A Model for an Innovative 5G-*Oriented* Architecture, Based on Small Cells Coordination for Multi-tenancy and Edge Services

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Abstract. The "core" aim of the *SESAME* EU-funded research project is to design and develop a novel 5G platform based on the use of Small Cells, featuring multi-tenancy between network operators and also attach to them edge cloud capabilities to be offered to both the network operators and the mobile users. SESAME aims at providing a fresh 5G mobile network architecture so as to support the ambitious goal of small cell virtualization, multitenancy and edge cloud services. In the present work we assess the fundamental SESAME components and their role in the respective systems, while analysing the initial framework of the essential relevant architecture to implement the critical targets of the respective approach. Finally we identify future potential extensions.

Keywords: Fifth generation mobile technology (5G) · Mobile edge computing (MEC) · Multi-tenancy · Network Functions Virtualization (NFV) · Software Defined Networking (SDN) · Small cell (SC) · Virtualised network function (VNF)

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1 Introduction

Internet and electronic communication networks are fundamental “enablers” of our modern economy as they promote, support and disperse an extended variety of digital applications and enhanced facilities, satisfying both residential and corporate customers’ various needs. In particular, the immense penetration and the continuous growth of wireless data services driven by mobile Internet and smart devices has further promoted the investigation effort of the fifth generation mobile technology (5G), which is expected to “fulfill” the demands and business contexts of the year 2020 and beyond. 5G is expected to assist an entirely mobile and fully connected and converged society as well as to endow a diversity of socio-economic transformations in immeasurable ways, many of which are unimagined today, including those for productivity, sustainability and well-being [1]. The claims of a modern society where both mobility and connectivity are among the “core” features are characterized by the incredible growth in connectivity and density/volume of traffic, the required multi-layer densification in enabling this, and the broad range of use cases and business models expected to assist any relevant process [2]. Therefore, in 5G there is a need to “push” the envelope of performance to provide, *where necessary*, much greater throughput, much lower latency, ultra-high reliability, much higher connectivity density, and higher mobility range. This enhanced way of performance is expected to be provided along with the capability to “control” a highly heterogeneous environment with the aim, *among others*, to ensure security and trust, identity and privacy [3]. 5G is to become the fundamental means to realize the full potential of the global “networked society”. The new capabilities of 5G span several dimensions, including tremendous flexibility, lower energy requirements and improved energy efficiency, greater capacity, bandwidth, security, reliability and data rates, as well as enhanced indoor coverage lower latency and device costs [4].

Technology advancements of the recent years (e.g., SDN [5], NFV [6, 7], big data, All-IP) can drastically modify the way networks are being constructed and managed. These changes “enable” the development of a highly flexible infrastructure that allows cost-efficient development of networks and of associated services. The 5G architecture should comprise modular network functions that could be further expanded and scaled on demand, to accommodate several use cases in an agile and cost-efficient manner [8]. As a consequence, future networks are becoming highly dynamic and distributed, typically consisting of various multi-operator heterogeneous networks and a huge number of network elements and users’ devices/equipment.

In order to efficiently deal with automated network management solutions able to “address” resource utilization, one current trend is to “*move functionality at the network edge*”, thus reducing complexity at the network core, leveraging on the increasing computing and processing power of the end-user devices [9]. Network virtualization and Software Defined Networking (SDN) compose a much promising solution for orchestrating the allocation of physical and virtual resources that can be instrumental in this direction. Network Functions Virtualization (NVF) distinguishes logical services from physical resources, also allowing for moving resources to other network locations [10]. This concept is different from the notion of SDN networks which proposes the full decoupling of the network control and data planes, moving the control of the network behavior to third party software running in external dedicated or distributed servers [9]. Delivering services at the edge of the modern network enables service providers to offer services and a user experience that cannot be surpassed in terms of responsiveness and performance.

Future networks will also have to be expanded much more densely than today's networks and will become significantly more heterogeneous than today, especially in terms of: transmit power, antenna configuration, supported frequency bands, transmission bandwidths, directional blindness, multi-hop architecture and duplex arrangements. The radio-network architectures of the nodes are expected to vary from stand-alone base stations (BSs) to systems with different degrees of centralized processing, depending on the sort of the available backhaul technology [1]. One major venue in future 5G networks is dense deployment of Small Cells (SCs) coexisting with micro- and macro-cells as well as other systems (such as WiFi, 4G and 3G), thus comprising a Heterogeneous Network (HetNet) [11]. As the number of mobile devices and data traffic increases following a clear exponential growth, the installation of SCs appears to be a "*suitable and efficient way*" so that to achieve enhanced performance and capacity to both indoor and outdoor places/locations, with significant impact upon all any of the corresponding market-*related* scenarios. Small Cells are radio transmitters [12] whose complexity range from just antennas and radio circuits (i.e. remote radio head) up to a full functioning evolved Node B (eNodeB) base station. Small cells are increasingly recognised by the global telecom operators as "*playing an essential role*" in future broadband networks. They address - quite satisfactorily- [13] many of the key challenges faced by market actors such as: (i) increasing capacity (*which actually appears to be the most critical challenge*); (ii) improving depth of coverage, especially inside buildings; (iii) improving user experience, especially the typical available data rates, *and*; (iv) delivering value added services, especially those enabled by high-precision location information. Future 5G networks will be "denser" to realize the capacity increase offered by the deployment of SCs. In that sort of considered scenario, reducing the overall costs becomes an issue of major importance. One option of realizing this is by enabling an effective "sharing" of the network infrastructure. To this aim, Radio Access Networks (RAN) virtualization techniques are ultimately to provide logical isolated pieces ("slices") of the access infrastructure to individual tenants, so they can operate them as *"if each virtual slice were a single real physical infrastructure"*. A well-coordinated sharing of the access infrastructure yields a higher throughput per area.

The target of the SESAME EU-*funded* H2020 5G-PPP project (*Grant Agreement No. 671596*) [14] is to design and develop a novel 5G platform based on small cells, featuring multi-tenancy between network operators and also attach to them edge cloud capabilities to be offered to both the network operators and the mobile users. Thus, the key innovations proposed by SESAME focus on the novel concepts of a multi-operator (multi-tenancy) enabling framework and also on providing an edge-*based*, virtualised execution environment. SESAME aims at providing a fresh 5G mobile network architecture so as to support the ambitious goal of small cell virtualization, multitenancy and edge cloud services. The present work discusses a model for architecture able to fulfil multi-tenancy purposes within a small cell-*based* concept as developed by the actual SESAME effort, still being in dynamic progress. In Sect. 2 we identify several essential definitions, as well as the fundamental SESAME components and their roles. In Sect. 3 we focus upon the proposed architectural approach and we discuss the corresponding "key features" affecting the entire scope. Finally, in Sect. 4 we summarize and we also propose some potential extensions, in parallel with options for future work in more enhanced environments.

2 The SESAME-*Based* Conceptual Approach

In reference to the fundamental SESAME approach, the Small Cell concept is evolved so that not only be able to provide multi-operator radio access capacity with virtualised Small Cells that can be integrated within the operator (tenant) infrastructures, but also to be capable of providing a virtualised implementation environment for delivering Cloud services at the network's edge. In order to achieve this, *however*, the Small Cell needs to offer mobile-edge computing (MEC) capabilities which, *sequentially*, will allow the virtual or mobile operators to increase the capacity of their own 4G/5G RAN infrastructures or to spread the range of their provided services, while preserving the essential agility to be able to offer these extensions, *on demand*.

In order to achieve the previously mentioned essential aims, some further considerations need to be made on "*how to separate-or combine - the network and the computing resources*", and also, "*which small cell functions should be physical network functions*" and "*which ones should be virtual*". The SESAME approach to this challenge is performed by enhancing the Small Cells with Micro-Servers that are able to deliver virtualized computing and networking resources and by being able to "form" clusters, thus creating a kind of Light Data Centre (DC) at the edge. This Light DC is further complemented by supplementary components that reside either close to the edge or to the backbone, such as the VIM or the CESCM, in order to provide the proper reference points - or the scope - for the whole network (as depicted in Fig. 1). In order to "translate" the concept of that figure, we consider the following definitions that are also fundamental for the wider SESAME-*based* scope:

- *Execution infrastructure, micro-server (μS):* Specific hardware that is placed inside the Small Cell and provides processing power (also can potentially include some memory and storage capabilities).
- *Small Cell Network Operator (SCNO):* A legal entity that provides the physical connection to Virtual Small Cells and CESCs.
- *Virtual Small Cell Network Operator (VSCNO):* This implicates companies/legal entities that do not possess the equipment but lease it (through appropriate Service Level Agreements (SLAs) from another company), so as to provide wireless communications services and deliver services to end users.
- *Cloud Enabled Small Cell (CESC):* The Small Cell device which includes a micro-server in hardware form.
- *Cluster of CESCs:* A group of CESCs that are collocated, exchange information and are properly coordinated. As a trivial case, one CESC can be called CESC cluster.
- *Light Data Centre (Light DC):* The hardware entity composed by the micro-servers of the CESCs forming a cluster (see Fig. 3).

- *CESC Manager (CESCM):* The architectural component in charge of managing and orchestrating the cloud environment of the Light DC, as well as management of small cell functions. It can manage, at the same time, multiple clusters, a cluster or a single CESC.
- *Virtualised Infrastructure Management (VIM):* Manager of the HW and networking resources (i.e., lifecycle, provision, placement and operation) constituting of a cluster of micro-servers, namely the Light DC, and the networking nodes and links (i.e., both virtual and physical).
- *Backhaul Provider (BP):* A legal entity/company that provides the backhaul connection (either wired or wireless) of the Small Cells and Macro Cells. This could be an Internet Service Provider (ISP) or the traditional Mobile Network Operator;
- *"NMS"* stands for the respective *Network Management System* and "*EPC*" for the *Evolved Packet Core* (also known as the *System Architecture Evolution (SAE) Core*) which is amongst the main components of the SAE architecture and will serve as the "equivalent" of GPRS networks[1].

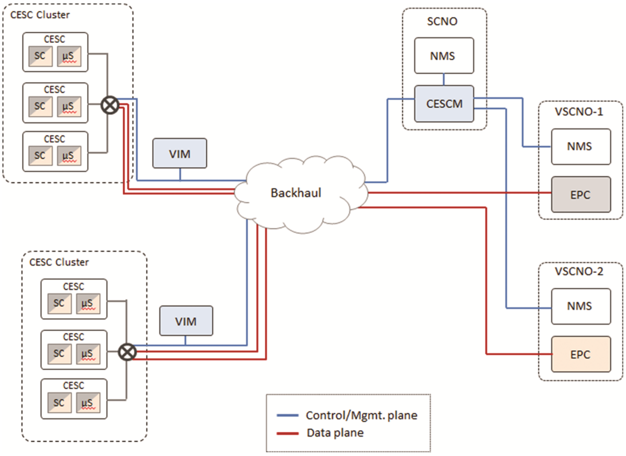

Fig. 1. Scope of SESAME components (physical view)

3 Key Features of the SESAME-*Based* Architecture

The key innovations proposed in the SESAME architecture do emphasize on the novel concepts of virtualising Small Cell networks by leveraging the paradigms of a multi-operator (multi-tenancy) enabling framework coupled with an edge-*based*, virtualised execution environment. SESAME falls in the scope of these two principles and "promotes" the adoption of Small Cell multitenancy - i.e., *multiple network operators*

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[1] More information about the detailed specific concept of the EPC can be found at: http://www.3gpp.org/technologies/keywords-acronyms/100-the-evolved-packet-core. (Additional supportive information is given in the references therein).

will be able to use the SESAME platform, each one using his own network "slice". Moreover, the principal idea is to "endorse" the deployment of Small Cells with some virtualized functions, with each Small Cell containing also a micro-server through appropriate fronthaul technology. A micro-server is based on a non-x86 architecture[2] using 64-bit ARMv8 technology[3]. Together with the SC, they form the Cloud- Enabled Small Cell (CESC), while a number of CESCs compose the "CESC cluster" capable to provide access to a geographical area with one or more operators. At this point, we illustrate a brief description of the two main technological fields that constitute the core innovative fields of the SESAME framework. This targeted way of "decomposition" has been the "starting point" for building, in the continuity, an accurate framework for the intended SESAME architecture. To that end, the NFV technology is going to be used as a fundamental enabler that will offer a virtualisation platform and "meet" the SESAME requirements, namely NFV-*driven* small cell functions and NFV-*based* network services. The left-hand side of Fig. 2 presents the Management and Orchestration (MANO) framework for the NFV part.

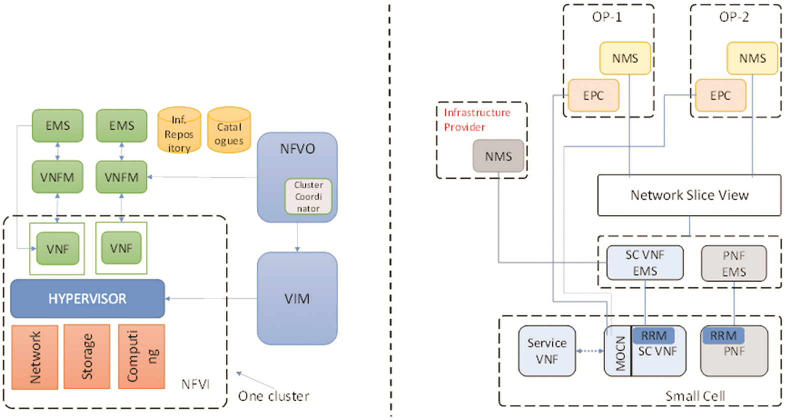

Fig. 2. Scope of SESAME components (physical view)

On the other hand, a Small Cell network capable to support more than one network operator is also envisaged (Fig. 2 – right-hand side). Relevant 3GPP specifications have already added some support for Radio Access Network (RAN) sharing [15]. Although two main architectures are identified, namely *Multi-Operator Core Network (MOCN)*, where the shared RAN is directly connected to each of the multiple operator's core networks, and *Gateway Core Network (GWCN)*, where a shared core network is deployed so that the interconnection of the multiple operator's core networks is done at

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[2] The *x86* is a family of backward compatible instruction set architectures based on the Intel 8086 CPU and its Intel 8088 variant. More related -and indicative- information for this case can be found, *for example*, at: https://en.wikipedia.org/wiki/X86.

[3] More relevant information about the corresponding technology can be found, *for example*, at: http://www.arm.com/products/processors/armv8-architecture.php.

core network level, the MOCN case has been identified as the exclusive enabler for multitenancy features in SESAME platform. The related infrastructure consists of a number of Small Cells and the corresponding SC network functions such as gateways and management systems. The adopted architecture is based on the current 3GPP framework for network management in RAN sharing scenarios [16, 17]. Assuming LTE (Long Term Evolution) technology as the contextual framework of basis, the interconnection of the SCs of the SCaaS provider to the Evolved Packet Core of the tenant is done through the *S1 interface*, delivering both data (e.g., transfer of end-users traffic) and control (e.g., activation of radio bearers) plane functions.

Based on the required functionalities as well as to the architectural principles that have been mentioned above, it is possible to derive an overall, high-level view of the SESAME system, as the one proposed by Fig. 3, below. To that end, the CESC offers computing, storage and radio resources. Through virtualization, the CESC cluster can be seen - or assessed - as a cloud of resources which can be "sliced" to enable multi-tenancy. Therefore, the CESC cluster becomes a neutral host for mobile Small Cell Network Operators (SCNO) or Virtual SCNO (VSCNO) who desire to share IT- and network-resources at the edge of the mobile network. In addition, cloud-*based* computation resources can be provided through a virtualised execution platform. This execution platform is used to support the required Virtualized Network Functions (VNFs) that implement the different features/capabilities of the SCs (and eventually of the core network), the cognitive management and *"self-x"* operations [18] (e.g. self-planning, self-optimising and self-healing)[4], as well as the computing support for the mobile edge applications of the involved end-users.

The CESC clustering enables the achievement of a micro-scale virtualised execution infrastructure in the form of a distributed data centre (i.e., the Light DC), enhancing the virtualisation capabilities and process power at the network edge. Network Services (NSs) are supported by VNFs hosted in the Light DC -constituted by one or more CESC-, leveraging on SDN and NFV functionalities that allow achieving a satisfactory level of flexibility and scalability at the cloud infrastructure edge. More specifically, VNFs are executed as Virtual Machines (VMs) inside the Light DC, which is provided with a hypervisor (based on the concept of a Kernel-*based* Virtual Machine (KVM)) specifically extended to support carrier grade computing and networking performance.

Over the provided virtualised execution environment (i.e., the Light DC), it is possible to chain different VNFs to meet/fulfil a requested NS by a tenant (i.e., a mobile network operator). Note that, in the context of SESAME, a NS is conceived as a "collection" of VNFs that jointly supports data transmission between User Equipment (UE)

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[4] Self-Organizing Networks (SON), also referred to as *"self-x"* features, include several techniques for automating the operation of the network, by automatically tuning different network settings; these can be implemented either as physical or as virtual network functions instantiated and executed in the micro server. Typical examples of *self-x* features include: Inter-Cell Interference Coordination (ICIC) to configure the power; time and frequency resources to minimize inter-cell interference; Coverage and Capacity Optimization (CCO) to adjust RF parameters; Automatic Neighbour Relationships (ANR) to manage neighbour lists; Mobility Load Balancing (MLB) to manage traffic loads between cells, *and;* Mobility Robustness Optimisation (MRO) to optimize the operation of handover procedures.

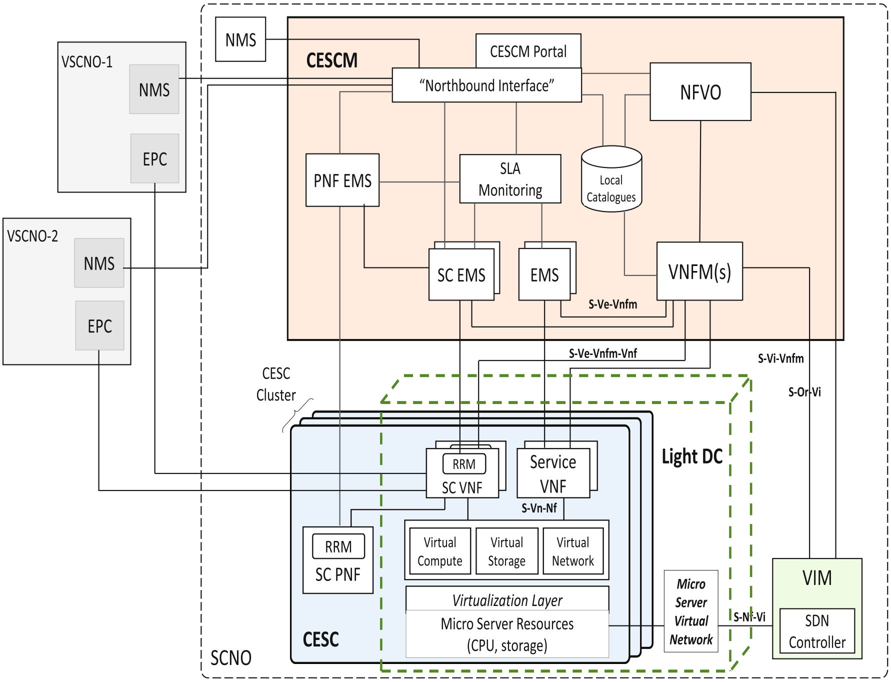

Fig. 3. SESAME overall architecture

and operators' Evolved Packet Core, with the possibility to involve one or several service VNFs in the data path. Therefore, each NS is deployed as a chain of SC VNFs and Service VNFs.

Finally, the CESC Manager (CESCM) is the central service management and orchestration component in the overall architecture figure. Generally speaking, it integrates all the necessary network management elements, traditionally suggested in 3GPP, and the novel recommended functional blocks of NFV MANO [19]. A single instance of CESCM is able to operate over several CESC clusters, each constituting a Light DC, through the use of a dedicated Virtual Infrastructure Manager per cluster. With regard to interfaces, it must be noted that Fig. 3 mostly depicts reference points -*which may contain one or more actual interfaces*- between architectural layers. Each reference point label starts with "S-"to differentiate it from interfaces defined in ETSI NFV ISG documents[5] (and in specific Vi-Vnfm, Or-Vi, Ve-Vnfm, Nf-Vi) – although in several cases the functionality of the reference point will be almost "aligned" to the actual ETSI definitions.

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[5] More relevant information about the respective ETSI documentation can be found at: http://www.etsi.org/technologies-clusters/technologies/689-network-functions-virtualisation.

4 Concluding Remarks and Future Aspects

In order to suitably "address" the needs and requirements of a vigorous and agile network management in the forthcoming -purely innovative- 5G era, and though a proper building effort upon the pillars of NFV, mobile edge computing and cognitive management, SESAME's main goal is both the development/expansion and the demonstration of an innovative architectural model, capable of providing Small Cell coverage to multiple operators "*as a Service*", so that to strongly support multi-tenancy. To this fundamental aim which implicates an enormous business potential, SESAME envisages not only to "virtualise" but also to "partition" Small Cell capacity, while simultaneously aims to support enhanced edge cloud services by enriching Small Cells with dedicated micro-servers. This work has thus presented a "first conceptual approach" to the high-level overall architecture of the broader SESAME system. The SESAME architecture discussed in the present paper can be further extended based on several current trends towards 5G, in particular those already identified by the ETSI MEC standardization group. Recent virtualization technologies permit bringing mobile core functions "close" to the mobile edge, hence enabling the deployment of the respective service platform alongside the components of the EPC while still being in proximity to the involved users. There are several benefits coming from this way of deployment, since platform(s) can leverage on many tasks performed by legacy core components (e.g., the PDN Gateway), thus without the requirement of implementing them. Such tasks are related to, *inter-alia*, gating, GTP (GPRS Tunneling Protocol) encapsulation, QoS enforcement, charging, lawful interception and mobility support. The direct influence upon the current SESAME architecture would be to install/deploy the virtual EPC (vEPC) [20], alongside with the virtual small cell and allow the NFV components executing their tasks at the egress point of the core (i.e., the SGi interface[6]), instead of the ingress point (i.e., the S1 interface). In this manner, as aforementioned, NFVs can take actions directly on IP packet flows without the need for implementing GTP encapsulation/decapsulation mechanisms, as currently required in the SESAME architecture.

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[6] More informative data about this interface can be found at: http://lteworld.org/ltefaq/what-are-lte-interfaces.

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