged way. It means that some servers are working with controller, networking, storage and compute tasks. This architecture provides these benefits:

- A high available OpenStack installation can be deployed with only 3 physical servers.
- All hardware resources are fully used.

Figure 26 shows the major components of OpenStack and its deployment over the three main servers (IAS0 to IAS2) and the edge server (indicated as CAB1 in the figure). Since the CAB1 is located in the network edge, it will not act as a controller.

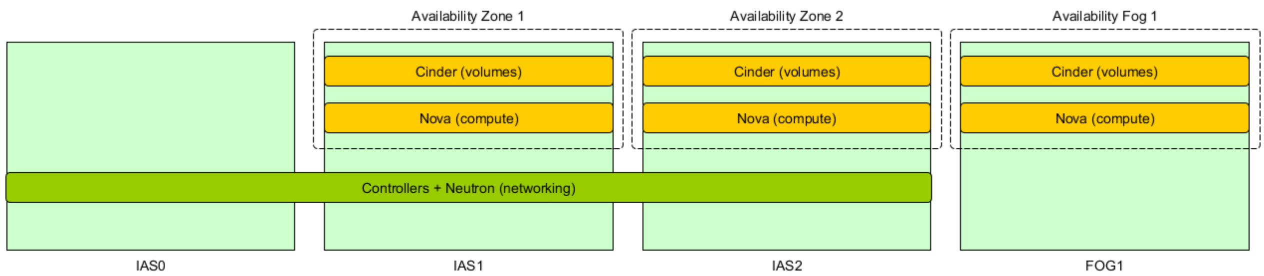


Figure 26 - Deployment of the OpenStack components in the 5GCity Metro/Edge Node.

3.1.5. Fibre infrastructure deployment in Barcelona

This section presents the work done by Cellnex Telecom to provide the dark fibre connection routes among the City of Barcelona main sites of the project. The routes covered by the dark fibre are:

- From IMI to BeTeVe (Plaça Tísner 1).
- From IMI to Barcelona Llacuna street MEC (Cabinet).
- From IMI to Eurona (directly at Eurona Premises).
- From IMI to i2Cat (Nexus at C/ Gran Capità 2).

The work consisted in a study of the dark fibre network underneath Barcelona by analysing one by one, the number of possible paths derived from all the connection boxes and fibre sections along with their capacity and the already performed connections plus spare connections and fibres in each section. From all these studies a final route with 2 fibres is generated for each site. Figures 27 and 28 present the resulted 2 fibres to be used for 5GCity. A more detailed description of the fibre connections is in annex section.

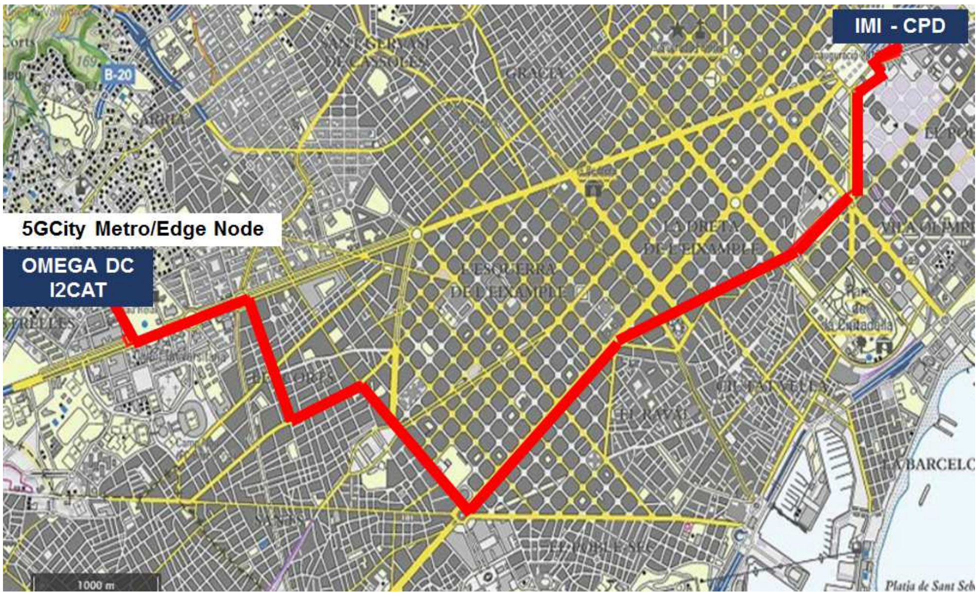


Figure 27 - Fibre from IMI to i2Cat (Nexus at C/ Gran Capità 2).

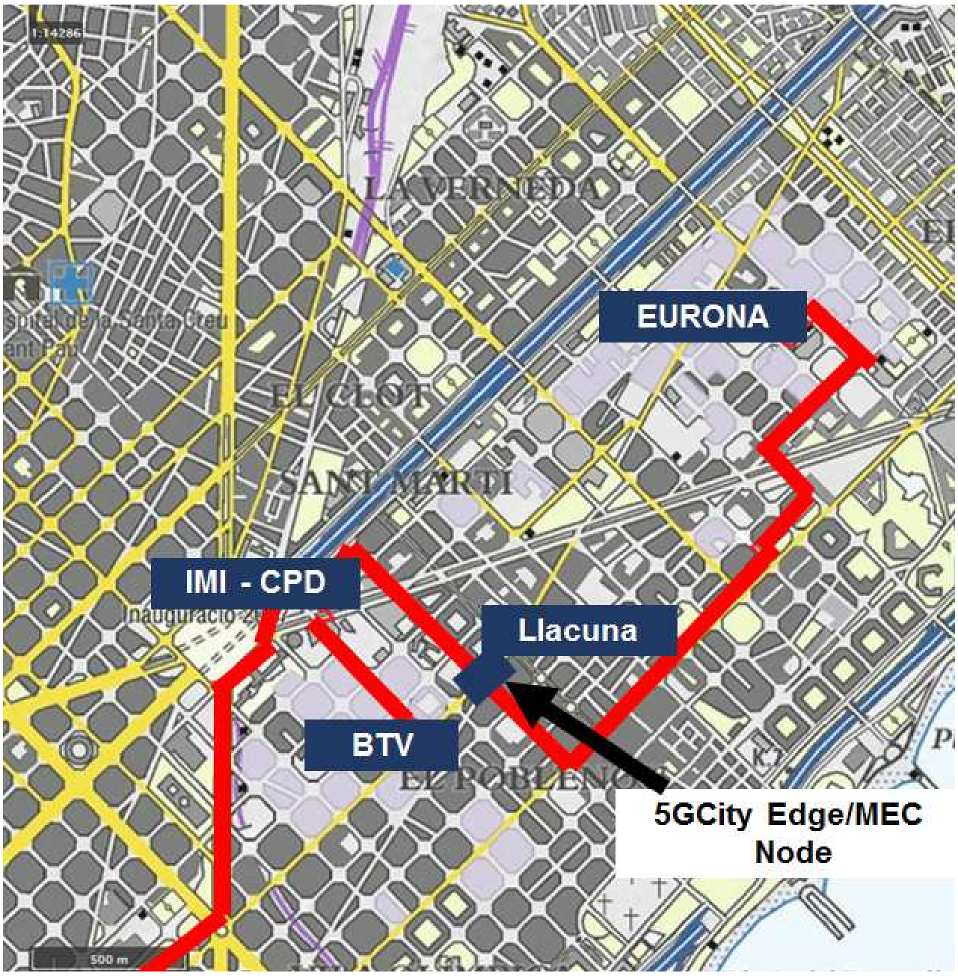


Figure 28 - Fibre connecting IMI with BeTeVe, with Llacuna street-cabinet (MEC) and with Eurona.

3.2. 5GCity Infrastructure Deployment in the City of Bristol

This subsection introduces the planned deployment of 5GCity infrastructure in the City of Bristol by including the area for the trials, the proposed infrastructure (5GUK-Test Network) and additional equipment required.

3.2.1. Area for The Trials in Bristol

In the City of Bristol, 5GCity infrastructure and use-cases trials will be deployed in the University of Bristol Smart-Internet 5GUK Test Network comprising four sites or areas; i) The High-Performance Networks Lab in the ground floor of the Merchant and Venture building (MVB) of the University of Bristol; ii) We-The-Curious (WTC) premises, iii) the Millennium Square (MS), and iv) the Harbour Side public area. Figure 29 presents the four sites were 5GCity infrastructure and use cases will be deployed and tested.

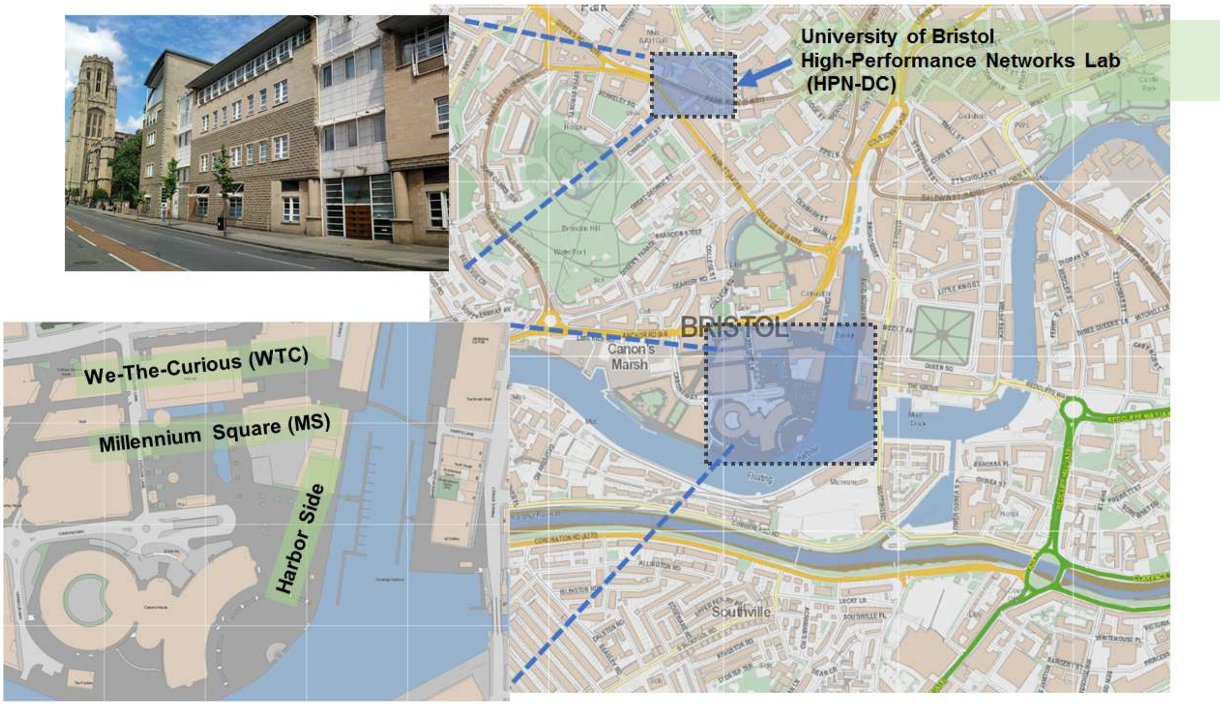


Figure 29 - 5GCity's Trials Area in the City of Bristol

3.2.2. Projected Deployment in Bristol

5GCity will house equipment in High-Performance Network Lab Datacentre (HPN-DC), in the WTC-DC, and, in the 5G Room (5G-RM) located in MS. The 5GCity Small Cells and 5GCity WiFi Nodes will be in 6 towers and three rooftop locations in WTC and MS (Figure 30).

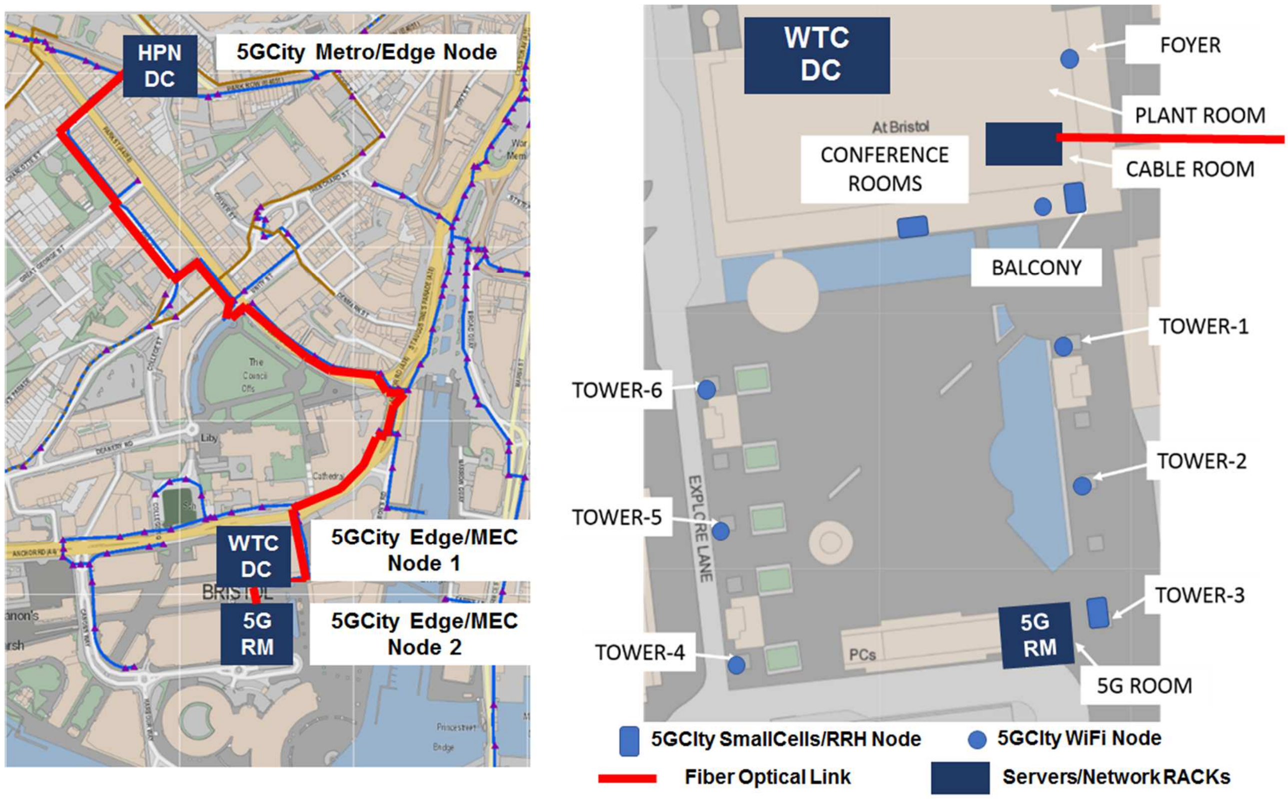


Figure 30 - 5GCity in 5GUK Test Network. a) Sites for 5GCity Metro/Edge and Edge/MEC nodes connected by fibre optics. b) Main sites and components of the test network in WTC and MS.

Figure 30 shows how the 5GCity infrastructure will be deployed in 5GUK Test Network elements. Figure 30(a) shows the metropolitan fibre optical connection between the HPN DC housing the 5GCity Metro/Edge DC, WTC-DC housing the 5GCity Edge/MEC node 1 and the 5G-RM (5G Room) housing the 5GCity MEC/Edge Node 2. Figure 30(b) presents the layout or WTC and MS with the physical location of the 5GCity Smalls Cells and 5GCity Wi-Fi Nodes. Figure 31 presents the detailed network diagram of 5GCity infrastructure deployment on 5GUK Test Network.

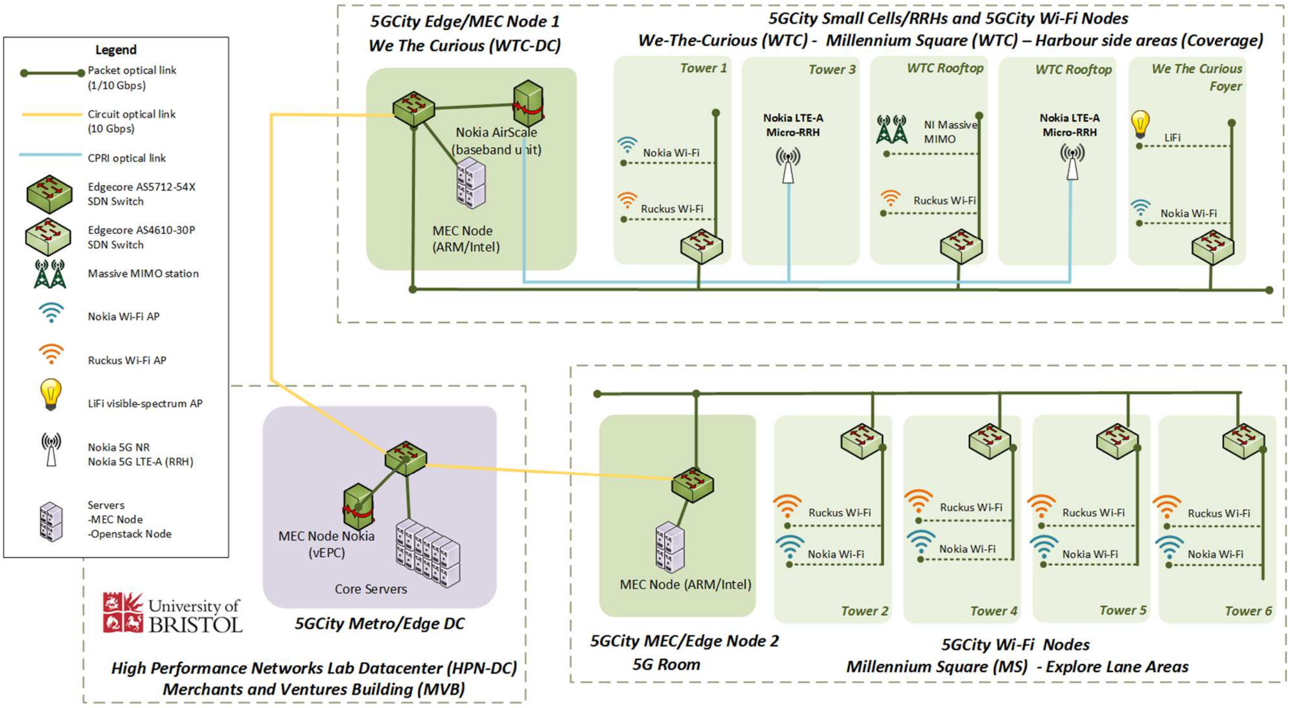


Figure 31 - Logical deployment of the 5Gity infrastructure components into the 5GUK Test Network.

Hence, the deployment projected of the three-level 5GCity infrastructure in the City of Bristol can be summarized as:

1. **5GCity Small Cells and 5GCity Wi-Fi Nodes**: will be available in 6 towers within MS and three cells on rooftop in the WTC rooftop. Some towers will host two different Wi-Fi access points to improve the coverage, throughput, and slice ability.

2. **5GCity MEC/Edge nodes**: will be housed between the street level and the orchestrator, the MEC nodes will host the computational power for deploying the last mile software components on demand. Three levels of MEC nodes will be tested in Bristol;
   a. Far edge MEC node installed in 5GCity MEC/Edge Node 2 on 5G Room. We also have the option to place smaller Compute nodes at the bottom of each tower, however in the small network configuration this is unlikely to give added advantage, which is a subject for network roadmap and future development.
   b. Neighbourhood level MEC node installed in 5GCity MEC/Edge Node 1 on WTC-DC.
   c. City level MEC server installed with our 5GCity Metro/Edge Node on HPN-DC.

3. **5GCity Metro/Edge Node**: will be housed in the HPN-DC. The 5GCity Metro/Edge Node will deploy the 5GCity platform that controls the operation of the infrastructure and host the orchestrator that manages the components distributed at different levels.

3.2.3. 5GCity Small Cells and Wi-Fi Nodes in Bristol

5GCity will use the NOKIA Air scale + RRH in 2.6 Ghz and an experimental National Instrument 3.5 Ghz 5GNR radio solution as 5GCity Small Cell. Later in November 2018, the solution for the 5GNR will be replaced with a product version from Nokia using the 5GNR at 2.5GHz, however we have no 5GNR compatible handset as part of this solution yet. The picture below shows the 5W micro cell 4x4 MIMO AirScale from Nokia (Figure

32). During the deployment and integration of the 5GCity platform is highly probable that more changes as-well additional number of Small Cells Nokia and/or Accelleran (Already in the project).

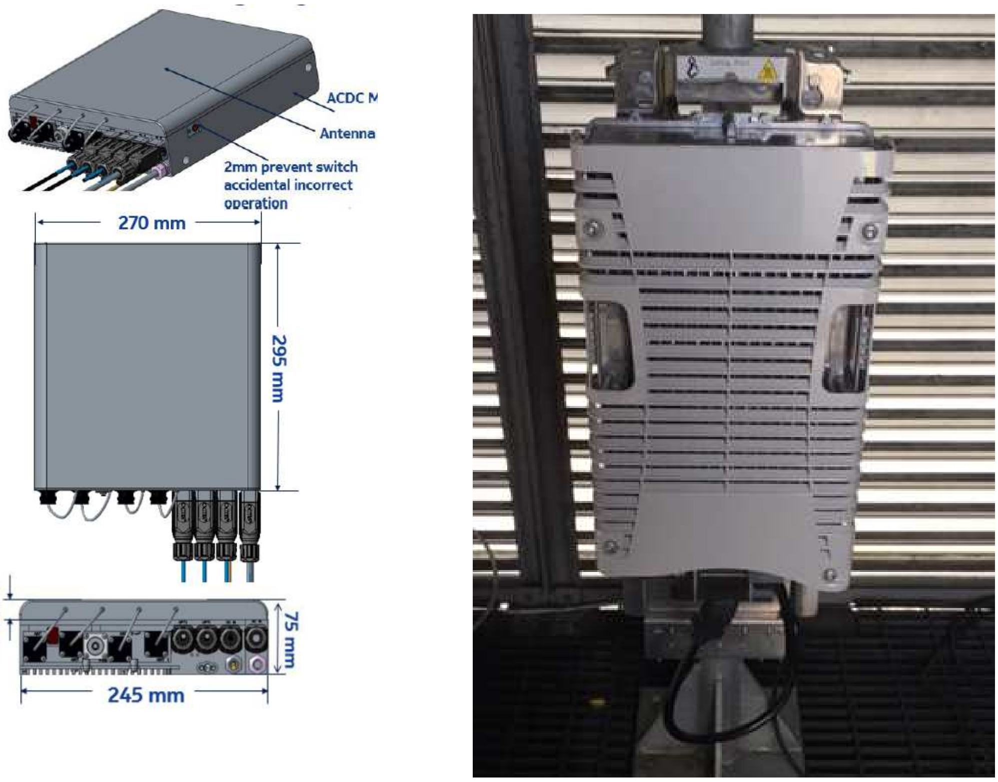


Figure 32 - Nokia Air Scale RRH.

Two types Wi-FI access points (APs) will be available for 5GCity to be used as 5GCity Wi-Fi Node, the Nokia AirScale Wi-Fi AC400 (Figure 33) and the Ruckus T710 (Figure 34). The Nokia AirScale Wi-Fi Access Point AC400 key specifications are:

- 802.11ac Wave2 Outdoor Wi-Fi Access Point (Figure 33).
- Omnidirectional 4x4 MIMO.
- 2.4GHz and 5GHz concurrent dual band.
- Dual 10/100/1000 Ethernet ports.

Figure 33 - Wi-Fi Node Nokia.

Ruckus T710 outdoor Wi-Fi AP

- 802.11ac Wave 2 Outdoor Wi-Fi Access Point (Figure 34).
- Omnidirectional 4x4:4 Stream.
- Omnidirectional Beamflex+ coverage,
- 2.4GHz and 5GHz concurrent dual band.
- Dual 10/100/1000 Ethernet ports.

Figure 34 - Wi-Fi Node Ruckus.

- 90-264 Vac, POE in and POE out.
- Fiber SFP slot.
- GPS embeded.
- IP-67 Outdoor enclosure.
- -40 to 65C Operating Temperature.

5GCity Small Cells and Wi-Fi Nodes are deployed in six towers connected to the WTC-DC via 6 fibres. 4 of these fibres terminate in a street cabinet (base tower) and 2 at the top (radio devices). There is therefore a direct link from the top of each TOWER to the WTC-DC for MEC applications:

At the base of each tower (Figure 35), a small street cabinet contains the following equipment:

- 1U APC PDU AP7920B.
- 1U Edgecore 4610-30P switch.
- 1U Netgear GS110TP switch.

Each tower has 6 Cat6 Ethernet cables from top to bottom. These are used to power and connect the radio equipment. The configuration for the top of TOWERS-2,4,5,6 is as follows (Figure 35):

- 1 x Ruckus T710 outdoor Wi-Fi AP.
- 1 x Nokia AC400 outdoor Wi-Fi AP.
- 4 x fibre connection to WTC-DC.
- 1 x two ways 230V AC switched mains outlet.

Each of these devices are connected via two Cat6 Ethernet links to the Edgecore switch. Power for the Ruckus and Nokia Wi-Fi APs is provisioned through PoE+. This outlet is switched via the APC PDU located at the base of the TOWER.

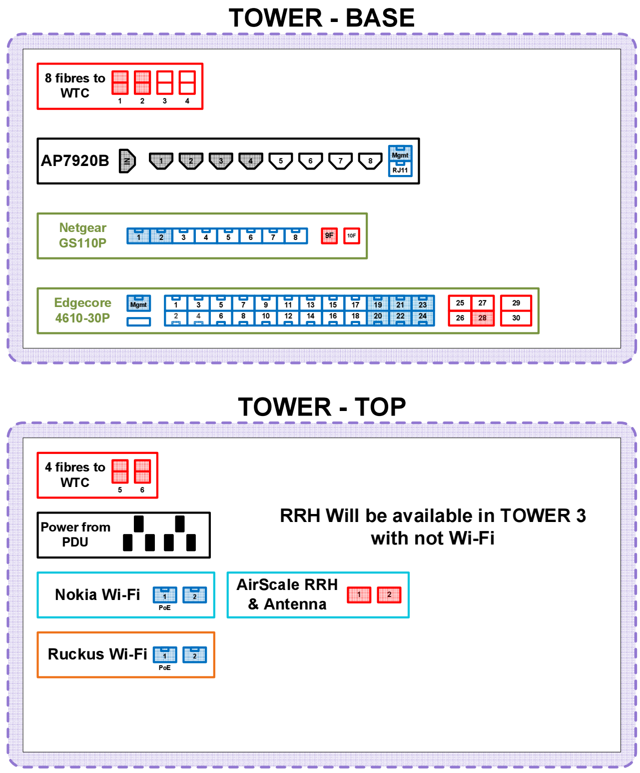


Figure 35 - Equipment available on each TOWER – BASE (cabinet) and TOP (radio).

The configuration for the top of TOWER-3 includes the Nokia AirSpace LTE/RRH mounted inside the grilled enclosure. At the base of TOWER-3 there is an 8-way fibre patch panel (4 pairs) back to WTC-DC, one APC PDU with four outlets in use, one Netgear management switch with three ports in use and one Edgecore switch with seven ports in use. At TOWER-3 top there is a 4-way fibre patch panel connected to the Nokia RRH and onwards to WTC-DC, a double gang AC outlet switched from the PDU, two Wi-Fi APs both powered and connected through Ethernet to the Edgecore switch.

Another important location to be available for 5GCity Small Cells and WiFi Nodes are the Cable Room and Balcony (WTC Roof top as described on Figure 36).

The Cable Room houses a 10U wall mount rack. This rack contains the following equipment:

- 1U 48 fibre LC optical patch.
- 1U APC PDU AP7920B1U Edgecore 4610-30P switch.
- 1U Netgear GS110TP switch.

Figure 36 shows the PDU, management and data plane switched in the Cable Room rack. The fanout to other locations is visible here since both the Netgear and Edgecore have additional ports utilised for onward connectivity.

On the Balcony area of WTC, a short pole will house the Nokia RRH/antenna. This position allows LTE coverage of Millennium Square and Harbour Side Area. Connectivity will be provided to the RRH through two fibre pairs. And energy is provided by a switched PDU via an external AC socket.

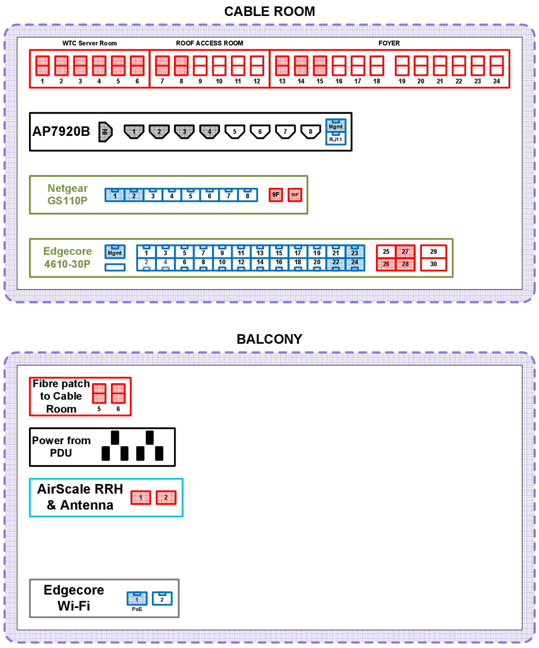


Figure 36 - Equipment and port to be available for WTC rooftop.

The Foyer of We-The-Curious could be used to extend the 5GCity trials, as a results LiFi, Wi-Fi, and LTE radio components will be available as shown in Figure 32, giving users the chance to experience new technologies in an indoor crowded environment. The architecture for the Foyer is split into two parts, a small rack near the Café, and the Li-Fi exhibit on top of the porch.

The equipment deployed in the café rack is:

- 1U 12 fibre LC optical patch.
- 1U PDU AP7920B.
- 1U Edgecore 4610-30P switch.
- 1U Netgear GS110TP switch.
- 1 high power PoE injector for Pico BTS.

The 12-way fibre connects to the Cable Room, providing onward connectivity for both management and data planes to the WTC Server Room. Six Cat6 Ethernet cables are provided between the Café rack and the porch for connectivity to LiFi, Wi-Fi and LTE nodes.

Figure 37 shows the port utilisation for all equipment in the Foyer café rack and deployed on the porch. The Pure Li-Fi Ores modules are powered and illuminated via PoE+, supplied by the Edgecore switch. These modules are controlled by an EMS which resides in the UoB infrastructure. The PoE injector is required for the Nokia FlexiZone Pico BTS as it demands PoE++ for operation. Please refer to section for an understanding of the connectivity and patching between devices.

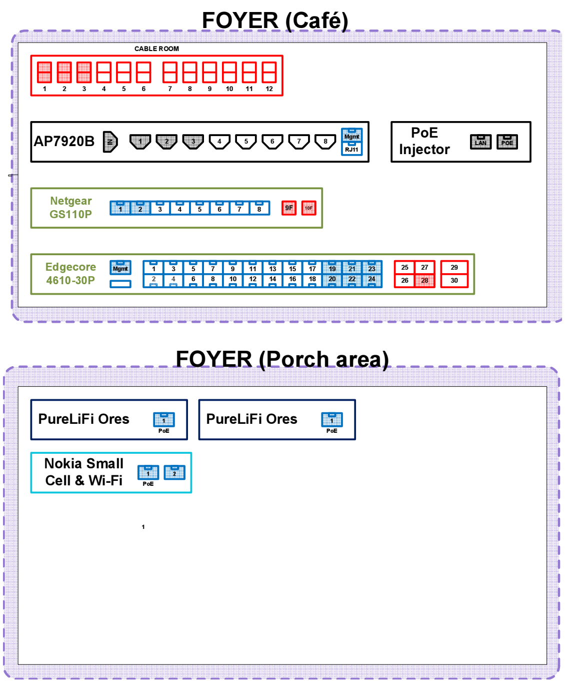


Figure 37 - Equipment and port state in the Foyer

3.2.4. 5GCity Edge/MEC Nodes in Bristol

Three edge DCs will house MEC nodes in the 5GCity deployment through the City of Bristol. The larger MEC Node will be in the 5GCity Metro/Edge node and the other two will be housed in the WTC-DC and 5G-RM. The Nokia MEC node consists mostly in a software deployed in an Intel server a proprietary operational system and application that provide edge level orchestration (i.e., ONAP) and capability for hosting several virtualized functions including the virtualized evolve packet core (vEPC). In contrast to Intel and ARM MEC nodes, Nokia MEC will be only tested in Bristol.

ARM MEC node will be used to run the Trusted Extensions (EdgeVIM and EdgeNFVI) in the 5GCity Infrastructure Layer as well as the wireless virtualization. They will be deployed in the street cabinets and lampposts of each city tested. The 5GCity ARM servers are equipped with Arm TrustZone, exploited to enable Trusted services, with a multi-core CPU and 4GB of RAM (to run more than two VMs) and optionally with hardware accelerators (e.g., FPGAs). Thanks to the EdgeVIM/EdgeNFVI Trusted Extensions, the system will be extended with the capability of scheduling specific functions only on trusted devices. This enhancement can be utilized and demonstrated in UC2 (Neutral host). ARM Cortex-A53 APU (up to 1.5GHz), ARM Cortex-R5 RTPU Up to 600MHz (Dual Core), ARM Mali-400 Based GPU, 4GB of RAM, Slot for FPGA, and TrustZone security application.

The 5GCity Edge/MEC Node located in WTC is the most important processing and switching component of the network, because it concentrates the physical connections to the towers and to the 5GCity Metro/Edge node, it comprises one 42U 19” rack for networking, compute, and radio resources. This rack contains the following (Figure 38):

- 42U Datacel 800 x 1000 Server Rack.
- 1U APC switched PDU Vertical.
- 1U 10GBit Edgecore 5712-54X.
- 1U 1GBit Netgear M4300-24X24F.
- 2 x 1U 48-way optical patch panels LC.
- 2 x 1U MEC Server (To be provided by Intel and/or ARM).
- 3U AirScale basestation (BBU).
- 2U AirScale PSU.
- 1U AirScale power splitter.
- 3U Shelf.

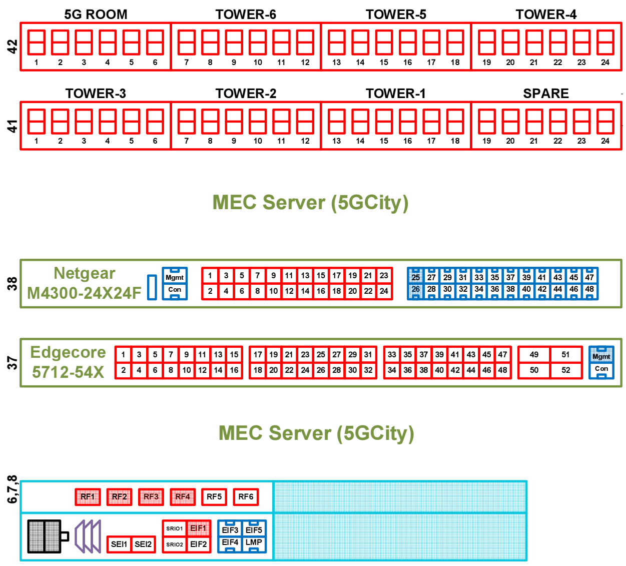


Figure 38 - Equipment and ports in WTC rack.

12 fibres (6 pairs) are hard spliced from this rack to each of TOWER-1,2,3,4,5,6 and the 5G ROOM (5G-RM).

Figure 38 shows the equipment to be available in WTC-DC. The Nokia AirScale system module backhauls will provide baseband services through IP infrastructure provisioned via the Edgecore switches. The Netgear switch connects a dedicated management network for out-of-band management of the active equipment.

A MEC server will be housed in this rack to became 5GCity Edge/MEC Node 1. We plan to host the introduced Intel MEC node and/or the ARM MEC node **(**This configuration will be subject to changes during the 5GCity deployment and integration).

The other important location for 5GCity equipment in the Edge is the 5G ROOM (5G-RM) which acts as a fibre termination and junction point where the 96-core fibre from WTC-DC joins the 6 x 6 core fibres from each Tower. This room houses a half height (27U) floor standing rack with enough space for compute resource. Rack mount tray for mounting small items shows the PDU, management and data plane switches in the 5G-RM rack.

Figure 39 shows the equipment and port of 5G-RM to be available for 5GCity MEC/Edge Node 2. One MEC Server will be also housed here and four towers will be connected as show the diagram on Figure 40.

This rack on 5G-RM contains:

- 3U LC optical patch (some hard splice to TOWERS).
- 1U PDU AP7920B.
- 1U Edgecore 4610-30P switch.
- 1U Netgear GS110TP switch.
- Ruckus R720 indoor Wi-Fi AP.
- Rack mount tray for mounting small items.

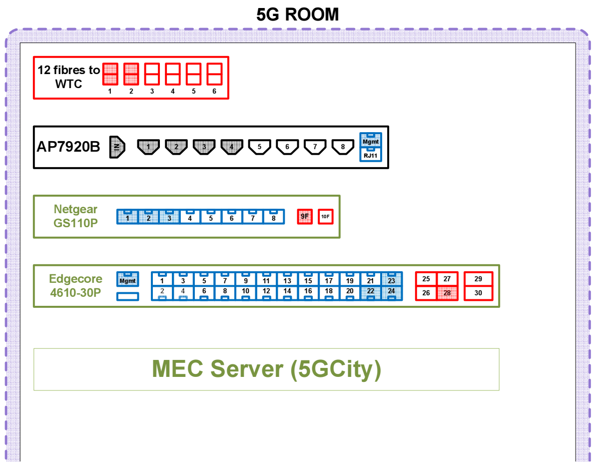


Figure 39 - Equipment and ports in 5G-RM rack.

3.2.5. 5GCity Metro/Edge Node in Bristol

The 5GCity Metro/Edge node of Bristol will be housed in the High-Performance Network Lab Datacentre (HPN-DC) located at the premises of Merchants and Ventures Building (MVB). It mainly consists of 3 servers providing computing resources and one SDN enabled core switch (Table 14). The four servers with similar specification (CPU, RAM, Storage) will play different roles. The servers will also connect to the Internet to interact with the partners and tenants of 5GCity during the trials.

Name	Roles	Software	vCPU (#*GHz)	Memory (GB)	Storage (GB)	Ethernet ifaces (GbE)	PCIE
5GC1	Controller, Compute, Volumes	Ubuntu 16.04.3, OpenStack Ocata	24 x 2.4GHz	64	400 SSD 1000	2	8
5GC2	Controller, Compute, Volumes	Ubuntu 16.04.3, OpenStack Ocata	24 x 2.4GHz	64	400 SSD 1000	2	8
5GC3	Controller, Compute, Volumes	Ubuntu 16.04.3, OpenStack Ocata	24 x 2.4GHz	64	400 SSD 1000	2	8

Table 14 - 5GCity Metro/Edge Node hardware for Bristol.

3.2.6. Fibre infrastructure in Bristol

This section introduces the fibre optical deployment to be used by 5GCity to connect the whole infrastructure. Figure 40 shows the fibre connectivity throughout the 5GUK Test Network planned to be available for 5GCity. All fibres terminate in the WTC-DC patch panel and are single mode terminated with LC with bandwidth between 1 Gbps or 10Gbps (1310nmASE-LR).

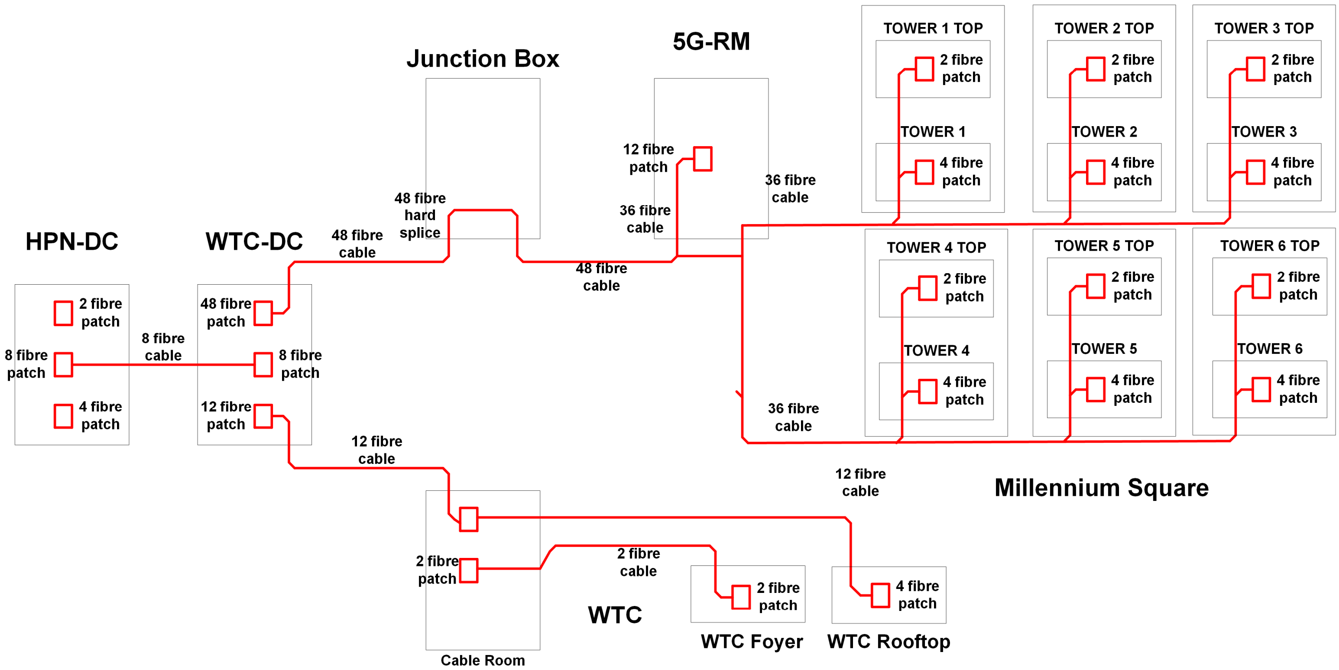


Figure 40 - Fibre optics cabling available for 5GCity in Bristol UK.

3.3. 5GCity Infrastructure Deployment in the City of Lucca

3.3.1. Area for The Trials in Lucca

The area of influence of the 5GCity project is in the sector of the city characterised by some interesting aspects useful to evaluate the potentialities of the 5GCity: the area in Lucca is traffic restricted and specially designing to mobility of the people: walking, play, reading, cycling or making others open air activities. The global area of the city involved in the project is illustrated in the image reported in Figure 41.

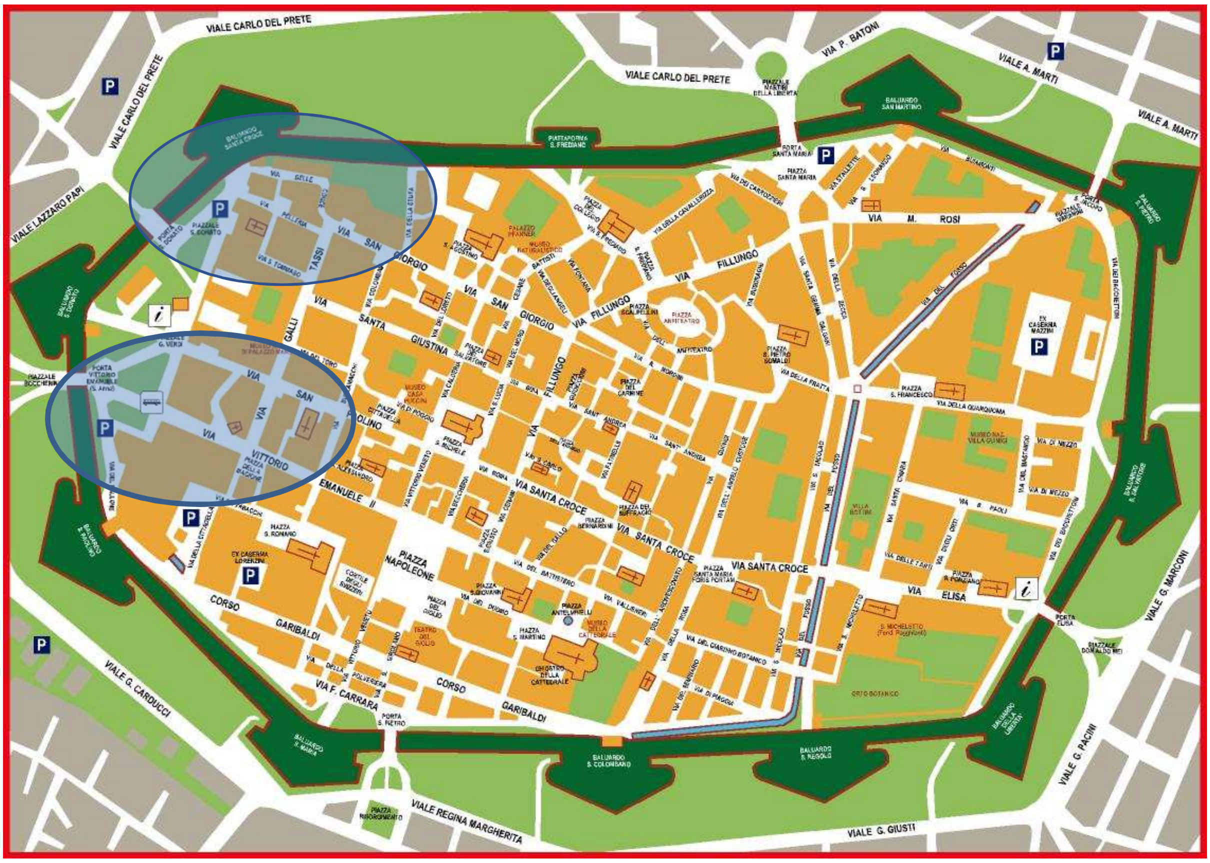


Figure 41 - 5GCity Lucca Main trials location

In the Figure 41 the mobile coverage of the city of Lucca is indicated; for the trial, the neutral host use case and for the other 2 foreseen use cases the coverage is improved using small cells. In Lucca the following use cases are foreseen:

- UC1 Unauthorized Waste Dumping Prevention
- UC2 Neutral Host
- UC4 UHD Video Distribution - Immersive Services

For each use case, specific areas of the city will be involved. Figure 42 introduces the UCs trial locations including metropolitan datacentre that will house the 5GCity platform.

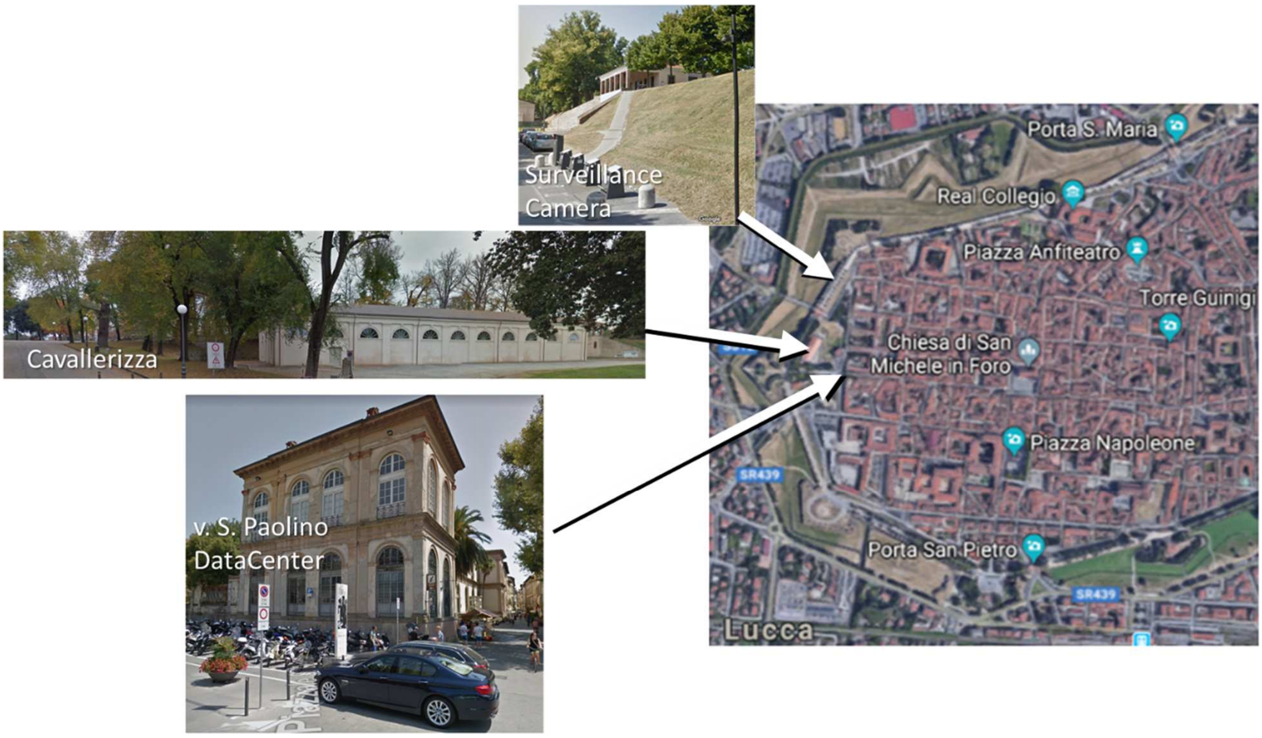


Figure 42 - Lucca Use Cases locations

3.3.2. Projected Deployment in Lucca

According to the 5GCity architecture described in [2], for the realization of 5GCity testbed in Lucca the global chain starting from the Radio Access Network (RAN), the Edge components, the MEC nodes, and the resources in the datacentres are considered, to realise the following logical connection schema correlated to the physical one.

In the Figure 43 all the involved components are introduced: combined edge and network infrastructure provide a multi-tenant platform for deploying virtualized, heterogeneous services and supporting the three-tier 5GCity infrastructure and use cases.

Hence, the three-tier 5GCity infrastructure in the City of Lucca in similar way to the City of Barcelona and the City of Bristol will be deploy as follow:

1. 5GCity Small Cells (Accelleran 2.6 Ghz): to be placed in three locations to improve the coverage.
2. 5GCity MEC/Edge will be an Intel MEC Node housed in the Via della Cavallerizza street cabinets. Two types of MEC Nodes will be deployed in the City of Lucca, one street level MEC and another city-wide MEC.
3. 5GCity Metro/Edge Node equipment will be housed in the Datacentre of Villa Sao Paolino.

Figure 43 introduces the three tiers 5GCity infrastructure into the logical infrastructure, followed by its final physical deployment in Lucca infrastructure (Figure 44).

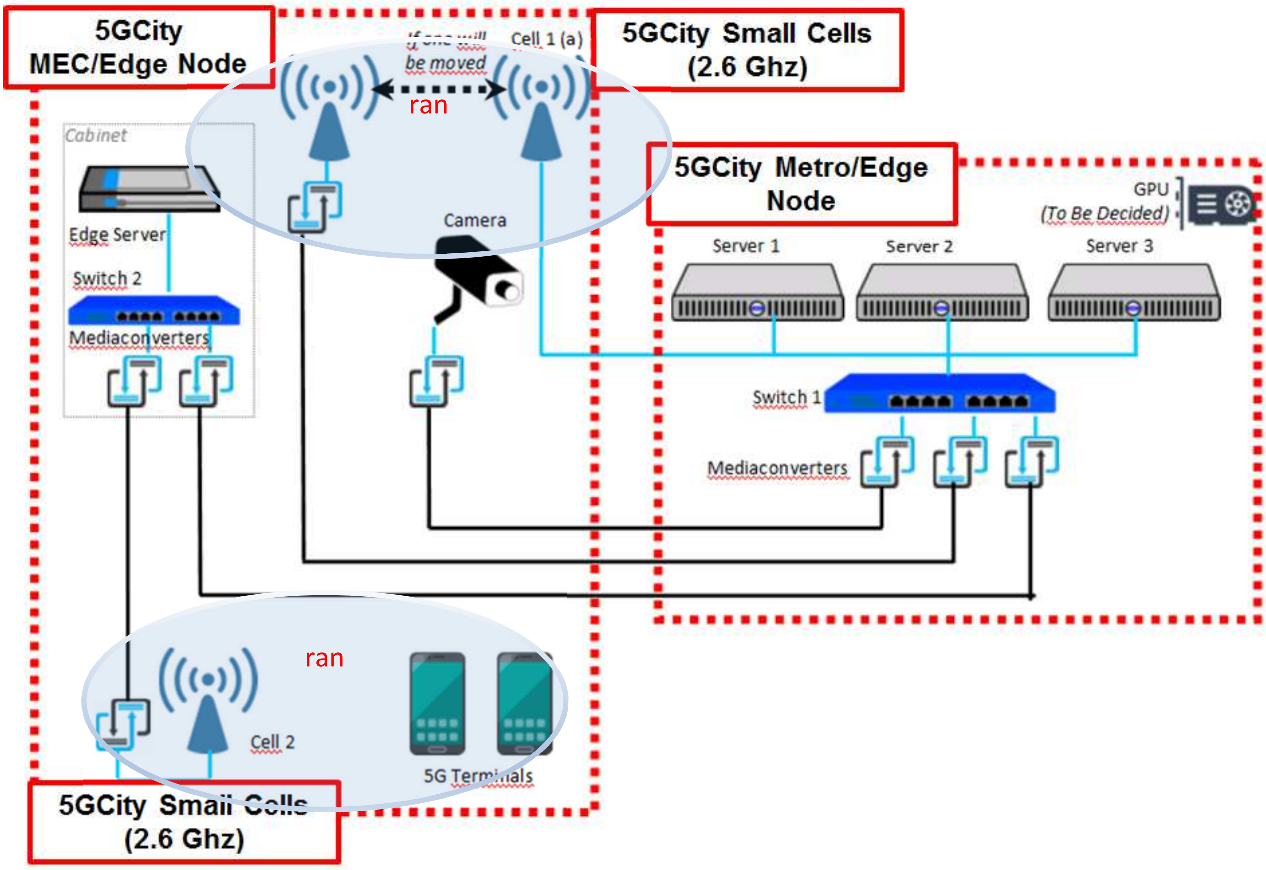


Figure 43 - Lucca 5GCity high level view of the logical connection.

According to Figure 43 the communication Network provides the connectivity among the different components according to the Lucca testbed requirements: these are wide ranging, covering the need to large data transfer volumes and wide-ranging latency requirements.

The figure shows the planned logical network with a distinct separation among the infrastructure on the edge and the infrastructure on the datacenter.

In the datacenter there are three distinct servers: "Orchestration Server" (Server #1) "application Server" (Server #2) and a Video Server (Server #3) with an optional GPU to improve its performance. In the case UC 4 this server will be located and used in the edge area. A switch connects al the server ETH interfaces. The switch is also connected by eth cable to the first 5G cell and by three media converters of fibre towards the Edge.

In the Edge area we have:

- A camera connected by mediaconverter to the fiber.
- A cabinet including an Edge server, a switch and two mediaconverter
- A 5G Small Cell connected by mediaconverter to the Datacenter fiber.
- A 5G Small Cell connected by media converter to the cabinet fiber.
- 5G terminals in the cells covered area.

Using the different components, according to the 5GCity architecture, it is possible to deploy the different use cases correlating to the different slices defined over the physical components managed by the neutral host. According to the high-level view illustrated in Figure 43 the communication Network provides the connectivity among the different components according to the Lucca testbed requirements: covering the need to large data transfer volumes and wide-ranging latency requirements. in the following Figure 44 the general schema of the physical component is inserted:

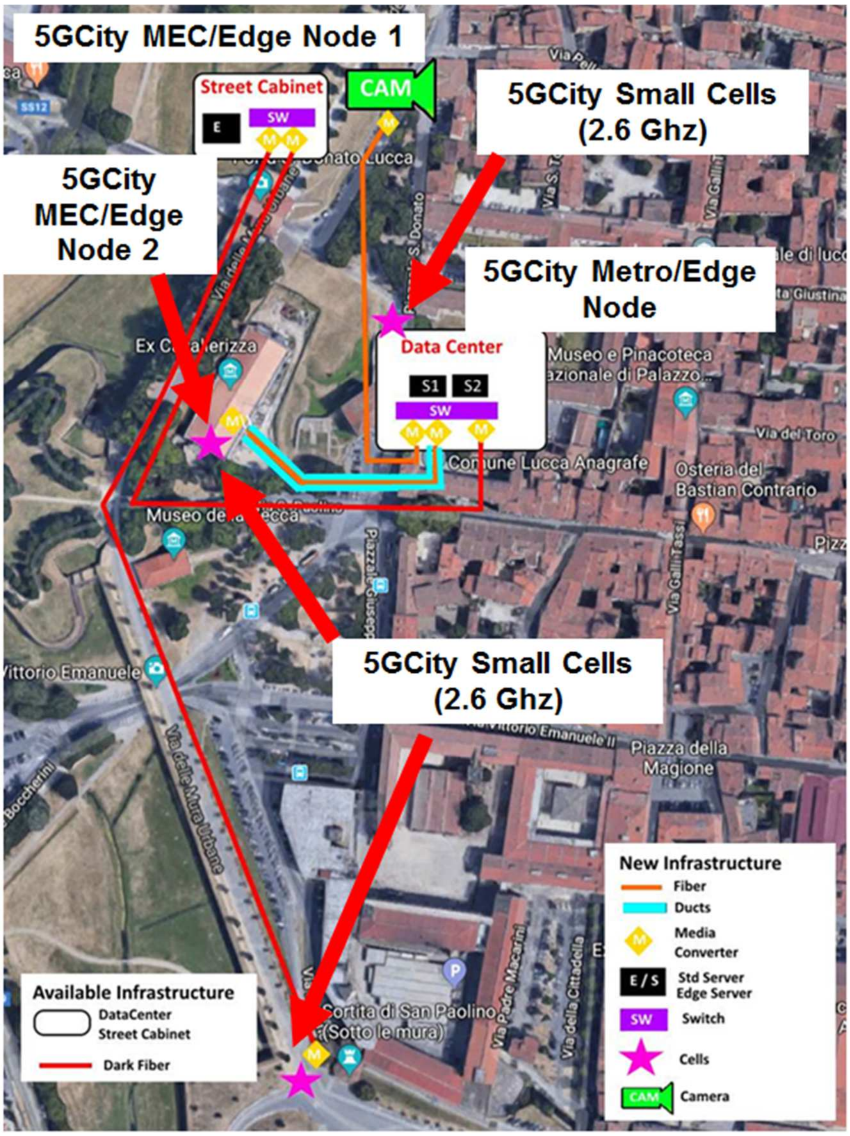


Figure 44 - Lucca 5GCity Infrastructure.

3.3.3. 5GCity Small Cells in Lucca

In the City of Lucca, like in Barcelona the 5GCity Small Cells will be based on LTE RAN access components based on Accelleran commercial technology (Accelleran E1013) by using the 2.5GHz frequencies (2579-2595 MHz, B38) assigned to Wind Tre. A total of 2 Small cells will be available to provide the connectivity required by the use cases deployed in Lucca. The user terminals will be TDD (MNC/MCC 99 or 88 – free Access Class or Reject on LA/RA on Accelleran system).

The LTE RAN will also implement the RRU component of the 3-Layer based architecture, while the associated vRAN Controller will run in the edge: the small cell 1 in Figure 434 will be installed in "façade" to provide the connectivity required by the use case 1 or 4. The same small cell can be used also for indoor test in the Cavallerizza site. One lampposts will be equipped with this RAN technology (cell 2 in Figure 434).

The fibre connection for the lamppost equipped with 5GCity Small Cell and for the façade site will be aggregated at the street cabinet. The Accelleran E1000 Small Cell Series (E1013) will be deployed with the Accelleran Small Cell Software Solutions to provide the virtualized function to cope with the EPC.

The EPC will be provided with its own HSS; this allows to configure in the small cell and EPC any PLMNID.

3.3.3.1. ACCELLERAN E1013 Small Cell

The B38 variant of the Accelleran E1000 Small Cell Series E1013 (Figure 45)

Figure 45 - Accelleran E1013 LTE Small Cell

The characteristics of the 2500 MHz E1013 Small Cells are the following:

- LTE TDD 3GPP Compliant.
- Local Area Small Cells.
- 1 transceiver per unit (single cell).
- 24 dBm/250 mW (TDD) RF power per antenna port.
- 1 transceiver per unit (single cell).
- per antenna port.
- 2x2 MIMO.
- 5, 10, 15 & 20MHz Channels.
- TDD Bands 38, 40, 41, 42, 43*, B48/CBRS.
- Integrated GNSS (GPS, GLONASS, BDS).
- Gigabit Ethernet Connectivity (PoE+).
- Optional Embedded EPC (Network-in-a-box).
- Flexible Remote Management Interface.
- 56V PoE270 x 200 x 65 mm (3.5 litres exc. antennas).
- IP67.
- 2.8 Kgs.
- -40ºC to +50ºC operating temperature.

Besides the small cells supports the 3GPP Release 9 (upgradeable to Release 10); up to 64 active users could be connected and the Cell Selection/Re-selection is available.

The antennas recommended for general deployment with the E1010 Small Cells are single pole vertically polarised fiberglass antennas with N-type connections that can either be directly attached onto the E1010 Small Cell or mounted separately and connected via RF feeder cables. The Radiation Patterns at 2500 MHz (H-Plane and E-Plane) are illustrated on Figure 46.

The characteristics of the recommended antenna for the frequency range 2500 – 2700 MHz are in the following introduced:

- Bandwidth: 100 MHz.
- Gain: 6 dBi.
- Vertical Beamwidth: 25.
- VAWR: <= 1.5.
- Impedance: 50 Ohms.
- Polarisation: Vertical.
- Max Power: 100 W.
- Connector: N-Type female.
- Dimensions: Ф40 mm x 500 mm.
- Weight: 220g (Without bracket).
- Pole diameter: Ф40 mm-Ф50 mm.

The Accelleran E1013 supports an internal GNSS receiver for location and timing reference. An outdoor antenna is provided with each unit which must be fitted for normal operation to be possible.

Figure 46 presents the radiation pattern of the E1013 small cells for 2500 MHz:

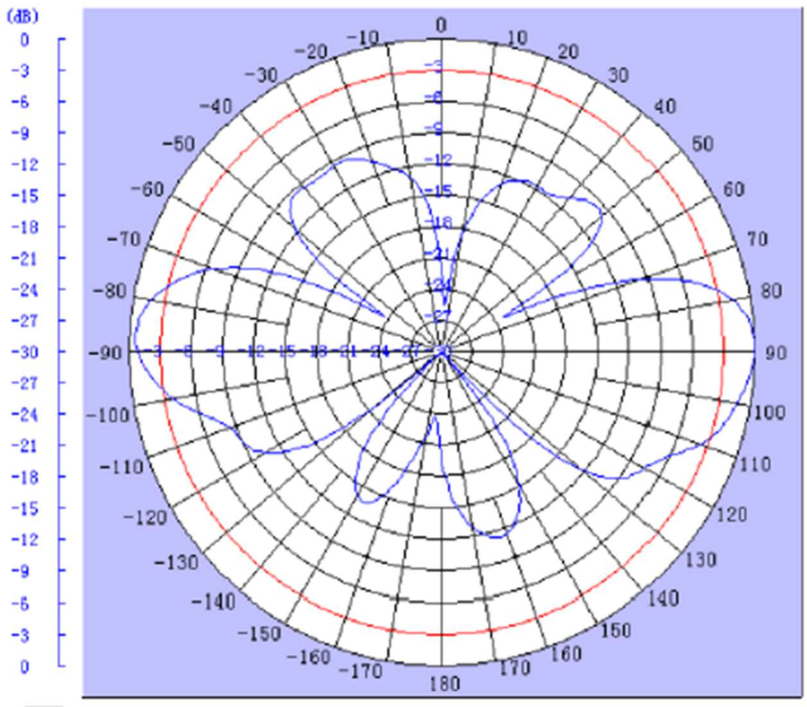


Figure 46 - Radiation patterns at 2500 Mhz.

3.3.3.2.Virtual RAN and MEC Gateway

Accelleran supports a virtual RAN configuration useful in the 5GCITY to support Neutral Host applications. In the vRAN configuration the networking interface between the RRU (E1013) and the BBU (edge vRAN) transports the following interfaces:

- RRC Control from vRAN BBU to RRU.
- User traffic to BBU.
- Configuration and monitoring flows from vRAN BBU to RRU.

Besides the instantiation of a vEPC function on the E1013 platform itself ("Network in a Box") provide local termination of user traffic for Multi-access Edge Computing applications. Lifecycle management of the vEPC instance and associated networking is orchestrated by the 5GCity platform.

The Accelleran vRAN solution supports also the possibility to have end-to-end network slicing via its software defined networking architecture. And these features can be supported in 5GCity platform.

3.3.4. 5GCity MEC/Edge Node in Lucca

Two 5GCity MEC/Edge nodes will be installed one in Cavalerizza and another Sortita San Paolino. they will be connected to the DC via fibre using a GB switch (4 ports) (Aruba 2530-8) to provide a comprehensive and scalable set of Layer 2 and Layer 3 VPN services in a compact package.

ADLINK Cabinet server will be also included in the infrastructure to deploy the functionality foreseen for the use case 1 in the 5GCity MEC-Edge node located in the Sortita San Paolino. A Video server will be also installed in the MEC Edge Node located at Cavalerizza building.

For the MEC nodes we have the following elements as described in Table 15:

Name	Roles	Software	vCPU (#*GHz)	Memory (GB)	Storage (GB)	Ethernet ifaces (GbE)	PCIE
Server_edge1	Compute, Volumes	Ubuntu 16.04.3	4 x 3.6GHz	32	256 SSD	1	3
Server_edge2	Compute, Volumes	Ubuntu 16.04.3, OpenStack Ocata	12 x 1.5 – 2.10 GHz	128	1800 SSD	2	1

Table 15 - 5GCity Metro/Edge Node hardware for Lucca

Other components will be installed is listed in Table 16:

Name	Roles	Storage (GB)	Ethernet ifaces (GbE)
Camera1	High resolution Camera	512	RJ-45 (10/100BASE-T)
Switch_edge1	GB switch (4 port)(HP Aruba 2530-8)	NA	8 RJ-45 autosensing 10/100/1000 ports 2 dual-personality ports; each port can be used as either an RJ-45 10/100/1000 port (IEEE 802.3 Type 10Base-T; IEEE 802.3u Type 100Base-TX; IEEE 802.3ab 1000Base-T Gigabit Ethernet) or as a SFP slot (for use with SFP transceivers) ports
Small Cell_1	Accelleran Small Cell E1013	Accelleran	Gigabit Ethernet Connectivity (PoE)
Small Cell 2	Accelleran Small Cell	Accelleran	Gigabit Ethernet Connectivity (PoE)
Server_edge1	Cabinet server by ADLINK	TBD	TBD
Server_edge2	VideoServer RAI	TBD	TBD
Terminals for end user	5 CPE compliant with the assigned frequencies	TBD	TBD

Table 16 - 5GCity Metro/Edge Node – other components in Lucca.

3.3.5. 5GCity Metro/Edge Node in Lucca

Fibre multi lambdas can are installed for high speed communication among the Metro DC and the MEC nodes and cabinets. The Internet connection provides up to X Gbps of up/downstream speed. First of all we introduce the “Orchestration Server” (Server #1) to host the 5GCity platform; in this case to have the best performance the following server has been selected: a DELL PowerEdge T630 (2CPU Intel® Xeon® E5-2640 v4 with 192GB RDIMM, 2xHDD 300GB 10K RPM SAS 12Gbps 2.5in) + 4xHHD1.2TB 10K RPM SAS 12Gbps. An application server it is foreseen to host the application required to realise the different use cases. In the case of the Server #2 it could be possible to consider also the possibility to improve its capabilities adding a GPU module Optional as a Tesla P4 8GB. To complete the description, we must consider the switches and the transceivers equipment and other ethernet connection listed in Table 17:

Name	Roles	Software	vCPU (#*GHz)	Memory (GB)	Storage (GB)	Ethernet ifaces (GbE)	PCIE
Server 1	Compute, Control Volumes	Ubuntu 16	1CPU Intel® Xeon® E5-2680 v4	32	300 SAS	2	2
Server 2	Compute Volumes	TBD (*)	1CPU Intel® Xeon® E5-2680 v4,	64	300 SAS	2	2

Table 17 - 5GCity Metro/Edge Node hardware for Lucca.

(*) As far as concerned the software, the components will be decided according with the requirements coming from WP 4 during the deployment phase. Table 18 introduces additional elements to be installed.

Name	Roles
Switch1	GB switch (4 ports) (HP Aruba 2530-8)
Switch 2	GB switch (4 ports) (HP Aruba 2530-8)
Transceiver 1	N°1 External Transceiver
Transceiver 2	HPE X121
Transceiver 3	HPE X121
Rack 1	Rack and accessories (KVM and KVM switch)

Table 18 - 5GCity Metro/Edge Node – other components in Lucca.

In the 5GCity infrastructure components energy protection is included: at DC side a Chloride EDP 50/10 equipment is used. The datacenter is cooled by 4 floor fan coil units supplied by a dedicated air conditioning system.

The following images complete the description of the testbed location in Lucca: an example of the street cabinet, the camera pole and the converter that will be used in the 5GCity project:

Figure 47 - The cabinet at the edge (Viale delle Mura Urbane)

Figure 48 - The camera pole at the edge (Piazzale San Donato)

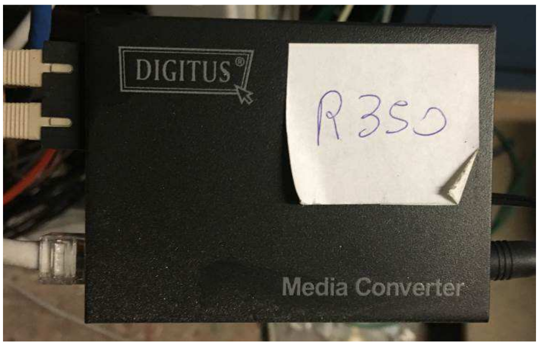


Figure 49 - Media converter (ODM>MP & ODM>DC) at the edge (Piazzale San Donato)

4. 5GCity UCs deployment on City Infrastructure

This section introduces simplified examples of UCs deployment in each defined city infrastructure. The first set of examples correspond to the UCs for city of Barcelona followed by the ones to be run in the cities of Bristol and Lucca. In Table 19, the list UCs is presented with a tentative period for their first test or trials in 5GCity infrastructure. However, the given dates or months can be revised, or changes based on the overall city progress in the project. Deploying an infrastructure in a city is much more complex than in a lab, and many uncontrolled variables may impact the deployment

ID	Use Case Name	City			First Trials
		Barcelona	Bristol	Lucca	
UC1	Unauthorized Waste Dumping Prevention	No	No	Yes	Q4 2018
UC2	Neutral Host	Yes	Yes	Yes	Q1 2019
UC3	Video Acquisition and Production Community media engagement in live events	Yes	Yes	No	Q1 2019
UC4	UHD Video Distribution Immersive Services	No	Yes	Yes	Q1 2019
UC5	Mobile Backpack Unit for Real-time Transmission	Yes	No	No	Q1 2019
UC6	Cooperative, Connected and Automated Mobility (CCAM)	Yes	No	No	Q2 2019

Table 19 – 5GCity Use Cases Trials Tentative Plan on 5GCity infrastructure.

4.1. UCs Deployment on Barcelona Infrastructure

In the 5GCity infrastructure of the City of Barcelona four UCs will be deployed and tested, the UC 2 Neutral Host, UC 3 Video Acquisition and Production Community media engagement in live events, UC 5 Mobile Backpack Unit for Real-time Transmission, and UC 6 Cooperative, Connected and Automated Mobility (CCAM). This section presents an example of how each UCs will be deployed in the city of Barcelona.

4.1.1. Example of UC 2 Neutral Host Deployment in Barcelona

Two main schemes are nowadays considered, MOCN and MORAN. In the project we aim at testing both architectures. The main objective is to increase the knowledge in edge computing and how to distribute the intelligence of the 5G system along the network while guaranteeing the service requirements or constraints.

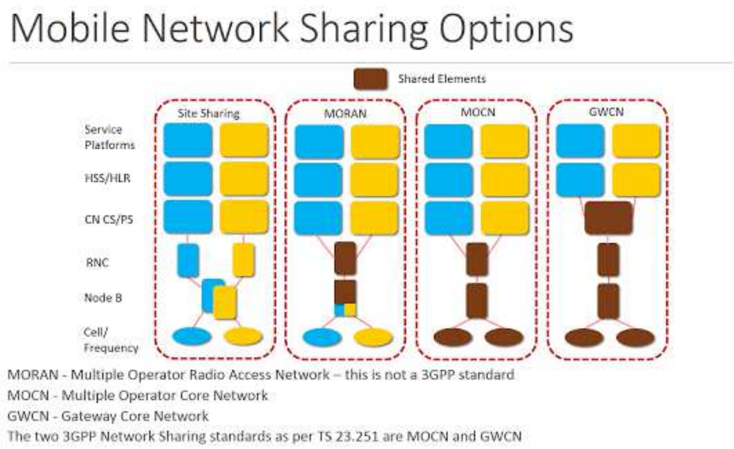


Figure 50 - Mobile Network Sharing Options

In the MOCN architecture, the cabinet hosts centralised Small Cell components of a cluster of physical Small Cells deployed in the city lampposts. Moreover, RAN deployed in lamppost are single frequency. In this case the spectrum resources are shared by different participating Mobile Operators. This will be the case of sharing LLacuna and Tanger cabinets for the 4 lampposts defined in previous sections. MEC and RAN are common for all service providers (Figure 51). The key issue here is to guarantee quality of service. Depending on the service quality the asset to be guarantee will translate into bandwidth, coverage, latency etc

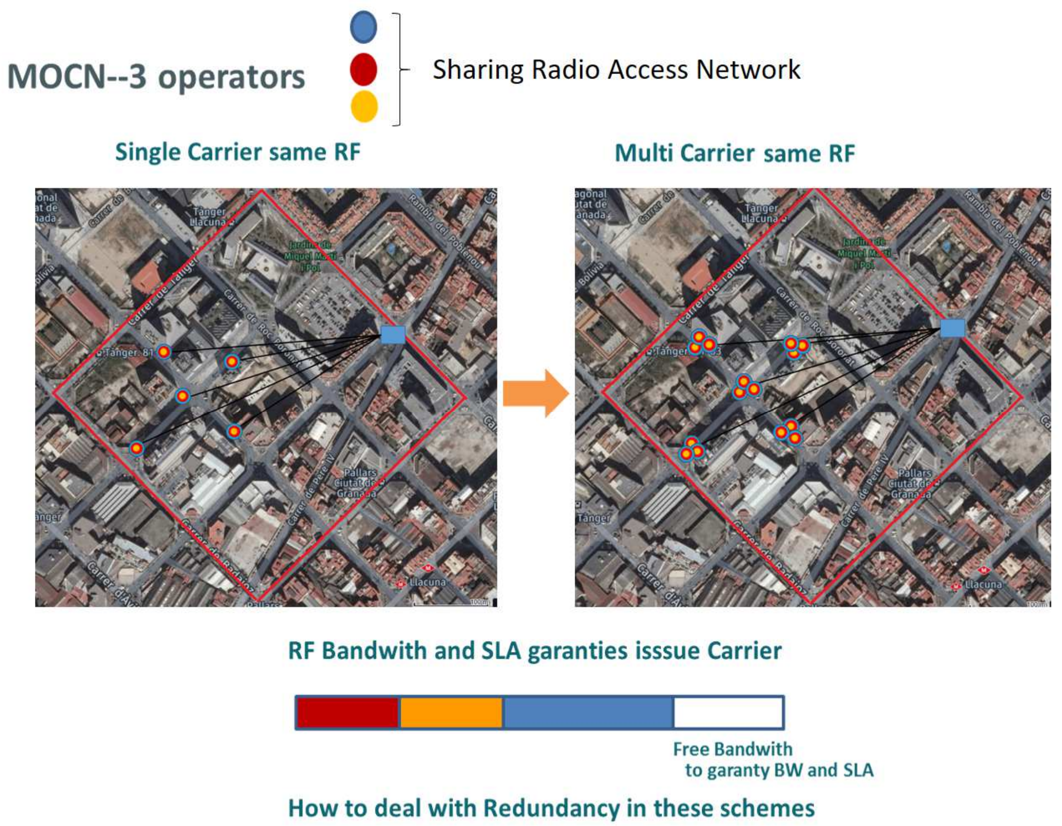


Figure 51 - Example of UC 2 Neutral Host into the Barcelona Infrastructure – MOCN Case.

In the "virtual" MORAN architecture, where each Mobile Operator intends to use their own spectrum, the different physical Small Cells can be dedicated to a Mobile Operator in single frequency or to multiple operator y Multi Carrier. They are controlled by the centralized Small Cell cluster functions in the cabinet, which offer a "virtual" MORAN view of the physical small cells deployed in the lampposts. The centralized Small Cell cluster control function running in the cabinet has the advantage that it will offer the same functionality and services regardless on whether the physical Small Cells deployed are single or multicarrier capable. At the same time, the centralised Small Cell cluster functions, together with MEC functionality in the cabinet, will enable the support of certain stringent requirements such as ultra-low latency needed for some services. In this schemes deployment and coverage is the key point to have an efficient system.

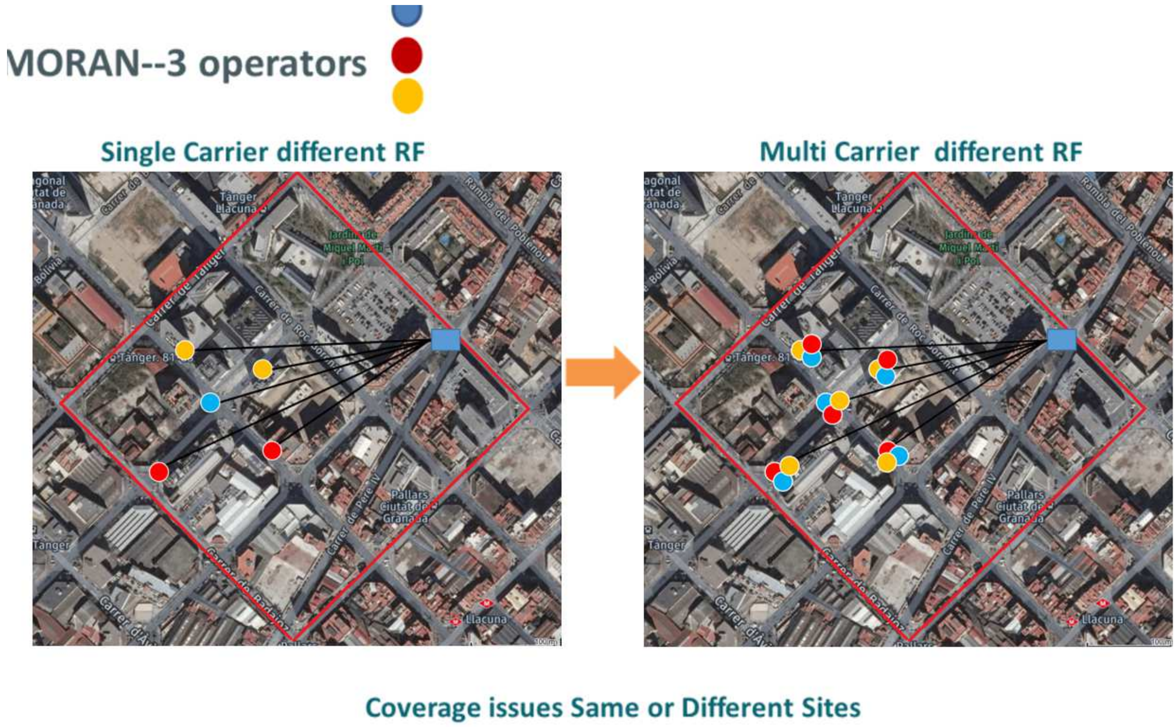


Figure 52 - Example of UC 2 Neutral Host into the Barcelona Infrastructure – MORAN Case.

To accomplish the objectives presented in for this use case, the consortium will make the necessary provisions to develop an edge base solution that will dynamically enable the dynamic spectrum to guarantee the SLA of a minimum bandwidth. The real architecture that is intended to be deployed is the one presented in Figure 53. The plan is to have up to 3 virtual operators or EPC and try the previous 2 schemes using the MEC node in Tanger and LLacuna. The hardware implementation or deployment in the use case of neutral host in Barcelona is the following one. MEC and DC metro must guarantee slicing and NFV to provide SLA service for the 3 EPC or mobile operators. With this example it is possible to observe, how the neutral host UC will be demonstrated by 5GCity.

4.1.2.Example of UC 3 Video Acquisition and Production Deployment in Barcelona

The use case takes advantage of the infrastructure to be deployed in the city of Barcelona and demonstrates the flexibility of 5GCity architecture. The UC3 had a special need in terms of physical infrastructure, it is necessary to install and connect special video servers in the city of Barcelona. The city is prepared for this situation, when the generic MEC servers can't process the data, the data can be routed to the metro datacentre. The metro datacentre will house the 5GCity Metro/Edge Node which can be expanded with the addition of a new server by increasing the processing and storage capability. A private cloud needs to be connected to the internet to expose the controls to the video operator. The operator can do clean cuts between the available feeds and send the result to the broadcaster, over the internet and/or intranet. The Metro DC and the venue are linked by fibre, connecting the cabinet closest to the venue and the data centre. In the case of Barcelona, the MEC node is limited in capacity and so the cabinets. As a result, the additional server can only be placed in the Metro DC. Figure 54 introduces the way UC3 will be deployed in Barcelona. In the case of Bristol and Lucca the situation changes. For the trials of the UC 3 a public event can be organized in the coverage are of the 5GCity infrastructure.

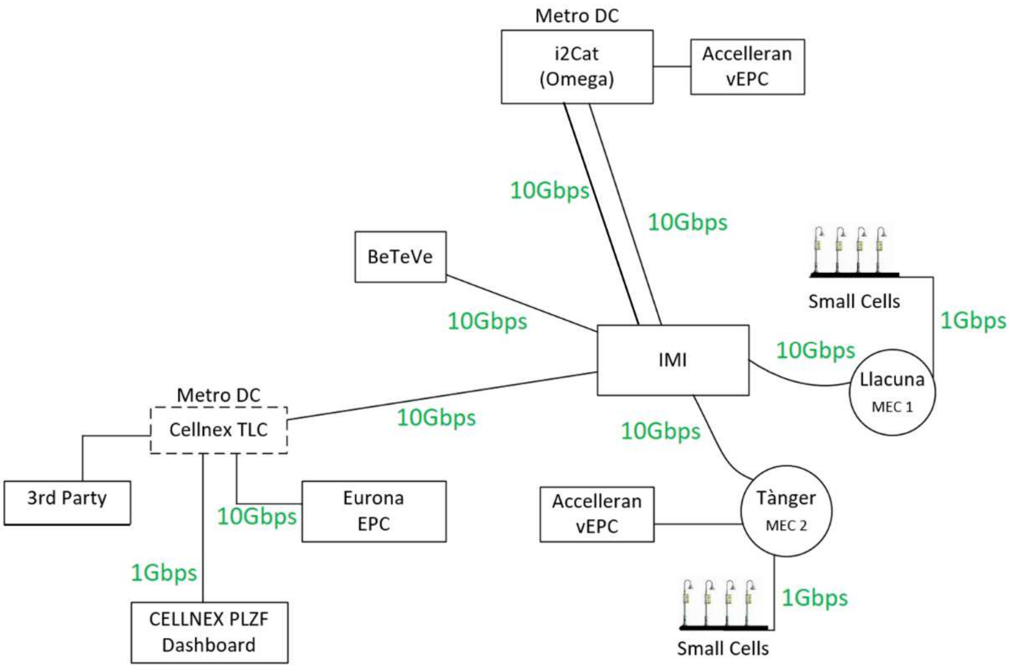


Figure 53 – Three Virtual Operators with different EPC.

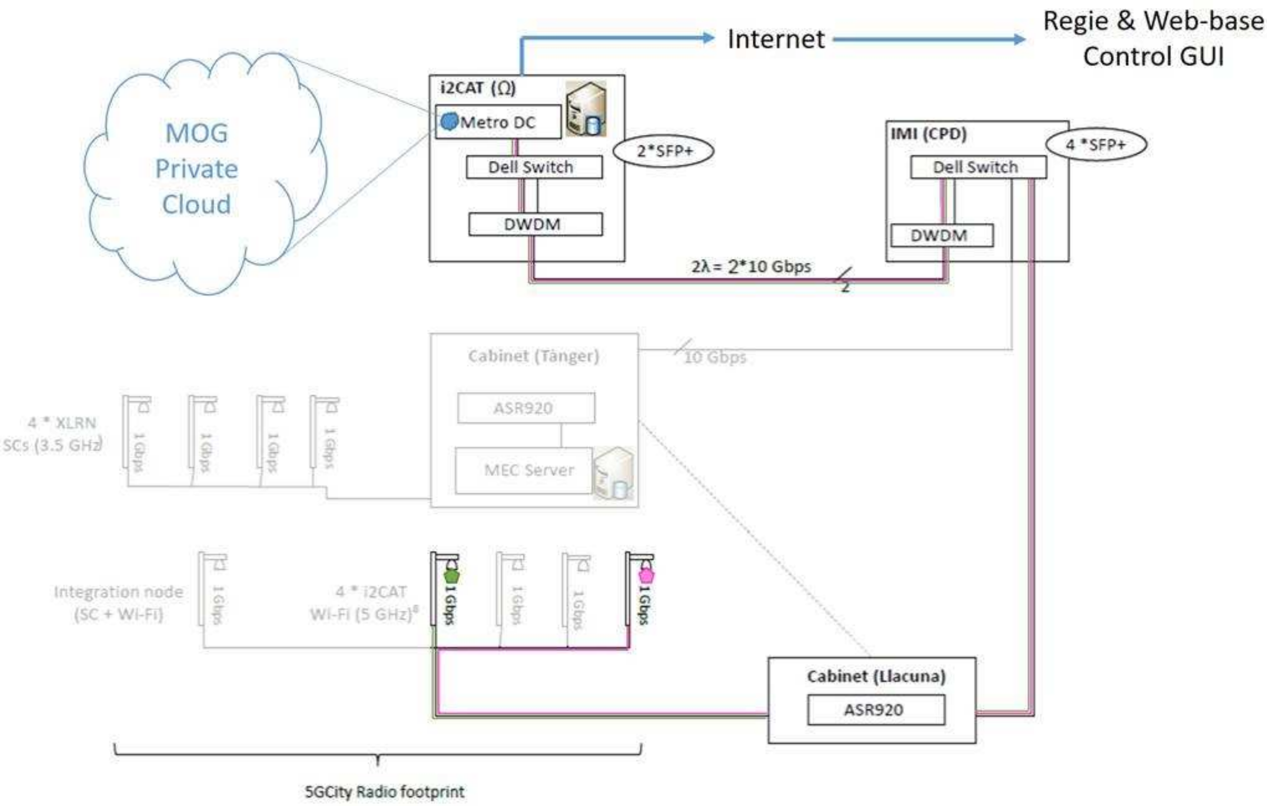


Figure 54 - Example of UC 3 video acquisition and production.

Figure 55 introduces how UC 3 will be demonstrated, where two groups of mobile users "Consumers and Event" are involved. 5GCity Wi-Fi nodes are in the event and the potential consumers are close by the 5GCity Small Cells. The event video is recorded by mobile users in the event area and produced in the 5GCity Metro/Edge Node, minutes later the consumer can access the resulted video. In this scenario the area video production and consumption can be tested and the benefits of 5GCity infrastructure can be evaluated.

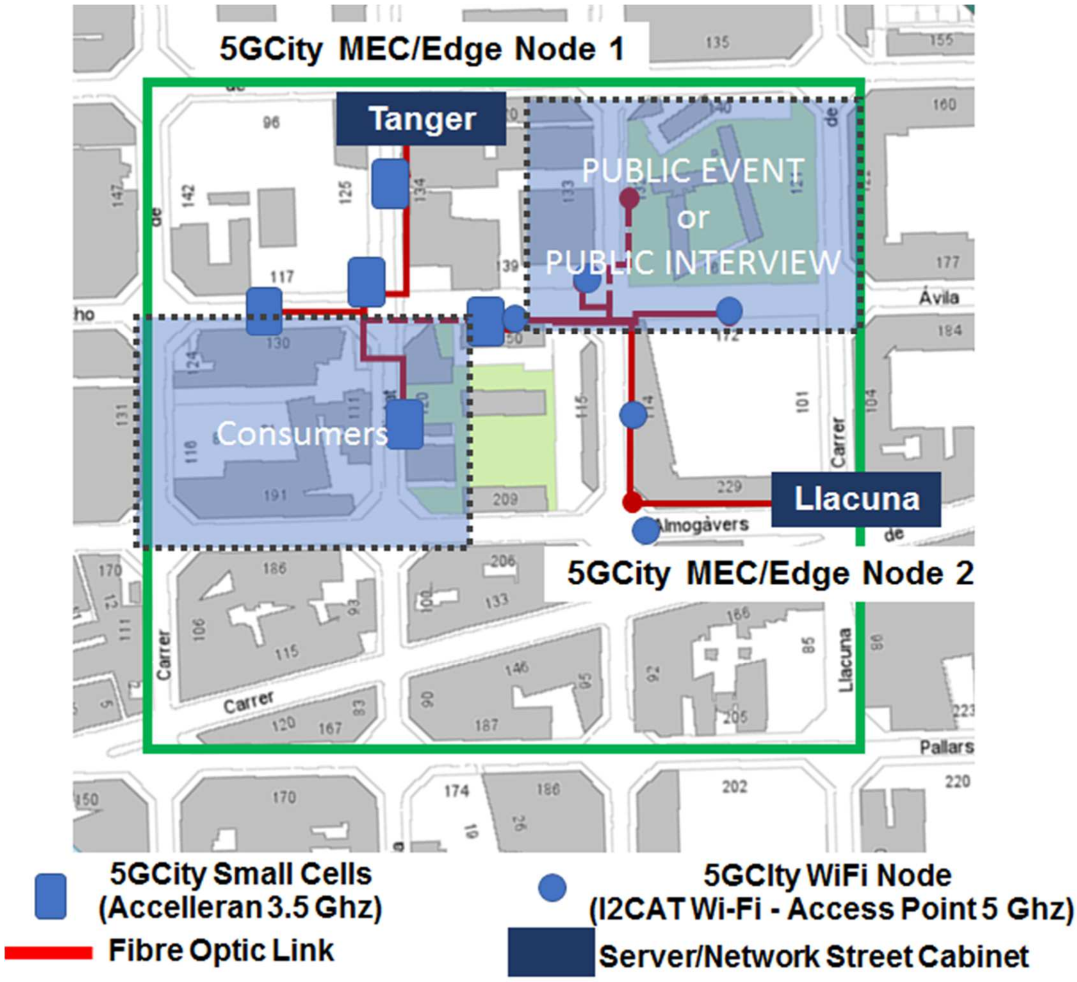


Figure 55 – Demonstration places of UC 3 and UC 5 in Barcelona.

4.1.3. Example of UC 5 Mobile Backpack Unit for Real-time Transmission in Barcelona.

The UC 5 will be deployed in Barcelona 5GCity testbed, in Tanger street, Pere IV street and surroundings, betevé studios are close to this area, and will be connected to the 5GCity infrastructure trough IMI CPD.

One plan is to transmit an interview from the street using de lamppost in Tanger street (on top of Figure 55), or like this example in Public activity area by sending it to Betevé studios. For the 3rd part of the test, processing in the 5GCity MEC/Edge Node hosted in Tanger cabinet or Llacuna cabinet will be needed, the signal for three different cameras will be transmitted to this MEC Node where the virtual mixer will be allocated. Immediately, the resulted production will be processed and transmitted to betevé studios, at the same time, a back connection to the cabinet will be needed to send the necessary instructions to the video mixer. Finally, when the video is ready, it can be send again to the mobiles phones in the other side "consumers" area for distribution. It is expected to have delays not only from communication but from processing time and human intervention. This is only an example of how we plan to demonstrate this UC. The final plan will be provided along the next deliverable.

4.1.4. Example of UC 6 Cooperative, Connected and Automated Mobility (CCAM) in Barcelona

In the context of this project, the CCAM use case has been designed having the uRLLC requirements of such scenarios, providing that a reliable and low latency communications system is key to potentiate a safer autonomous driving experience. It has been selected to be deployed at Barcelona's testbed, whose network topology is ideal to showcase the edge computing paradigm in practice, thanks to its distributed deployed resources. As such, and as to demonstrate how these services will have to deal with the mobility nature of these networks (vehicles as high-speed moving mobile nodes), different resources available at two different lampposts and one street cabinet will be assigned to this deployment. The goal is to demonstrate how edge computing could be used to deploy (i) a special CDN (Content Delivery Network), conveying and efficiently coordinating information transmitted between different end-users (vehicles) and (ii) a distributed network of worker nodes whose responsibility is to asynchronously process the dispatched data and to securely store such data closer to the end-user. The overall architecture of this use case is depicted Figure 57 To demonstrate such capabilities and cooperative scenario, a single vehicle (referenced as V1) will be responsible to detect a road hazard and to transmit such information to the Edge Application deployed at the cabinet, via the deployed Small Cells, which will store it temporarily, along with the object's location (this should happen when the vehicle is in Small Cell A's range); afterwards, a second moving vehicle (V2) should move in the opposite direction and should be alerted by the infrastructure of this road hazard, so it can react accordingly in a timely manner even before its own sensors, if available, have identified such hazard. To achieve the uRLLC requirements of such warning to the passing vehicle, the MEC Node application, upon being notified of a new User Equipment connection with the network (via the local breakout to the vBBU), will immediately send the information that has been marked as critical for that particular geographical area (the cached data). Upon successful connection, the vehicle must be warned of any potential road hazard or any sort of incident in the vicinity in less than 10ms.

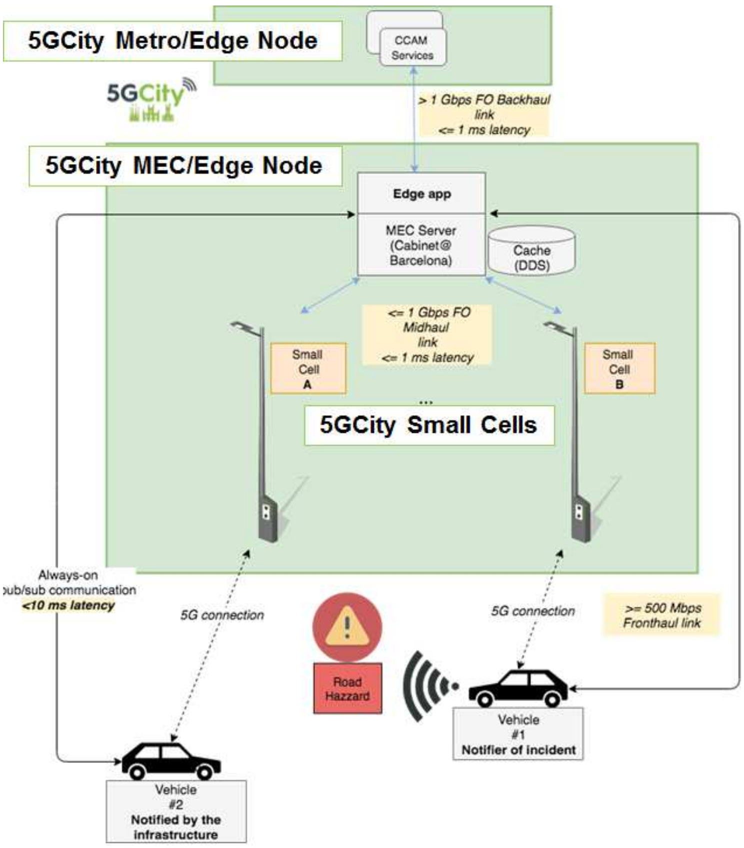


Figure 56 - UC 6 overall architecture.

As depicted in Figure 57, the edge application is expected to be instantiated at the highlighted MEC Server, while the other Extended Edge application will be deployed at the lampposts in the dedicated ARM nodes (highlighted in orange, next to the other allocated Small Cells). LTE (3.5GHz) connectivity to the end-user will be provided via the two different Small Cells from Accelleran.

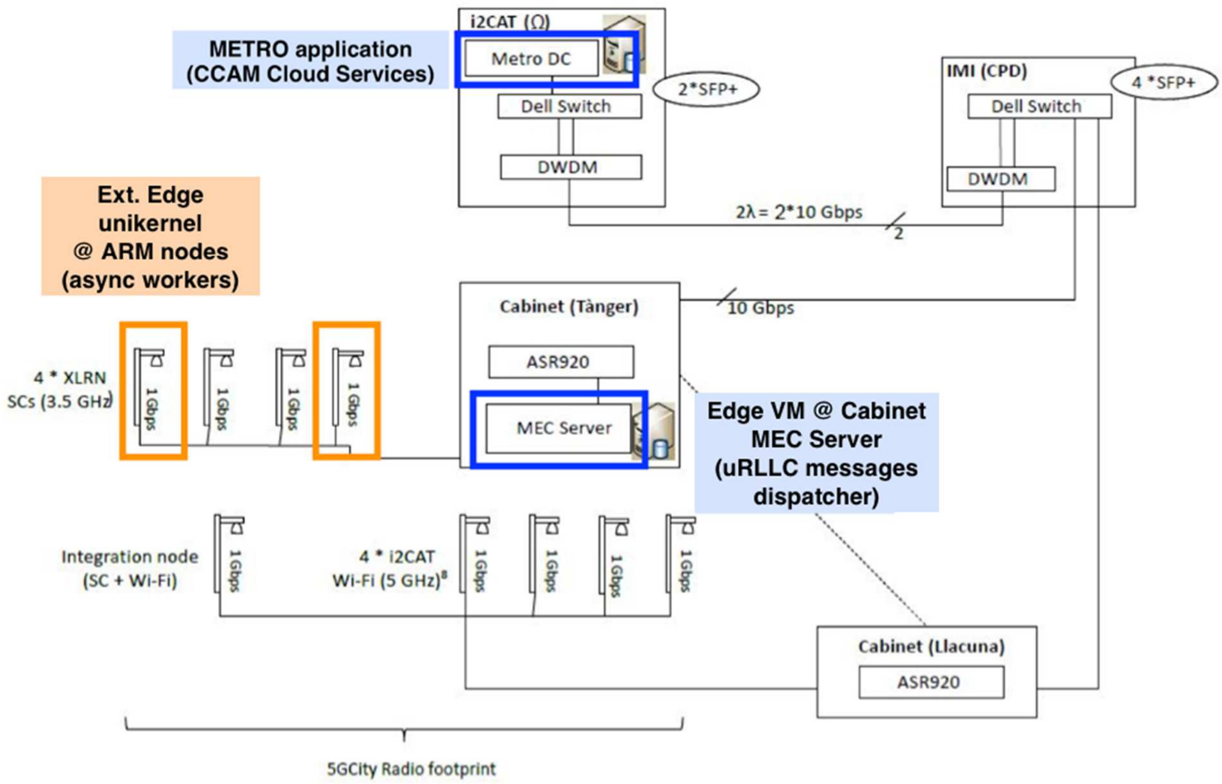


Figure 57 - UC 6 distributed 3-tier applications (Core, Edge, Ext. Edge).

The mobility scenario associated with the use case will be planned according to the traffic flow imposed by the infrastructure. Figure 58 depicts the possible resources where the different Extended Edge applications should be deployed (two out of four available lampposts) and the traffic flow around their vicinity (where the vehicles should be moving around).

The overall goal is to foster a cooperative and connected automated environment where every involved actor relays its knowledge to the network and edge which should act as a distributed cache. The MEC application should clear its database of alerts relayed by connected vehicles after a certain amount of time if no other reports regarding the same incident is reported. This same application will also relay its own context to other cloud-based solutions, so third-party entities can access this knowledge (identified as CCAM services at METRO-level). Demonstrating this autonomous efficient coordination of knowledge will make way for other network-demanding solutions to surface where hundreds of vehicles will be connected to the infrastructure and relaying information to and from the Cloud and Edge, such as crowdsourced LIDAR mapping of its surroundings, where bandwidth will be key.

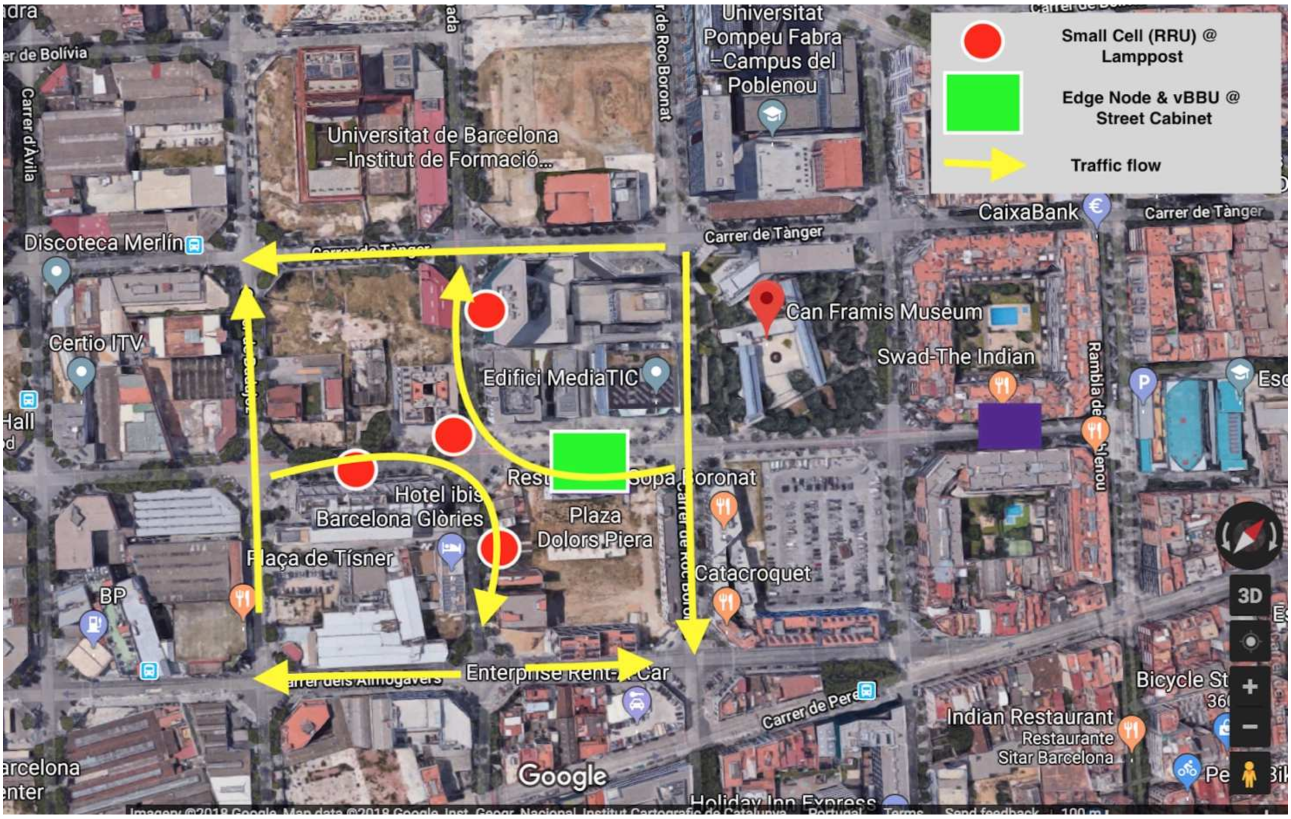


Figure 58 – Demonstration area plan for the UC6 in Barcelona.

4.2.UCs Deployment in Bristol Infrastructure

In the City of Bristol three UCs will be deployed; UC 2 Neutral Host, UC 3 Video Acquisition and Production Community media engagement in live events, and UC 4 UHD Video Distribution Immersive Services.

4.2.1. Example of UC2 2 Neutral Host Deployment in Bristol

In the city of Bristol, a very special place (Millennium Square) has been selected to deploy the 5GCity trials. The Neutral Host use case is specially characterized by sharing network resources, and here the infrastructure can make use of the following two modes, MORAN (Sharing CORE) and MOCN (Sharing CORE and RAN).

In the MORAN architecture, each Mobile Operator intends to use their own spectrum, then each different Small Cell can be dedicated to a Mobile Operator in single frequency or to multiple operator if Multi Carrier. They are controlled by the centralized Small Cell cluster functions in the cabinet, which is offering a "virtual" MORAN view of the physical small cells. The centralized Small Cell cluster control function running in the cabinet has the advantage that it will offer the same functionality and services regardless on whether the physical Small Cells deployed are single or multicarrier capable (Figure 59i). Here the deployment and coverage are the key point to achieve an efficient system.

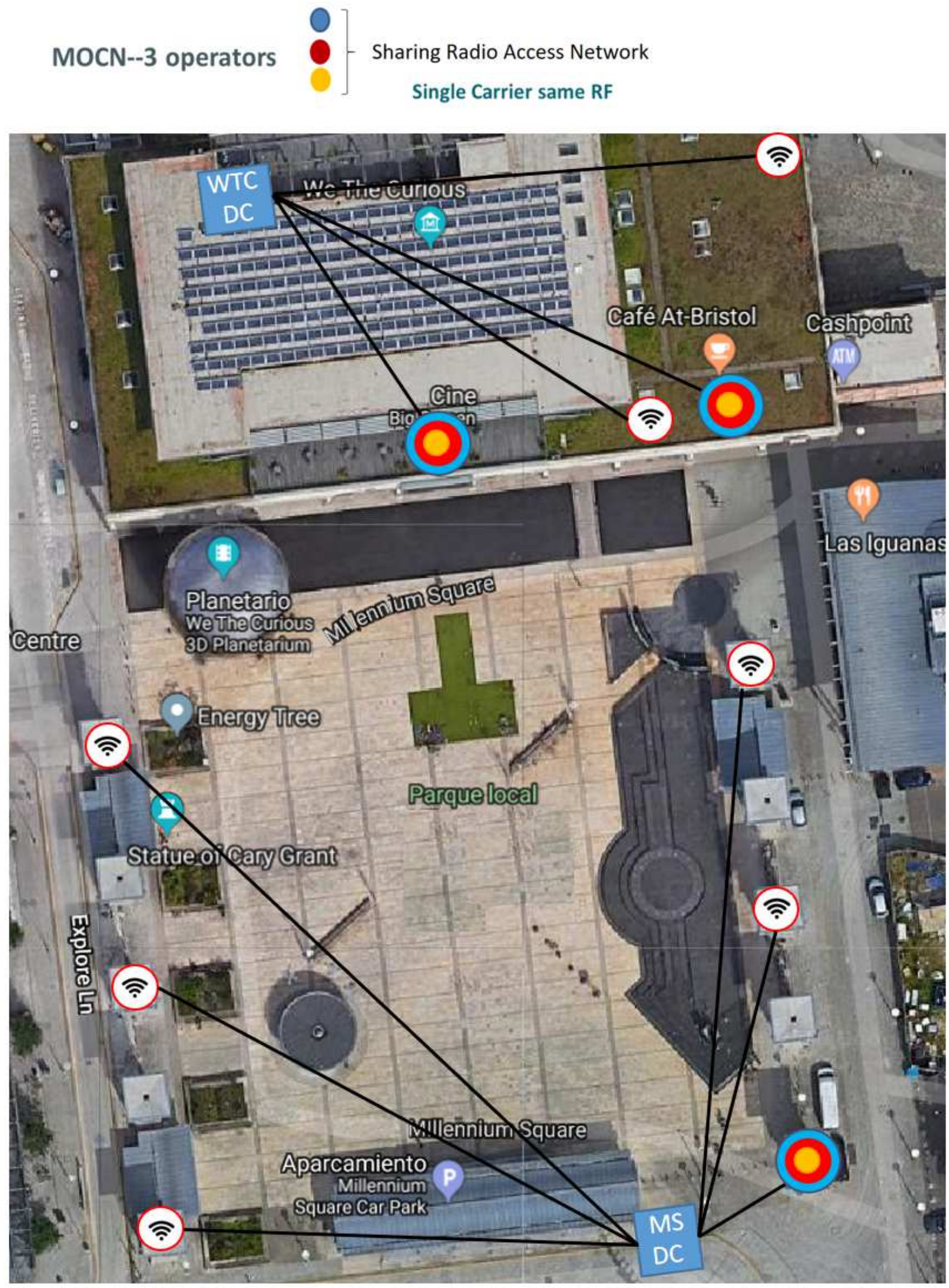


Figure 59 - Example of UC 2 Neutral Host into Bristol Infrastructure – MOCN Case.

In the MOCN architecture (Figure 59), the MS-DC or 5G-Rroom is hosting centralized Small Cell components of a cluster of physical Small Cells (1 in MS or 2 in WTC). Moreover, the RAN deployed are single frequency and in this case spectrum resources are shared by different participating Mobile Operators. In the case of "We -he-Curious" zone, MEC and RAN are common for all service providers for two small cells and for one small cell in Millennium Square. The key issue here is to guarantee a certain quality of service. Depending on the expected service quality the asset to be guaranteed will need to be bandwidth, coverage or latency. The MORAN example in Bristol is introduced in Figure 60.

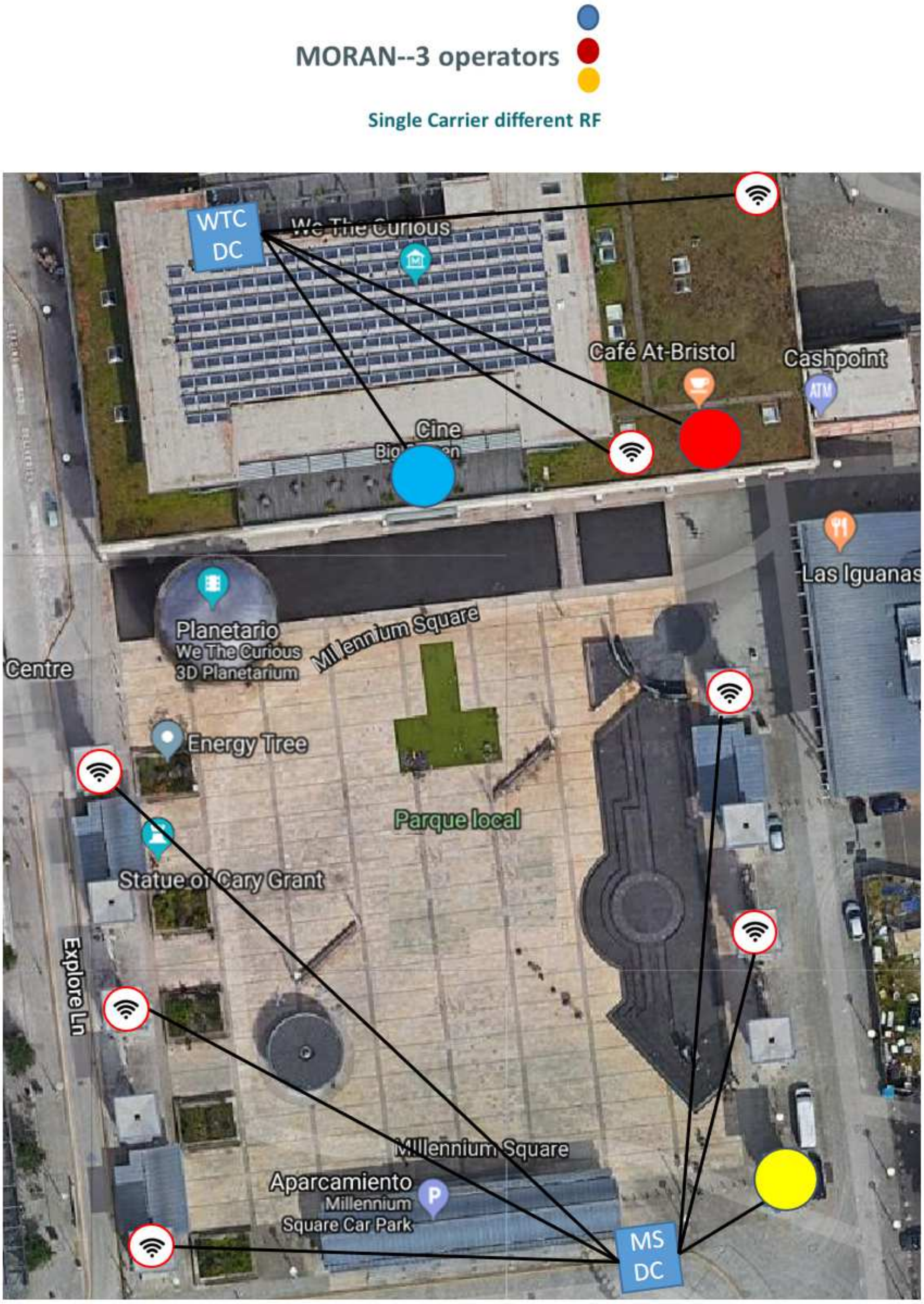


Figure 60 - Example of UC 2 Neutral Host into the Bristol Infrastructure – MORAN Case.

4.2.2. Example of UC 3 Video Acquisition and Production Deployment in Bristol

The UC 3 Video Acquisition and Production have a special need in terms of physical infrastructure, it is necessary to install and connect special video servers in the *We The Curious* datacenter which will host the 5GCity MEC/Edge Node. The data center have free rack space to scale the current processing power or connect special equipment for processing data. The free rack space will be used to host MOG servers where MOG's private cloud will be running. The servers will be connected to the Switch with 10 Gbps links to have access to the city infrastructure and to the internet. The private cloud need to be connected to the internet to expose the controls to the video operator. The operator can do clean cuts between the available feeds and send the result to the broadcaster, over the internet and/or intranet. The DC and the venue are linked by fibre, connecting the cabinet closest to the venue and the datacenter. Figures 61 demonstrates how the MOG use case will be placed in Bristol infrastructure:

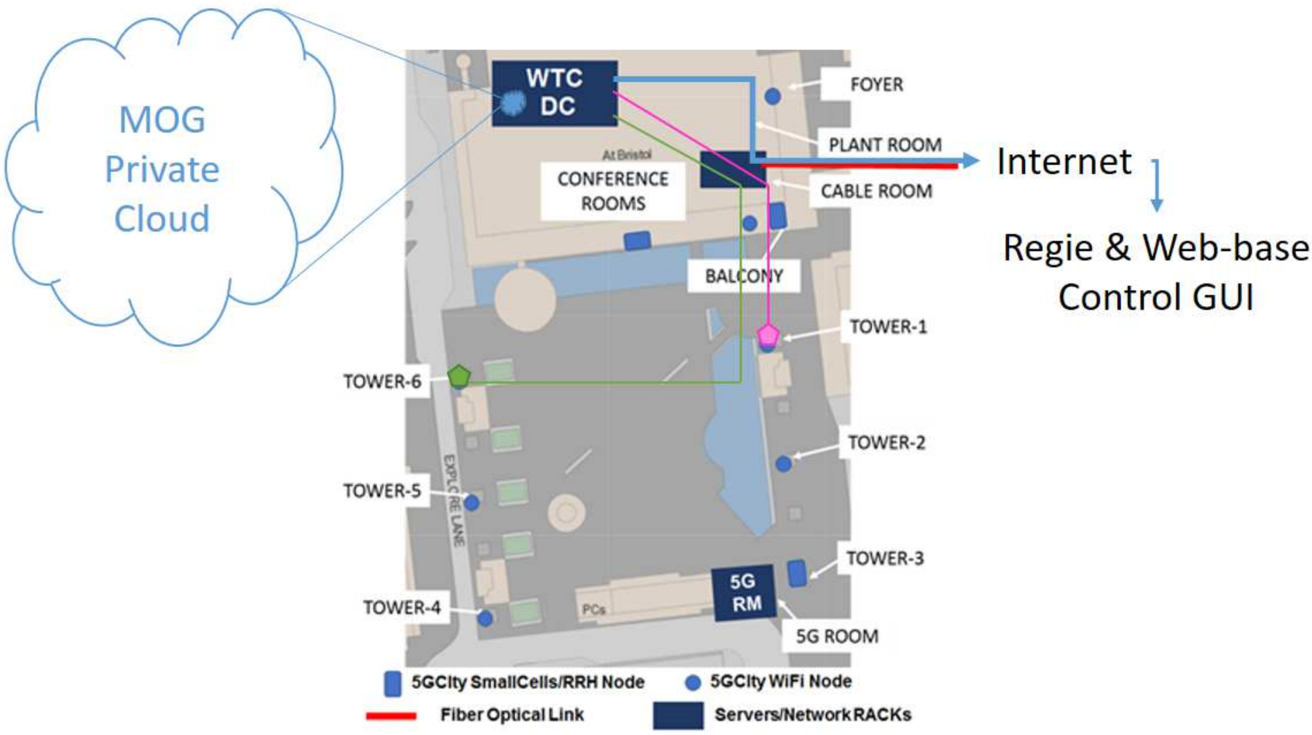


Figure 61 – Deployment of UC 3 in Bristol

4.2.3. Example of UC 4 UHD Video Distribution and Immersive Services Deployment in Bristol

In Bristol, the immersive part of the project will be deployed 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 VR/AR/MR-like devices. Also, with the production of video 360° to improve the immersion of the user experience. At the same time the visual search allows matching images or videos captured by the user, such as buildings, statues, paintings, with contents present in databases thanks to visual similarities.

In Bristol, new Video 360 contents will be produced for the users, just to create “a virtual tour” in a hypothetical journey that include more information and A/V. This use case requires ultra-high bandwidth, to carry high quality UHD/4K video signals and a very low system latency, which should enable to implement effective interactive applications.

In Bristol the UC4 is implemented using the following schema with a complete merge of the infrastructure capabilities.

Content	Cameras 360	
MEC-Edge	ADLINK SERVER Streaming Server	Edge/MEC node Millennium Square
Edge/metro Data Center	Orchestration Server #1 Application server#2 Video contents (Server#3)	HPN DC 5GCity Metro/edge node
RAN	Towers in Millennium Square	Millennium Square
End User terminal	Smartphone Tablet PC Large TV screen for 4K-HDR view Hololens	

Table 20 – Components for UC4 with Locations

A server for the UC4 we'll provide: 1 Server (Rack mounted) Fujitsu Celsius in the DC of We-The-Curious will be installed. The server will be equiped with 2 CPU Intel Xeon CPU E5-2620 v3 @ 2,40GHz, a NIC Intel I217-LM, a RAM of 32 GB, and 2 HDs of 500 GB each.

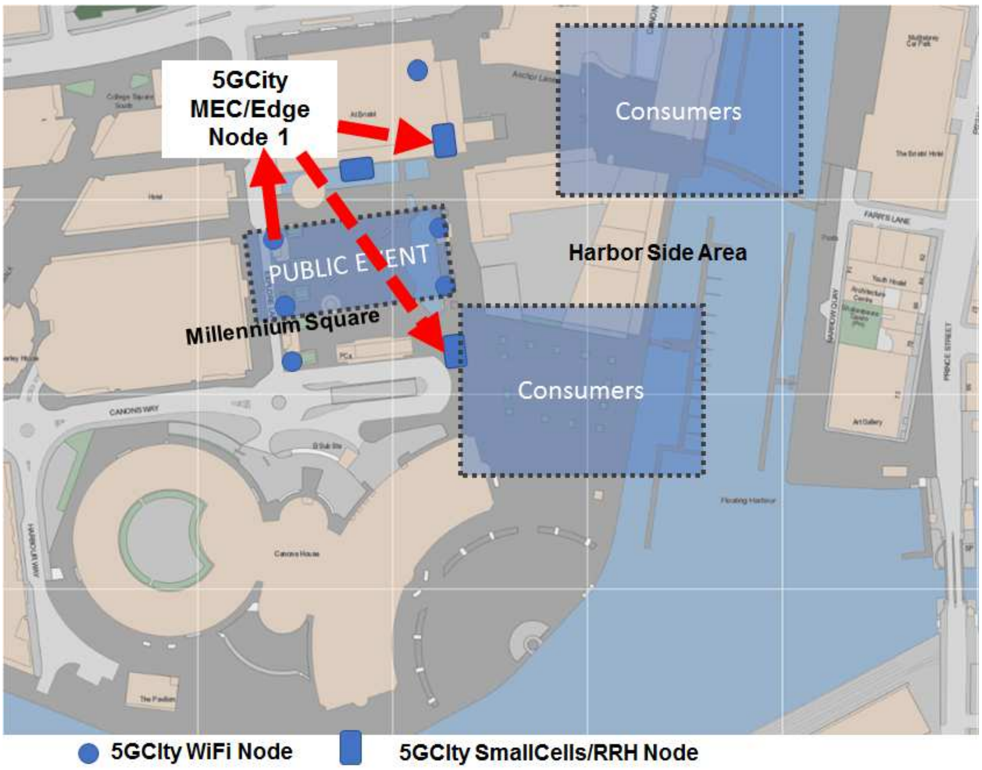


Figure 62 – Example of Media Production and Distribution Experiment with UC 3 and UC 4 in Bristol.

Like Barcelona, for the UC 3 will have an area for production with mobile devices “Public Event” and another for “Consumers” (Figure 62). The plan is to use two RRHs or Small Cells to transmit video from the 5GCity MEC/Edge Node (WTC-DC) after produced from the Millennium Square by a set of Wi-Fi and Smalls cells connecting mobiles phones. UC4 will also use the same approach, with the main differences in the tools and type of services which will demand poor processing. In this way the immersive reality service can offer though the harbour and produced in Millennium square.

4.3.UCs Deployment in Lucca Infrastructure

The city of Lucca will deploy three UCs; UC 1 Unauthorized Waste Dumping Prevention; UC 2 Neutral Host; and the UC 4 UHD Video Distribution and Immersive Services.

4.3.1.Example of UC 1 Unauthorized Waste Dumping Prevention deployment in Lucca

The present document describes the scenery of application of the survey automatic mechanism of the environmental abuse covered by Use Case 1 "Unauthorized Waste Dumping Prevention" in the scope of 5GCityEuropean project. The selected waste collection bay is the one in Piazza S.Donato (Figure 63) in the historical centre of Lucca . The target is to realize smart automatic system of survey of the violation related to the illegal ways of Waste Dumping in the collection bayes, transmission of an alarm to nearest terminals 5G terminal and support to the immediate individualization of the transgressor.

Figure 63 - Piazza S.Donato waste collection bay.

The Collection bays are monitored by two high resolution camera, identical and placed on the same pole (Figure 64). The first one is connected to the Municipal Police video imaging recording system and is currently used by penalty mechanism. The second one is exclusively dedicated to the 5GCity project.

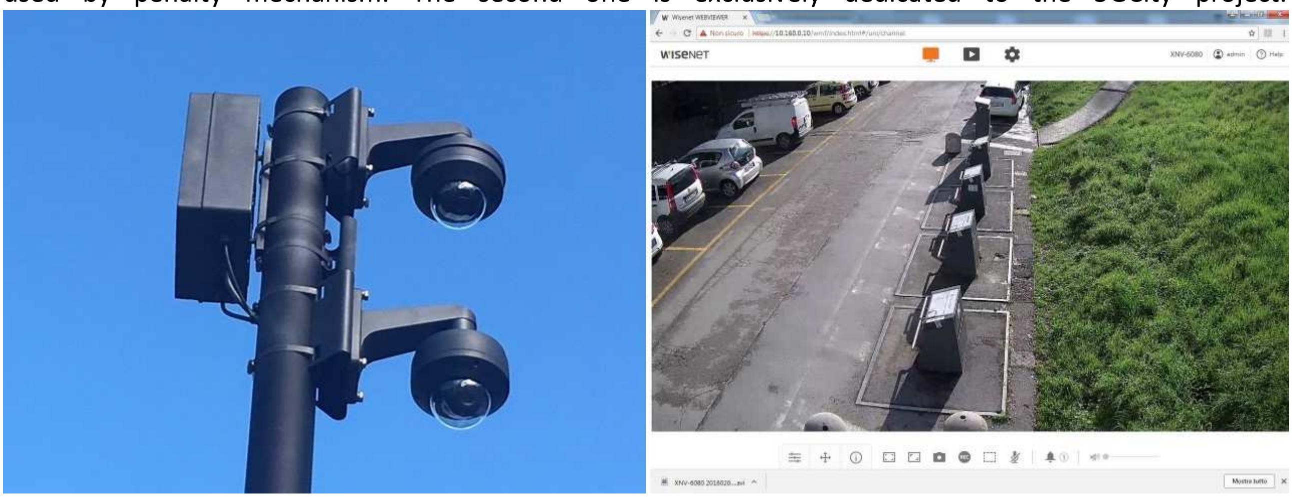


Figure 64 - Camera detail and images from 5GCity camera.

The camera is connected by fibre optics to the 5GCity Metro/Edge Node in Lucca and to a cabinet next to the Castello di San Donato on the city Walls. According to the next decision analysis and/or alarm software will be installed in a low power device (Edge Computer) in the cabinet and /or in a server placed in the datacenter of communa de Lucca housing the 5GCity Metro/Edge Node (Figure 65).

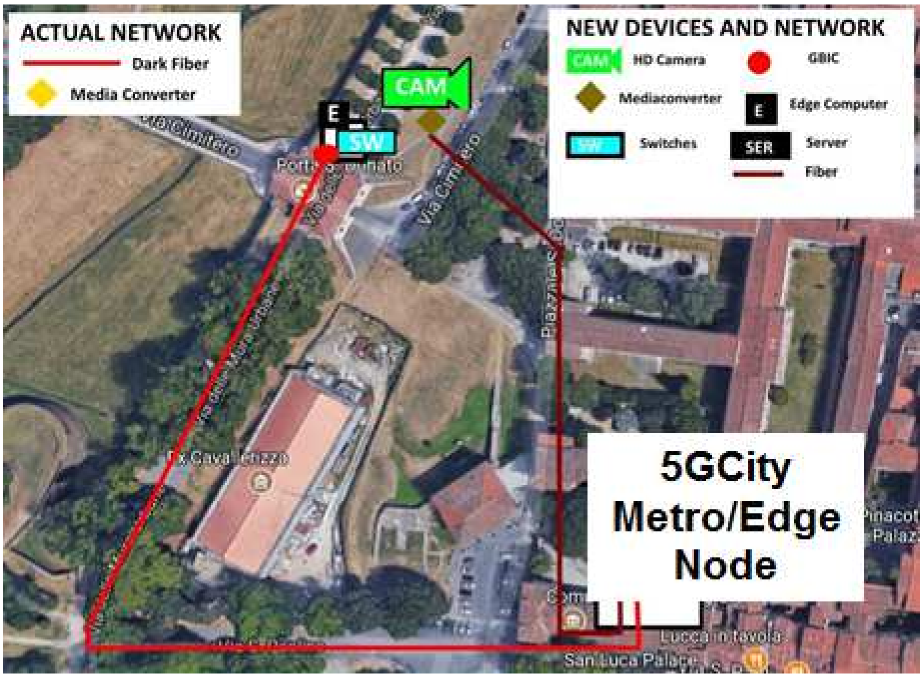


Figure 65 - UC 1 infrastructure (in operation).

We summarise in the following

Content	Camera	Via delle Mura
MEC-Edge	ADLINK SERVER	Cabinet via delle Mura sortita San Paolino
Edge/metro Data Center	Orchestration Server #1 Application server#2	Via San Paolino
RAN	Small Cell 1	Via San Paolino
End User terminal	TDD User equipment	-

Table 21 – Component of UC1 with locations.

Current detection system.

Due to citizen report, or due a direct detection of waste conferment outside the disposal bay, some municipal police officer scans the recorded images searching of the conferment scene. Then two typical events happen:

- The transgressor was arrived by vehicle with a plate (i.e. car or motorbike).
- Officer query national DB plates searching of the owner. If the owner is an individual (not a company) and if it corresponds in sex and age to the transgressor officer search his face image in Identity

document PhotoID DB. If it doesn't correspond in sex or age the officer extend his search in members of his/her family. If he found a corresponding image he writes the ticket, otherwise he stops.

- The transgressor was arrived on foot or by vehicle without a plate (es bike).
- If the officer knows directly the transgressor he can write the ticket otherwise he stops. This system has some referable weak points related to the not identification of the transgressor (immediate or deferred) that causes the missed penalty.

Enhancement in 5G environment

Through the technology deployed in the 5GCity environment it is possible to improve the process of penalty with the following elements:

- Immediate alert (during the illegal dump) with no need of a later citizen's or agent's report a.
- Automatic selection of the illegal conferment's scene with no need of search.
- Dispatch of the video sequence to nearest agent's smartphone.

This scenario allows nearest agent to gather the transgressor in flagrancy or in his/her immediateness, reducing the number of unpunished infringements.

4.3.2. Example of UC 2 Neutral Host Deployment in Lucca

In Lucca the "Neutral Host" model is implemented to densify the access network and maximize the use of available resources by using a single hosting operator (the Municipality) that provides access to network resources (e.g. radio frequencies, physical spaces such as cabinets, etc.).

The solution will be deployed to demonstrate how using the Network Slicing and Network Virtualization different services and different applications will be implemented on a single common infrastructure according to different Service level agreement.

The physical component will support to demonstrate how Virtual Network Functions can be exposed in this multi-tenant open platform, we consider an outdoor scenario represented for example by an on-site live event characterized by: high number of devices generating traffic simultaneously, high bit rate, localized coverage and high reliability.

Regarding the Mobile Network sharing options for the Neutral Host Use Case in Lucca will test the Multiple Operator Radio Access Network where each Mobile Operator use their own spectrum, the different physical single carrier Small Cells supporting different bands can be dedicated to a Mobile Operator.

In Lucca, given the characteristic of the city, also the rationalization criteria to minimize the impact on public and shared space will be a focus, according to the needs of citizens, administrations and the market.

In Lucca the UC2 is implemented using the following schema with a complete merge of the infrastructure used for Use case 1 and use case 4.

Content	Camera	Via delle Mura
MEC-Edge	ADLINK SERVER Streaming Server with GPU	Cabinet via delle Mura sortita San Paolino Casermetta
Edge/metro Data Center	Orchestration Server #1 Application server#2 Video contents (Server#3)	Via San Paolino

RAN	Small Cell 1 Small Cell 2	Via San Paolino(#1) Cavallerizza (#2)
End User terminal	TDD User equipment	

Table 22 – Physical coponents for UC 2 in Lucca.

Using the different components and the slices capabilities, it is possible to realise the different use cases based on the Neutral host model: in the slices offered by the neutral host (Use case 2) are mapped on the physical structure to realise the Use Case 1 and Use Case 4:

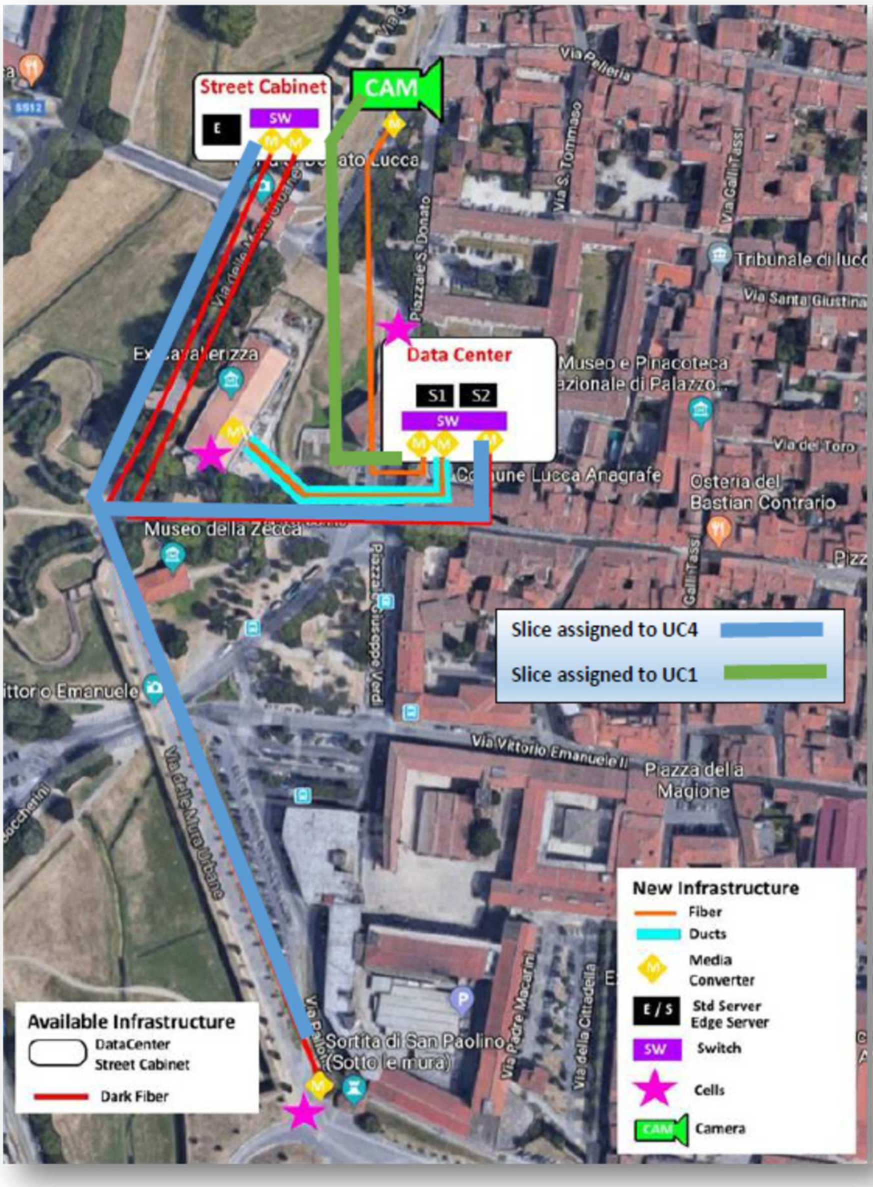


Figure 66 – Example of UC2 connectivity in Lucca.

To complete the description in the Figure 670 and 71 different aggregation shows how the different resources are aggregated to realise Use Case 1 and Use Case 4.

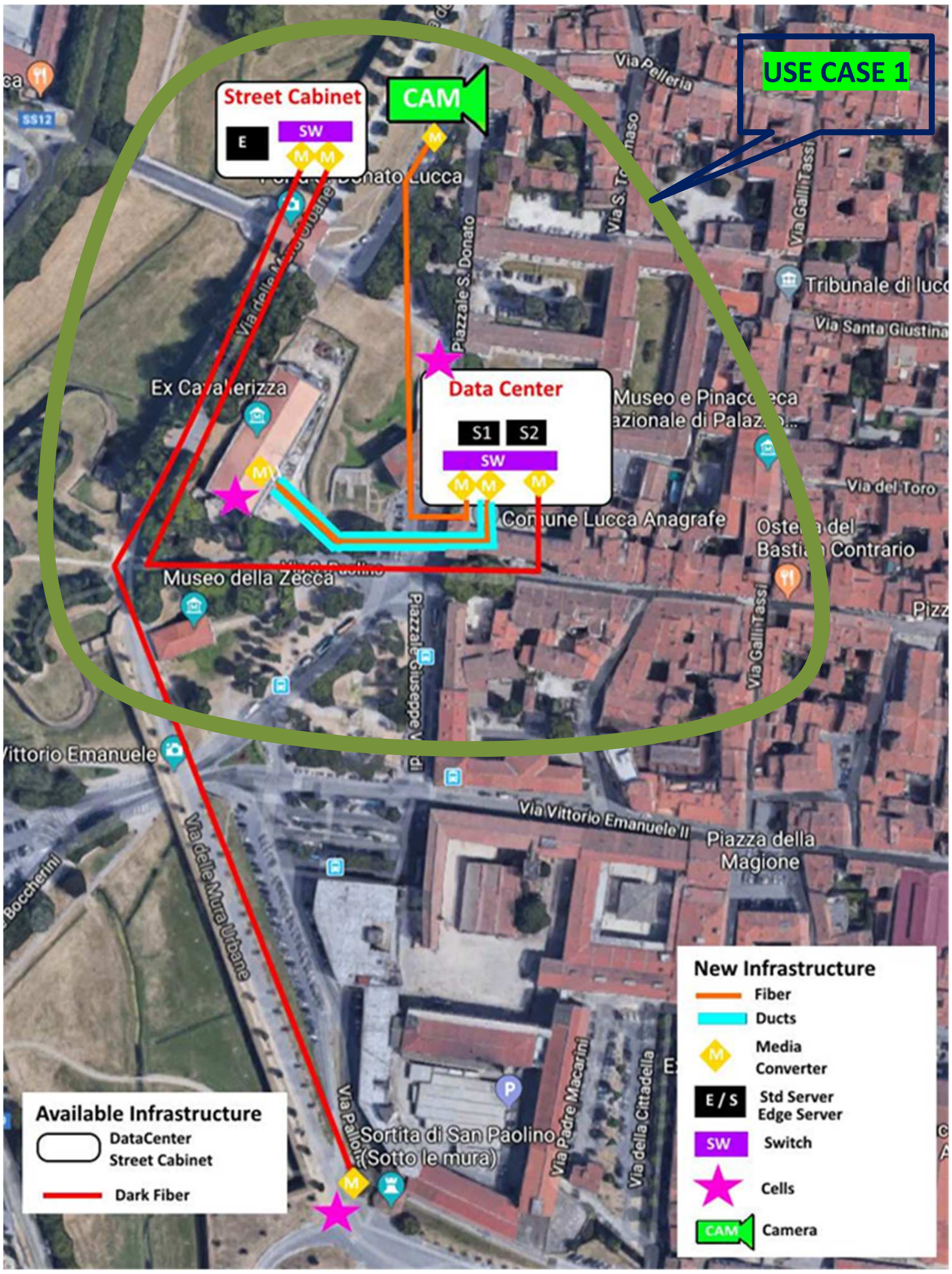


Figure 67 – Area for UC 1 in Lucca.

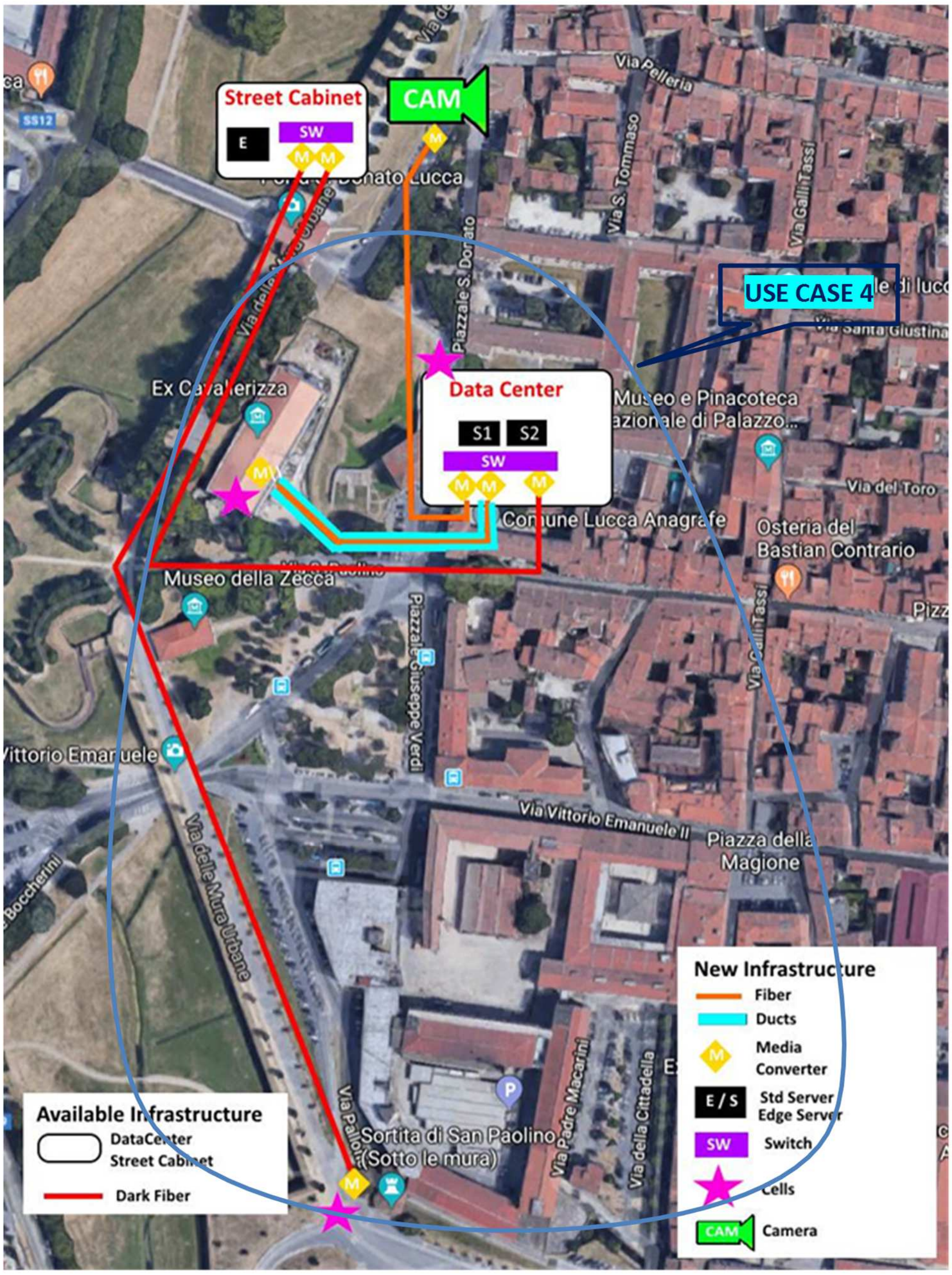


Figure 68 – Physical area for UC 4 in Lucca

4.3.3. Example of UC 4 UHD Video Distribution and Immersive Services Deployment in Lucca

In Lucca, the immersive part of the project will be deployed 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 VR/AR/MR-like devices. Also, with the production of video 360° to improve the immersion of the user experience. At the same time the visual search allows matching images or videos captured by the user, such as buildings, statues, paintings, with contents present in databases thanks to visual similarities.

In Lucca, new UHD/4K contents will be produced for the users, just to create “digital pills” in a hypothetical journey that include more information and A/V. This use case requires ultra-high bandwidth, to carry high quality UHD/4K video signals and a very low system latency, which should enable to implement effective interactive applications.

In Lucca the UC4 is implemented using the following schema with a complete merge of the infrastructure capabilities.

Content	Camera	Via delle Mura
MEC-Edge	ADLINK SERVER Streaming Server with GPU	Cabinet via delle Mura sortita San Paolino Casermetta
Edge/metro Data Center	Orchestration Server #1 Application server#2 Video contents (Server#3)	Via San Paolino
RAN	Small Cell 1 Small Cell 2	Via San Paolino(#1) Cavallerizza (#2)
End User terminal	Smartphone Tablet PC Large TV screen for 4K-HDR view Hololens	

Table 23 - Physical coponents for UC 4 in Lucca.

5. Conclusion

5GCity project aims to create real-world impact by deployment of its 5G-based edge platform in three distinct smart cities: Barcelona, Lucca, and Bristol.

Six relevant use cases have been analysed, to define and design a new infrastructure to be able to test and demonstrate the benefits of the 5GCity architecture and platform.

A mapping of each use-case into the three-tier 5GCity infrastructure was assessed before introducing the proposed infrastructure.

In this document a novel 5GCity infrastructure for each of the three cities was presented by considering each city profile and the requirements of the use cases.

In addition, examples of UCs deployment in each proposed city infrastructure was introduced.

Finally, it is expected that each city will inaugurate their novel infrastructure by following the summarized plan introduced in Table 24.

The next objectives of WP5 include the inauguration of the proposed city infrastructure and the first 5GCity trials in each of the cites.

The three cities will use existing and new information and technology (IT) infrastructure by deploying and integrating new equipment and software. In table 2 summarizes the 5GCity deployment on each city with tentative dates to be ready or fully operational.

City	5GCity Metro/Edge Nodes	5GCity Edge/MEC Nodes	5GCity Small Cells 5GCity Wi-Fi Nodes	Date
Barcelona	I2CAT – Omega building IMI - Glories Office	Street Cabinets - Llacuna Street - Tánger Street	Superblock @22	12 2018
Bristol	UNIVBRIS – HPN Lab - MVB Building	We-The-Curious (WTC-DC) Anchor road side. 5G Room (5G-RM) Cannons way side.	Millennium Square Harbour Side	11 2018
Lucca	LUCCA – Datacenter – Via San Paolino, 140, 3rd floor.	Street Cabinet on Viale delle Mura Urbane	Cavalerizza and Sortita San Paolino	12 2018

Table 24 - Summary of 5GCity infrastructure deployment goals.

Abbreviations and Definitions

5.1. Abbreviations

DMP	Data Management Plan
DoA	Description of Action
EC	European Commission
GA	General Assembly
IPR	Intellectual Property Rights
MST	Management Team
PC	Project Coordinator
PMO	Project Management Office
PO	Project Officer
TB	Technical Board
TC	Technical Coordinator
IM	Innovation Manager
TL	Task Leader
WP	Work Package
WPL	Work Package Leader

References

[1] ETSI, “NFV Management and Orchestration; Network Service Templates Specification”, ETSI GS NFV IFA 014, onli
http://www.etsi.org/deliver/etsi_gs/NFV-IFA/001_099/014/02.01.01_60/gs_NFV-IFA014v020101p.pdf

[2] ETSI, “Mobile Edge Computing (MEC) Framework and Reference Architecture”, ETSI GS MEC 003 V1.1.1, (2016-03)

[3] D2.2: 5GCity Architecture & Interfaces Definition

[4] C. Colman-Meixner, Pedro Diogo, M. S. Siddiqui, A. Albanese, H. Khalili, A. Mavromatis, Luca Vignaroli, A. Ulisse Nejabati, and D. Simeonidou”5G City: A novel 5G-enabled architecture for ultra-high definition and immersive infrastructure”, IEEE International Symposium on Broadband Multimedia Systems and Broadcasting (BMSB), Va May, 2018.

[5] I. Neokosmidis, T. Rokkas, D. Xydias, A. Albanese, M. S. Siddqui, C. Colman-Meixner and D. Simeonidou, "Are 5G the Neutral Host Model the Solution to the Shrinking Telecom Market", (To be presented), in the 3rd Symposium of Intelligence to the Network Edge” (5G-PINE 2018), 14th IFIP International Conference on Articial Intelligence Ap Innovations (AIAI 2018), Greece, May, 2018.

[6] D3.1: 5GCity Edge Virtualization Infrastructure Design.

[7] D4.1: 5GCity Orchestrator Design, Service Programming, and Machine-learning Models

Appendix A

Details of the deployed dark fibres in the city of Barcelona

The work consisted in a study of planning the dark fibre network underneath Barcelona by analysing one by one, t possible paths derived from all the connection boxes and fibre sections along with their capacity and the alrea connections plus spare connections and fibres in each section. From all these studies a final route with 2 fibres is gene site.

In this document we want to show the details of the fibres routes calculated within the Barcelona city map area consid of the deployed dark fibres.

Several tables are also listed between the figures to have a complete information of the dark fibre status. These table spare fibres in each city section. This information is crucial when deploying dark fibre to assess if these routes are vali know if any future services or upgrading could be deployed.

IMI (Glòries) to BeTeVe technical room

Initial map with the route to follow by connecting fibres from IMI (Glòries) to the block where BeTeVe and its techn placed (Plaça Tísner 1). In this map it is also shown the connection boxes (with their names) for each section.

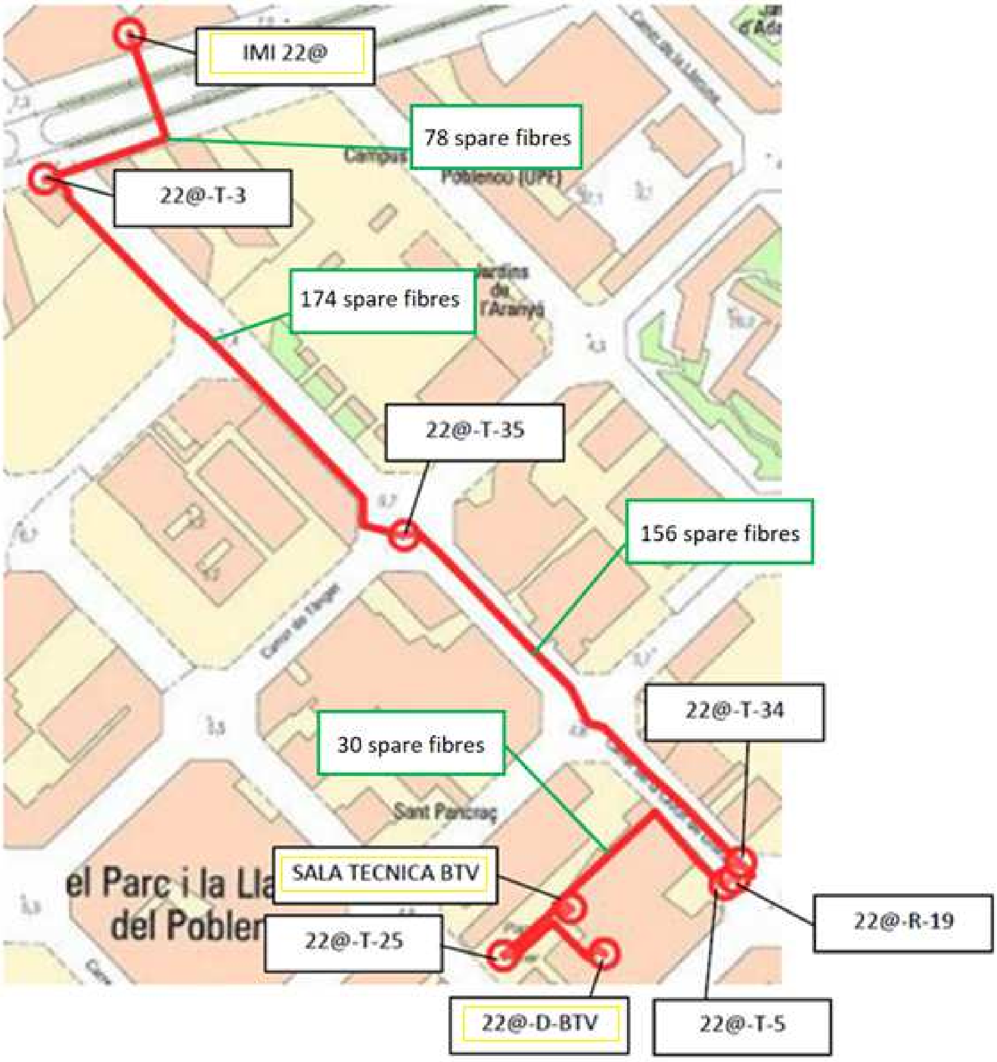


Figure 1: Fibre IMI to BETEVE.

In the table 1 there is a list of used cables and the number of spare fibres for each section.

Cable	Fibres Lliures
(22A-T-25)-(22A-D-BTV)	110
(SALA TECNICA BTV)-(22A-T-25)	84
(SALA TECNICA BTV)-(22A-T-5)	30
(22A-T-5)-(22A-R-19)	72
(22A-T-34)-(22A-R-19)	80
(22A-T-35)-(22A-T-34)	156
(22A-T-3)-(22A-T-35)	174
(22A-T-3)-(IMI-22A)	78

Table 1: Fibre elements between IMI and BETEVE.

IMI to Barcelona street Cabinet in Llacuna

Initial map with the route to follow by connecting fibres from IMI (Glòries) to the block where the cabinet (5GCity Edge is placed (C/ Llacuna / PereIV). The map of Figure 2 shows the connection boxes (with their names) used in each sectio

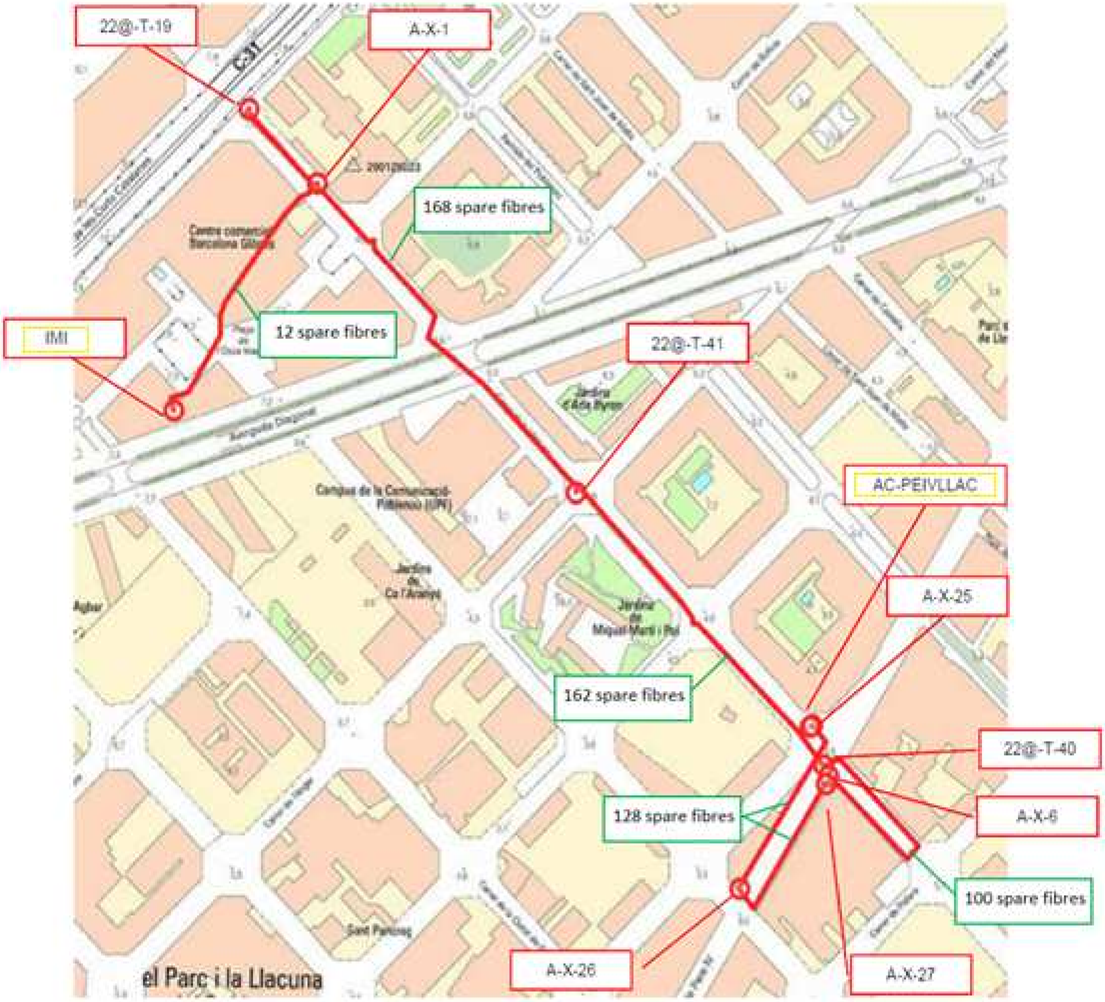


Figure 2 Fibre deployment between IMI premises and street cabinet Llacuna

In this route there are two types of fibres, the 22@ ones belong to the backbone and the A-X one belongs to the local the table 2 presents the list of used cables and the number of spare fibres for each section.

CABLE	SPARE FIBRES
F144/(AC-PEIVLLAC)–(A-X-25)	130
F144/(A-X-25)–(A-X-26)	128
F144/(A-X-26)–(A-X-27)	128
F144/(A-X-27)–(A-X-6)	134
F128/(A-X-6)–(22@-T-40)	100
F192/(22@-T-40)–(22@-T-41)	162
F192/(22@-T-41)–(22@-T-19)	168
F48/(22@-T-19)–(A-X-1)	168
F48/(A-X-1)–(IMI)	12

Table 2: Fibre elements between IMI and street cabinet Llacuna

IMI to Eurona

Fibre connection directly from IMI Glòries to Eurona premises (Agricultura street). Initial map (Figures 3 and 4) showin follow by the dark fibres deployment from IMI Glòries to the Eurona street block.

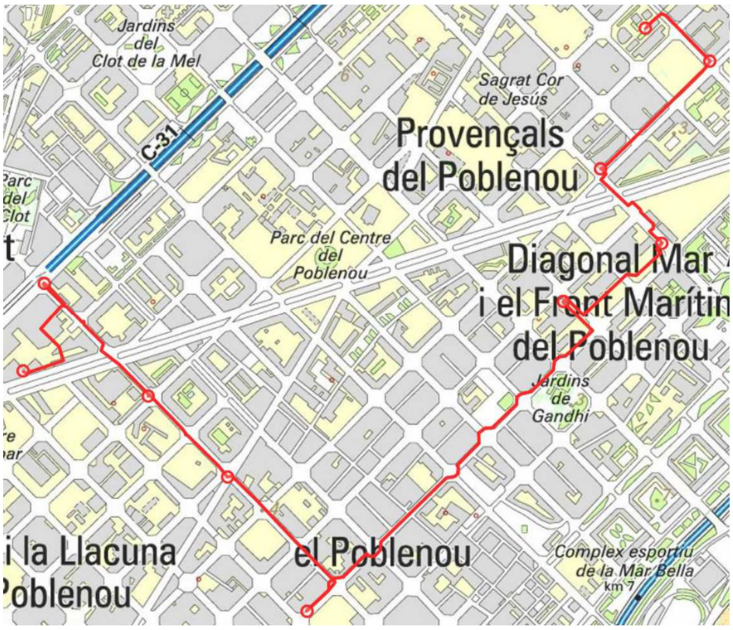


Figure 3: Fibre between IMI and Eurona

In the following map we have added the connection boxes names that join each section.

Figure 4: Fibre between IMI and Eurona with cabinets locations.

The following map of Figure 5 is showing the connection detail inside the street block of Eurona.

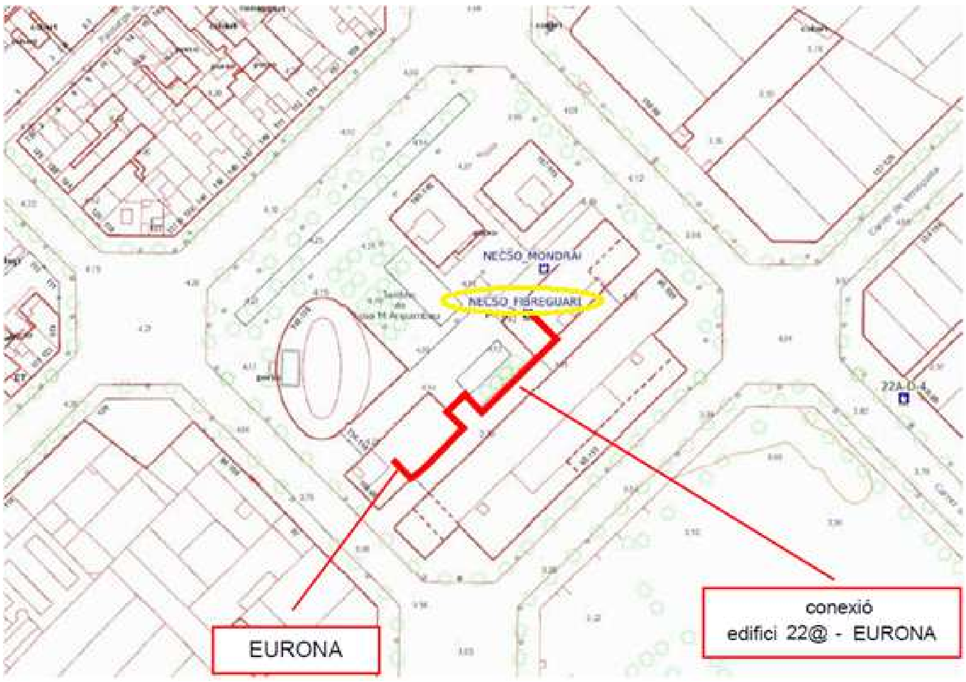


Figure 5: IMI - Eurona fibre connections

It is proposed to connect to the Eurona building from the existing dark fibre boxes in RITI IMI room at 22@ (Barcelo 22@). The showed path could not be the final one as when in the field it could appear some minor modifications dep structure of the underneath room. Table 3 presents the list of spare fibres for each section.

Cable	Fibres Lliures
(22A-T-2)-(NECSO_FIBREGUARD)	102
(22A-T-2)-(22A-T-15)	70
(22A-T-15)-(22A-T-7)	80
(22A-T-38)-(22A-T-7)	52
(22A-T-38)-(22A-T-36)	102
(22A-T-40)-(22A-T-36)	178
(22A-T-41)-(22A-T-40)	160
(22A-T-19)-(22A-T-41)	166
(22A-T-19)-(IMI-22A)	128

Table 3: IMI-Eurona fibre boxes.

IMI to i2Cat (Campus Nord)

Connection directly from IMI Glòries to i2Cat at Campus Nord area in Barcelona. The following map pictures are shov to follow by the dark fibres deployment from IMI Glòries to the i2Cat DC (Data Center).

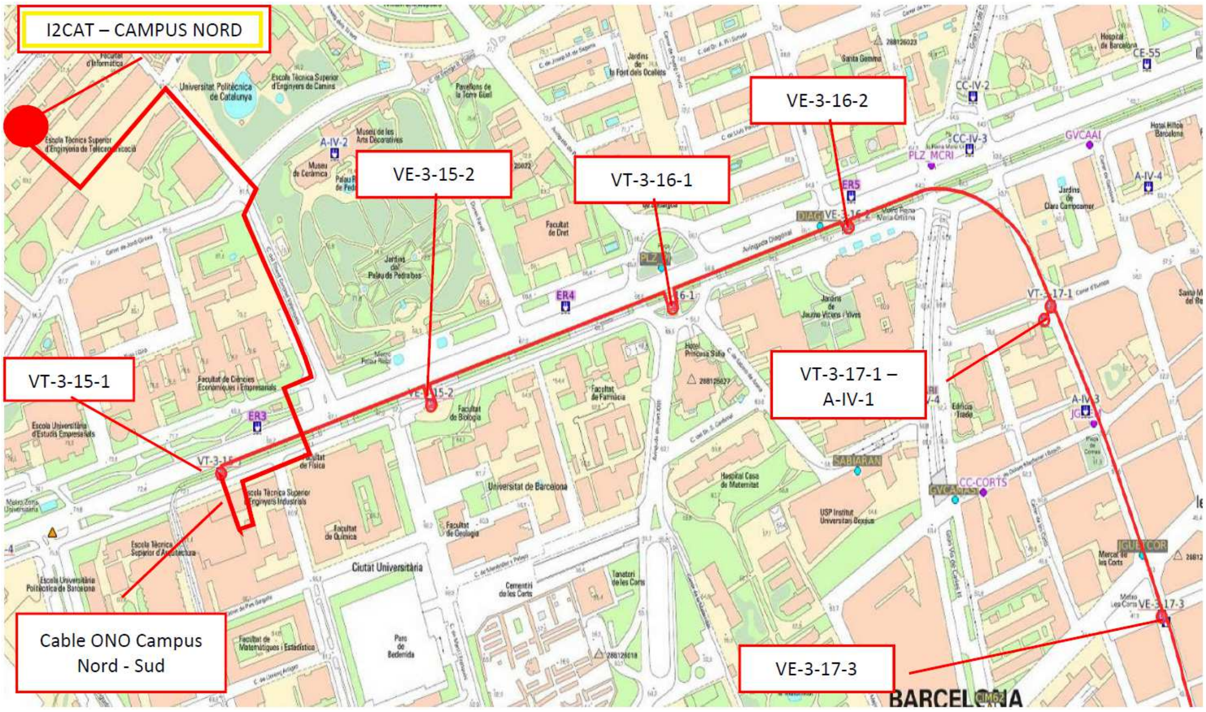


Figure 6: IMI-I2CAT (I)

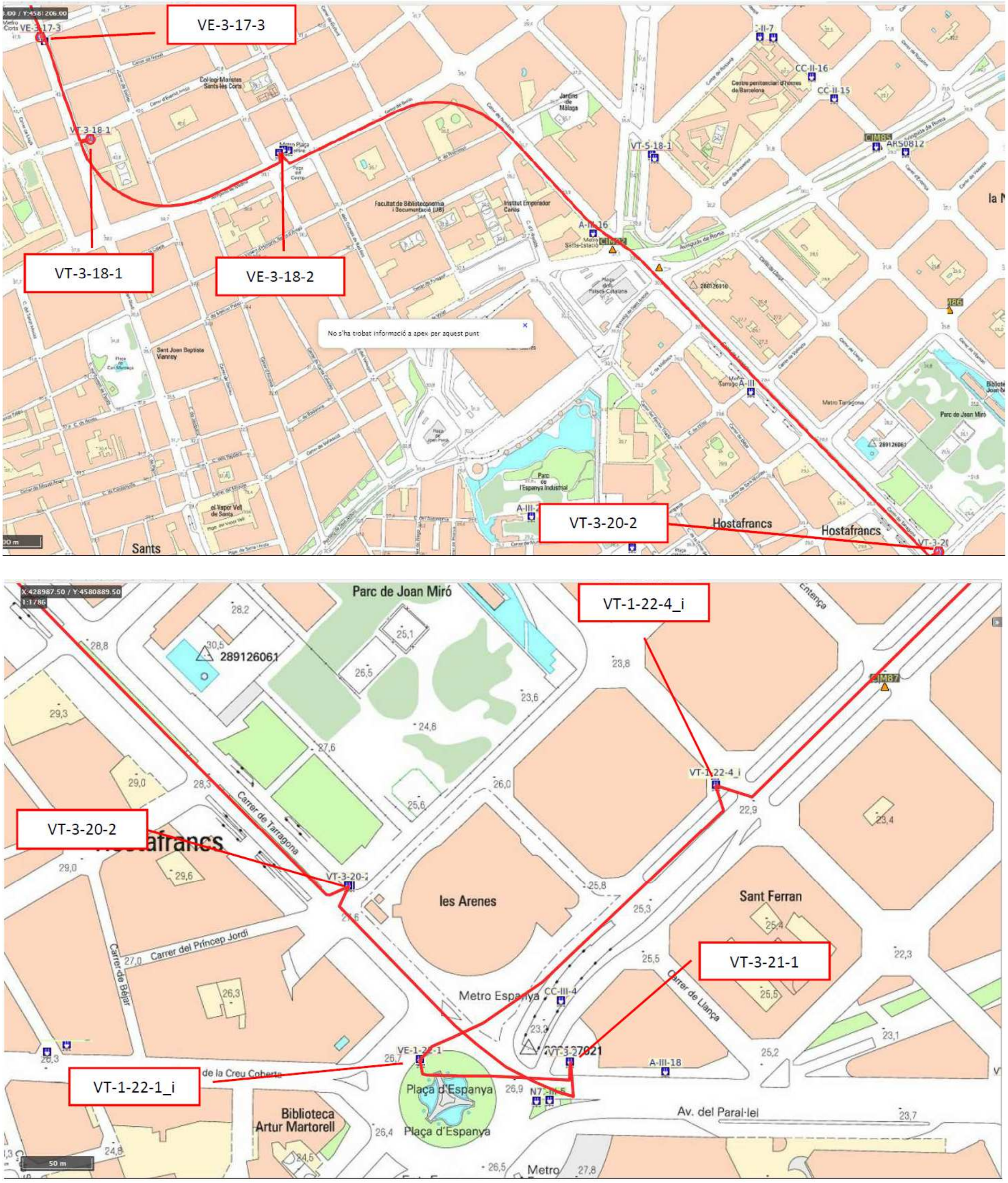
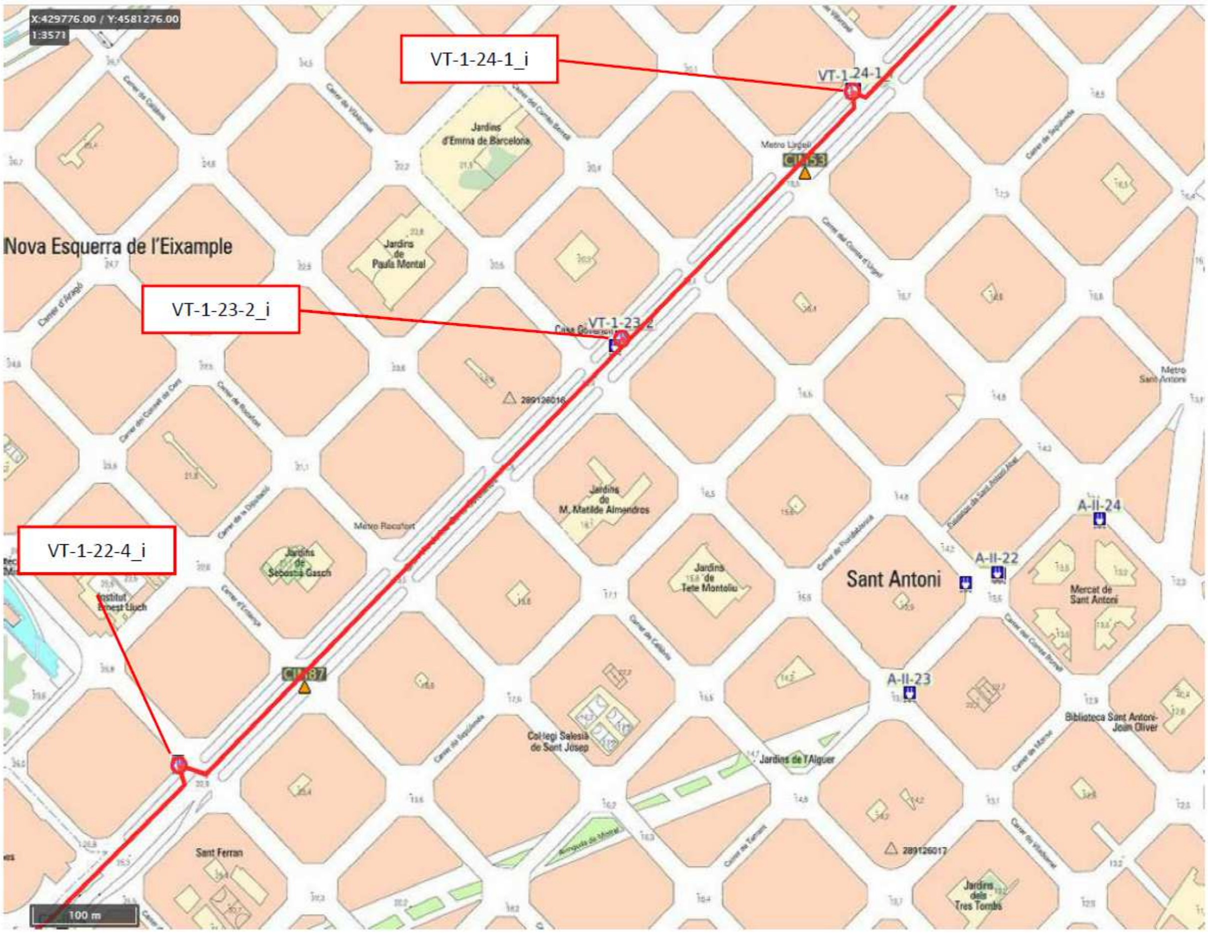


Figure 7: IMI-I2CAT (II)



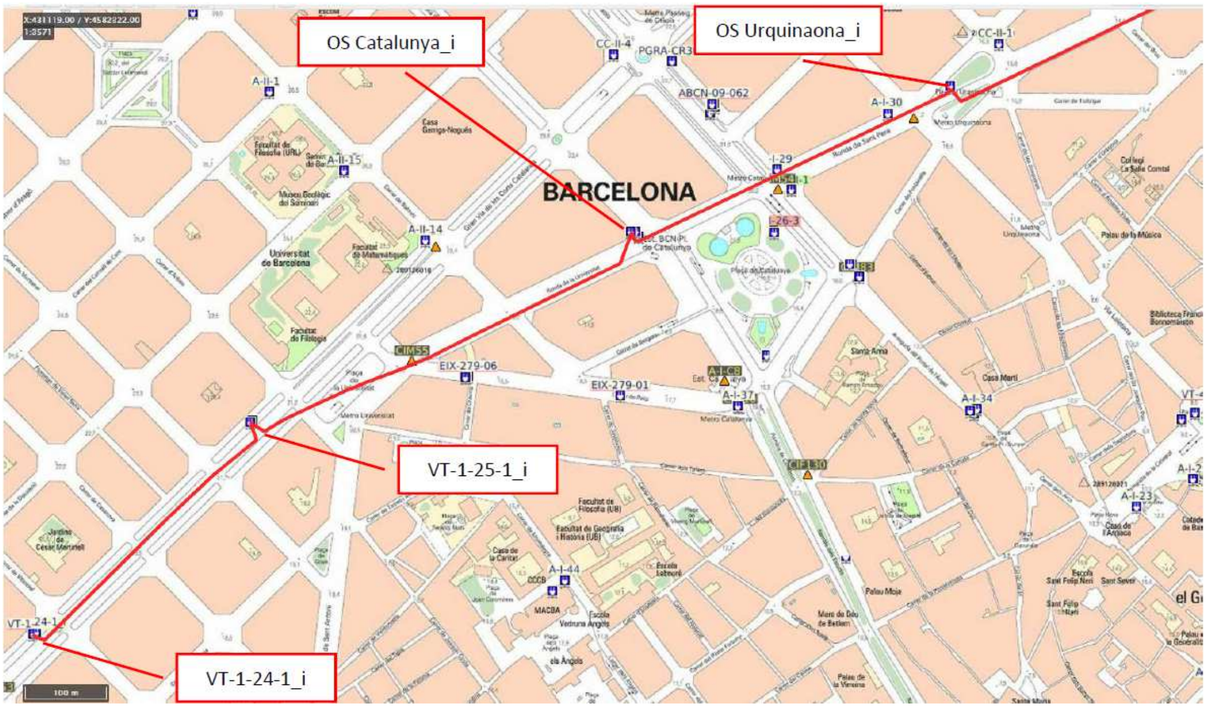
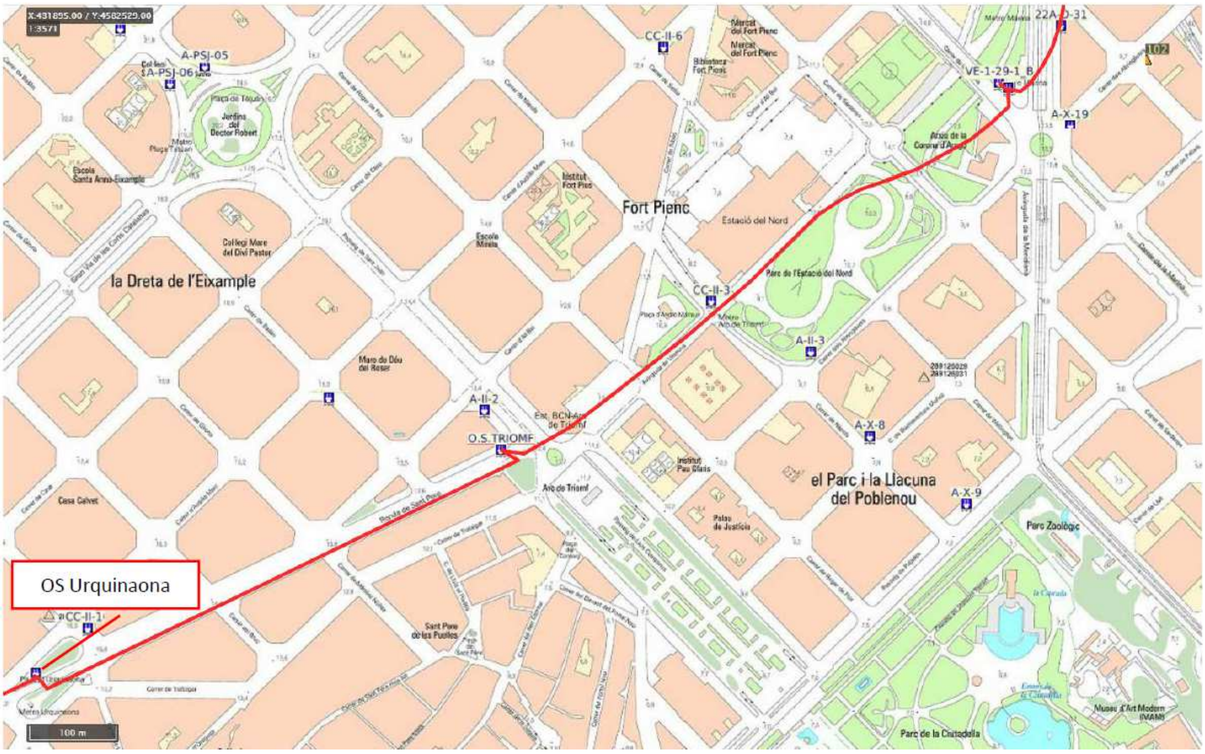


Figure 8: IMI-I2CAT (III)



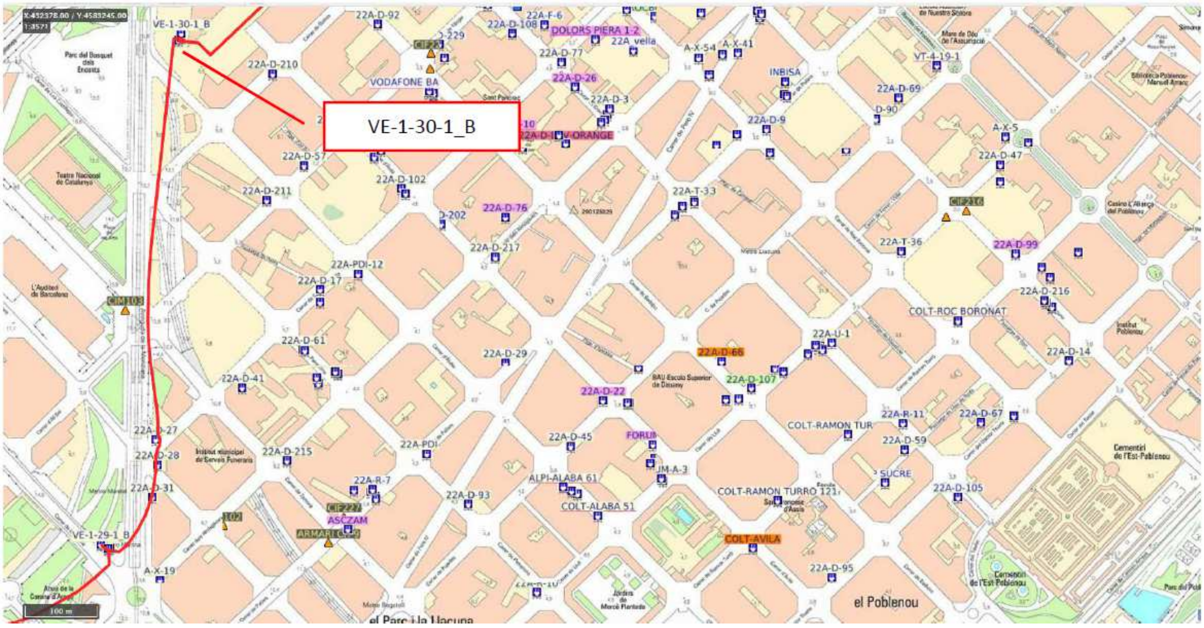


Figure 9: IMI-I2CAT (IV)

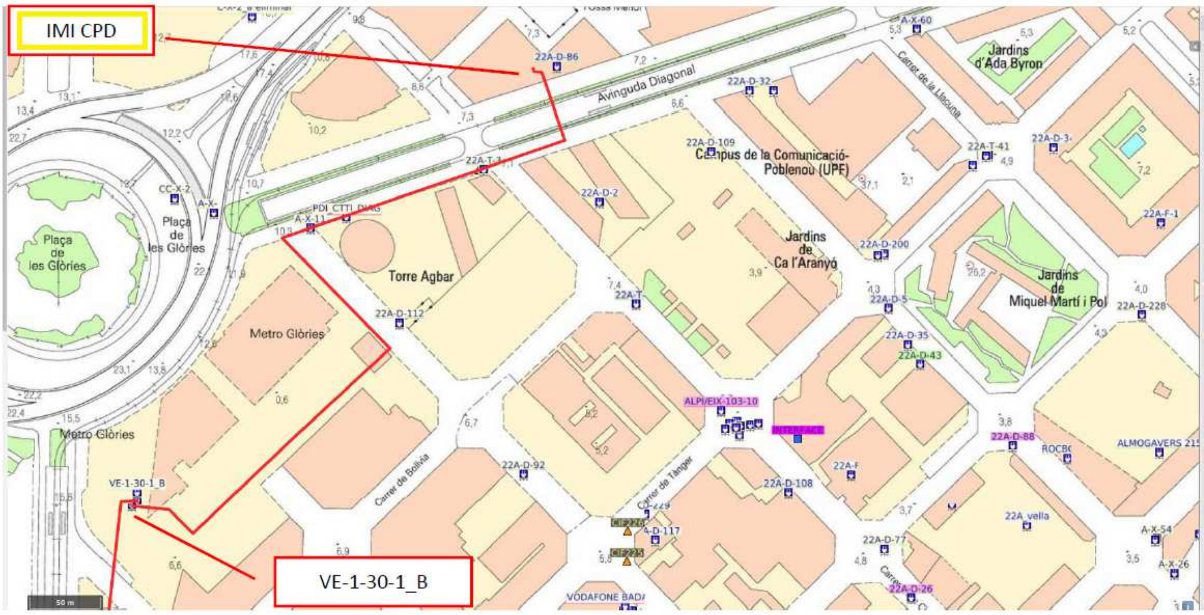


Figure 10: IMI-I2CAT (V)

In the Table 4 is the listed spare fibres for each of these sections:

CABLE	SPARE FIBRES
F128/(IMI)–(VE-1-30-1_B)	90
F128 /(VE-1-30-1_B)-(VE-1-30-1_i)	100
F128 /(O.S.CATALUNYA_i)-(VE-1-30-1_i)	100
F128/(VT-1-25-1_i)-(O.S.CATALUNYA_i)	100
F128/(VT-1-25-1_i)-(VT-1-24-1_i)	100
F128/(VT-1-23-2_i)-(VT-1-24-1_i)	100
F128/(VT-1-22-4_i)-(VE-1-22-1_i)	100
F128/(VT-3-21-1_i)-(VE-1-22-1_i)	100
F128/(VT-3-21-1_i)-(VT-3-21-1)	100
F128/(VT-3-21-1_i)-(VT-3-21-1)	100
F24/(VE-3-21-1)-(VT-3-20-2)	100
F24/(VE-3-18-2)-(VT-3-18-1)	100
F24/(VT-3-18-1)-(VE-3-17-3)	100
F24/(VE-3-17-3)-(VT-3-17-1_B)	100
F24/(VT-3-17-1)-(VT-3-17-1_B)	100
F24/ (VE-3-16-2)-(VT-3-17-1)	100
F24/ (VT-3-16-1)-(VE-3-16-2)	2
F24/(VE-3-15-2)-(VT-3-16-1)	2
F24/(VT-3-15-1)-(VE-3-15-2)	2
I2CAT – CAMPUS NORD	8

Table 4: Spare fibre IMI – I2CAT.

<END OF DOCUMENT>