

5GCity - Source: IMI

Connecting Future Cities: 5GCity Project Final Outcomes

May 2020- Beyond connectivity, the #5G technology and deployment is opening new scenarios; where a whole revolutionary range of services for a variety of verticals are becoming possible, such as:

- Media, Entertainment, Tourism services

- AR/VR for immersive sightseeing and museum visits
- UHD distribution during festivals and sports events
- Participatory media in public events/places

- Smart City services

- Public safety & video-surveillance for security
- Transportation and environment monitoring
- Energy management
- Connected cars
 - o Traffic monitoring and optimal routing

With 5G deployment, new business opportunities for traditional & new stakeholders will open to: Telcos/NSPs, Vendors, Virtual Service Providers, Service brokers, SMEs & start-ups, Municipalities, etc.

Exploring some of these scenarios and services, with the corresponding business models was among the main goals of the <u>5GCity project</u>.

This <u>5G PPP Phase 2 project</u> had its kick-off in June 2017 and it has reached the final stage last March 2020. There were 34 months of development, deployment and testing; and with a pinch of pride, it can be said that 5GCity project has satisfactorily achieved all its challenges, objectives, and milestones. These results have been reached thanks to the unequalled and continuous Partners' involvement and commitment. The synergy created between the <u>18</u> partners from 7 European countries has allowed the achievement of successful use cases, reaching important results from development work, while handling the complexity of deploying scenarios in real live trials.

The project is among the very few from 5G PPP projects that has validated orchestration & innovations solutions in three different cities with live trials in: Barcelona (ES), Bristol (UK) and Lucca (IT).



Three-tier 5GCity Infrastructure - Source: 5GCity

In its lifespan, the 5GCity project has designed, deployed, and validated a **three-tier infrastructure** coupled with an **orchestration platform** to implement the **Neutral Host model**:

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

In its three yeas lifespan, the project had to address several **Key Challenges** during its execution, specifically during the second period:

- i. *Release of a unified control and orchestration framework* for the orchestration of all 5Gbased edge services and capable also to control the underlying city infrastructure.
- ii. *Release of powerful APIs* through which it is possible to access, define and program the different edge services and the orchestrator functionalities.

- iii. *Offering access via a service SDK* to a rich set of primitive functions for network slices, functions, and vertical application services (e.g. programmable connectivity with QoS, media acquisition and transcoding, traffic monitoring).
- iv. *Run-time management,* densely interconnected and decentralized cloud & network infrastructure
- v. Tighter-loop interactions, between computing and network.
- vi. *Performance issues,* use of resource-constrained devices placed at the edge of the network.
- vii. Virtualization Platform, constrained devices at edge (x86 & ARM).
- viii. *Radio network virtualization,* wireless virtualization for 802.11 radio and for LTE trusted ARM computing zones.
- ix. *Slicing and Neutral Hosting*, scalable edge management, orchestration. Service design via SDK.

OBJECTIVES

The level of achievement obtained at the end of the 5GCity project for each of the 6 main objectives can be briefly summarized in the follows points:

1- <u>5GCity distributed, 3-tier architecture implementing network</u> <u>sharing, slicing and mobile edge computing capabilities</u>

A core result of 5GCity project is the reference architecture for the 5GCity Neutral *Host*. The main inspiring idea behind this activity has been the aim of designing a service orchestration architecture for distributed virtualization infrastructures which could turn cities into "digital fabrics". These fabrics are conceived to exploit distributed and multi-tenant edge infrastructures of the cities, integrating 5G services and exposing neutrally resources and services to Verticals. More on deliverables: 5GCity System Requirements and Use Cases (D2.1). Architecture & interfaces definition (D2.2). 5GCity Final Architecture & Interfaces (D2.4). Read Paper: View on 5G Architecture.

A techno economic analysis has also been reported, which describes major dimensioning aspects and related investments from e.g. small cell network operators, projected operational expenditures, revenues, and financial outcome.



5GCity Functional Architecture - Source: 5GCity

2- <u>5GCity MEC Node Virtualization Platform and Guest Optimizations</u>

This objective has specifically targeted the *development of technologies and solutions for edge node virtualization* which could optimise resources and implement additional trust capabilities in heterogeneous, recourse-constrained devices.

On the area of guest optimisation, the project chose to work with **Unikernels** as approach for optimised guest workloads at edge. More on <u>Unleashing the Power of Unikernels with</u> <u>Unikraft</u>.

Related to trust at edge infrastructure, the project adopted **EdgeVIM**, and specifically worked on **OpenStack** and on the Trusted Execution Environment implemented by **ARM TrustZone** and **OP-TEE**. See <u>Secure location aware VM deployment on the edge through OpenStack and</u> <u>ARM TrustZone</u>. They perform node authentication, kernel integrity verification and geofencing.

To complement the tasks in this area, the 5GCity team also worked on the creation of specific VNF data models, i.e. **NFV and SDK descriptors**, which have been used to implement the 5GCity use cases.



Unikernels and EdgeVIM overview - Source: 5GCity

All the work was reported in design deliverables: 5GCity Edge Virtualization Infrastructure Design ($\underline{D3.1}$). 5GCity Virtualization Infrastructure Interim Release ($\underline{D3.2}$). 5GCity Virtualization Infrastructure Final Release ($\underline{D3.3}$). More see paper: <u>A novel pflua-based</u> <u>OpenFlow implementation for VOSYSwitch</u>.

3- <u>5GCity network virtualization</u>

RAN provisioning in dense edge deployments requires the instantiation of multiple virtual functions and virtual networks over a shared infrastructure. 5GCity tackles this virtualization challenge with support for Multi-PoP in OpenStack and virtualization of LTE and Wi-Fi wireless devices. The **5GCity wireless virtualization solution consists in defining a configuration and management plane between the physical devices and the 5GCity platform**, to enable sharing of physical wireless interfaces among a set of tenants in form of wireless slices.



5GCity Network virtualization - Source: 5Gity

More, see deliverables: 5GCity Edge Virtualization Infrastructure Design (<u>D3.1</u>). 5GCity Virtualization Infrastructure Interim Release (<u>D3.2</u>). 5GCity Virtualization Infrastructure Final Release (<u>D3.3</u>). Read Paper: <u>A practical approach to Slicing Wi-Fi RANs in Future 5G Networks</u>.

4- Scalable edge management & orchestration, and 5GCity edge service programming models

5GCity has developed a platform for managing network slice lifecycle management, network service design and orchestration, optimized resource, and monitoring. The platform covers a wide set of management functionalities, and the most innovative elements.

Two major results of the 5GCity project fit into the innovations for NFV management and orchestration layer: i.e. **the 5GCity SDK** and the **5GCity Orchestration Platform**.

The *5GCity SDK* integrated within the 5GCity dashboard: a graphical environment to edit and compose functions in end-to-end services, an adaptation layer which hides the complexity of 5GCity NFV infrastructure; a validation/translation module which performs the formal validation of the service template designed by the users and verify the consistency of the end-to-end pattern and translates into NFV MANO standard descriptors.



SDK Toolkit- Source: 5GCity

The **5GCity Orchestration** allows to manage the registration of resources (compute nodes, physical networks, and radio access points), as well as their partitioning (``chunking'') to create slices as collections of chunks with (NFV) Network Services running in them. The **5GCity Orchestration platform is compliant with the ETSI NFV MANO model** and integrates **ETSI OSM** as core NFVO engine on top of a VIM layer implemented via **OpenStack** and **fog05** as MEAO on top of a MEC-VP implemented again via fog05.



Multi-layer Orchestration - Source: 5GCity

The work on orchestration has been all released in the major deliverables from WP4: Design (D4.1), Software releases (D4.2) Location-aware ML Mechanisms (D4.3). Final (D4.4). Also **5GCity orchestration platform code and SDK are released as open source in GitHub** and documented for users and developers through 5GCity website dedicated <u>Software page</u>. More, read paper: <u>Computing and Network Virtualization at the edge for 5G Smart Cities</u> <u>Neutral Host Infrastructures</u>.



As anticipated, **5GCity has validated orchestration solutions innovations in three different cities with live trials: Barcelona (ES), Bristol (UK) and Lucca (IT).** In all three cities, it was completed the **deployment of Metro DC, MEC node (street cabinet) and wireless network**. The **licensed spectrum used** in each city was:

Barcelona: B42 TDD 3400-3600MHz

Bristol: B42 TDD 3400-3600MHz, B7 FDD 2500-2570 MHz UL / 2620-2690 MHz DL

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

Lucca: B38 TDD 2570-2620MHz

5GCity use cases in the three cities: Barcelona, Bristol, Lucca

The execution of the same test suite in the three city pilots allowed to produce comparable performances indicators; identifying the more effective configurations for the use case trials.

For each of the executed use case tested, the results reported of outcomes of trial, the explanation of the testing conditions, the technological results showed substantial achievements of all the KPIs set for 5GCity platform and infrastructure; e.g. related to service creation and instantiation time, as well as of most of the Use case specific KPIs:

- One media pilot demonstrator deployed per city:
 - UC3 run and demonstrated in Barcelona and Bristol
 - UC4 run and demonstrated in Lucca and Bristol
 - UC5 run and demonstrated in Barcelona.
- One common pilot demonstrator deployed in the three cities:
 - \circ ~ UC2 run and demonstrated in all the three cities.
- One neutral host pilot demonstrator deployed in one city:
 - UC2 run and demonstrated in all the three cities.
- One smart city pilot demonstrator deployed in one city:
 - UC1 run and demonstrated in Lucca.

More on deliverables: 5GCity Infrastructure Design and Definition (<u>D5.1</u>). Validation and Integration of the Developed Modules and Solutions (<u>D5.2</u>) and Use Case City-Wide Implementation (<u>D5.3</u>) paper: <u>Path to 5G Smart Cities: Experiences from Media and Public</u> <u>Safety Pilots in 5GCity</u>. **All Videos** on UCs, city deployments and Testbeds can be seen on <u>5GCity YouTube channel</u>.

6- <u>5GCity dissemination, commercialize outreach, and</u> <u>standardization</u>

During the three years of execution, the **5GCity Consortium carried out a rather large range of dissemination and communication outreach and standardization activities**; that have shown a continuous growth of results and initiatives, generating a considerable output in terms of visibility for the project, its partners, in the 5G wide community, and among Vertical industries, especially the Media.

Some numbers on dissemination & communication, commercialization, exploitation, and standardization outreach results:



Source: 5GCity

- **47** participations at important and well-known international events (**23** Industrial **Events**; **19** Scientific Events; **5** EU Events): with 5GCity presentations, keynotes, and panels participation. Two programmed events were cancelled in 2020 due to COVID-19 outbreak.
- 19 demos have been executed in various events (IBC 2018, Lucca Comics and Games 2018, SCWEC 2018, ICT 2018, MWC2019, European Digital Forum 2019 Lucca, EUCNC2019,) and other 3 demos were ready to be shown at MWC2020 before cancellation.



Live HD TV streaming from Torre Guinigi to Real Collegio, Lucca (IT) – 6-7 June 2019 Source: 5GCity



Live HD TV streaming from #Valencia5Gweek, Valencia(ES) – 18-20 June 2019 Source: 5GCity

- **5GCity website** launched since the beginning of project; it is continuously updated with new contents, achieving relevant numbers in terms of impressions (>1 million) and direct links (>15k direct clicks to 5GCity.eu).
- 5GCity Social Channels establishing a bold presence (data from July2020):
 - Twitter > (<u>https://twitter.com/5GCity</u>) the account reached 2,430 followers, with an intense activity: 3,606 Tweets with a monthly average of 32 mentions, 273 Profile visits, and 63,7K impressions. With Engagement score of 80/100
 - **LinkedIn** > (<u>www.linkedin.com/groups/8607896/</u>) the group reached 169 members, sharing more than 60 posts.
 - YouTube Channel > (www.youtube.com/channel/UCqakofF2vjTdyEihpadfvLQ) with 36 self-produced videos and other interesting videos from EC on 5G.
- **7 Newsletters** were produced and highly advertised in the large 5GCity and 5GPPP network.
- **25 Technical Papers accepted/published** out of 30 submitted (23 Conference Papers, 2 Journal publications) 22 papers registered on the PP; 19 papers published in <u>Zenodo</u> repository, 27 published in <u>5GCity website</u>.
- **15** <u>Technical Blog posts</u> published and disseminated.
- **11 5G IA & 5GPPP Working Groups** contributions with continuous involvement to obtained best technical and strategic results (positioning papers, joint events, joint papers, task forces, etc.)
- Contribution to **Unikraft** established as first <u>Xen Project</u> under the Linux Foundation; and then as solid independent community (<u>http://unikraft.org/</u>).
- Contribution to **Eclipse IoT Consortium** that formed the <u>Eclipse fogØ5 Project</u> which then evolved into an independent community (<u>https://fog05.io/</u>).
- Contribution to Open Fog Consortium Reference Architecture, ETSI MEC (19)000120 -MEC011-MEC010-2 ME App Start-up and Termination procedures, SMPTE TC-32NF-60 DG Studio Video over IP (SVIP), AMWA NMOS Networked Media Incubator, and started interactions with EBU 5G Deployment Group.
- **7 Standardization Bodies contribution**: ETSI MEC whitepaper on Edge Computing and to various Specialist Task Forces at ETSI NFV and ETSI MEC on testing and OpenAPI.
- **9 Open Source community contribution:** KVM hypervisor patches, ETSI OSM VIM connector for Eclipse fog05, ETSI OSM Support of multiple VIM accounts.
- **4 Joint Exploitation Activities:** Smart Lamppost, 2 new H2020 projects following up on specific 5GCity research, Wi-Fi, and small cell radio NETCONF management and control interface, Barcelona TV video acquisition via Neutral Host.
- Liaison with 6 EC projects, successful collaboration was achieved with relevant projects: <u>Matilda</u>, <u>NGpaas</u>, <u>5GEssence</u>, <u>5GTango</u>, <u>5GXCast</u>, <u>5GMedia</u>.

In relation to the Dissemination actions, it is necessary to highlight the relevant presence at international level events where a maximised visibility for project concepts, progress, and results was achieved. The consortium also obtained a high level of relevance by its participation in international conferences. Great results were achieved also in terms of published papers, being most of them the direct result of joint collaborations between 5GCity partners.

The project has organised, as well, two hackathons, the 1^{st} Hackathon in July 2019 hosted by University of Bristol and 2^{nd} Hackathon in November 2019 hosted by Commune di Lucca. The two hackathons not only tested the developed platform and deployed infrastructure; but also helped improve it. Furthermore, both events highlighted the results of the project and enabled dissemination in open source communities such as ETSI OSM.

In reference to standardization, 5GCity progressed on part of contribution to SDOs and open source community with direct code contribution to <u>Unikraft</u> XEN project, **ETSI OSM**, and <u>Eclipse fog05</u>.

Further dissemination & communication, commercial outreach and standardization activities have been fully detailed in required deliverables released: 5GCity Dissemination and Communication plan (D6.1). Standardization and Exploitation plan (D6.2). Interim report on Dissemination, Exploitation, and Standardization activities (D6.3). Dissemination, Exploitation and Standardization activities M24 (D6.4 Final report on dissemination, exploitation and standardization activities (D6.5).

Finally, a post-project activity will present **Joint Exploitation** plans for:

-City Hub as clusters of different partners:

- Barcelona hub: "E2E Multi-carrier NH platform deployment and commercialization" and "Video acquisition service using dedicated slices of the NH infrastructure."
- Lucca hub: "Immersive Video Services for Smart Cities."
- Bristol hub: "Real-time video transmission for Content providers and broadcasters."

-Joint Actions:

Joint Exploitation Action	Description	Partners	
Smart Lamppost	Commercial street urban furniture supporting EV charging and Telco modules	A(telleran ubiwhere	
Common Wireless Interface	SDN-based wireless controller including cellular small cells and WiFi access	A(lelleran Oi2 cat [,]	
Barcelona TV Video acquisition	TV platform for real-time video acquisition and distribution using Neutral Host environment	betevé eretevisión	
New H2020 Joint Initiatives	 5GZORRO: AI for network management and orchestration 5GaaS: decentralized market-place for Telco ecosystem 	A(lelleran)2cat Television	



5GCity Joint Exploitation Actions

More, read paper: <u>"Enabling 5GCity Neutral Host: 5GCity Architecture and Business Model."</u>; and Deliverable: 5GCity Business models & Tecno-economics (D2.5-under request).

CONCLUSIONS:

In conclusion, <u>5GCity partners</u> can proudly announced that the H2020 project, funded by the European Commission to work on convergent technologies for flexible 5G network applications, has designed and developed a distributed cloud and radio platform for municipalities and infrastructure owners acting as 5G Neutral Hosts. The 5GCity platform and service tools allow to orchestrate and deploy services in a completely de-centralised 3-tier architecture, where compute, storage, and networking are allocated between core and edge segments of the 5G network in the City.

With great satisfaction, it can be said that **the outcomes for the six Uses Cases, and all the relevant activities of 5GCity project were successfully achieved**. Throughout these three years, the project outcomes were challenging and demanding; but the consortium was able to build successfully a consistent and relevant expertise exchange of knowledge and knowhow, demonstrating great capacity to collaborate between partners and extensively networking and creating liaison activities with other H2020 projects, EC organizations and the 5G community.



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