



White Paper

Enabling 5G Neutral Hosts: 5GCity Architecture and Business Model

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TRANSFORMING CITIES INTO **HYPER-CONNECTED WORLD**

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Introduction

Forecasts for eleven billion of mobile devices connected by the year 2020 [1] have paved the way to the rapid development of the 5th generation (5G) of mobile telecommunication networks. In these years, initiatives worldwide by industry, standard organizations and public bodies – e.g. like the 5G Public Private Partnership (5G PPP) in Europe [2], IMT2020 at the ITU-T [3], 5G Americas [4] and many others – have heavily supported the fast realization of early releases of 5G networks in production. Today, various 5G production networks are available which offer commercial services, though they remain of limited scale (i.e. up to city-scope in various countries, not yet full country-wide in large nations). Most of these production 5G networks offer enhanced Mobile Broadband (eMBB) services through the 5G New Radio (5G NR) recently standardised at 3GPP. But 5G technology is not mature yet for Ultra Reliable Low Latency Communications (URLLC) and massive Machine Type Communications (mMTC), as well as for higher levels of softwarization of network functions which will cover in full the needs of the various needs of the Vertical industries.

At the core of 5G, there is the quest for enhanced flexibility in controlling, managing and operating the new hardware and software elements of the network infrastructures, coupled with the possibility to achieve improved performances in terms of bandwidth, latency, coverage, supported device compared predecessor generations [5]. In 5G networks, computing and storage resources are also moved from the core to peripheral areas of the network (edge) in order to support users' application requirements closer to where these applications run. The combination of these design factors, i.e. flexible and software defined control/orchestration, improved performances of the data plane, and high distribution of computing functions, allow to achieve lower latency and to reduce traffic aggregation required by many digital services (e.g., by vertical media, energy industry, etc.) as largely demonstrated in literature [5][6]. Flexibility in 5G is enabled through software defined networks (SDN) and network function virtualization (NFV, [7]) solutions. SDN/NFV allow to implement logically isolated virtualized networks, i.e. Network Slices, with guarantee of QoS, isolation and flexibility across the end-to-end infrastructure, from the Radio Access Network (RAN) to the edge and core.

Given this 5G development landscape, a Neutral Host architecture and business model has been developed within the 5GCity project [8], which essentially turns a city into a distributed, third party, multi-tenant edge infrastructure, capable to extend the cloud model all the way to the edge for dynamic, fast, and interoperable provisioning of 5G-based services. The open access neutral host model for 5G is especially relevant in urban scenarios where dense deployments of Small Cells are required to serve multiple businesses, shopping districts, and crowded events. For example, a neutral host operator (i.e., the infrastructure owner) could deploy and manage Small Cells while leasing out slices of network capacity to the different 5G service providers on a fair basis to foster competition. Municipalities are in a privileged position to act as future 5G neutral hosts because of three fundamental reasons: (i) municipalities own and manage the best urban spaces to host 5G Small Cells, which are already equipped with backhaul and power; (ii) municipalities are themselves undergoing a digital transformation towards becoming Smart Cities, whose services and cloud and/or edge computing platforms highly benefit of 5G; and (iii) municipalities constitute a perfect neutral host whose main aim is to benefit end customers, i.e., citizens.

The H2020 5GCity project [8], part of the 5G PPP Phase II projects 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. Live instantiations and trial demonstrations of the 5GCity architecture have been run in three different cities: Barcelona (ES), Bristol (UK) and Lucca (IT).

In this whitepaper, we briefly present the key functional aspects of the 5GCity platform architecture, the inspiring Neutral Host concept and a potential business model regulating its deployment in production. Details on performance and validation experiments conducted in the three live city trials are not included in this whitepaper and can be found in public 5GCity deliverables available for download from the 5GCity website.

The Neutral Host in 5G

Business motivation and scenario

Network densification seems to be the only means to address the increasing traffic demand and to meet users' needs. However, the deployment of dense 5G networks is not be an easy task mostly due to the lack of space, electricity and fiber availability for backhauling. One should also take into account the need for in-building coverage to satisfy more use cases (85% of use cases are at least hybrid and indoor) as well as the health regulations that will not allow mass proliferation of radio nodes. Hence, the traditional model (Figure 1 (a) and (b)) where each operator deploys its own network seems to be not only obsolete but also impractical and cost inefficient. In order to reduce the congestion of masts in urban areas and support the deployment of 5G networks in areas, mainly rural, where private investments are not profitable, the Neutral Host has been proposed.

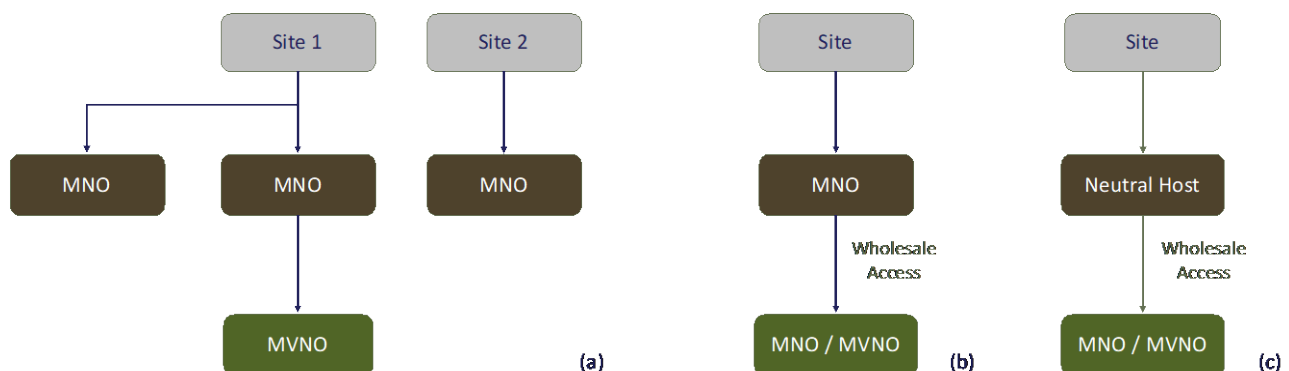


Figure 1 – Deployment models for mobile networks.

The Neutral Host model introduces intermediaries, like municipalities, that offer wholesale access to those interested in providing their services by acquiring sites in dense urban areas and indoor public spaces and deploying their own infrastructure (Figure 1 (c)). The Neutral Host model, as the name suggests, combines two important concepts, those of 'hosting' and 'neutrality'. Depending on the level of involvement of the Neutral Host in operating the network, there exist different Neutral Host models. These include pure passive model, passive and active model, operator model etc. The number

of possible models can be further increased by combining the above models with spectrum, spectrum sharing and spectrum brokerage.

It should be highlighted that the Neutral Host concept is feasible due to the technological advancements of 5G, ones that allow the provision of multiple network slices (virtual networks) with different characteristics using the same physical infrastructure (Figure 2).

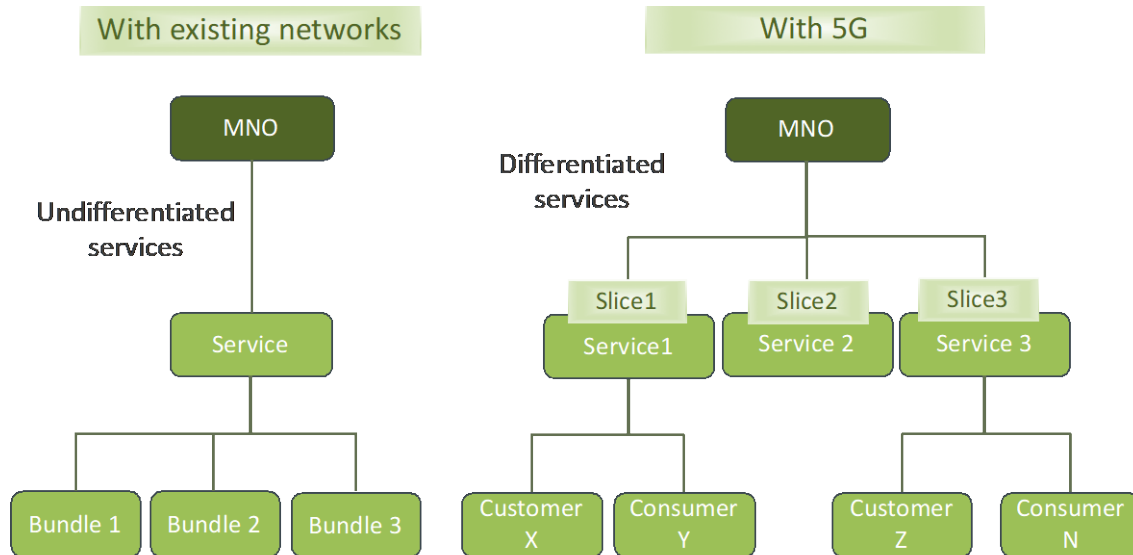


Figure 2 – Service differentiation in 5G networks

The Neutral Host model can be beneficial for all the involved stakeholders. Mobile network operators are expected to receive the maximum benefits from the model. It is anticipated that they experience a significant cost reduction mainly due to the reduced need for both investments and operating activities like maintenance. This allows them to use their time and budget to more productive activities like applications and services development focusing on customers' needs. Apart from operators, vendors and regulators, several stakeholders, such as municipalities, landlords and real estate developers, gain a key role in this model as issuers of permits, issuers of rights of way or infrastructure owners. Deploying 5G networks will involve not only installing more antennas, but also accommodating new edge and core infrastructure, building new communication services, etc. This requires new roles in the 5G ecosystem to ensure to capture all various interests and to allow fine balance between competition and investments. To meet the above conditions and achieve a smooth transition to 5G, a flexible and all-encompassing regulatory framework is also necessary, which promotes simplified processes and encourages network deployment.

Technical aspects

The main characteristic of a 5GCity is to turn city communication infrastructures into a "digital fabric" capable to exploit distributed and multi-tenant computing infrastructures, to integrate new Vertical services (from Media, Industry, Energy, Security, etc.), to use orchestration and service programming tools to manage the available connectivity and computing/storage resources across the large footprint from edge to cloud.

A 5G Neutral Host can be the network infrastructure owner, who uses its infrastructure and networks to provide communication services on its own and to offer infrastructure and logical networks (network slices) to other operators and Verticals. As a result, Virtual Mobile Operators and Verticals

can complement their capabilities and extend their services in areas not covered with resources and services instantiated through the Neutral Host in agile and highly flexible way, hence reducing associated capital and operational costs of their networks.

Apart from scenarios in which only passive infrastructure elements (e.g. housing, power, masts, conduits, etc.) are offered, the 5GCity Neutral Host offers in addition:

- Network slices, consisting of a set of virtualized network and computing resources in RAN, edge/far-edge and core network, which can be leveraged to flexibly increase coverage and extension of mobile networks for an operator or any other Vertical parties willing to deploy their services in a given area;
- A Service Development Kit (SDK) to allow Vertical application developers and service providers to create new functions and services or to compose pre-existing ones available in a catalogue to empower new application workloads in 5G.

The Neutral Host can have its own spectrum to share, or it can re-sell spectrum owned by a Mobile Network Operator (MNO) depending on country regulations.

Key principles of the 5GCity architecture

5GCity enables a Smart City to offer its digital services to citizens and Vertical industries leveraging on various 5G technologies spanning from the radio access to the virtualization edge and core elements. The approach followed in developing the 5GCity architecture was to integrate the Cloud and Edge computing paradigms into a single end-to-end infrastructure.

The 5GCity network consists of the major sections depicted in Figure 3 (see also [9][10]).

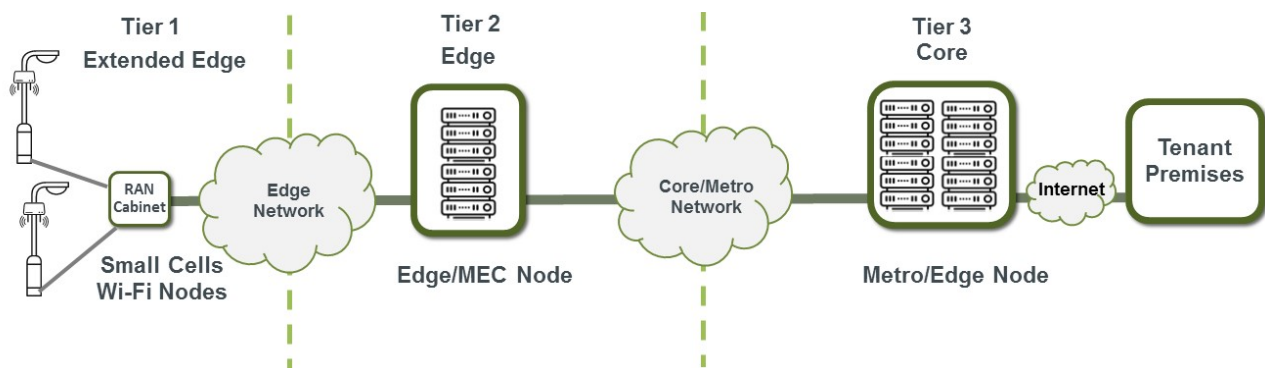


Figure 3 – 5GCity Three-Tier Topological Architecture

From a physical perspective, 5GCity follows a three-tier architecture blueprint, where tiers correspond to different geographical areas of the city where the actual infrastructures elements for digital services are deployed:

- **Tier 1**, far-edge area wireless devices (Small Cells or Wi-Fi) are deployed together with micro computing elements;
- **Tier 2**, edge area corresponding to street cabinets (where other still constrained computing resources are available);

- **Tier 3**, central/core area, which typically corresponds to a data center, where massive computing resource are deployed;

From a functional perspective and to better fit with the 5G requirements, the 5GCity architecture contains functional blocks to combine distributed cloud technologies and edge network virtualization making full use of the new city edge infrastructure deployments such as street cabinets, city-owned edge servers, wireless access points and small cells.

The 5GCity architecture has been designed to split vertically across three layers (see Figure 4):

- **Service/Application Layer**, where specific set of functions/tools are made available for the operators of the infrastructure, their customers, subcontractors and any third-party actor
- **Orchestration & Control layer**, which is the entry point of network services (Dashboard), core orchestration components (5GCity orchestrator), as well as control between the central orchestration platform and the infrastructure (WAN managers, VIMs, and SDN controllers)
- **Infrastructure layer**, where the actual radio and computing virtualized infrastructure is deployed which spans from far-edge to data center

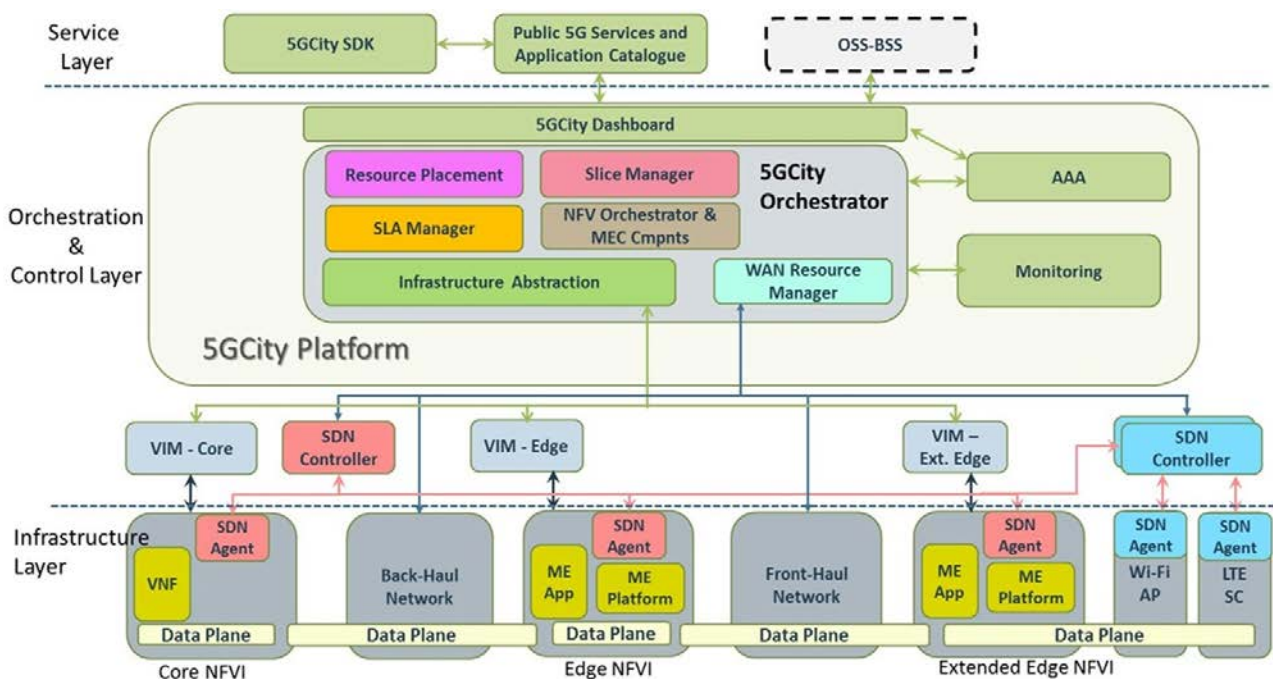


Figure 4 – 5GCity high-level architecture functional design

To give a more clear view of the idea behind the 5GCity architecture, Figure 5 shows the software mapping/deployment with respect to the city infrastructure. Typically, radio resources are deployed at the far-edge/lamppost, Virtual Network Functions (VNFs) can be deployed at edge/MEC node or in Metro/Edge node depending on the specific use case deployment scenarios and requirements (e.g. local processing or reduced latency) to be fulfilled; orchestration platform components and service design and management portals are deployed at core.

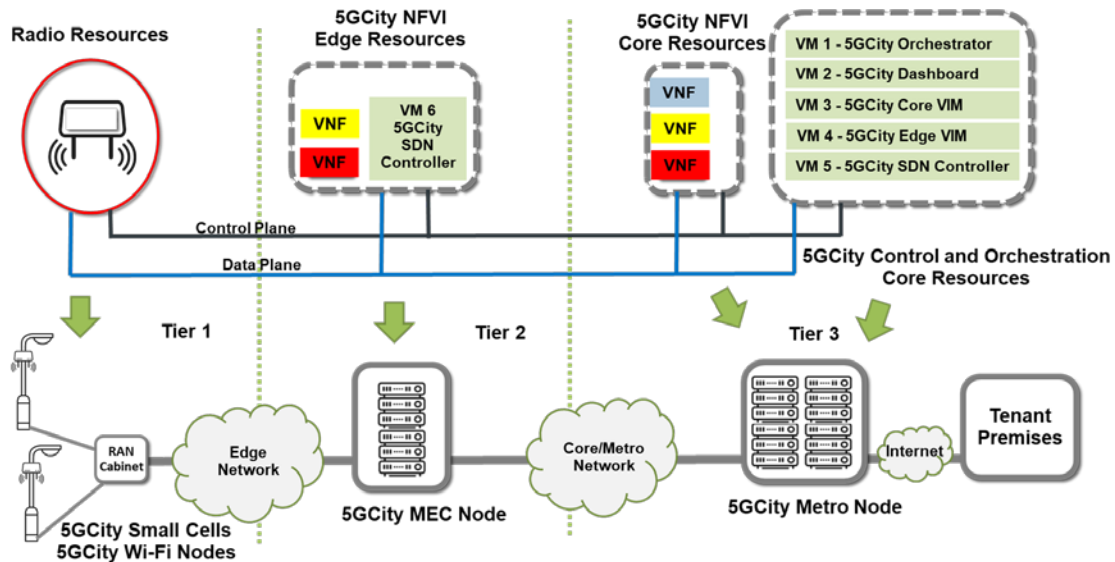


Figure 5 – Three-Tier 5GCity ‘topological’ architecture along with SW mapping/deployment

Functional description of the 5GCity architecture

The Service Layer

The 5GCity Service layer consists of functionalities needed by infrastructure operators, their customers, subcontractors and any third-party actor to design, manage and request deployment of network slices and services in the 5GCity infrastructure.

In 5GCity, we look at the municipality as a clear example of citizen infrastructure owner who can offer shared pools of virtual resources for 5G to various “virtual” Vertical Service Providers (e.g. for Media production, broadcast & distribution, for connectivity - Virtual Mobile Operator, for city security, etc.). Each of these service operators has its own requirements in terms of QoS, hence they should be able to design network service within the assigned slice specifically tailored to the needs of their business.

In light of this, a Service Development Kit (SDK) is a fundamental component of the Service Layer, because it allows to open-up the virtualization advantages to third-party Vertical industries, also in terms of commercial relationships. The 5GCity SDK is a self-contained, stand-alone software platform designed to provide service designers (i.e. application developers and Vertical service operators) with a set of tools which allow to define and compose 5G service functions and 5G network services in a simplified and guided mode. Therefore, the 5GCity SDK highly abstracts the NFV MANO infrastructure [7] and overcomes the complexity of its information models and descriptors for non-network professionals. In fact, the 5GCity SDK has been designed having in mind two main objectives:

- Providing application developers with tools for designing Service templates and Service Functions in abstract mode related to atomic functions realized by their services. Atomic functions constitute the building blocks for more complex, end-to-end, composite services. In 5GCity, atomic functions correspond to VNF packages or Network Services as defined in raw NFV contexts, but they result simpler to define and package with respect to the NFV counterparts; services correspond to [nested] Network Services.

- Providing vertical users (belonging to vertical sectors like Media, Industry, and Automotive) with a design platform through which to compose complex Services templates with customization of the service functions defined by the developers. The modelling is based on an abstract and simplified view of the Network Services and VNF packages, without requiring any detailed knowledge of infrastructure level requirements.

The 5GCity SDK comes integrated within the 5GCity dashboard and comprises:

- a **graphical environment to edit and compose functions in end-to-end services**. The SDK allows wiring, in an arbitrary sequence, a set of pre-defined functions to implement a logical service pipe across subsequent service functions. This operation exploits the flow-based programming to create network services, represented as service templates, ready to be deployed in 5GCity infrastructures.
- an **adaptation layer** which hides the complexity of 5GCity NFV infrastructure and the low-level details of Management and Orchestration tasks. In fact, it automatically translates functional components and business requirements into an operational service deployed over virtual computing and networking resources.
- a **validation module** which performs the formal validation of the service template designed by the users and verify the consistency of the end-to-end pattern.

The abstraction implemented by the 5GCity SDK is one of the main innovations introduced by 5GCity project and it offers major advantages in comparison with other similar solutions available in state of the art. In fact, other SDK toolkits for 5G NFV-enabled infrastructures (e.g. from other EU projects like SONATA [9], SuperFluidity[17], Charisma [18] or embedded in open-source MANO solutions like OSM [21] or Openstack Tacker) still require the user to have a full understanding of ETSI NFV MANO information models and require deep awareness of the NFV MANO stack operation details. Contrarily, the 5GCity SDK allows the user to play with more abstract and business-oriented concepts for services, functions, their interconnection and monitoring.

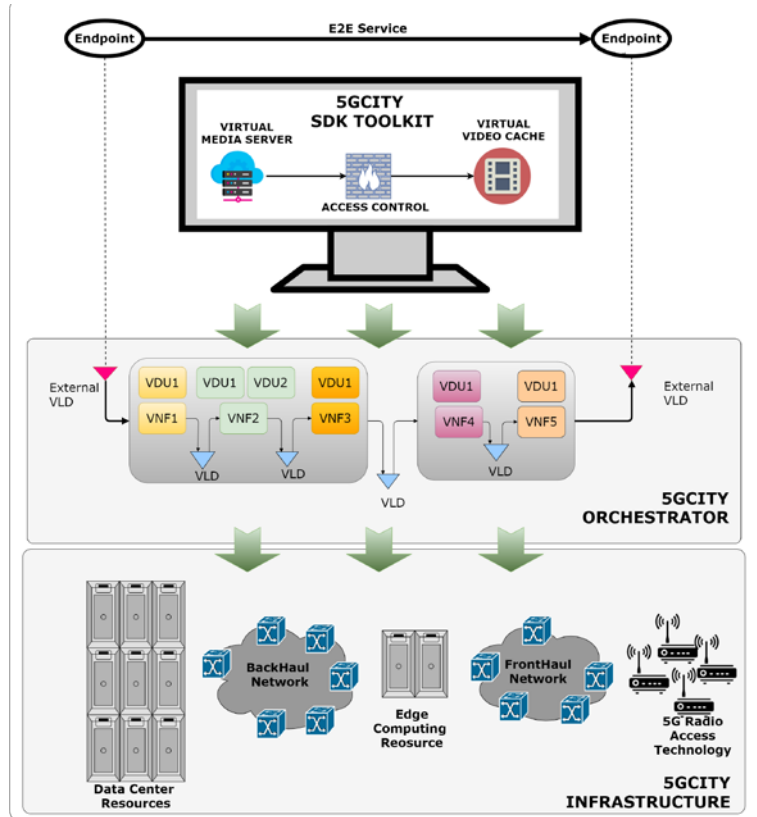


Figure 6 – 5GCity SDK concept

The 5GCity SDK toolkit can facilitate the service planning and design phase in a 5G Neutral Hosting environment. For more details on SDK implementation and tests see [12][14][15].

The Orchestration and Control layer

After the services have been created and published by the 5GCity Service layer (or by using similar technologies), the 5GCity Orchestration and Control layer is responsible for the runtime management and operation of those services, as well as the infrastructure and the network slices that these services will run on. The orchestration platform is a software solution that facilitates the sharing of 5G network infrastructure among different network service providers (telecom operators and/or vertical industries) by leveraging new network virtualization and dynamic configuration solutions. It aims to help 5G infrastructure owners -which in this case could notably be municipalities or "telecom tower companies"- make their (shared) resources available for on-demand slice creation, involving the following main parts:

- **Northbound Interfaces** can be used in order to manage the registration of resources (compute nodes, physical networks, and radio access points), as well as the partitioning ("chunking") of those resources and the creation of slices as collections of such chunks with (NFV) Network Services running on top of them.
- Beneath these interfaces lies a series of **components that seamlessly automate and optimize** the steps required in such processes, e.g., **configuration and interconnection** of different Radio Access Network (RAN) technologies (some of which like **Accelleran dRAX™ Open Interface RAN Intelligence** [19] include Virtualised/Cloud Native Neutral Host RAN components managing Small Cells implementing Physical Network Functions), seamless launching of (mobile) network core components (e.g., vEPC, DHCP, DNS), injection of Monitoring tasks and alerts, placement optimizers, and more.
- At the very bottom, the platform connects to various other **infrastructure controllers**, such as OpenStack for VIM, ETSI OpenSourceMano for NFV core Orchestration, a proprietary RAN controller, and more, in order to enforce many of the required actions.

Figure 7 gives a better feeling of these capabilities by showing a typical view of the 5GCity Dashboard, which is also a part of this layer. This view relates to preliminary infrastructure registration steps, during which computing, network and RAN resources are added to the 5GCity platform (see Figure 7 a); then it shows slice creation and illustrates how specific (virtual) resources of the previously registered infrastructure can be reserved for a specific slice, so that they are exclusively used by the network services of this slice (see blue icons in Figure 7 b).

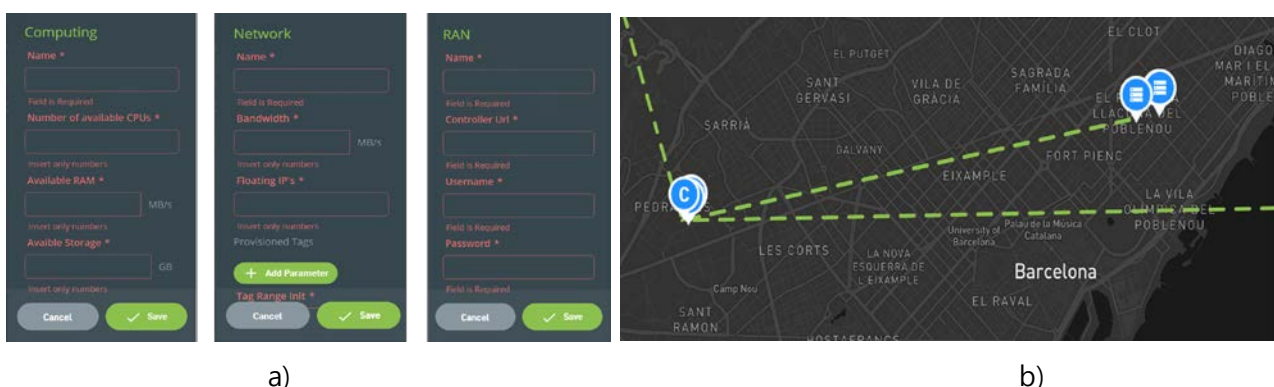


Figure 7 – Registration of resources and creation of network slice via 5GCity Dashboard

Figure 8 shows the split of the Neutral Host-enabled Small Cell network functionality between Virtualised RAN components running at the 5GCity Edge Node and the Physical RAN components

deployed at the urban infrastructure. More details on the orchestration platform and its performances are available in [15].

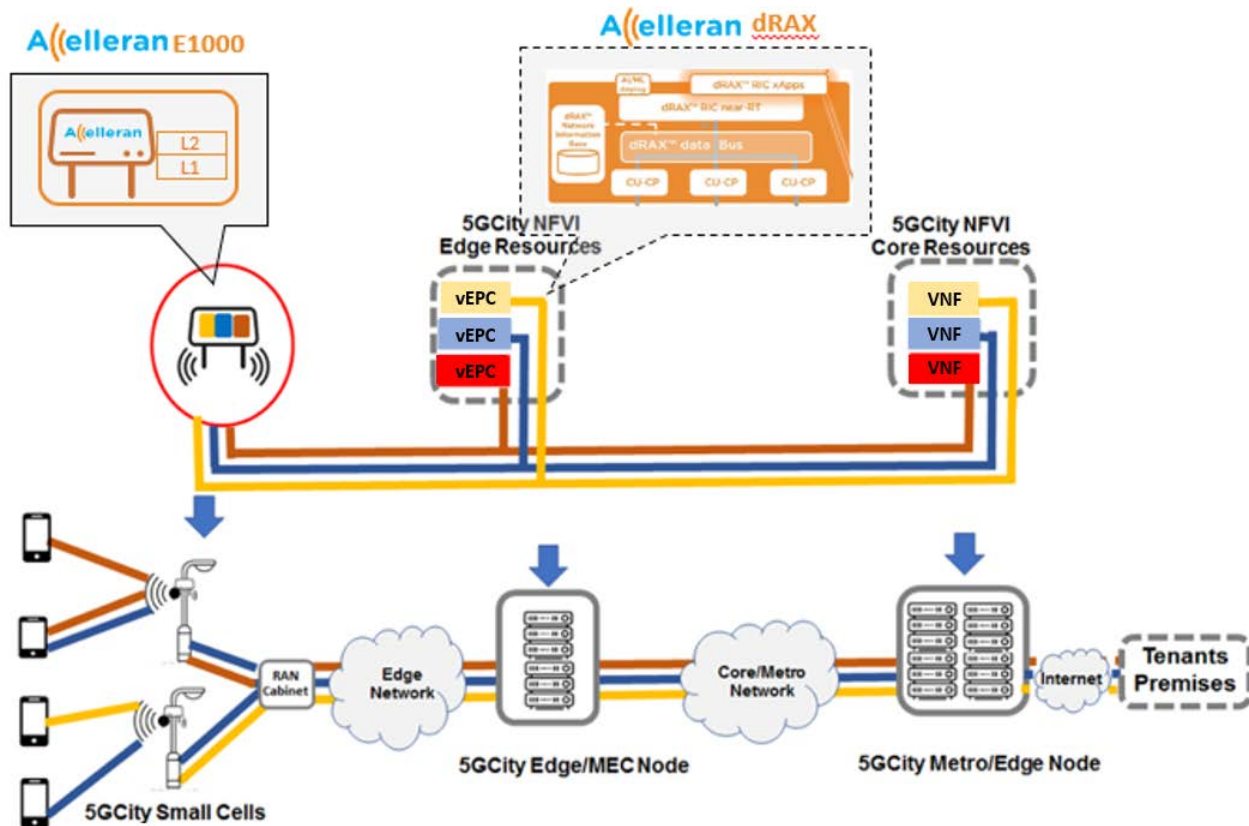


Figure 8 – vRAN in three-tier 5GCity architecture

The Infrastructure Layer

In addition to the Service layer and Orchestration & Control layer, 5GCity also make specific improvements at the infrastructure layer to ensure that its KPI targets are achieved. In this section, the different improvements developed during the project are briefly introduced. More details are available in [11][14][15].

EdgeVIM

EdgeVIM is an OpenStack based VIM that leverages on Edge NFVI, a set of virtualization extensions developed with edge security requirements in mind. In fact, security and trust are particularly important in smart cities environments because of their distributed architecture and the potential privacy issues related to the data they use. The 5GCity Edge VIM and Edge NFVI provide a virtualization-based security and trust infrastructure for Arm-based edge devices that enable enhanced security, authenticated devices, geo/asset tagging and secure storage.

At the base of the 5GCity Edge VIM and Edge NFVI extensions there is **VOSYSmonitor by Virtual Open Systems**, a system partitioner for Arm devices that leverages Arm TrustZone to enable a Trusted Execution Environment (TEE) (i.e., a secure area of the main processor that provides an isolated and trusted environment).

The 5GCity Edge VIM is based on OpenStack and leverages the Edge NFVI to support trusted computing functions. Asset tagging and geo-tagging are supported thanks to specific extensions to the OpenStack scheduler that have been developed in order to use an attestation service, coupled with an attestation agent that runs on each trusted compute node.

Extended Edge NFVI

The Extended Edge NFVI support the closest to the user's tier of the three-tier 5GCity architecture and provides computing, networking and storage resources closest possible to the user (in the access node itself or in the same lamppost). It also provides an environment for Multi-access Edge Computing (MEC) applications.

This NFVI is managed by the Extended Edge VIM, **Eclipse fog05** [20], and everything is orchestrated by the **Multi-tier orchestrator** of the 5GCity platform. It is worth to say that the actual deployment of the instances is done by the ETSI OSM orchestrator that is able to communicate with Eclipse fog05, this connector has been developed within the 5GCity project and the process of contribution to the ETSI OSM [21] community is in progress.

Within 5GCity project, a PoC of MEC Platform was developed and contributed to Eclipse fog05 as well as the Mobile Edge Application Orchestrator and the MEC Platform Manager, those components are the key components of an ETSI MEC [22] deployment. The MEC Platform is designed to provide a way to MEC Services and Apps to discover each other and provide or consume services coming from other apps or services. It was also developed with lightness in mind in order to be deployed on those devices that compose the Extended Edge NFVI.

The 5GCity Business Model

A new ecosystem

In 5G, the traditional model of providers is likely to become outdated as more relationships between different stakeholders are identified and new players enter the 5G value chain. Moreover, the adoption of advanced technologies as well as the development of innovative tools and solutions by 5GCity leads to the creation of a new ecosystem where municipalities do have a key role acting as facility manager, neutral host or/and connectivity provider. In particular, the new ecosystem around 5GCity includes the following players:

Facility Manager, who provides space (malls, stadiums, streetlights, etc.) to operators, verticals and/or Neutral Host for equipment installation.

Neutral Host (NH), who provides wholesale access to passive (energy, safety, access, air conditioning, etc.) or/and active (IT and network equipment etc.) network infrastructure.

Connectivity provider, who provides connectivity (fiber, transport, wireless backhaul) from sites where the equipment is installed to the external network (typically to the MNO networks) and among them.

Mobile Network Operator (MNO), who provides wireless access to end users in wide areas.

Spectrum owner, who owns and rent spectrum licenses to interested parties (MNOs, verticals or NH). Although MNOs must currently possess spectrum licenses, this may not be the case in the future. It is interesting to note that the Neutral Host can act as a spectrum owner becoming more powerful in the new ecosystem.

End-user, who can be residential or business consuming services and using products. Vertical industries (e-Health companies, Manufacturing companies, Energy companies, Media & Entertainment companies, etc.) also fall into this category. It should be highlighted that end-users can also act as content providers, additionally enhancing business relationships within the ecosystem.

Service Provider, third parties that provide products to end users (EUs). These include (bundles) of network functions or/and end-to-end network services, e-services (storage, processing etc.) and value-added services (VAS).

HW manufacturer and equipment vendor, an entity manufacturing and providing IT and network equipment such as servers, switches, routers, EPC, etc.

SW / Functions Developers, who supplies virtual network appliances, gateways, proxies, firewalls, transcoders, etc., eliminating the customer's need to acquire install and maintain specialized hardware. They are also developing several types of software.

Content / License provider, who purchases content (e.g., text, graphics, news, audio, video, etc.) developed by content producers and supplies (sells) content for use on websites or other platforms.

The Neutral Host business model

The Neutral Host provides wholesale access to network infrastructure and allows the creation of new services through two dashboards integrated in the 5GCity platform. In more detail, the 5GCity Neutral Host infrastructure dashboard allows operators and interested parties to develop slices using a set of virtualized resources according to their needs. It should be noted that network slices of different tenants are properly separated for security reasons. Apart from network slicing, 5GCity architecture also enables SDN-based virtual RAN slicing and RAN function virtualization for 5G, LTE and Wi-Fi. Moreover, 5GCity Neutral Host is also aligned to 5G performance requirements by providing edge computing capabilities. This will result in real-time access to radio network information unlocking the potential of advanced future applications.

The innovative nature of the 5GCity business model is further enhanced by the services platform providing an SDK tool. This tool is very useful for network functions developers. It also allows service providers to combine pre-existing functions to deploy new services. Both infrastructure and services dashboards provide advanced functionalities (e.g. billing) offering increased flexibility to mobile operators and other interested parties motivating them to adopt the Neutral Host model.

Figure 9 illustrates 5GCity Neutral Host business model canvas. It can be deduced that 5GCity model can unlock new revenue streams and provide new charging schemes. The main income source will stem from the provision of wholesale access to the infrastructure. However, this can include a variety of charging schemes. Access to infrastructure can be charged in a monthly fee or dynamically. In the latter case, a pay-per-use model can be adopted. Thus, when a "network slice" contract is established, a basic pricing should be associated. However, final pricing should be adapted in terms of real usage of the virtualized network services. This will reduce the prices and help towards the optimization of resources usage and as such it will be beneficial for both the operators and the Neutral Host.

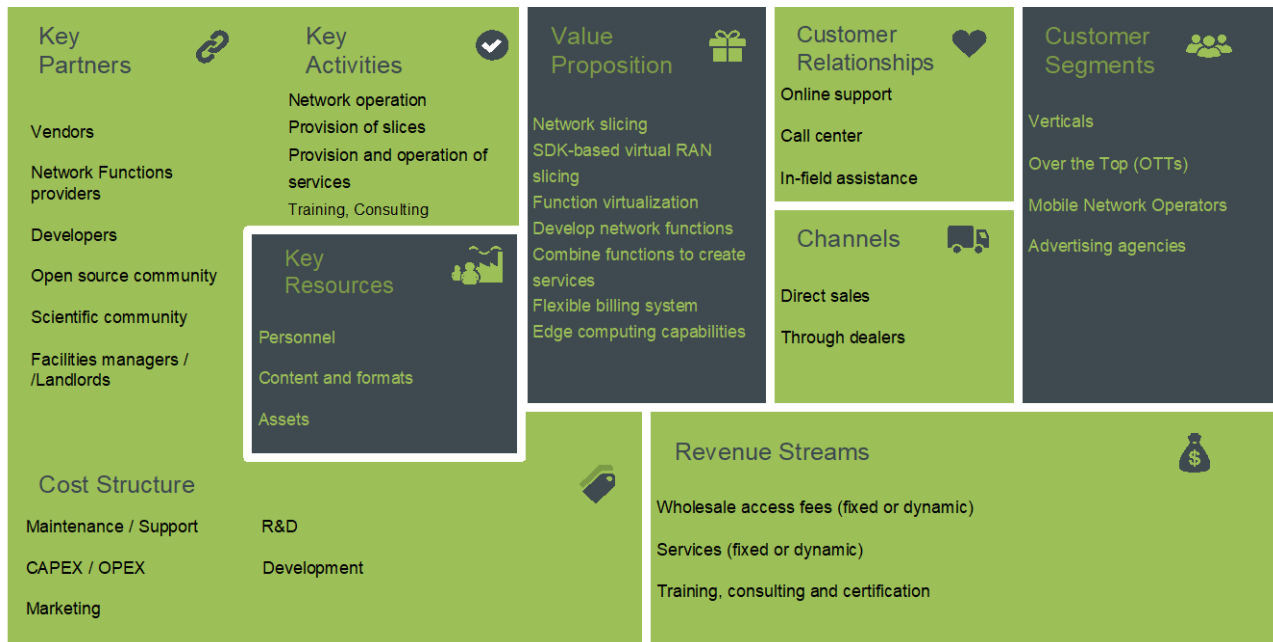


Figure 9 – 5GCity Neutral Host business model canvas

Alternatively, the use of the dashboard in order to create services can also generate revenues. This use can be charged in a flat rate in the form of a subscription fee or a fee per package of N services. A more dynamic scheme can also be used by charging per service or per number of services and/or functions used for the creation of the new service. In addition, the platform can be sold to a vertical industry in a private mode. In this case, the vertical industry can use the platform to host its own resources and services for its employees/users. This will be the evolution of the “private LTE” networks currently available.

Despite good value behind the Neutral Host model, some operational, technical, and legal aspects need to be carefully considered before deployment and require further investigation at various levels, including regulation. These aspects can limit the model adoption and can be briefly summarised as in the following.

- In general, operators prefer not to share their data or other characteristics of their traffic since the latter is considered as a valued asset for their business. Traffic routed through the Neutral Host could possibly be measured, profiled, sniffed and, somehow, tracked. Furthermore, negotiating SLAs with the Neutral Host requires the exchange of information that is not typically shared by the operator.
- Seamless interoperability of all systems of the communication network is key for reliable services. Interoperability is generally difficult to manage even within an operator’s own network (e.g. products from different vendors, different standards or versions of the same standard). The introduction of a Neutral Host would introduce an additional layer of interoperability further extended to multiple parties (i.e. beyond the current 1:1 business practice among operators)
- Spectrum is a very expensive asset. Use/sharing of spectrum among actors is not well regulated and aspects of fair monetisation are essential – though still unresolved - also in 5G.

Conclusions

The fifth generation (5G) network technologies will bring new opportunities for the global market attached to several technological requirements. The H2020 5GCity project has designed an architecture for a platform capable to transform cities in fully sliceable and neutral infrastructure for ubiquitous coverage and distributed cloud, edge, radio platform in support of new 5G services.

In this whitepaper we introduced the foundation concepts of the 5GCity architecture, split across three main layers from service to infrastructure. We also described the motivations and business model for Neutral Hosts using the 5GCity platform.

The 5GCity project concluded its activities in March 2020 with demonstrations of various use cases. More details on architecture design, platform implementation and validation results from live trials in the cities of Barcelona (ES), Bristol (UK) and Lucca (IT) are available in 5GCity project deliverables [10]-[15] available for download at the 5GCity website.

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