Small cElIS coordinAtion for Multi-tenancy and Edge services

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System Use Cases and Requirements

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Abstract

The SESAME EU-funded project targets innovations around three central elements in the wider 5G context: (i) The placement of network intelligence and applications in the network edge through Network Functions Virtualization (NFV) and Edge Cloud Computing; (ii) the substantial evolution of the Small Cell concept, already mainstream in 4G but expected to deliver its full potential in the challenging high dense 5G scenarios, and; (iii) the consolidation of multi-tenancy in communications infrastructures, allowing several operators/service providers to engage in new sharing models of both access capacity and edge computing capabilities.

SESAME proposes the Cloud-Enabled Small Cell (CESC) concept , which is a new multi-operator enabled Small Cell that integrates a virtualized execution platform (i.e., the Light Data Centre (DC)) for deploying Virtual Network Functions (VNFs), supporting powerful self-x management and executing novel applications and services inside the access network infrastructure. The Light DC will feature low-power processors and hardware accelerators for time critical operations and will constitute a high manageable clustered edge computing infrastructure. This approach will allow new stakeholders to dynamically enter the value chain by acting as neutral host providers in high traffic areas where densification of multiple networks is not practical. The optimal management of a CESC deployment is a key challenge of SESAME, for which new orchestration, NFV management, virtualization of management views per tenant, "*self-x*" features and radio access management techniques will be developed.

This document describes scenarios, use cases and system requirements relevant to the SESAME project. It hereby inherently provides the first definition of terminology and parameters used throughout the entire project. The document realizes a proper elaboration upon the definition of the SESAME System use cases, together with a detailed identification of the fundamental limitations addressed, envisaged innovations and key system requirements, *per distinct case.*

The use case descriptions as well as the resulting system requirements serve as a "base-line" for future effort in other work packages which build on and further elaborate the given use cases and functional requirements from their specific perspective.

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Glossary

Acronym	Explanation
3GPP	3rd Generation Partnership Project
4G	4^{th} Generation (of mobile communications)
5G	5^{th} Generation (of mobile communications)
5GMF	5G Mobile Communications Promotion Forum
5G-PPP	5^{th} Generation-Public Private Partnership
AI	Artificial Intelligence
ARPU	Average Revenue per user
BS	Base Station
BSS	Business Support System
CAPEX	Capital Expenditures
CASE	Computer Aided Software Engineering
CC	Cloud Computing
CDR	Call Detail Record
CESC	Cloud Enabled Small Cell
CESCM	Cloud Enabled Small Cell Management
CSP	Communications Service Provider
CPU	Central Processing Unit
DC	Data Centre
DoA	Description of Action
DoW	Description of Work
DSP	Digital Signal Processing
DPI	Deep Packet Inspection
E2E	End-to-End
EC	European Commission
EIT	European Institute of Innovation & Technology
EMS	Element Management Systems
EPC	Evolved Packet Core
ETSI	European Telecommunications Standards Institute
EU	End-User
EU	European Union
FP	Framework Programme
FP	Function Provider
FP7	7^{th} Framework Programme
FPGA	Field-programmable gate array
GA	Grant Agreement
GPU	Graphics Processing Unit
H2020	Horizon 2020
HDTV	High-Definition Television
HTC	Human-Type Communication
HTTP	Hypertext Transfer Protocol
HW	Hardware
I/O, i/o	Input/Output
IaaS	Infrastructure as a Service
ICT	Information and Communications Technology
IEEE	Institute of Electrical and Electronic Engineers
IETF	Internet Engineering Task Force
IMT	International Mobile Communications
IoT	Internet of Things
IP	Integrated Project

ISP	Internet Service Provider
IT	Information Technology
ITEV	IT Equipment Vendor/manufacturer
ITU	International Telecommunications Union
KPI	Key Performance Indicator
LAN	Local Area Network
LB	Load Balancer
LDC	Light Data Centre
LTE	Long Term Evolution
μS (μServer)	micro-Server
M2M	Machine-to-Machine
MAC	Medium Access Control
MEC	Mobile Edge Computing
METIS	Mobile and wireless communications Enablers for Twenty-twenty (2020) Information Society
MNO	Mobile Network Operator
MO	Mobile Operator
MOCN	Multi-Operator Core Network
MTC	Machine-Type Communication
N.A.	Not Applicable
NAT	Network address translation
NF	Network Function
NFV	Network Functions Virtualization
NFVIaaS	NFV Infrastructure as a Service
NGMN	Next Generation Mobile Networks
OAM	Operation, Administration and Management
OPEX	Operational Expenditures
OSS	Operations Support System
OTT	Over-The-Top
PDCP	Packet Data Convergence Protocol
PEP	Performance Enhancement Proxy
PHY	Physical Layer
PoC	Proof of Concept
QoE	Quality of Experience
QoS	Quality of Service
R&D	Research and Development
RAM	Radio Access Manager
RAN	Radio Access Network
RAS	Radio Access and Spectrum
REA	Research Executive Agency
RIA	Research and Innovation Action
RLC	Radio Link Control
RRC	Radio Resources Control
RRM	Radio Resources Management
RTP	Real-time Transport Protocol
SC	Small Cell
SCF	Small Cell Forum
SDO	Standards Developing Organization
SDN	Software-Defined Networking
SecTro	Secure Tropos
SF	Service Function
SFC	Service Function Chaining
SLA	Service Level Agreement
SME	Small- and Medium-sized Enterprise

SME	Storage Made Easy
SO	Spectrum Owner
SON	Self-Organizing Networks
SP	Service Provider
SW	Software
TCP	Transmission Control Protocol
TF	Task Force
TR	Technical Report
TV	Television
UC	Use Case
UDP	User Datagram Protocol
U-HDTV	Ultra - High-Definition Television
VIM	Virtual Infrastructure Manager
VLAN	Virtual Local Area Network
VNF	Virtual Network Function
VO	Venue Owner
VSCNO	Virtual Small Cell Network Operator
VSCO	Virtual Small Cell Operator
WP	Work Package

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1. Introduction

The present deliverable, which will serve as a “reference document” for all upcoming work packages of the SESAME project, covers important issues on the description of scenarios, use cases and requirements. The actual work involves consideration of several meaningful scenarios as starting point, and identification of actors’ role for validation, through functional or non-functional evaluation. In addition, the deliverable “collects” a variety of architecture and system requirements and related assumptions.
The deliverable comprises of 6 separate sections.

Section 1 offers a brief introductory overview.

Section 2 presents the methodology adopted by SESAME, in order to perform a multi-directional analysis of the proposed use cases. It provides definitions of the corresponding methodology concepts and terms, as well as the relevant (explicit and/or implicit) interrelations between them. All involved actors in the SESAME value chain are thus described here along with their interactions, in terms of services and of related infrastructure(s).

Section 2 also gathers targeted KPIs aligned with the wider 5G-PPP program. It analyses the methodology employed for the selection of specific use cases, while it also provides use cases’ classification and requirements prioritization.

Section 3 discusses the three initial target scenarios as already identified in the SESAME’s DoW, and the way *how a number of specific use cases can be formed -or structured- based on these explicit scenarios*.

Section 4 provides a review of the existing literature about potential scenarios and use cases, published by Standards Developing Organizations (SDOs), regional initiatives and industry fora. In this section, *in particular*, scenarios are categorized as “residential”, “enterprise”, “urban” or “rural and remote”, while use cases are classified as a “particular instantiation of a specific scenario under a set of given conditions”. Each use case is mapped to the probable operating scenario(s), and vertical sectors associated with the use cases are briefly analysed.

In *Section 5*, a set of 11 individual technical use cases is defined. The description of every proposed use case includes involved actors, deployment topology, evaluation, relevance to SESAME and extracted requirements. A description of the high level technical requirements is also provided.

Finally, *Section 6* offers a summary of the key issues discussed in the full context of the document.

2. Methodology

This section presents the methodology which has been adopted by the SESAME-*based* context, in order to perform a multi-directional analysis of the proposed use cases, as these have been selected with the aim of purely serving the well-defined SESAME aims. Such kind of analysis will be "multi-directional", because it will enable the actual deliverable D2.1 to serve as a "reference document" and/or a kind of "technical guide" for the more specific work, which will be further carried in the different work-packages (WPs) and especially during the scheduled trials.
In this sense, the methodology will allow us defining the technological benefits that will result from SESAME-*based* outcomes, the enabling context, as well as any corresponding evaluation criteria for the level of fulfilling such outcomes and benefits.

2.1. Concepts and Terms

In this subsection we provide definitions for the essential corresponding methodology concepts and terms; moreover, the interrelations between such concepts are also given. The presented methodology is actually based on a "set of concepts and terms" which will be used in the preliminary part of the use cases' analysis, in order to define the key technological aspects which are related to the project's specific objectives. The following terms are taken into account:

- **"Scenario"**: Scenarios describe application examples, highlighting key benefits of the SESAME context, by attributing those to the dedicated scenario.
- **"Use case (UC)":** A particular "instantiation" of a specific scenario, having the goal to elaborate upon a particular parameter of the corresponding scenario, under a set of given conditions.
- **"KPIs":** Key Performance Indicators are used to evaluate factors that are crucial to the success of the system under consideration.
- **"Requirements":** These are categorized as "functional" and as "non-functional". A requirement pertains to the technical aspects that the corresponding system must fulfil.
- **"Evaluation":** An attribute usually representing some property subject to change[1]. Examples for potential parameters of a small cell network can be, *for example*: Coverage increase and increase in functionality offered to the user.
- **"Metric":** A quantitative measure of the degree to which a system, component, or process, possesses a given attribute.
- **"Actor":** Actors and actors' interactions are being analyzed explicitly in the subsection below**.**

2.2. Actor Description aligned with Architecture

In the present part we provide several essential definitions, relevant to the potentially involved actors, based upon their relevance to the underlying infrastructure(s).

- **Venue Owner (VO)**: This implicates, *for example*, a mall or a stadium or an enterprise or a municipality or large building owner, etc.
- **IT Equipment Vendor/manufacturer (ITEV)**: The term stands for companies/legal entities that develop and/or sell IT equipment, e.g., small cells.

[1] Institute of Electrical and Electronic Engineers (IEEE) (2000). IEEE 100: The Authoritative Dictionary of IEEE Terms, 7th Edition. IEEE Press, December 2000.

- **Small Cell Network Operator (SCNO)**: The term implicates companies/legal entities that possess the equipment so as to provide wireless communications services as well as to provide wireless access to end-users in wide areas, locally.
- **Virtual Small Cell Network Operator (VSCNO)**: The term implicates companies/legal entities that do not possess the necessary equipment but lease it from another company/legal entity, so as to provide wireless communications services and deliver services to end-users.
- **Mobile Operator (MO)**: The term implicates companies/legal entities that possess the equipment so as to provide wireless communications services and provide wireless access to end-users in wide areas.
- **Fixed Telecom Provider/Operator/Internet Service Provider (ISP)**: The term implicates a provider of backhaul connection for the Small Cells.
- **Service Provider (SP):** An entity whose business is to provide telecom and other services to the end-user (corporate, residential or other).
- **Over-The-Top Player (OTT)**: The term implicates third parties that produce, control and distribute services over the MNO (Mobile Network Operator) / VMNO (Virtual Mobile Network Operator).
- **Function Provider (FP)**: The FP supplies virtual network appliances, gateways, proxies, firewalls, transcoders, etc., thus eliminating the need for the customer to acquire, install and maintain any kind of specialized hardware.
- **End-Users (EU):** A person or an SME enjoying services through the SESAME network model**.**
- **Spectrum Owner (SO):** The company/legal entity that owns -or leases- spectrum for commercial exploitation purposes.

2.3. Actor Interaction

Several "actors" are involved in the SESAME value chain. ***Figure 1,*** below, illustrates the main actors participating in the SESAME system along with their interactions in terms of services and/or infrastructure. It should be noticed that the corresponding diagram represents the simplest case regarding the interactions between the potential x-providers.
The diagram can thus progressively become "more complex", as new actors may be added or new interactions are to be emerged.

The main actors identified in SESAME are described below:

- **End-Users (EU):** They consume services provided by the Service Providers (SPs).
- **Service Provider (SP) / Over-The-Top Player (OTT):** The term implicates third parties that provide products to the end-users. These can be a network function or a bundle of network functions from one -or from multiple- Function Providers (FPs) or just a kind of end-to-end (E2E) network service.
- **Function Provider (FP):** The FP supplies virtual network appliances, gateways, proxies, firewalls, transcoders, etc., thus eliminating the need for the customer to acquire, install and maintain specialized hardware.
- **Virtual Small Cell Network Operator (VSCNO):** The term implicates companies/legal entities that do not possess the equipment but lease it (through appropriate SLAs), so as to provide wireless services to the end-users.
- **Small Cell Network Operator (SCNO):** A legal entity that provides the physical connection to Virtual Small Cells and CESCs.
- **Mobile Operator (MO):** MO provides connectivity to Small Cells or provides wireless access to end-users in wide areas.
- **Fixed Telecom Provider/Operator/Internet Service Provider (ISP):** A legal entity that provides backhaul connection.

- **IT Equipment Vendor/manufacturer (ITEV):** The term implicates companies/legal entities that develop and/or sell IT equipment to SCNOs, MOs and Fixed Telecom Providers/Operators/Internet Service Providers.
- **Spectrum Owner (SO):** A Spectrum Owner possesses and rents spectrum licenses to operators (SCNOs or MOs). Although MOs must currently possess spectrum licenses, this may not be the case in the future.
- **Venue Owner (VO):** This implicates, *for example*, a mall or a stadium or an enterprise or a municipality or large building owner, etc. A Venue Owner can facilitate the deployment of Small Cells.

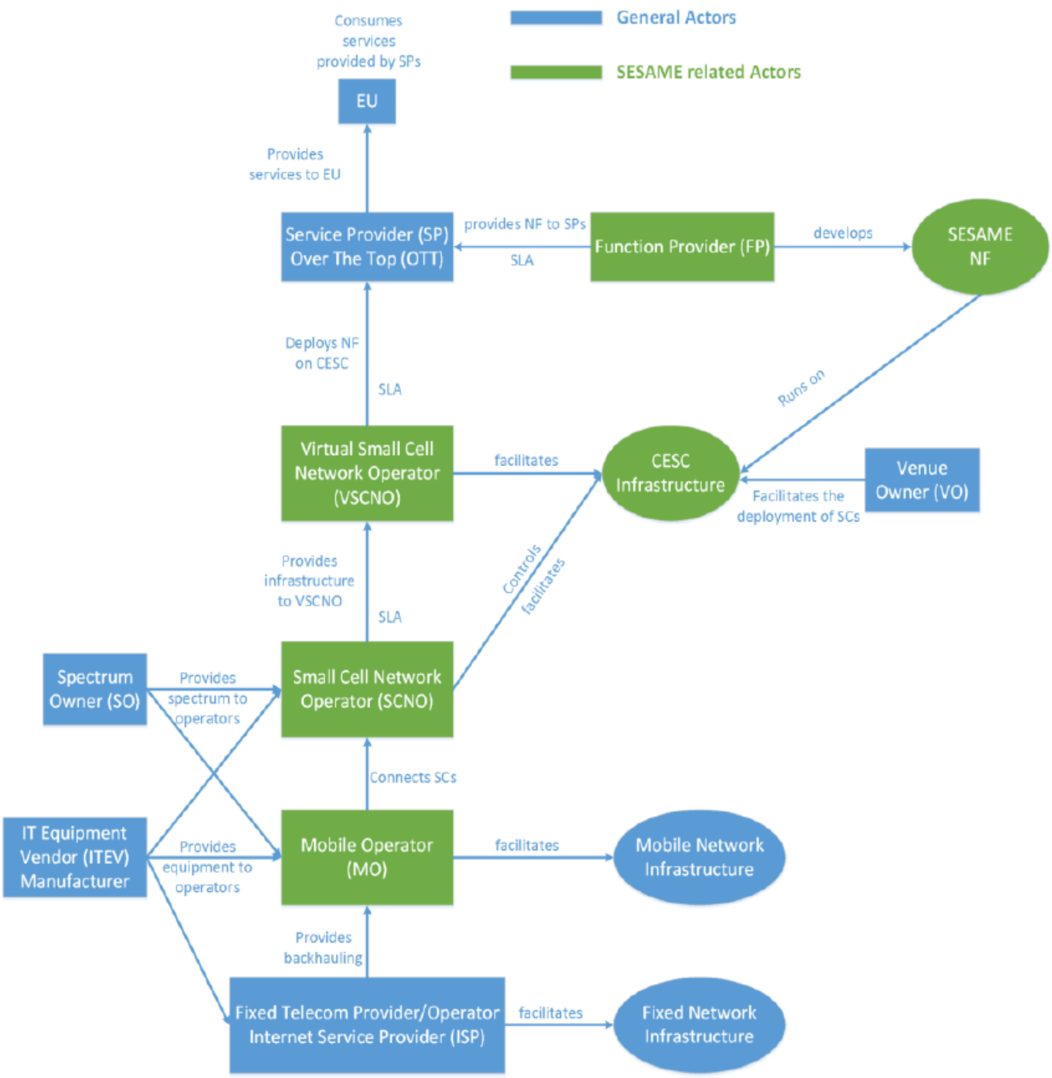

Figure 1: SESAME actors and interactions

2.4. 5G-PPP KPIs in the scope of SESAME

SESAME is fully aligned with the 5G-PPP context[2], *as prompted by the European Commission*. In particular, the SESAME project aims at achieving the target KPIs established and promoted by the 5G-PPP framework, *as listed in the following **Tables 1-3***. In case the specific KPI does not apply in the context of SESAME, it is indicated explicitly.

These KPIs have been classified in three main categories:

- Performance KPIs (as in ***Table 1***);
- Societal KPIs (as in ***Table 2***), and;
- Business-*related* KPIs (as in ***Table 3***).

Performance KPIs

KPI		**Relevance** (High/Medium/ Low/Not relevant.)	**Details on planned project contribution towards achieving the KPI**
P1	Providing 1000 times higher wireless area capacity and more varied service capabilities, *as compared to those of 2010.*	Low	The SESAME project is preparing to address the challenge of higher traffic and capacity per geographical areas by deploying high-density multi-service small cell networks. The small cells' deployment process will densify the network and will be beneficial for the provision of much higher data rates.
P2	Reducing the average service creation time cycle from 90 hours to 90 minutes *(as compared to the equivalent time cycle in 2010).*	High	The flexible design of the CESC platform and the associated management layers will promote a shared virtualized infrastructure, i.e., a cloud environment, right at the network's edge. This will allow multiple services as, *for example*, Virtual Network Functions, to be deployed at a lower time scale.
P3	Facilitating very dense deployments of wireless communication links to connect over 7 trillion wireless devices serving over 7 billion people.	Not relevant	Not relevant
P4	Creating a secure, reliable and dependable Internet with a "zero perceived" downtime for	Medium	While SESAME is not innovating in designing new air interfaces or massive spectrum aggregation techniques, the basic notion of the project is to allow rapid integration of multiple virtual operators sharing

[2] The 5G Infrastructure Public Private Partnership, in short 5G-PPP, has been initiated by the EU Commission and industry manufacturers, telecommunications operators, service providers, SMEs and researchers. The 5G-PPP will deliver solutions, architectures, technologies and standards for the ubiquitous next generation communication infrastructures of the coming decade. The challenge for the 5G-PPP is to secure Europe's leadership in the particular areas where Europe is strong or where there is potential for creating new markets such as smart cities, e-health, intelligent transport, education or entertainment & media. More information can be found at: https://5g-ppp.eu/ .

	services provision.		the CESC provider's infrastructure, thus allowing isolated and secure provision of vertical services for massive amount of connected devices. In this way, network resources can be provisioned and offered where they are needed the most, rebalancing (or repurposing) them from where they are underused to where they are actually needed. The deployment of Small Cell devices combined with edge computing paradigm of the Light Data Centre will have the immediate effect of bringing and managing services much closer to the end-users, which imply significant latency reduction already.

Table 1: Performance KPIs

Societal KPIs:

KPI		**Relevance** (High/Medium/ Low/Not relevant)	**Details on planned project contribution towards achieving the KPI**
S1	Enabling advanced User controlled privacy.	Not relevant	Not relevant
S2	Reduction of energy consumption per service up to 90% (*as compared to 2010*).	Not relevant	Not relevant
S3	European availability of a competitive industrial offer for 5G systems and technologies.	Medium	The CESC management framework, is being designed and prototyped in order to manage the multi-tenant SESAME infrastructure, leveraging the novel edge-computing architectures and deploying the "self-x" and optimization procedures, directly at the network edge. CESC mobile-edge computing capabilities will provide a new ecosystem and value chain for new applications and service delivery at lower costs due to the higher efficiency in resource usage. Software and application providers can serve the new ecosystem by developing and bringing to the market innovative and ground breaking services and applications.
S4	Stimulation of new economically-viable services of high societal value like U-HDTV and M2M applications.	Not relevant	Not relevant
S5	Establishment and availability of 5G skills development curricula (*in partnership with the*	Not relevant	Not relevant

	EIT).		

Table 2: Societal KPIs

Business-*related* KPIs:

KPI		**Relevance** (High/Medium/ Low/Not relevant)	**Details on planned project contribution towards achieving the KPI**
B1	Leverage effect of EU research and innovation funding, in terms of private investment in R&D for 5G systems in the order of 5 to 10 times.	Not relevant	Not relevant
B2	Target SME participation under this initiative commensurate with an allocation of 20% of the total public funding.	High	The consortium includes three high-tech SMEs (*Virtual Open Systems, Athonet* and *ORION*) and *INCITES* (an experienced player in the techno-economics field), which contribute to the technical roadmap and objectives in SESAME and are involved in the key technological component development and innovation aspects of the entire project. The SMEs are well positioned to leverage the technological expertise and exploit them within the 5G market space either through the consortium or as individual entities.
B3	Reach a global market share for 5G equipment & services delivered by European headquartered ICT companies at, or above, the reported 2011 level of 43% global market share in communication infrastructure.	Low	SESAME will greatly improve the capabilities of service providers to add new revenue streams for innovative services that have added value and better QoE delivered closer to the end-user. Placing relevant applications closer to the edge and slicing the infrastructure to offer multi-tenancy capabilities, will offer end-users more economically-viable applications.

Table 3: Business-related KPIs

2.5. Methodology for selecting SESAME use cases

The employed methodology aims at coherently deriving the system requirements as well as high-level use cases from the goals or expected high-level technical requirements from the SESAME project, as described in the project's DoA, *within the respective GA*.

The process which is to be developed will be used for "identifying" use cases covering all potential scenarios, and for highlighting any corresponding requirements. In addition, the employed methodology produces an enhanced set of KPIs and/or requirements that have been considered as "most relevant for SESAME", as of the views of all partners involved for the definition of the various uses cases presented and discussed in the present deliverable.

This kind of information will be used to further discuss and classify use cases, KPIs, requirements and metrics which will be derived in the future, coming from possible lab simulations and field trials.

The following figure (***Figure 2***) visualizes the employed methodology.

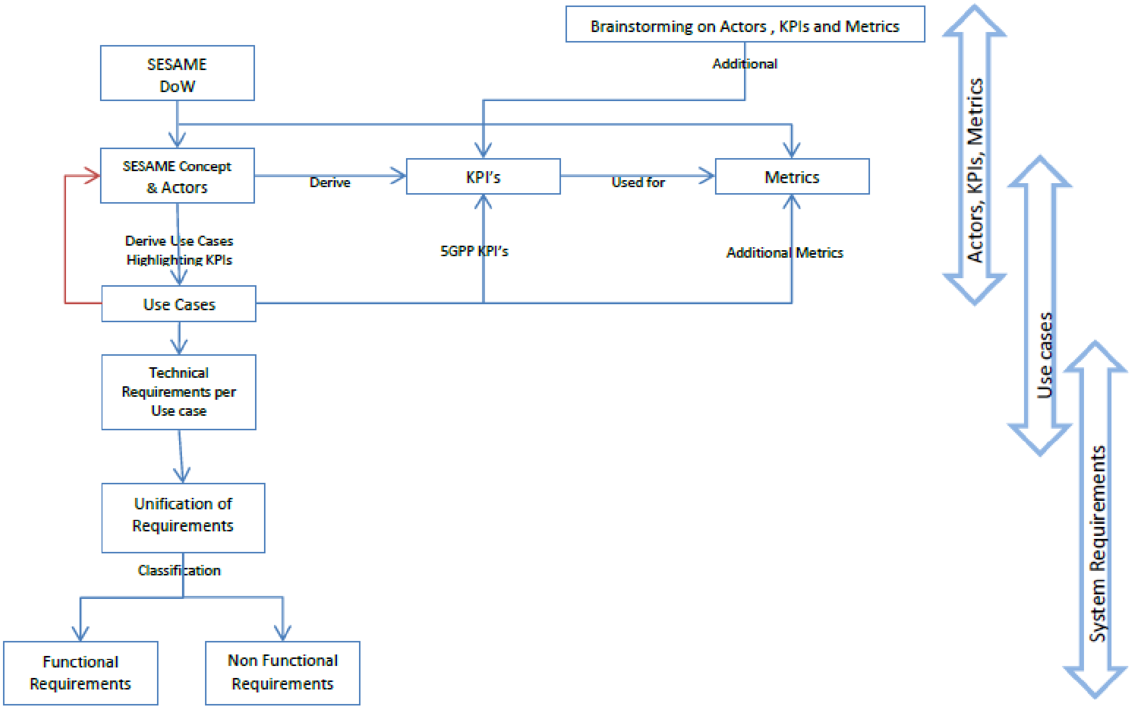

Figure 2: Employed Methodology within SESAME concept

As an initial step, the SESAME concept and actors have been summarized. Here, the term *"SESAME concept"* is defined as *"an attribute illustrating the advantage in technology introduced by SESAME".*

This concept is further defined and detailed on a scientific and technological level by dedicated work packages of the SESAME project, so as to "enhance" it with some concrete technological relevance.

Scenarios already existing in DoW are understood as a high-level synopsis of an application scenario within a specific environment, accounting for situations and events helping to highlight and illustrate the concept of SESAME. For example, the concept of *"self-x features"*[3] reflects on *"self-x enabled small cells"* and it comes along with the property of network elements to act autonomously.

[3] There is a multitude of the so-called "self-x" (or "self-*") properties in the international literature. The top most so called CHOP (for Configuration, Healing, Organization and Protection) are extended by the self-explanation and context-awareness. The term usually implicates features of self-organization, self-configuration, self-optimization, self-healing and self-protection. More information can be found, *for instance*, at: https://en.wikipedia.org/wiki/Organic_computing#Self-.2A_properties.

The second step aims at obtaining (directly measurable) properties subject to change along with key performance indicators. Furthermore, use cases have been specified. Use cases are understood as "an instantiation of a (partial) scenario" and have the clear goal of elaborating one -or several- feature(s) of the corresponding scenario, under a set of given (*pre-* and *post-*) conditions.
Use cases have been selected in a way to "highlight" certain technical requirements which will be introduced by the project. Therefore, each use case can identify, *in a future step*, the metrics that will be under observation. To assure consistency in the process, use cases' evaluation is performed.

The final step of the methodology is the extraction of high-level technical requirements. A requirement is a statement that identifies a necessary characteristic or quality of a system, in order for it "to have value and utility". High-level requirements show what elements and functions are necessary for the particular project.

2.6. Use Cases Classification

According to the applied methodology, the use cases will be used for the integration processes as they provide collection of fundamental functionality fragments of the SESAME architecture to be developed. The collection of issues presented in the use cases indicates the complexity of the scope associated with the Cloud-Enabled Small Cell (CESC), a new multi-operator enabled Small Cell that integrates a virtualized execution platform (i.e., the Light DC) for deploying Virtual Network Functions (VNFs), supporting powerful *self-x* management and executing novel applications and services inside the access network infrastructure.

The technical scope and directions of the SESAME project are captured by a set of specific SESAME principles, thus constituting the overall SESAME concept.
In turn, each of the principles is further specialized by a set of high-level technical requirements, based on the presented methodology. Essentially, a requirement reflects a certain technical aspect or technical area, whereas a principle is "translated" into a more specific aspect, in terms of more detailed technical features.
The evaluation of each use case is based on the SESAME concept which can be summarized in the following principles:

- Multitenancy;
- Virtualization at the edge (Infrastructure / Small Cells) along with exploitation of edge computing acceleration;
- VNF execution at the edge;
- Dynamic coordination of Light DC clusters;
- Self-X features, *and*;
- Service Function Chaining (SFC).

2.7. Security analysis approach

A selected number of Use Cases will be evaluated by using the Secure Tropos (SecTro) methodology[4]. *Secure Tropos* is a security-*aware* software systems development methodology[5], which combines requirements' engineering concepts (such as actor, goal and plan) together with security engineering concepts (such as threat, security constraint and security mechanism), under a "unified" process to support the analysis, *at different levels*, and development of secure and trustworthy software systems.

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[4] Mouratidis H., Giorgini P. (2007). Secure Tropos: a security-oriented extension of the Tropos methodology. *International Journal of Software Engineering and Knowledge Engineering,* (Apr. 2007) 17(02), 285-309.

[5] More detailed information about the broader SecTro concept can be found at: https://www.brighton.ac.uk/lhp-research-groups/cem/computing/secure-tropos.aspx.

In particular, this methodology can be used to identify, model and analyze security issues from the early stages of software development within an organization/legal entity and its social setting - or it can be used to model and analyze threats and vulnerabilities in existing software and socio-technical settings. The Secure Tropos methodology is supported by the SecTro tool, a Computer Aided Software Engineering (CASE) tool that guides and supports the developers in the construction of the appropriate models of Secure Tropos and it supports a set of automated analysis based on the models created.

3. Overview of Scenarios

Three initial "target" scenarios have been identified as "promising fields" for the applicability of the SESAME concepts, which can be further used as the basis for the formulation of a number of specific use cases. A description of the three scenarios is given in the following subsections, by highlighting the main challenges, the applications and services in-scope as well as the respective SESAME components and capabilities.

3.1. Scenario 1: Enterprise Services in Multi-Tenant Large Business Centres

A typical scenario where the SESAME system can be exploited is illustrated in ***Figure 3***. The respective figure depicts a situation of one CESC provider which owns, deploys and maintains the network infrastructure of Small Cells and of a Light DC (i.e., ensemble of micro-servers) inside premises where different enterprises/legal entities are hosted. In this case, the CESC provider shall establish a Service Level Agreement with each customer enterprise to enable enterprise users accessing different services (including Internet access, voice communications, video conferencing, access to mail system and repositories, web browsing and open and closed subscriber groups with embedded high security credentials, *just to name a few*).
The deployment of µServers (µSs or micro-servers) can lead to achieve close-to-zero latency, with clear benefits for enhanced Quality of Experience (QoE) of media flows. Indeed, this can be achieved by resorting to content caching at the level of the Light DC, or -in other words- by storing content at different µS locations. It is also worth stressing the fact that within a headquarter, hosting different enterprises' traffic may fluctuate greatly, *depending on the time of the day and on the nature of specific events held*, thus requiring a flexible system which can be scaled up and down, *depending on the situation*. As shown in ***Figure 3***, the enterprise scenario will leverage on SESAME features such as intrinsic support of multi-tenancy, since Small Cells operators can provide network services and connectivity over the network owned by the infrastructure provider. Furthermore, SESAME will optimize service delivery to the enterprise's end-users thus adapting the network behaviour by means of self-organizing network techniques.

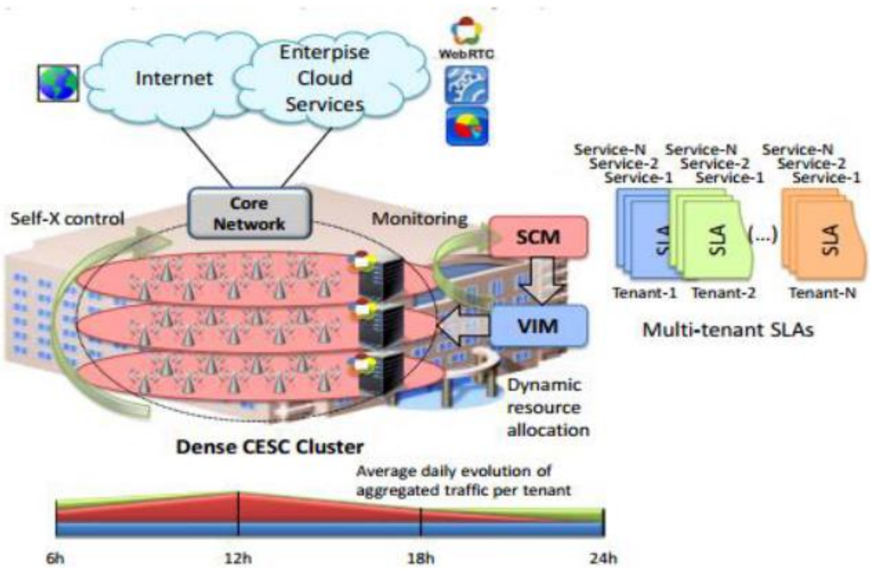

Figure 3: Enterprise Services in multi-tenant Large Business Scenario

3.2. Scenario 2: Enhanced Service Experience *on the move*

In this scenario, a CESC provider manages three distributed CESC clusters deployed in geographically adjacent areas and so supports a single mobile network provider who is offering services to his end-users through the CESC infrastructures. The relationship between the entities is regulated by different SLAs which are established between the CESC operator and the service provider and between the service provider and his end-users. The main actors and interactions of this scenario are depicted in ***Figure 4.***
In order to demonstrate different SESAME capabilities in this setup, the mobility of a reference end-user is taken into account, together with his requirements for service continuity and quality as he handovers across the different CESC clusters. The type of traffic generated by the user is assumed to be high-definition real-time content that requires low-latency data access times.

The application of the MEC paradigm, implemented in the SESAME architecture through hardware and software components running at the edge of the network and in the proximity of the moving user, allows for an efficient monitoring of the user location and its related radio conditions, with real-time reporting and the actuation of coordination actions with close-to-zero latency.

The enhanced handling of the end-user mobility is thus a consequence of the SON (Self-Organizing Networks) or “self-x” features of the CESC clusters, which take advantage of edge monitoring capabilities to seamlessly manage the handover process across neighbouring cells. As for decision making, limiting the processes within the boundaries of a CESC (or CESCs cluster), allows for the fast application of policies aimed at increasing the overall quality perceived by the user. In order to take into account more stringent requirements (for example across all users), some decision making processes resulting in the reconfiguration of services for the fulfilment of the SLAs can also be completed at the level of the CESCM, which has a wider view of the status of the resources across the CESC clusters.

With respect to user traffic, the scenario highlights how low-latency edge caches can be deployed across the CESC installations to allow the end-user an uninterrupted access to content. Pre-provisioning cached data while anticipating the user handover (monitored through signal inspection) is an effective way to offload the user equipment from the task of storing data locally.

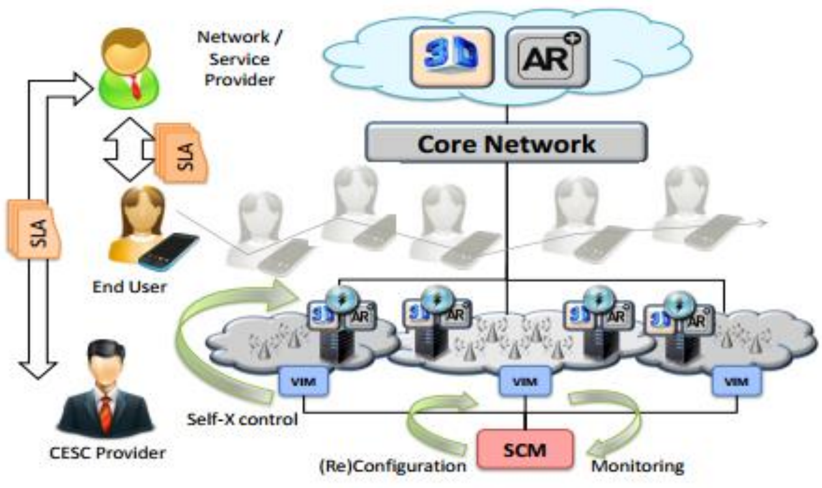

Figure 4: Enhanced Service Experience *on the move*

3.3. Scenario 3: Service Provisioning in Flash Events

Another relevant scenario addressed by the SESAME system is presented in ***Figure 5***, where the sudden concentration of people at a specific geographical location and time of the day, creates an unexpected hot-spot zone in which a variety of different traffic types require proper management. The sudden gathering of crowds can be due to unexpected live events or emergency situations.

This scenario is relevant to leverage the CESC cluster resources, which are essentially the collection of a number of CESCs (i.e., Small Cells with their micro-servers). In addition, the scenario allows showing that multi-tenancy can be considered as a built-in function of the system. In the first place indeed, the CESC infrastructure deployed by an infrastructure provider shall support different mobile operators in serving their customers. In such a situation, CESC cluster resources have to be provisioned to each tenant operator, and in order to efficiently handle the unexpectedly intense traffic generated by the users, self-organizing network techniques are thus required. At the beginning, the CESCM shall interface with an operator's OSS/BSS to retrieve tenant configuration parameters; afterwards, communications and QoS are supported at the CESC level.
It is interesting to notice that this scenario is built on the edge computing capability of the system since computationally intensive tasks can be offloaded from the mobile terminals to the µSs while, *at the same time*, optimizing the use of backhaul resources.

The two main traffic types which need to be supported and optimized by the CESC cluster are live video streaming (e.g., users film and posting video contents in social media) and real-time group communications (e.g., small community of users exchanging files or videos).
Deep packet inspection, video transcoding and data analytics can be enabled in the CESC cluster, whereby hardware accelerators, in order to optimize the management of the traffic from/to the CESCs.

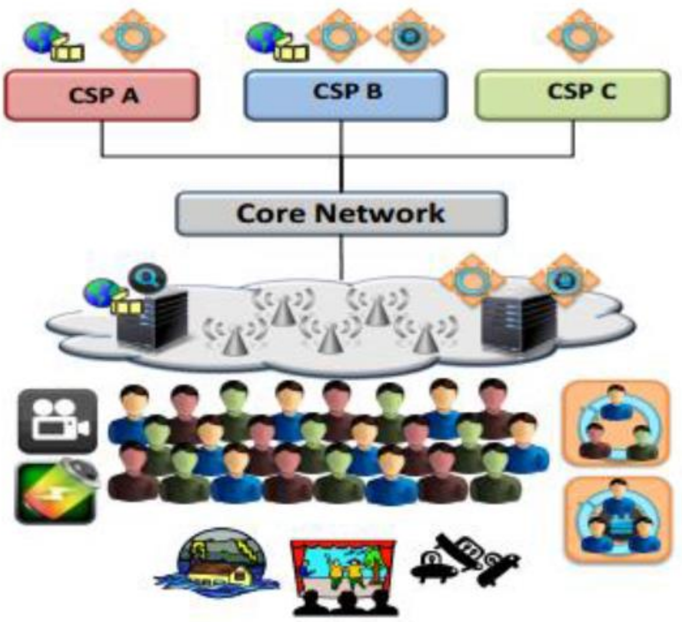

Figure 5: Service Provisioning in Flash Events

4. Literature Review

On the basis of the aforementioned concepts, this section analyses the existing literature published by standardization bodies, regional initiatives and industry alliances about potential scenarios and use cases.

In order to perform the multi-directional analysis of the proposed use cases, the first task to complete is the categorization of the potential scenarios targeted in SESAME. Next, the relevant literature is reviewed to get a comprehensive list of current and prospective use cases, along with their classification into two level schemes. Then, with the objective of facilitating the association of system requirements, the identified use cases are mapped to probable scenarios. Finally, as a "complement" to the previous study, a brief analysis of the application of the use cases to existing vertical sectors is performed.

4.1. Sources of information

Table 4, below, summarizes the list of institutions that provide inputs for the study.

Standards developing organizations (SDO)	
FG IMT-2020 ETSI MEC 3GPP A GLOBAL INITIATIVE	
Regional Initiatives	
Europe	European Commission; SEVENTH FRAMEWORK PROGRAMME; 5G PPP
Korea	5G Forum
Japan	5GMF The Fifth Generation Mobile Communications Promotion Forum
China	IMT-2020 (5G) Promotion Group
USA	4G americas
Industry Fora	
ngmn the engine of broadband wireless innovation; SMALL CELL FORUM	

Table 4: Sources of material for literature review

4.2. Categorization of Scenarios

As defined in Section 2.1, a scenario describes general application examples that exhibit a collection of properties that influence the service provision.

The Small Cell Forum[6] provides the definition of four main categories of scenarios as general contexts:

- **Residential[7]:** This category includes small cells intended for home or small office applications. These applications are based typically indoors and involve locations where a single small cell is sufficient. It is considered as a mature market, already exploited in 4G.

- **Enterprise[8]:** An Enterprise Small Cell deployment is described as generally indoor, premises-*based* deployment beyond home office, expectedly encompassing large geographic areas and high numbers of users. It is a primarily coverage-driven scenario category, with a need of high reliability, and where capacity will often be important. The deployment may involve multiple parties (for service, site, facilities) becoming, *thus*, an important market niche for multi-tenant services. Given appropriate products and deployment, similar small cell architectures can "meet" the needs of many types of organizations/legal entities (i.e., from small businesses and retail shops to hotels, hospitals, stadiums and other sorts of organizations).

- **Urban[9]:** Urban small cells are defined as compact public-access base stations (BSs) deployed by operators to enhance capacity and coverage in dense environments such as city centre hot-zones, transportation hubs and retail. They are often referred as microcells, pico-cells or metro-cells, and represent an evolution of the technologies that have been combined to make residential and enterprise small cells a success. They need to retain characteristics of being compact, easy to install, offering scalable extension to network coverage and capacity for operators. Additionally, they need to be deployable in busy public spaces (indoor and outdoor), and integrate with the existing coverage of macro-cells networks.

- **Rural and remote[10]:** Rural and remote small cells are oriented to "bring" mobile communication to hard-to-reach locations. The associated services include: coverage for underserved rural community beyond range of normal service; coverage for remote industrial workers at a side hard to reach from existing infrastructure; coverage for emergency service and first responders that belong to public safety services; rapid reinstatement of coverage after extensive damage to mobile infrastructure and support for on-going humanitarian efforts; services for temporary planned gatherings as special events; service for military personnel and services for passengers and operational needs on all classes of shipping, aircraft and trains.

After the definition of the four main categories of scenarios for small cells, the next section identifies the use cases as a particular "instantiation" of a specific scenario, under a set of given conditions.

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6 The *Small Cell Forum* is a Body that supports the wide-scale adoption of small cells and accelerates the delivery of heterogeneous networks. This implies two main areas of focus: (i) Standardization, regulation and interoperability, *and*; (ii) marketing, promotion and business case. Detailed information about the wider scope of the activities performed can be found at: http://www.smallcellforum.org/.

7 Small Cell Forum (SCF) (2014, June). *Document 101.05.03. "Home: Overview" – Release Five*. SCF, UK.

8 Small Cell Forum (SCF) (2013, December). *Document 102.05.01. "Enterprise: Overview" – Release Five.* SCF, UK.

9 Small Cell Forum (SCF) (2014, June). *Document 104.05.01.* "*Urban Small Cells: Overview" – Release Five.* SCF, UK.

10 Small Cell Forum (SCF) (2015, February). *Document* SCF 105.05.01. *"Rural and remote: Overview" - Release Five.* SCF, UK.

4.3. Use case identification and classification

The identification of use cases for 5G small cells requires a deep understanding of the evolution of the business context form 4G, characterized by changes in customer, technology and operator settings[11]. Although smartphones are expected to stay as the main personal device, other supporting devices, *such as wearables and sensors,* will gain relevance. Supported by cloud technology, personal devices will “advance” in the exploitation of services such as high quality (video) content production and sharing, payment, proof of identity, cloud gaming, mobile TV, and supporting smart life, *in general*. The development of those services will transform health, security, safety, and social life applications, as well as controlling home appliances, cars and other machines.

On the other hand, the borderlines between personal and enterprise usage of devices “fade”, as many of the tendencies in the consumer market also apply to the industry. Mobility becomes a main “enabler” for increased productivity and, in the next years, enterprises will progressively make their applications available on mobile devices. Supported by cloud-*based* services, application portability will provide new competitive advantages, but will also entail new challenges to be managed, such as privacy, security or performance.

Moreover, operators have already started to take benefit of partnerships with OTT (over-the-top) players to deliver packaged services to end-users with new requirements on demand, and in highly flexible and programmable way.

In this context, a global business model evolution of mobile operators’ services will include the evolution of current services as well as the emergence of new ones such as automated industries and smart user environments, public safety and mission-critical services. Leveraging capabilities such as big data, proximity, geo-community services and many others will develop many other services.

Summarizing, ***Table 5*** compiles the use cases identified in the literature provided by the standardization bodies (ITU, ETSI, 3GPP), regional initiatives (METIS[12], RAS[13], 5G-PPP, 5G Forum[14], 5GMF[15], IMT-2020 Promotion Group[16], 4G Americas[17]) and industrial alliances (NGMN[18], SCF).

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11 Next Generation Mobile Networks (NGMN) (2015, February). *NGMN 5G White Paper*, NGMN, Frankfurt, Germany. https://www.ngmn.org/uploads/media/NGMN_5G_White_Paper_V1_0.pdf

12 *METIS* (Mobile and wireless communications Enablers for Twenty-twenty (2020) Information Society). METIS has been co-funded by the European Commission as an Integrated Project (IP) under the Seventh Framework Programme for research and development (FP7). The project has so provided an important platform for a European-led early global consensus on fundamental questions connected to the development of the future mobile and wireless communications system, and pave the way for future standardization. The project objective was to “lay the foundation” for a future mobile and wireless communications system for 2020 and beyond. METIS was a consortium of 29 partners, coordinated by Ericsson. Approximately 80 persons have been dedicated full time to METIS during its 30-month duration. The strong consortium included manufacturers, network telecommunications operators, academic institutions, automotive industry and a research centre. Information can be found at: https://www.metis2020.com/

13 *Radio Access and Spectrum (RAS)* is a cluster activity comprising a portfolio of more than 20 research projects participating in the 7th Framework Program (Objective 1.1 - *Future Networks*) and investigating Radio Access and Spectrum aspects of future wireless networks. More information can be found at: http://www.ict-ras.eu/.

14 The annual *5G Forum USA* brings together decision makers from key carriers, solution providers, associations & enterprises discussing use cases and exploring technical challenges to enable you to capitalize on opportunities offered by 5G. More information can be found at: http://5gforumusa.com/.

15 The *Fifth Generation Mobile Communications Promotion Forum (5GMF)* was created to conduct research & development concerning the fifth Generation Mobile Communications Systems and research and study pertaining to standardization thereof, along with liaison and coordination with related organizations, the collection of information, and dissemination and enlightenment activities aimed at the early realization of the Fifth Generation Mobile Communications Systems, all with the aim of thereby contributing to the sound development of the use of telecommunications. More information can be found at: http://5gmf.jp/en/.

16 The *IMT-2020* (5G) Promotion Group was jointly established by three ministries of China (including MIIT, NDRC and MOST) based on the original IMT-Advanced promotion group in February 2013. The members include the main operators, vendors, universities and research institutes in China. The Promotion Group is the major platform

The corresponding references are included in the respective *References' Section* of the present deliverable.

	SDOs	REGIONAL INITIATIVES	NGMN	SCF
1. Pervasive video	[1]	[5], [11], [13]	[16]	[22]
2. Operator cloud services	[1], [2]	[4], [5], [9], [7], [12], [13]	[16]	[17], [22]
3. Dense urban society/Smart city		[3], [4], [7], [11], [12], [15]	[16]	[17], [21], [22]
4. Smart office/Unified enterprise communication	[1], [2]	[3], [7], [8], [11], [12], [13]	[16]	[17], [18], [20], [22], [23], [24]
5. Smart home	[2]	[4], [11], [12], [13], [15]		[17], [20], [22], [23]
6. HD video/photo sharing in stadium/open-air gathering		[3], [4], [5], [11], [12], [13], [15]	[16]	[19], [22], [23]
7. 50+ Mbps everywhere	[2]	[4], [10], [12]	[16]	[22], [23], [24]
8. Location-*aware* services	[1], [2]	[11]		[17], [18], [19], [21], [22], [23]
9. Ultra-low-cost networks		[4]	[16]	
10. High speed vehicles	[2]	[5], [11], [12], [13]	[16]	[23], [24]
11. Moving hot-spots	[2]	[4]	[16]	[23], [24]
12. Remote computing	[2]	[3]	[16]	
13. Vehicular networks	[1]	[3], [4], [5], [10], [11], [12], [13], [15]		[23], [24]
14. 3D connectivity	[2]	[4], [11]	[16]	
15. Fleet management/Logistics	[2]	[10], [8], [12]		
16. Smart wearables	[2]	[4], [7], [8], [11], [13]	[16]	
17. Sensor networks	[2]	[3], [9], [7], [8], [11], [12]	[16]	[17], [19], [24]
18. Data analytics	[1]	[7], [11]		
19. Machine-to-machine (M2M)	[2]	[4], [5], [8], [11], [12], [13], [15]		[18], [19], [22], [23], [24]
20. Mobile video surveillance	[1]	[3]	[16]	[17]

to promote 5G technology research in China and to facilitate international communication and cooperation. More detailed information can be found at: http://www.imt-2020.cn/en/introduction.

17 *4G Americas* is an industry trade organization composed of leading telecommunications service providers and manufacturers. The organization's mission is to advocate for and foster the advancement and full capabilities of the LTE mobile broadband technology and its evolution beyond to 5G, throughout the ecosystem's networks, services, applications and wirelessly connected devices in the Americas. More specific information can be found at: http://www.4gamericas.org/en/.

18 The vision of the *NGMN (Next Generation Mobile Networks) Alliance* is to expand the communications experience by providing a truly integrated and cohesively managed delivery platform that brings affordable mobile broadband services to the end user with a particular focus on 5G while accelerating the development of LTE-Advanced and its ecosystem. More information can be found at: https://www.ngmn.org/home.html .

21. Tactile Internet	[2]	[4], [11], [13]	[16]	
22. Gaming	[1]	[4], [5], [12], [13], [15]		
23. Augmented reality/Virtual reality/Assisted reality	[1], [2]	[3], [4], [5], [10], [8], [11], [12], [13], [15]		
24. Natural disaster actions	[2]	[3], [5], [11], [15]	[16]	[23], [24]
25. Military actions	[2]	[3], [5], [11], [15]		[23], [24]
26. Mission critical services	[2]	[3], [5], [11]		[23], [24]
27. Smart Grid and critical infrastructure monitoring		[9], [13]		
28. Automatic traffic control & driving	[2]	[3], [4], [10], [11], [12], [13], [15]	[16]	
29. Collaborative robots	[2]	[8], [11], [12]	[16]	
30. Remote object manipulation/Remote surgery	[2]	[4], [5], [7], [8], [11], [12], [13], [15]	[16]	
31. eHealth: Extreme life critical	[2]	[4], [5], [7], [11], [12], [15]	[16]	
32. News and information	[2]	[11]	[16]	[17]
33. Broadcast-*like* services: local, regional, national	[2]	[4], [11]	[16]	
34. Context-*aware* services	[2]	[11], [15]		[18], [19], [22]
35. Remote education		[11], [13]		

Table 5: Use case identification in reviewed literature

Using the categorization of use cases established by [8] as a basis, the items listed in ***Table 5*** are grouped into 15 categories that are furthermore arranged in eight use case families.

Figure 6 illustrates this classification, considering that there are not separate groups, since a use case may fall into one or more categories/families.

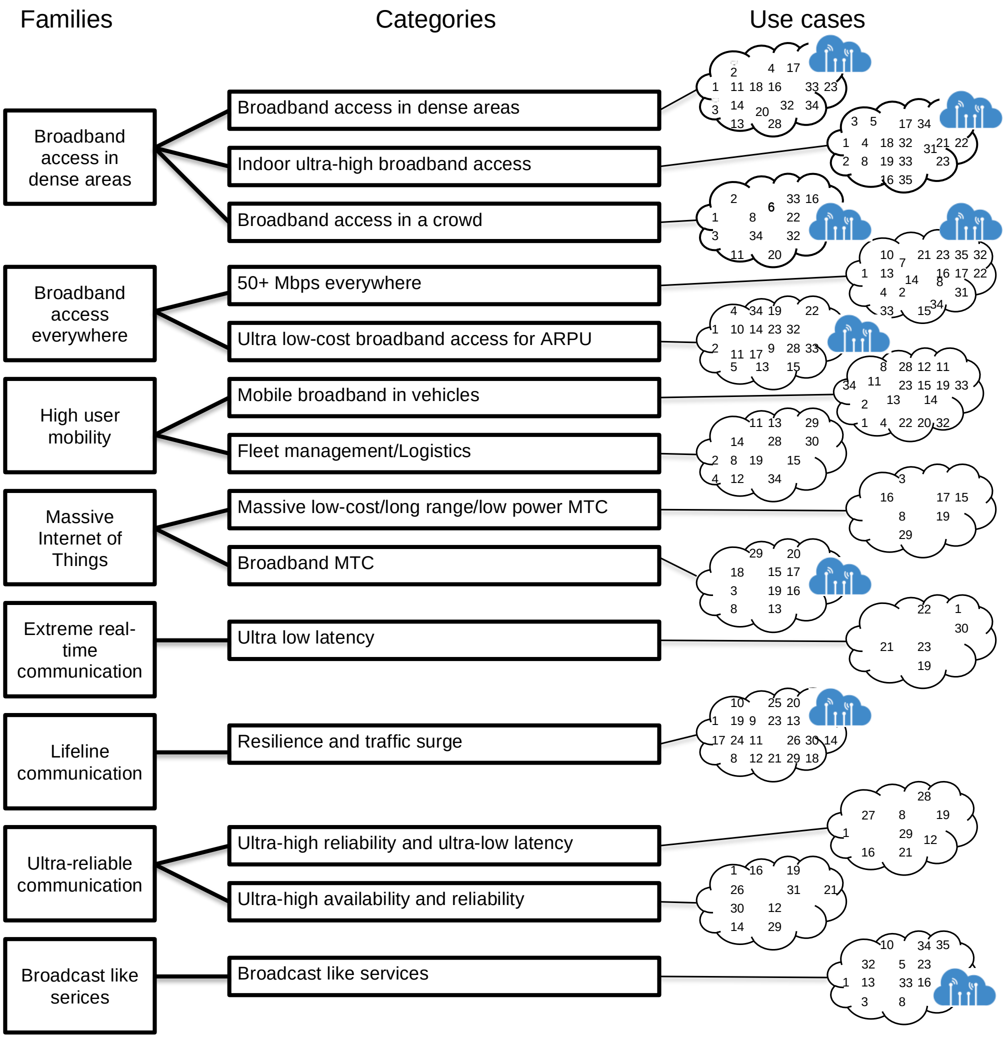

Figure 6: Classification of use cases with NGMN categories

The ***Broadband Access in Dense Areas*** family includes all the use cases related to the growing variety of new services and applications related to a fully connected society in very-densely connected society. This premise entails the need for pervasive and normalised communications in dense city centres, buildings, stores or events, while context recognition, augmented reality, multi-user interaction and 3D skills will play an increasingly relevant role, thus ensuring delivery of customized services to the end-users.

The ***Broadband Access Everywhere*** family focuses on the access to broadband service provision everywhere, even in hard-to-reach locations, *such as suburban or rural areas*, where cost is a key factor in the provided services.

The ***Higher User Mobility*** family highlights the growing demand for mobile services in vehicles trains and even aircrafts, either for entertainment, Internet access, autonomous driving or real-time information.

The ***Massive Internet of Things (IoT)*** family covers the new services associated to the proliferation of devices, such as sensors, actuators or cameras, with a wide range of features and requirements and including both human-type communication (HTC) and machine-type communication (MTC).

The ***Extreme Real-Time Communications*** family comprises use cases with a high demand in terms of real-time interaction. Depending on the specific application, this may require extremely high throughput, mobility, critical reliability and high availability of strict latency requirements.

The ***Lifeline Communication*** family covers the use cases related to public safety and emergency systems. In fact, it is expected that the mobile network acts as a lifeline, requiring a very high level of availability in addition to the ability to support traffic surges.

The ***Ultra-reliable Communications*** family includes the new use cases related to the leverage of reliable MTC by industries not just in the areas of automotive, health and assisted living, but also in manufacturing or agriculture. The requirements here involve remote operation and control, as well as extreme low latency.

Finally, the ***Broadcast-like Services*** family covers the use cases related to the customization of information, both real-time and non-real-time, and including a feedback channel (uplink) for interactive services.

Besides the classification of the identified use cases, ***Figure 6*** also highlights the categories where the small cells may play a major role in providing multi-tenancy and edge services, which is the final aim of SESAME project.

4.4. Scenario/use case mapping

After the definition of four general scenario categories and the identification of potential use cases for the future 5G services, the next step is to "map" those use cases to the probable operating scenarios.
Table 6, as appears below, displays this categorization and highlights the use cases that may take more profit from SESAME, adapted to each scenario class. (*Note:* The included numbering in registries of ***Table 6*** is according to the sequence of the use cases coming from the international literature as previously identified in ***Table 5***; each number is related to a dedicated use case of the ***Table 5***).

URBAN	1, 2, 3, 6, 7, 8, 9, 11, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 27, 28, 29, 30, 32, 33, 34
RURAL & REMOTE	1, 2, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 19, 20, 24, 25, 26, 27, 28, 30, 34
RESIDENTIAL	1, 2, 5, 7, 8, 16, 17, 19, 22, 23, 27, 30, 31, 32, 33, 34, 35
ENTERPRISE	1, 2, 4, 7, 10, 12, 13, 15, 16, 17, 18, 19, 20, 21, 23, 27, 29, 30, 31, 32, 33, 34, 35

Table 6: Mapping of identified use cases into SCF scenario categories

Again, the use case distribution shown in ***Table 6*** is not discriminatory and, *thus*, ***Figure 7*** depicts the overlap of use cases through the four defined scenario categories.

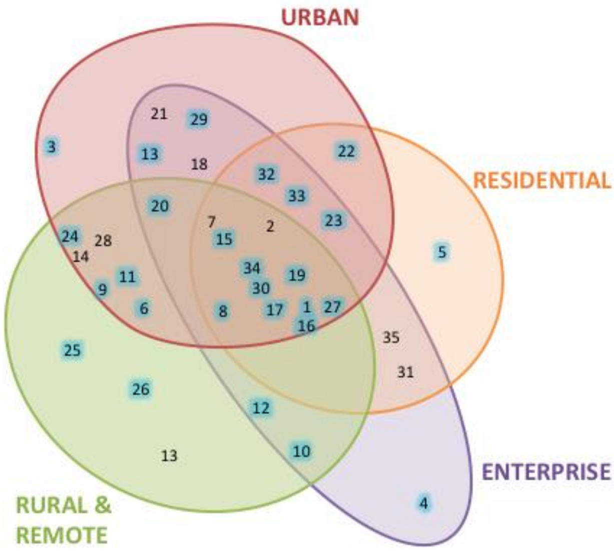

Figure 7: Mapping of identified use cases into SCF scenario categories.

4.5. Brief analysis of vertical sectors

As a final consideration, another valuable point of view in the identification of use cases comes from the business context. The next forward leap of mobile communication is related to the automation of industries and industry processes. Precisely, it is what has been generally referred to as the IoT and MTC. The creation of new services and applications for vertical industries such as health, automotive, entertainment or energy will not be limited to connectivity but can require enablers from cloud computing (CC), big data management, security, logistics and other network-enabled capabilities.

Table 7 shows the classification of the use cases that may provide competitive advantages in five relevant vertical sectors such as: Energy; automotive; eHealth; manufacturing, and; broadcasting & entertainment. (*Note:* The included numbering in registries of ***Table 7*** is according to the sequence of the use cases coming from the international literature as previously identified in ***Table 5***).

Energy	2, 3, 5, 9, 13, 17, 18, 19, 24, 25, 26, 27, 30, 34
Automotive	1, 2, 3, 4, 5, 7, 8, 10, 11, 13, 14, 15, 16, 17, 19, 23, 25, 26, 28, 32, 34
eHealth	1, 2, 3, 4, 5, 7, 13, 16, 17, 18, 19, 24, 26, 30, 31, 34
Manufacturing	4, 7, 12, 13, 15, 16, 17, 19, 23, 29, 30, 34
Broadcasting & Entertainment	1, 2, 3, 5, 6, 7, 8, 10, 11, 13, 21, 22, 23, 32, 33, 34, 35

Table 7: Classification of use cases associated to 5G-PPP vertical sectors

As in the previous classifications, the resulting groups are not separate and ***Figure 8*** depicts the existing overlapping of use cases in several vertical sectors.
These overlaps emphasize the relevance of the most valuable use cases for the assessment the outcomes and benefits of SESAME.

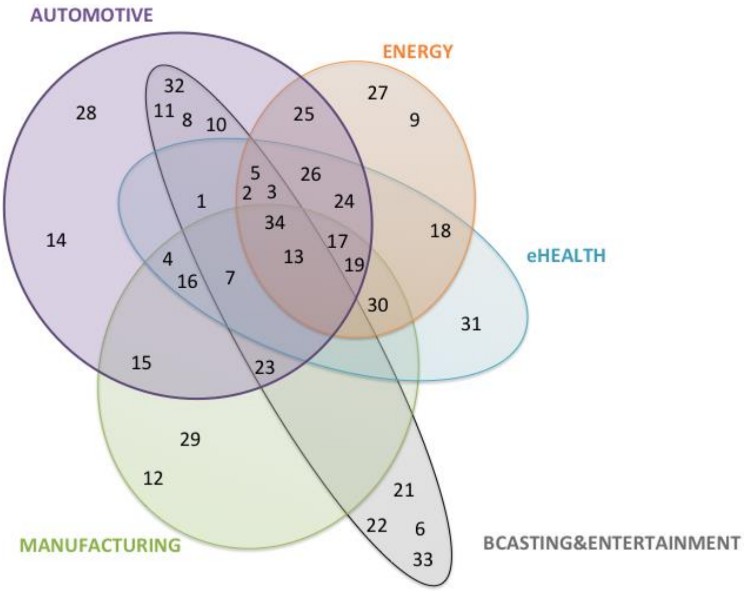

Figure 8: Classification of use cases associated to 5G-PPP vertical sectors.

5. Use cases and Requirements

Main focus of SESAME is the support of the above mentioned scenarios via elaborating different use cases, in different contexts and applications, while serving a wide diversity of service provision aspect. These include: changes in network topology; increasing capacity requirements in dense environments, etc. These scenarios will exploit system capabilities and solutions together with network and topology integration.

Hereinafter a set of technical use cases is defined as “linked” to the above described scenarios. It should be noted that every use case touches a limited sector inside the overall SESAME scope. The combination of all results shall help to define a set of system requirements which, again, shall lead to a project-*wide* reference framework and architecture. Afterwards, system components can be derived accordingly, accompanied by their functional architectures and interfaces to “better reflect” the technical work-packages effort.

5.1. Description of use cases

In engineering, use cases constitute an important part of a methodology that helps to design a complex system composed of smaller blocks; in this context, a use case “reflects” such a typical smaller block.
Use cases are important so as to extract system requirements and then capture non-conventional requirements, by exploiting corresponding interrelation between the technical use cases thus correlating, *for example*, different attributes and parameters in different use cases.

5.1.1. Use Case1: Elastic operator SLAs enforcement in multi-operator CESC with edge monitoring and control

Overall Description

An SCNO is supporting two distinct VSCNOs within its infrastructure (VSCNO1 and VSCNO2) and has stipulated an SLA with each (SLA1 and SLA2, *respectively*).
VSCNO1 and VSCNO2 “share” the infrastructure of the CESC (or CESC cluster) and serve their respective users base (EU1, EU2). The total resources required at time 1 (T1) to support EU1 requests, would violate SLA1, but EU2 is using less resources than what SLA2 would guarantee at T1.
The SCNO is able to monitor the status of its resources at the CESC (edge monitoring) in real time and the CESCM can apply dynamic policy of elasticity by allowing VSCNO1 to benefit from a larger SLA than SLA1 at T1 with no additional costs.
Additional virtual resources for VSCNO1 are deployed dynamically over the CESC (cluster) and traffic generated by EU1 at T1 is supported.
At T2 (T2 > T1), traffic from EU2 increases and, when added to that of EU1, would exceed the available resources at SCNO.
The monitoring tools detect the situation and dynamically control it by scaling down VSCNO1 to its original SLA1. Both SLA1 and SLA2 are respected.

Actors involved

- *Small Cell Network Operator:* Owner of the infrastructure that VSCNOs use to serve their end-users, stipulates SLA with each VSCNO.
- *Virtual Small Cell Network Operator:* Users of the infrastructure owned by the SCNO, stipulate SLA with their end-users and with the SCNO.
- *End-Users:* They use the networking service offered by the VSCNO.

Deployment Topology Example

An example of the proposed topology for the use case of the elastic operator's SLAs enforcement in multi-operator CESC with edge monitoring and control is given below, in ***Figure 9.***

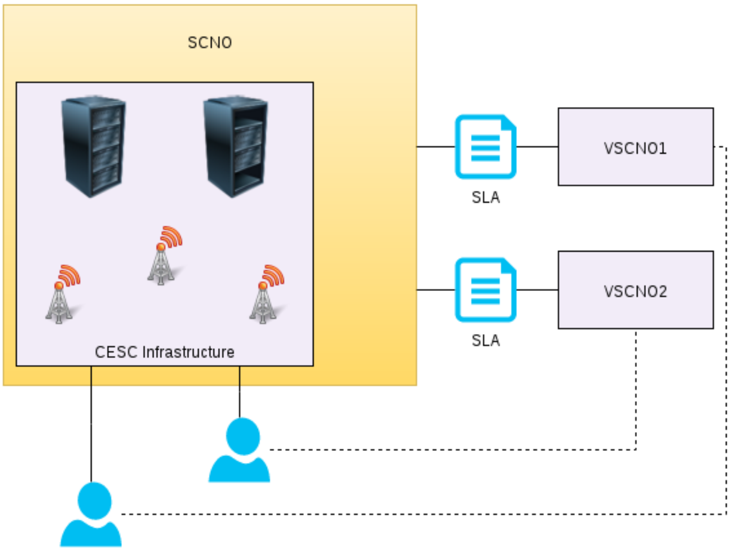

Figure 9: Elastic operator SLAs enforcement in multi-operator CESC with edge monitoring and control

Evaluation of Each Use Case

To evaluate the use case, it is required a CESC deployment that is accessed by two different VCSNOs. Traffic needs to be generated by users in a way that demonstrates the possibility to over provide resources for one of the VSCNOs, only until the other VSCNO is not using the full capacity he could obtain as per its SLA.
With reference to the instant of times T1 and T2 defined in the "Overall Description", the shape of the traffic in time can be represented in the following graph (as in ***Figure 10***):

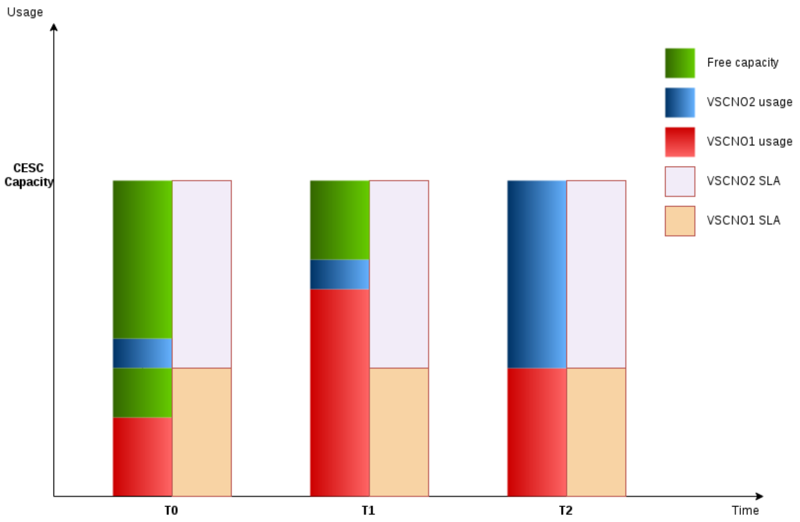

Figure 10: Estimated traffic in time in multi-operator CESC with edge monitoring and control

The use case can be demonstrated by implementing and enabling the following key features:

- Monitoring of current resources utilization of each VSCNO in relation to SLAs.

- Re-allocation of resources of the CESC to VSCNO, to increase the performance for EUs.
- Application of scale-down policies to ensure that the SLA of each VSCNO is properly met.
- Service level experienced by EUs exceeds the one agreed when resources can be over-provisioned, due to low utilization from other tenants.

The above use case addresses and requires features of SESAME that span through different layers of its architecture (i.e.: radio management, VNF management, resources monitoring and control). A possible demonstration could combine simulated components (including users' traffic and/or radio interfaces) and emulated ones (i.e.: VIM, CESCM modules) to show *how resources can be allocated in time to maximize the usage of the Light DC*.

Relevance to SESAME

A powerful cloud environment, such as the one characterizing the CESC, enables dynamic and responsive control over the administered resources. With a shared infrastructure across different VSCNOs, the SESAME architecture allows RRM functions and VNFs to be modified according to the current status of the network (using *"self-x"* functionalities and cloud components for monitoring and control) and exploit over-provisioning of individual tenant's resources with respect to their SLAs. This use case demonstrates edge monitoring mechanisms that allow maximization of CESC infrastructure usage and benefit to network operators in a shared infrastructure scenario; it also demonstrates how an SLA can be enforced dynamically, by scaling-down resources assigned to a network operator.

The use case highlights the definition of new business interactions in SESAME multi-operator scenarios, where an entity owns the infrastructure and allocates it to different virtual operators with a dynamic control over resources. The cloud-*enabled* nature of the small cell and the additional services running at the CESCM, allow for elastic provisioning and management of the VNFs so that VSCNOs can provide services to EUs in a way that maximizes utilization of resources and performance.

The development of the use case could be envisaged in the following work packages:

- WP3: *"Self-x"* features, virtualization of the small cell resources.
- WP6: Orchestration, monitoring, dynamic reconfiguration of virtual resources.

The above use case is related to *SESAME Scenario 2* ("monitoring and management of SLA, edge monitoring, CESC decision making, dynamic reconfiguration") and *SESAME Scenario 3* ("multi-operator").

Requirements Extracted from the Use Case

- The CESCM must be able to monitor the current utilization of each network operator relying on that CESC.
- The CESCM must be able to determine the compliance of the supported VSCNOs with respect to their SLA (VSCNO to SCNO agreement).
- The RRM must expose interfaces to the CESCM to allow for a dynamic control of radio slicing across tenants (e.g., assign maximum capacity to tenants to obtain a target data rate).
- The VIM must support fast, dynamic scale-out of virtual resources assigned to tenants.
- The CESC must support fast reconfiguration of the VNFs (a KPI of 5-10 minutes can be supported in case of complete re-deployment of VNFs).

5.1.2. Use Case2: Indoor Small Cells

Overall Description

This use case motivates and spurs the adoption of the SESAME system in a variety of indoor environments of different size and complexity. For this use case we have to consider small, medium and large enterprises, hospitals, public administrations, hotels and retail shops, *to name a few*. The CESC infrastructure (either a single CESC or a cluster of CESCs) and the flexible management in combination with the Light DC suit very well to all these situations. Since a large fraction of the whole Internet traffic carried over the mobile network is generated indoor (more than 70%)[19], it can be envisioned that the CESCs can be used to enable service providers to reach customers, as well as to dynamically serve user's demand. Resources available in the CESC include compute, storage and network.

More specifically, this use case is meant to suit indoor locations with potentially high concentrations of users, which vary depending on the specific time of the day and location of people inside building(s). In such scenarios there is the need to provide highly reliable communication links with improved radio signal quality, as well as to provide network capacity and computing power, dynamically. Furthermore, content caching is seen to play an important role, in order to store popular content(s) near the network edge, hence relieving traffic on the backhaul and potentially reducing end-to-end latency.

Hereinafter, the description of two concrete deployments of this use case is provided to give more insight of the involved SESAME features. The two specific deployments as described below, namely the *"Business Centre Small Cells"* and *"Hotels Wants Quality Cellular Service"* have been selected since they are clearly perceived as pressing situations by the market itself.
Therefore, these two specific deployments are seen as particularly appealing for the *Indoor Small Cells use case* to "attract" the attention of the interested stakeholders around the SESAME concepts and visions of future mobile networks.

"Business Centre Small Cells"

An example of *Enterprise Small Cells use case* is provided by Small Cells in a Business Centre. A Small Cell Network Operator (SCNO) is providing a radio interface to a number of distinct mobile operators (MOs), Virtual Mobile Network Operators (VMNOs) and Virtual Small Cell Network Operators (VSCNOs).
The SCNO may transmit by using licensed or unlicensed frequency spectrum over the air interface. In addition to the provision of radio coverage in the business centre and the orchestration of multi-tenancy, the SCNO provides a platform for mobile edge computing (MEC) for low latency and compute intensive applications and services (e.g. video transcoding).

The MOs, VMNOs and VSCNOs provide both in-house and third party services from Over-The-Top (OTT) players or service providers (SPs). The services provided can include: multi-person real-time videoconferencing, virtual presence 360^{o} video communications with meetings using virtual presence glasses/devices, and assisted reality to actively inform users of ambient interests such as danger warnings to support people with disabilities and improve their interactions with their surroundings.
The End-Users (EUs) benefit from fast and cost-effective access to a wide variety of innovative services from third party players.
MOs, VMNOs and VSCNOs benefit from extra market share. Venue owners (VOs) benefit from having a single set of radio and IT equipment installed on the premises, instead of having multiple installations from multiple network operators.

"Hotel Wants Quality Cellular Service"

A Hotel owner wants to obtain good service for their guests. They use a CESC Infrastructure Provider to install the hardware into the premises, and the Infrastructure Provider has use of some spectrum (e.g.

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[19] See, for example, the discussion within the document "*Cisco Visual Networking Index: Forecast and Methodology, 2014-2019 White Paper*". [*http://www.cisco.com/c/en/us/solutions/collateral/service-provider/ip-ngn-ip-next-generation-network/white_paper_c11-481360.html*].

shared spectrum allowed by the local regulator, or agreed with a Spectrum Owner) which the cells can use.
The Infrastructure Provider has a commercial relationship with the Virtual Small Cell Operators who provide telecommunications services by using the infrastructure. The Infrastructure Provider manages the CESC with commercial SLAs with the VSCNOs.

The VSCNOs require their own Operation, Administration and Management (OAM) views of the service they provide to customers so that they can manage the service to their EUs.
The Infrastructure Provider requires an OAM view of the CESCs so that they can manage the overall service. In this way, that they can manage the SLA policies that they have agreed with the VSCNOs, and thus require the KPIs and CDRs (Call Detail Records) for each VSCO to establish the bills and SLA conformance. The Infrastructure Provider wants to have caching shared across all the EUs, according to the different SLAs they might have with the different VSCNOs.

Some of the VSCNOs may have different SLAs to give differential service to their EUs in the event of service overload. The load on the CESCs in shared areas -such as the bar and dining spaces- have large variations through the day, as people congregate there at specific times, with fewer people in their rooms and conference rooms at these times.

Actors Involved

Following to the previous description involved actors comprise of: Venue Owner; IT Equipment Vendor; Small Cell Network Operators; Virtual Small Cell Network Operators; Mobile Operators; Service Provider/Over-the-Top; CESC Infrastructure Provider; Spectrum Owner, and; End-Users.

Deployment Topology Example

The subsequent figure (***Figure 11***) provides an illustration of the topology of the Enterprise Small Cells use case.

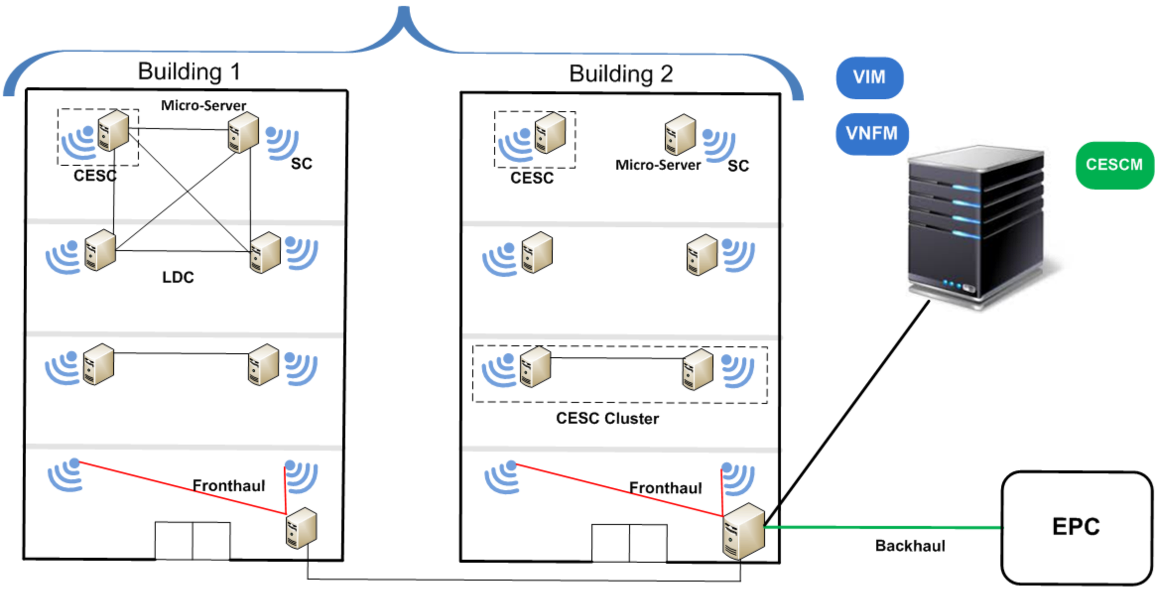

Figure 11: Enterprise Small Cells use case

Evaluation of Use Case

- CESC network capacity, data rate, delay and jitter and QoS related metrics, *in general;*
- Coverage area, blocking probability and signal-to-interference-plus-noise-ratio;
- Multi-tenancy: that is via the inclusion of a number of supported tenants;

- Dynamic load and orchestration of services to "match" (though this could be hard to be demonstrated in a PoC, depending also on the size of the demonstrator);
- Advantages from edge caching of contents.

Relevance to SESAME

The *Indoor Small Cells use case* intends to leverage on the modular deployment of CESCs and Light DC of the SESAME architecture. Customers located indoors can access services with superior quality or with services that traditionally they do not access while being mobile.

In a business centre or in hotel installations it is envisaged that the CESC components are deployed by the VO or a MO in different indoor locations and CESC clusters are likely to be formed. In other indoor scenarios such as retail shops, a single CESC could be more common to be deployed.

The SCNO/ VSCNO is thus able to establish SLAs with an SP that desires to expand the market serving better or more customers. The SCNO/VSCNO also needs to sign a contract with the owner of the infrastructure. In this case it is likely that the VO is the infrastructure provider and small cell operators can become VSCNOs in a multi-tenant environment.
The CESC infrastructure is then "shared" among tenant operators using multi-tenancy (virtualization of the MOCN function).

The CESCs need "self-x" features and functions to monitor the performance of each tenant (e.g. data traffic generated by the users). Decisions on *how to configure the CESC and CESC clusters* are taken by the CESC Manager (CESCM) on a longer time scale and enforced via the EMS to both physical and virtual infrastructures. The Virtual Infrastructure Manager (VIM) is responsible for allocating resources in the virtualized network, whilst the Virtual Network Function Manager (VNFM) superintend the creation, execution and termination of the virtual functions (i.e. lifecycle).

The key point is to enable the CESC clusters to follow traffic fluctuations and support user's demands. Therefore, CESC resources can be dynamically reallocated to different slices (in principle they belong to different operators in case of multi-tenancy) or even inside a single operator's network.

The specific cases of the "Business Centre Small Cells" and "Hotel Wants Quality cellular Service" leverage on the following specific features of the SESAME system (although these features can be extended to the general Indoor Small Cells use case):

- Multi-tenancy;
- Functions virtualization at the edge;
- Edge caching;
- Edge computing acceleration;
- Dynamic Coordination of micro-server clusters.
- Service Function chaining (SFC).

Figure 12 shows an example of the SESAME system deployment suitable to illustrate the specific case of Business Centre Small Cells. The figure illustrates the interconnections between the different components of the CESCM and the CESCs, in terms of VNF management and orchestration of network and IT resources. The figure also shows that different VNFs can be executed in different micro-servers and chained together *-if required-* to leverage more complex network and service functions.

In addition, ***Figure 12*** shows that the collection of network and IT resources distributed over different CESCs compose a CESC cluster.

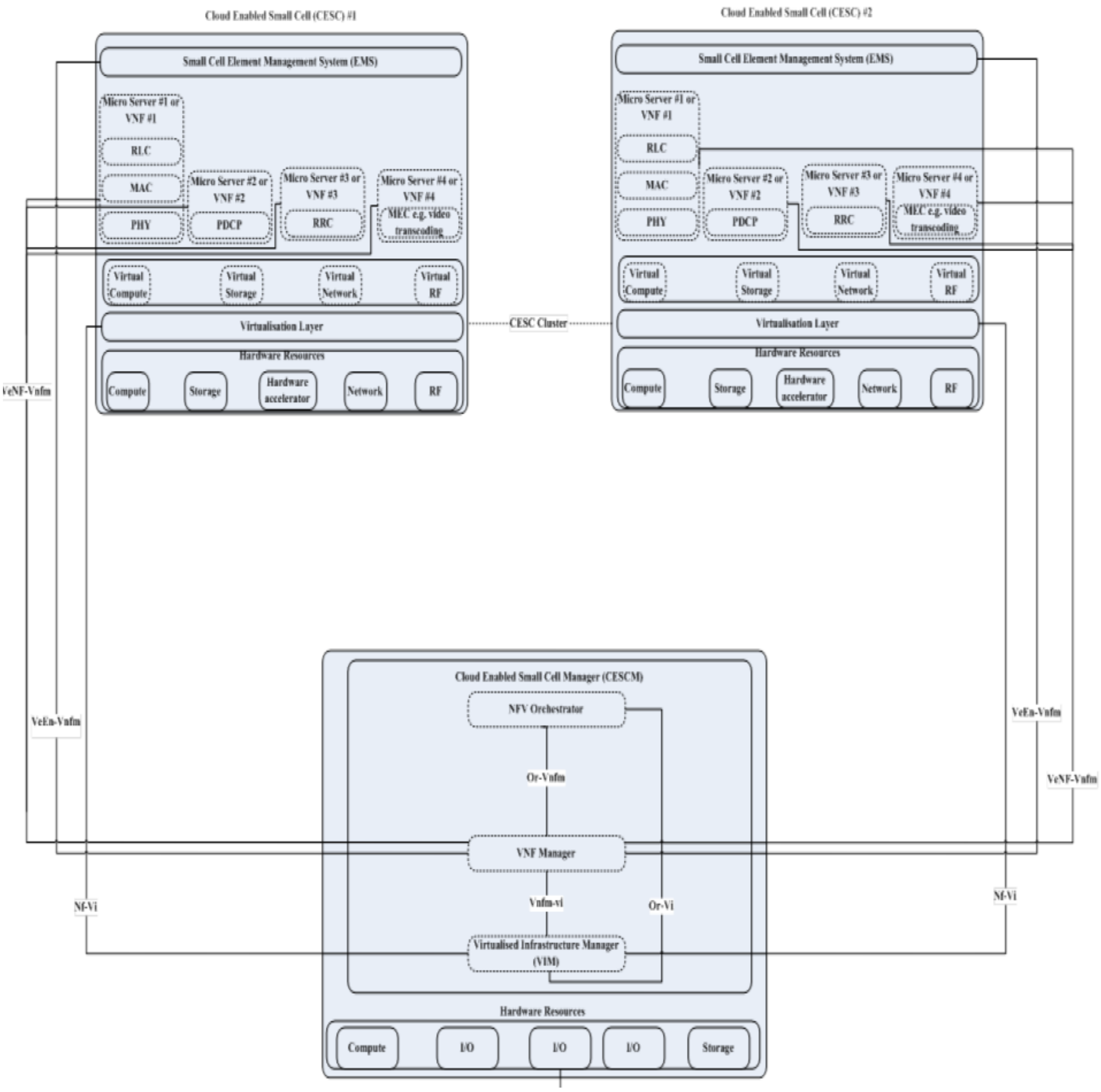

Figure 12: Business Centre Small Cells deployment of the SESAME system

An example of SFC for supporting video conferencing is illustrated in ***Figure 13*** below. After the radio signal is received, it will go through the VNF#1 (PHY, MAC, RLC) and VNF#2 (PDCP) for radio processing.

The processed packets will be further inspected via the VNF#5 (DPI). The traffic that belongs to the video conferencing application will be extracted and directed to the VNF#4 (Video transcoding) for video related processing. The chaining of these VNFs can be taken as a composed functionality package for the video conferencing service provisioning.

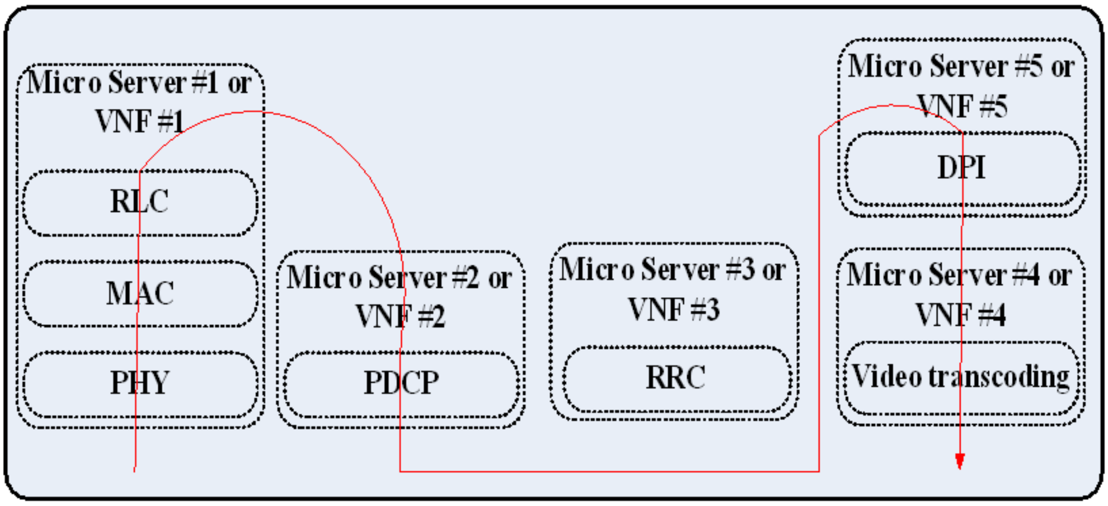

Figure 13: VNF chaining for video conferencing service provisioning

Requirements Extracted from the Use Case

- Multitenancy support: CESCs need to accommodate two or more SCNOs, and specifically slice the KPIs between different tenant operators.
- Virtual network functions for caching, MOCN and "self-x" features run in the micro-servers under the management of the VIM and in conjunction with the VNF Manager.
- The CESCM has to monitor network performance to configure the "self-x" features that enable self-configuration, self-adaptation and self-optimization of the small cells.
- The CESC infrastructure Provider must have the overall view of the CESCs deployed and their KPIs.
- SLAs between SCNO and multiple MOs, VMNOs and VSCNOs.
- Spectrum sharing agreements between SCNOs and spectrum owners, in licensed bands.
- Agreements between the SCNO and the VO.
- Backhaul interface between CESC -or cluster of CESCs- and both virtual/physical core networks.
- Resource management for multiple MOs, VMNOs and VSCNOs.
- The VNF orchestration has to distribute the caches over all the CESCs.
- The VNF orchestration has to avoid overloading the CESCs which have high cell load with too much of the value-added services, so move these services to lightly loaded CESCs.

5.1.3. Use Case 3: Managing inter-tenant smart traffic classification and network optimization and intra-tenant service-aware routing based on QoS differentiation

Overall Description

An SCNO is supporting two distinct VSCNOs within its infrastructure (i.e.: VSCNO1 and VSCNO2).

VSCNO1 and VSCNO2 share the infrastructure of the CESC and serve their respective users (EU1, EU2). The services for the users EU1 and EU2 from VSCNO1 and VSCNO2, *respectively*, are organized in tenant groups depending on the multiple enterprises' needs for service differentiation (like real-time communication, voice, video-conferencing, mail-clients, etc.).

SCNO relies on SDN technology and introduces SDN controller intercepting the communication from the two different VSCNOs in order to manage the network resources (VNFs), by implementing smart traffic routing techniques to optimize network overheads and increase network throughput etc., as defined within the SLA1 (between the CESC provider and the VSCNO1/VSCNO2).

At the same time, the SDN controller executes QoS policies within the tenants of a same VSCNO to achieve *per-service* and *per-usage* assignation of resources in a most optimal way, following SLA2 (between the CESC provider and the EU1/EU2).

Actors Involved

- Small Cell Network Operator: The owner of the infrastructure that VSCNOs use to serve their end-users; it deploys SDN technologies to monitor the flows of the VSCNOs it supports and achieves the SLAs while maximizing the usage of its network resources.
- Virtual Small Cell Network Operator: These are users of the infrastructure owned by the SCNO; they can differentiate the service they provide to their end-users by organizing them in tenant groups and achieving the desired QoS requirements.
- End-Users: They use the networking service offered by the VSCNO and experience a service quality according to their tenant groups.

Deployment topology

The deployment topology of the example of inter-tenant smart traffic classification and network optimization and intra-tenant service-aware routing based on QoS differentiation is presented in ***Figure 14***, below:

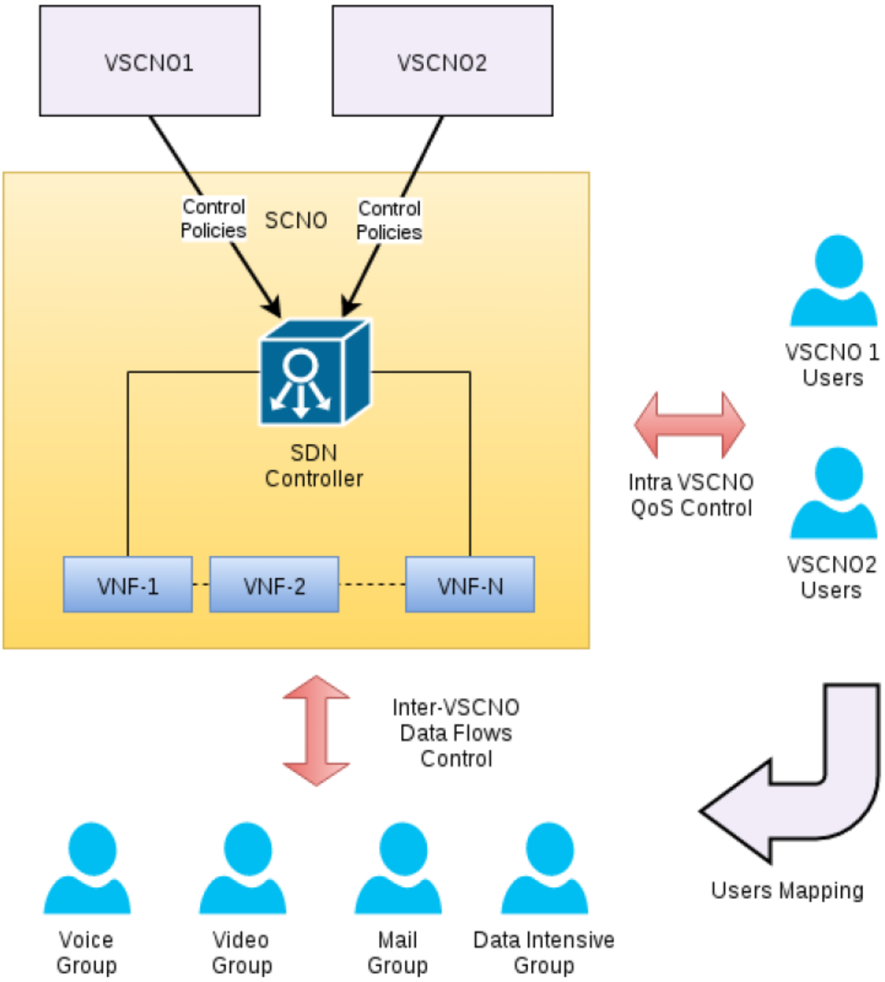

Figure 14: Managing inter-tenant smart traffic classification and network optimization and intra-tenant service-aware routing based on QoS differentiation topology example

Evaluation

A deployment to evaluate the scenario would include a CESC infrastructure with an SDN controller that manages the flows from the users and the VNFs. To demonstrate the inter-operator features, two VSCNOs are required.

A correct evaluation of the use case would demonstrate the following features:

- Users' received QoS complies with the tenant group users are belonging to.
- Resources of the CESC are maximized as the SDN controller determines VNF placement to SVCNOs.
- Overhead in network traffic is reduced by smart traffic policies applied to communications.

Relevance to SESAME

SDN technology in the CESC enables the separation of data and control flows.
SDN components run in the Light DC to optimize traffic flows by allocating resources (VNFs) to different VSCNOs appropriately and by reducing network overhead on the traffic flows.

The SDN controller retrieves inter-VSCNOs information (e.g., SLAs, monitoring parameters) by interacting with the CESCM and applies traffic policies to the different users' tenant groups. Within the same VSCNO, the SDN controller applies QoS policies to users by allocating and configuring VNFs to the operator.

This use case demonstrates *how SDN can leverage the support of different tenants' requirements over the virtualized infrastructure in both inter-tenant and intra-tenant scenario*. It also introduces the role of SDN to establish QoS based traffic differentiation.

This use case is related to S*ESAME Scenario 1* (*multi-tenancy, QoS differentiation*) and *SESAME Scenario 3* (*dynamic management of multi-user multi-operator scenario with different services and QoS setups*).

Requirements extracted from the UC

- The Light DC executes SDN components that are integrated with the VIM.
- The SDN controller accesses SLA information and CESC status from the CESCM.
- The SDN controller controls VNF placement decisions by communicating with the VIM.

5.1.4. Use case4: Service Function Chaining (SFC) in multi-tenant and multi-provider network

Overall Description

A CESC provider is supporting two distinct VSCNO within its infrastructure (VSCNO1 and VSCNO2). VSCNO1 and VSCNO2 "share" the infrastructure of the CESC and serve their respective users (EU1, EU2). Both providers offer applications/services (such as: network-*related* services, enterprise services, real-time communication, voice, video-platform, social networking, web server, multimedia applications, etc.).

In order to "differentiate" these services to each of the users in the EU1 and EU2 group, the mobile operators offer several NFVs (for ex. load-balancer, HTTP proxy, firewall, NAT, DPI, data analytics, transcoding, traffic redirection, bandwidth management, charging, etc.).

The NFVs can be deployed as physical or virtual functions running in the Light DC infrastructure of the CESC provider and they belong to multiple tenant entities. The NFVs will be provided by the CESC provider. The CESC provider offers Service Function Chain for the different NFVs (aka Service Functions (SF)) as value-added service to VSCNO1 and VSCNO2.

Depending on the type of the service, the subscription model (basic/premium users) or the network specific requirements, the mobile providers VSCNO1 and VSCNO2 rely on the SF chains to offer some of the following: Steer part of the traffic to specific applications, optimize service delivery, improve network performance, filter insecure traffic, ensure privacy, inspect headers etc.

An SFC example can be the following: Both VSCNO1 and VSCNO2 implement web traffic classification to their services for users EU1/EU2 to differentiate web from video traffic. A simple chain includes: Load Balancers (LB), which splits HTTP over TCP port 80[20] (or TCP port 443[21] for HTTPS) from the rest of the Internet traffic. For the video traffic, a separate VNF called as "Performance Enhancement Proxies" (PEPs) can be applied, in order to improve QoS that is crucial for video traffic, such as to reduce latency and jitter and to adjust bandwidth. This is performed by caching the web contents and thus this results to the provision of better QoE for the users groups EU1 and EU2.

Other example can be a video content application provided by the mobile operator VSCNO1 that uses VNFs from both itself and the operator VSCNO2 belonging to the different tenant groups on the CESC premises. The premium flows are classified as TCP traffic, and they "pass" through consecutive chain consisting of: a steering proxy that redirects HTTP traffic, a DPI-*based* controller to check for video content and an optimizer to transcode the real-time video to an appropriate format. The non-TCP flows are UDP/RTP voice or video traffic. Basic users may require lower quality video which undergoes NFVs such as: video transcoding or video compression.

Actors Involved

- Small Cell Network Operator: This legal entity is the owner of the infrastructure that VSCNOs use to serve their end-users; it provides Service Function Chaining capabilities.
- Virtual Small Cell Network Operator: These are users of the infrastructure owned by the SCNO; they can control the chaining of VNFs to provide different level of services to their end-users.
- Service Provider for NFVs: This legal entity provides some of the VNFs to the SCNO.
- End Users: They use the networking service offered by the VSCNOs.

Deployment topology

The related topology as for the actual use case is illustrated in ***Figure 15***, as below.

[20] For more details about the TCP port 80, see: https://en.wikipedia.org/wiki/Hypertext_Transfer_Protocol.
[21] For more details about the TCP port 443, see: https://en.wikipedia.org/wiki/QUIC.

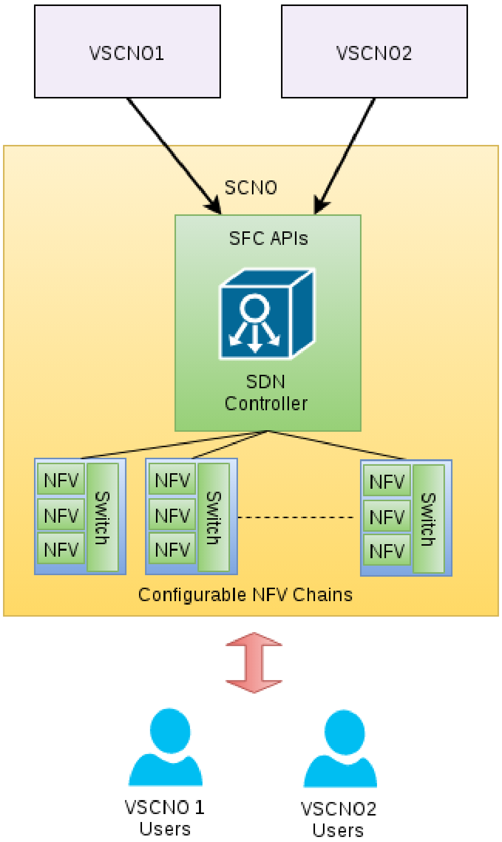

Figure 15: SFC in multi-tenant and multi-provider network topology example

Evaluation

The evaluation requires the availability of a set of VNFs and the ability for the SDN controller, to perform SFC.
An evaluation of the corresponding scenario should demonstrate the following key elements:

- Chained VNFs enable new services adding value to the offering of the infrastructure provider and the VCSNOs.
- Logical isolation of VNF chains per tenant.
- The re-configuration of VNFs into chains enhances the QoE perceived by end-users.

Relevance to SESAME

In the CESC, the flexible management of the virtual and physical resources allows a dynamic placement of VNFs and their configuration and interconnection by means of Service Function Chaining. This use case demonstrates the role of SDN applications and concepts aimed at implementing a chain of NFVs to traffic originating from different services with specific QoS requirements. Example NFVs can be: Deep Packet Inspection (DPI) and data analytics for multimedia content, specific transcoding tasks in the uplink to optimize the use of the core segment and security-related operations - like firewall NFV - for special closed groups.
The management and the implementation logic of such chains (like traffic steering and flows classification) can be performed by the VIM along with the SDN controller. The SDN controller engages to implement support of proper tenant isolation between the NFVs. It also applies the service chain between chosen set of NFVs to adapt the internet-based video content to be delivered to both subscriber types: basic and premium. VIM and the SDN controller are in charge also of the dynamic placement/removal/deployment of new NFVs and rewiring/redesigning/reconfiguring/testing new SFCs and network equipment.

On micro-server level, service chaining and tenant isolation are to be implemented using a software switch. It will interconnect NFV virtual machines trough shared memory between processes in order to accelerate packets processing. Isolation between tenants will be provided by assigning different VLAN to each VSCNO[22].

Requirements extracted from the UC

- The VIM offers interfaces to interconnect VNFs with Service Function Chaining.
- The SDN controller must be able to support the configuration of individual VNFs.
- The SDN controller must support SFC.
- Software switch must run on micro-server.

[22] Reference scenarios: IETF SFC Mobility Use Case (*https://www.ietf.org/id/draft-ietf-sfc-use-case-mobility-04.txt*)

5.1.5. Use case 5: Optimized Radio Network Capacity Planning and Operation mechanisms of the Small Cell Network Operator

Overall Description

This use case intends to highlight the SESAME functionalities so that to achieve:

(i) An advanced planning of the required radio capacity, to be proactively provisioned by CESCs *at any time* and *at any place,* and;

(ii) an optimized operation of the CESCs relying on the use of "*self-x"* functionalities to configure the radio parameters.

Actors Involved

This use case involves the Small Cell Network Operator (SCNO) that owns the CESCs and a number of Virtual Small Cell Network Operators (VSCNO).
The VSCNOs establish a set of SLAs with the SCNO in order to deliver services to their end users through the CESCs.

Then, thanks to the use of the automated radio network capacity planning and operation mechanisms relying on related *"self-x"* functionalities (i.e.: self-planning and self-optimization functions), the SCNO will be able to deploy and operate the CESCs in an efficient way, properly matching the VSCNO needs. This will result in a reduction of OPEX/CAPEX for the SCNO while meeting the VSCNO requirements.

Deployment topology

This use case assumes that the SCNO deploys a number of CESCs in a certain scenario, and it uses these dedicated CESCs to provide service to the VSCNOs, *as it is illustrated in **Figure 16***.
This use case is applicable primarily in *SESAME Scenario 1* (*Enterprise services in multi-tenant large business centres*), although it can also be considered in *Scenario 3* (*Service provisioning in flash events*).

Figure 16 highlights that this use case relies on the application of Artificial Intelligence- (AI) *based* tools for analyzing the environment to extract the relevant knowledge that will drive subsequent decisions made by self-planning, self-healing and self-optimization functions that will decide *how the CESCs will be deployed and configured*.

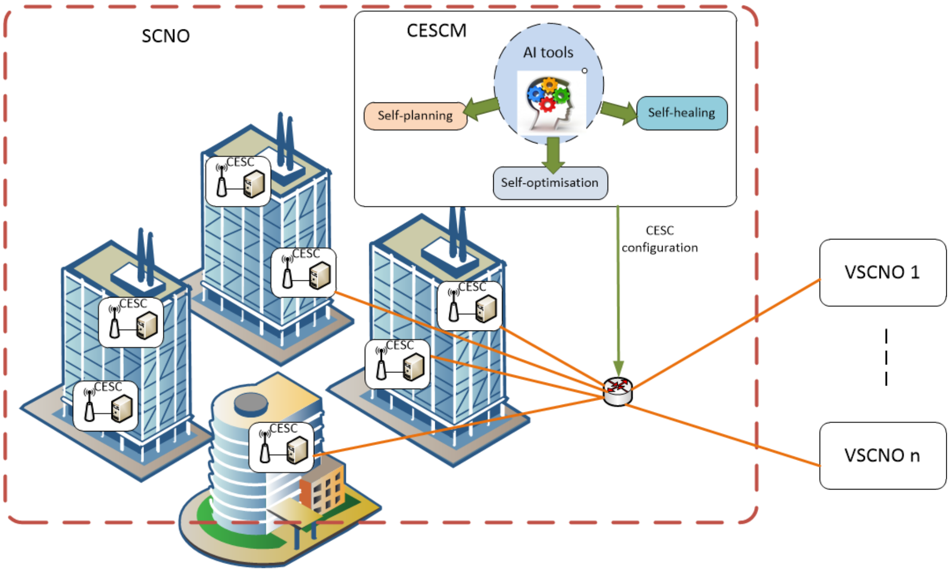

Figure 16: Illustration of the use case Optimized Radio Network Capacity Planning and Operation mechanisms of the Small Cell Network Operator

Evaluation

The evaluation of this use case will focus on assessing the performance obtained by the developed *"self-x"* techniques in front of different performance indicators, such as:

- QoS metrics of the services as perceived by the users of the VSCNOs (i.e.: experienced data rates, delays, etc.)
- Efficiency metrics (e.g., Capacity per area unit (b/s/km^2), Power per area unit (W/km^2), etc.)

Given that the evaluation of this use case will normally involve a high number of CESCs and users of the VSCNOs, it is envisaged that evaluation will be mainly based on simulations. This evaluation could be complemented by means of demonstrations in some selected situations with a reduced number of CESCs and users.

Relevance to SESAME

This use case will be used to illustrate the SESAME principles P1: Multitenancy; P5: *"self-x"* different types of input data (e.g. network data, user data, external data, etc.) in order to come up with exploitable knowledge that will be used to "drive" the decisions of the *"self-x"* functionalities.
Then, self-planning functionalities will make use of the extracted knowledge to automate the decision on *when and where the SCNO needs to provision new CESCs in the scenario*, as well as the amount and type (i.e., licensed, unlicensed, light-licensed) of spectrum required. This will be dependent on the specific needs of the different tenants.
In turn, self-optimization functionalities will make use of the extracted knowledge to autonomously configure the CESCs with the objective of ensuring the desired coverage, capacity and QoS to the different users in an optimum way, depending on the requirements of each tenant.
Finally, self-healing functions will be in charge of detecting, diagnosing and correcting faults in the CESCs.

The functionalities developed to solve this use case are initially associated to the Radio Access Manager (RAM) at the CESCM, although the split with the Element Management System (EMS) needs to be investigated. These functionalities will also rely on the monitoring capabilities of the CESCM that will provide the input data.

Requirements extracted from the UC

- The CESCM shall be aware of the radio parameters of the CESCs that can be dynamically reconfigurable through self-optimization functionalities.
- The CESCM shall collect operative and performance measurements from the CESCs and the User Equipments, on a *per VSCNO* basis.
- CESCs shall have the capability of reconfiguring radio parameters, within specific time constraints, as a result of the decisions made by the *"self-x"* functionalities.

5.1.6. Use case 6: Blind Spot

Overall Description

This use case motivates the adoption of the SESAME architecture at all locations where nowadays coverage of the mobile network is either insufficient or even not existing.
Locations which lack network coverage could be typical rural or mountain areas, as well as some specific urban environments. In the first case, operators typically do not have incentives to invest because of the low population density, whereas in the second case, buildings and the city layout in general might prevent from the reception of a good -or adequate- radio signal quality. Although it could be difficult to lay down a detailed coverage map for all blind spot locations, existing data from operators could be re-used to understand *where the deployment of the CESC infrastructure might be more convenient*.

Furthermore, in this use case, the SESAME system would clearly benefit from its wireless backhaul capacities, which makes the costly and time consuming installation of a dedicated infrastructure as "unnecessary". One advantage of blind spots -with respect to other use cases relevant to SESAME- is certainly to exhibit reduced -or even absent- interference from the macro-cell tier.
Mobile operators (MOs) or Small Cell Network Operators (SCNOs) which are willing to expand their business in geographical areas where investments are typically discouraged could take advantage of the modularity of the SESAME system. As a result, different situations can be envisaged in which either MOs or the SCNOs can bring SESAME components in those areas, sharing the infrastructure and amortizing costs at the same time.
Municipalities could also buy and deploy the SESAME infrastructure thus becoming Venue Owners (VOs). They could in this way open the infrastructure to Virtual Small cell Network Operators (VSCNOs).

Actors Involved

Actors involved in the present use case are the following ones: Venue Owner, Mobile Operators, IT Equipment Vendors, Function Providers, Small Cell Network Operators, Virtual Small Cell Network Operators.

Deployment topology

The deployment topology of the *Blind Spots use case* is illustrated in ***Figure 17***, as follows.

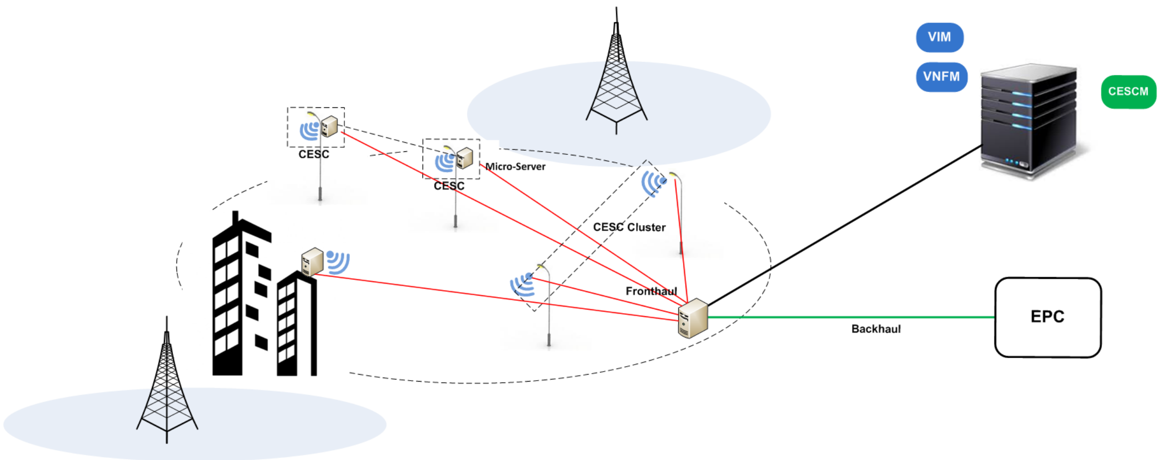

Figure 17: Blind Spots Use Case

Evaluation of the use case

As of the corresponding evaluation, we identify the following issues:

- Achievable capacity and latency.
- Achievable coverage area and spectral efficiency.
- Capability to support multi-tenancy: number of tenants.

Relevance to SESAME

The full SESAME system is envisaged to be deployed in this characteristic use case. In specific, this use case can leverage on the full potentials of multi-tenancy, taking great advantage of the Light DC computing facility at the edge. Resources of CESCs and clusters of CESCs are virtualized and assigned to different SCNOs/VSCNOs in the multi-tenant network environment.

Orchestration of the SESAME infrastructure is done by the CESCM for CESCs and cluster of CESCs over a time scale longer than radio resource scheduling, which occurs every one millisecond. Decisions taken by the CESCM are enforced whereby the EMS in both virtualized and physical small cells.

The Virtual Infrastructure Manager (VIM) is responsible for allocating resources for the virtual infrastructure, whilst the Virtual Network Function Manager (VNFM) is responsible for creating, executing and terminating virtual functions. It can be expected that in case of remote and less populated areas, CESCs require less frequent (re-)configuration and hence functions of the CESCM and VIM that pertains to reconfiguring resources within the cluster of CESCs being executed less frequently than in other use cases.

Anyway, it remains crucial to enable monitoring functions of the virtual and physical networks to raise awareness of the traffic created by the users, as well as to monitor and react to any failure that might occur in the network.

“Self-x” features such as self-configuring, self-healing, self-optimizing and self-coordinating functions are essential to enable automated operations inside individual CESCs and CESC clusters, thus requiring minimal human intervention. Such *“self-x”* features are also applied to the wireless backhaul to provide a stable communication between the CESCs and the core network.
It has to be noticed that, in this use case, the interference environment is more “relaxed” since small cells do not have to deal also with interference received from/created to the macro-cell. Furthermore, CESCs require adequate fronthaul/backhaul connectivity but it is expensive to bring anywhere high capacity low latency backhaul. For this reason, computing and storing capability of the Light DC can be conveniently exploited to cache content in a smart manner.

Requirements extracted from the UC

- Multi-tenancy support: CESCs need to accommodate several SCNOs, as well as RAN sharing to support multi-tenancy in the wireless backhaul.
- Virtual network functions for caching, MOCN and *“self-x”* features to run in the micro-servers under the VNFM.
- Self-configuration, self-adaptation and self-optimization of the small cells.

5.1.7. Use case 7: Communications in High Density Areas

Overall Description

This use case will examine the provision of services in areas that are characterized as “highly dense”. These are usually relative small outdoor areas, with different sizes, that a high number of people can be concentrated.

Some indicative examples are:

- People attending an event at a football stadium where 40,000 people are concentrated in an area of around 40,000m2; in this case several small cells are needed in order to support the high demand need.
- People around a square; in this case, people are passing through the square, meet people or sit in nearby cafes, restaurants etc. There is traffic at all times with some peak hours (morning going to work, during lunch time, special events, etc.).

Regarding the same use case there is also the possibility of an MVNO requiring capacity in order to offer targeted services. For example, the football team wants to offer specialized services to the fans, some promos, advertising, etc.

Actors Involved

Actors involved in the present use case are the following ones: SCNOs who are the owners of the infrastructure that will be used by VSCNOs through specific SLAs; on the other side, VSCNOs will provide services to end users also described in SLAs; Function providers.

Deployment topology

The corresponding deployment topology for the actual use case is shown in ***Figure 18***.

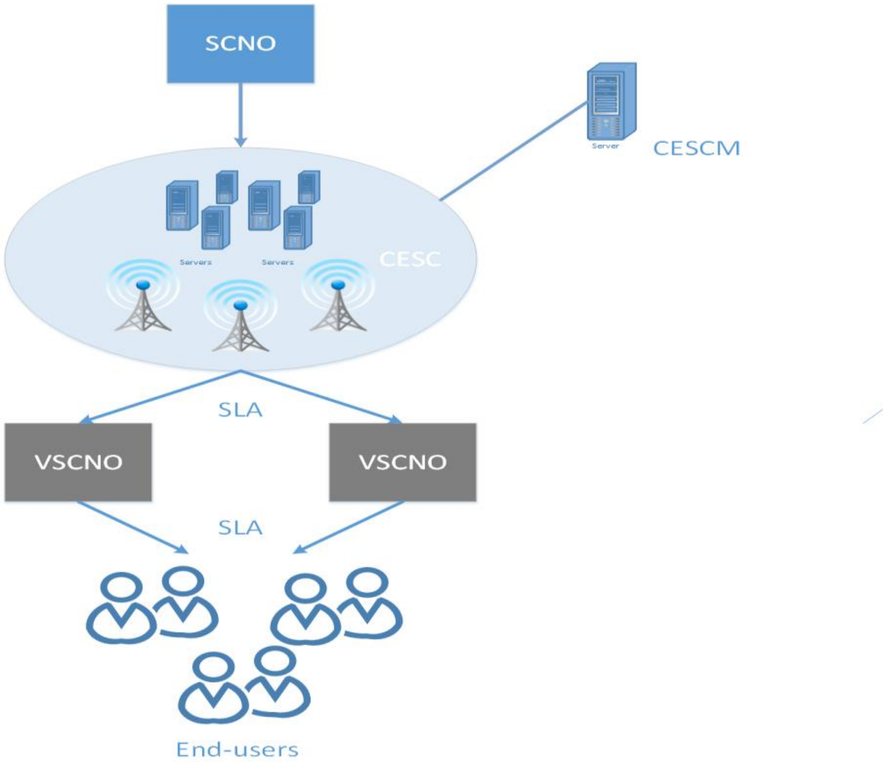

Figure 18: Communications in high density areas topology example

Evaluation

In order to evaluate this scenario, a CESC should be deployed, supporting at least two VSCNOs. Monitoring and re-allocation of resources can be implemented as a function at the edge. Data analytics used to isolate target groups for specialized services provision should also developed as functions.

The following KPIs should be investigated and met:

- QoS (data rate, low latency).
- Resource sharing and re-allocation efficiency.
- Level of target groups isolation.

Relevance to SESAME

This scenario is highly relevant to SESAME and its architecture. Two or more VSCNOs will be connected to SCNO forming a CESC (or a CESCs cluster). End-users will be served by one of the VSCNOs. By sharing the infrastructure of the SCNO, resources along with VNFs can be monitored and allocated accordingly to VSCNOs in order to meet the SLAs between SCNO and VSCNOs (multiple tenants) as well as between VSCNOs and end users.
At the edge, several functionalities should be developed such as monitoring of network status, re-allocation of resources (by CESCM) and decision making. Note that these functions should be dynamic since they must be adapted to network needs.

Content caching in the micro-servers should be developed, especially for the stadium case in which many people would like to replay the most significant actions. Furthermore, in case of service provisioning to

focused target groups VNF execution at the edge is required to analyze users' data and proceed to their isolation.

"Self-x" functionalities provided by SESAME will also be exploited in such environment. These are crucial in order to deal with interference and congestion of resources when not only people but all the CESCs are massively deployed.

Requirements extracted from the UC

- P1 Multitenancy.
- P2 Virtualization at the edge (Infrastructure / Small Cells).
- P3 VNF execution at the edge.

5.1.8. Use case 8: SESAME Platform Deployed for a moving hotspot

Overall Description

A Small Cell Network Operator (SCNO) is supporting multiple mobile network operators (MNOs) or multiple virtual small cell network operators (VSCNOs) to provide coverage for "mass events" such as walking demonstrations and cycling events. Different stages of the event could be covered by the one or more VSCNOs/SCNOs.

In addition to the provision of radio coverage in moving hotspot events and orchestration of multi-tenancy, the small cell network operator provides a platform for mobile edge computing (MEC) for low latency and compute intensive applications and services.

Services such as remote processing and remote data storage are becoming increasingly popular. When a terminal can "shift" certain high-demand tasks to a remote server, it can then reduce its workload to a minimum saving resources and energy (i.e., battery). At the same time, the end-user is relieved from the burden of maintaining and updating the application.

Currently, fast-moving users receive low Quality of Experience when using remote real-time low-latency services. This is due to inefficient mobility management of Service Providers and due to limitations of current cellular architectures. Potential users of such services can be humans or autonomous devices such as vehicles or low-capability Internet-of-Things (IoT) devices.
To address these challenges, Service Providers should bring the intelligence to the network edge and allow the remote application to be (fully or partially) executed in a cloud-enabled small cell (CESC). Furthermore, as the terminal moves between cells the QoE must not be degraded, this implicates that there is a need for transparent handovers among different small cells.

Actors Involved

Actors involved in the present use case are the following ones: Small Cell Network Operator (SCNO), mobile operators (MOs), Virtual Small Cell Network Operators (VSCNOs), Spectrum Owner (SO), Service Provider (SP), and end-users (EUs).

Deployment topology

The deployment topology corresponding to the actual use case is related to *SESAME scenario 3* (*Service provisioning in flash events*) and is depicted as in ***Figure 19.***

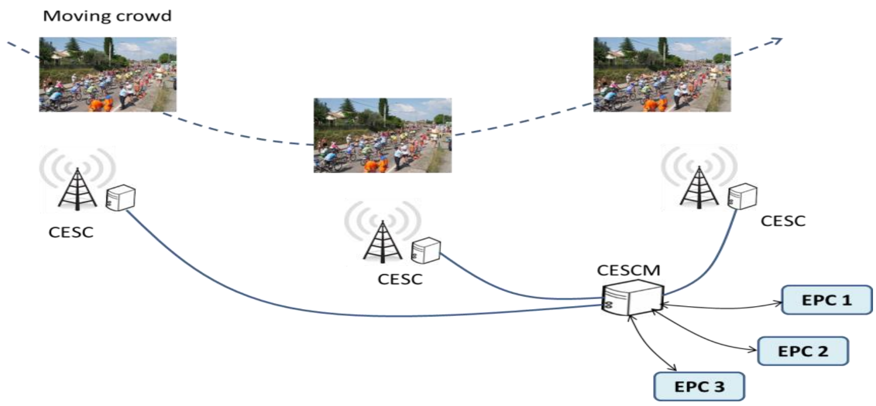

Figure 19: Moving hotspot topology example

Evaluation

The evaluation of this use case will be focused in the following fields:

- Quality of Service (QoS) and Quality of Experience (QoE) parameters of moving end users (EUs), such as, delay, latency, and data rate.
- End user (EU) terminal resource consumption (processing, storage, energy).
- Network capacity optimization, improvement of coverage area and spectral efficiency.
- CESC infrastructure and the CESC management with support for multiple mobile operators (MOs) and virtual small cell network operators (VSCNOs).
- Efficient management of network traffic. Monitoring can be implemented at the network edge.
- Dynamic co-ordination of small–cells clusters and deployment of services on the network edge, coming from the network intelligence

Relevance to SESAME

This use case demonstrates the ability of the CESC framework to provide coverage for spontaneous flash mass events and coordinate the service delivery to multiple mobile network operators and their respective user bases. Furthermore, the QoE is greatly enhanced by fully or partially executing remote applications within the CESC.

- Multi-tenancy: Shared infrastructure through Multi-Operator Core Network (MOCN) benefits mobile operators (MOs) and virtual small cell network operators (VSCNOs).
- Virtualization at the edge (Infrastructure / Small Cells): The small cell network operator (SCNO) provides a platform for mobile edge computing (MEC) for low latency and compute intensive applications and services, e.g. video transcoding.
- Exploitation of edge computing acceleration by Service Provider (SP) applications.
- VNF execution at the edge. The remote application can be executed at the CESC and managed by CESCM.
- Dynamic coordination of Light DC clusters.
- Service Function Chaining (SFC).

Requirements extracted from the UC

- SLAs between the small cell network operator (SCNO) and multiple mobile operators (MOs) and virtual small cell network operators (VSCNOs).
- Spectrum sharing agreements between the small cell network operator (SCNO) and the spectrum owners for licensed spectrum transmissions.
- Support for wired and wireless back haul.
- Resource management for multiple mobile operators (MOs), Service Providers (SPs), virtual mobile network operators (VMNOs) and virtual small cell network operators (VSCNOs).

5.1.9. Use case 9: Wireless Critical lifeline communication

Overall Description

In this use case, SESAME approach should be able to provide reliable communications that are needed after a natural disaster had occurred. There will be a need for a fast deployment while the terminals must have as low power consumption as possible, in order to operate the longest possible time interval. Another aspect is that possible survivors and injured people should be able to announce their location with high accuracy.

Actors Involved

Actors involved in the present use case are the following ones: IT equipment Vendors, SCNO, VSCNO, MNO and end-users.

Deployment topology

The proposed deployment topology is as shown in ***Figure 20***.

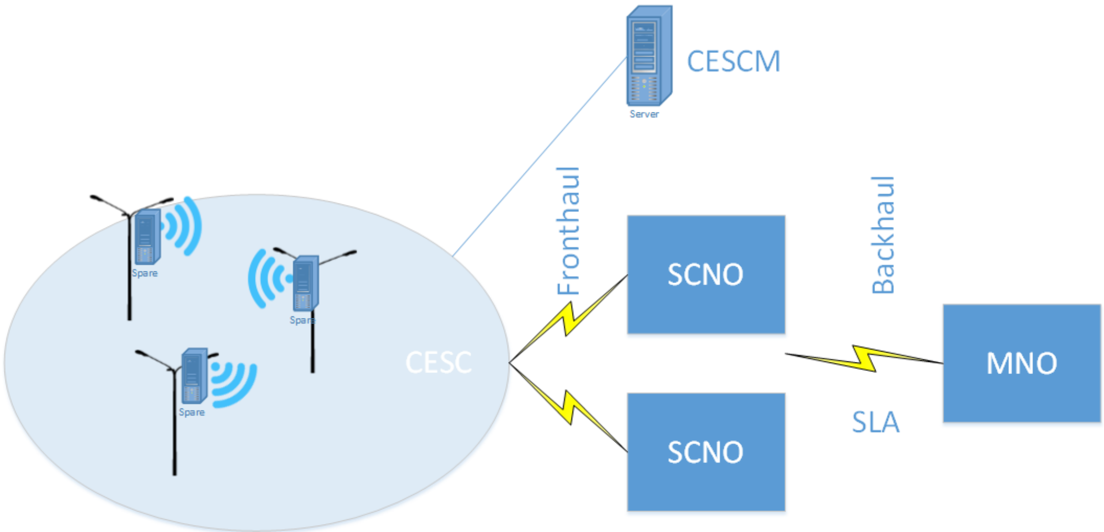

Figure 20: Wireless Critical lifeline communication topology example

Evaluation

Since the scenario describes emergency cases, its evaluation can be performed by analyzing the following metrics: Network robustness, resiliency and efficiency, handset energy consumption and speed of deployment.

Relevance to SESAME

Assuming that fixed telecom infrastructure is destroyed during the disaster, a number of CESCs should be deployed in an ad-hoc manner by SCNO. In this way, services can be provided to end-users through VSCNO.

Although this is based on SESAME architecture, it includes two critical points: (i) Power, *and*; (ii) backhauling. In case that the power grid is not affected by the disaster, CESCs can be deployed on lamp posts exploiting power connectivity at the same time. Otherwise, a deployment using solar panels should be investigated. Regarding the backhauling, this should be considered as an “extra module” in SESAME architecture using appropriate wireless interfaces. Through specific SLAs, multiple tenants can satisfy their requirements on both the front- and the backhaul.

"Self-x" within the CESC cluster (e.g., some CESCs are not damaged and others are) and multi-tenant wireless backhauling are "key issues" to address the impact of disasters on both CESCs and backhauling.

Requirements extracted from the UC

- P1: Multi-tenancy.
- P5: *"Self-x"* features.
- In addition, multiple MOs should be supported by small cells for reliability and resiliency purposes.
- Power supply needs in case that the power grid is destroyed.

5.1.10. Use case 10: Sporadic Crowd Event

Overall Description

This use case refers to a venue that at some time experiences high density of visitors due to an "event" (e.g., a festival, meeting, outdoors concert, etc.). At this case, extra network capacity is required because the high density of EUs cannot be served adequately by the existing macro-base stations. At the same time, EUs require increased network performance and reliable services.

The VO purchases CESCs from the ITEV and installs them to the venue. Alternatively, an SCNO asks the VO to lease space and install the CESCs. The VO -or the SCNO- installs backhaul connection through an ISP and the equipment with the CESCM and VIM. He then also purchases (from a FP) the Caching, DPI and Transcoding VNFs, so that each MO can deploy them to their own network slice at will.

There are two MOs that want to provide network coverage in that area (i.e.: MO1, MO2). Although each one among them has his own spectrum license, the VO selects one MO (MO-1) to be the ''primary" one and makes an agreement with him to utilize MO-1 spectrum at the access network. The MO-2 then makes an agreement with MO-1 to use radio access resources. Each MO provides his own EPC, and allows his users to associate with the access network of the primary operator.
VNFs can be deployed on a *per-operator* basis. The MO-1 provides enhanced services through caching deployment, while the MO-2 reduces the data traffic in the access network through a VNF for video Transcoding. This use case is related to *SESAME Scenario 3.*

Actors Involved

The VO wants to provide full network coverage to the high number of visitors (EUs). The VO capitalizes on his unique advantages, i.e., he is the owner of the premises and he has the monopoly on leasing spaces that can host HW equipment. The big number of visitors makes economically viable commercial exploitation of the related premises.

The MOs wish to be able to provide satisfactory communication services and network performance to the EUs. Taking also into account the aspect of economic viability, the CESC's ability for hosting multiple operators (i.e.: multitenancy) will be exploited. Each MO can benefit from a variety of tools in the form of virtual network functions.

In this case, the ITEV could be, for example, the company/legal entity that manufactures CESCs (i.e., Small Cells, micro-servers, hardware accelerators, EMS that are used in SESAME platform). That legal entity wants to maximize profits from selling devices/software.

Deployment topology

In this use case of *Sporadic Crowd Event*, the CESCs are deployed at an outdoor -or even indoor- venue that commonly becomes crowded for some time. Although it matches well the initial description of *Scenario 3* described in the DoW, some of its aspects are also relevant to *Scenario 1*.
A potential deployment of this use case is presented in ***Figure 21***.

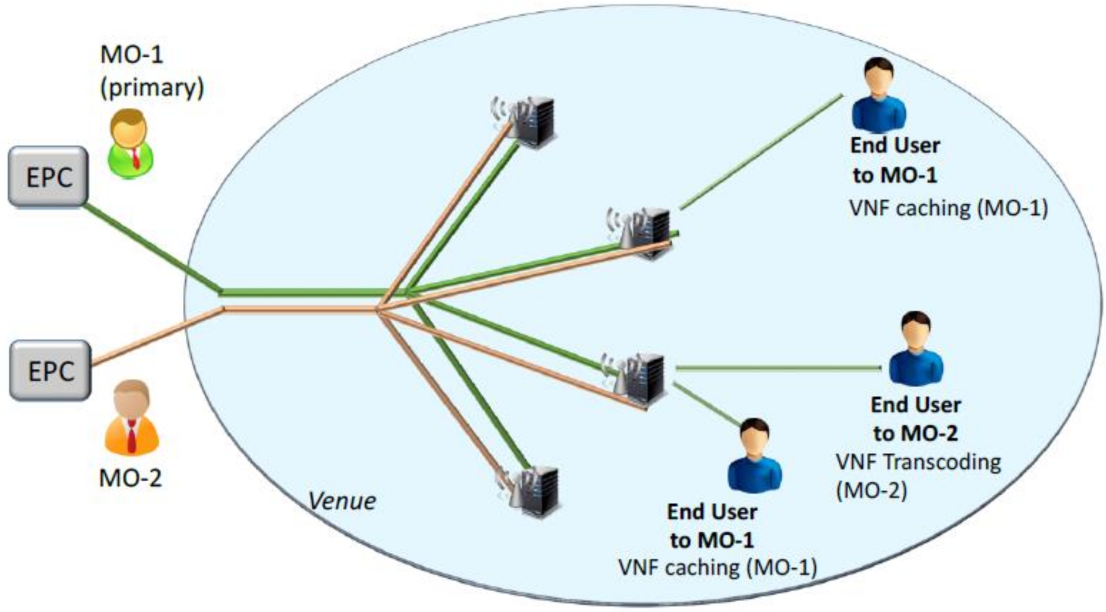

Figure 21: Sporadic Crowd Use Case Deployment - Example

Evaluation

This use case highlights the added value of hosting together MOs to a Small Cell and additionally to provide them the ability to run VNFs in the Light DC. Under this point of view, it may be well evaluated by being able to demonstrate at least two different MOs hosted in the same Small Cell.
Also the demonstration of VNFs on the 'network slice' of each MO is in scope.

Relevance to SESAME

Multitenancy addressed here is highly beneficial, because adopting the SESAME solution is one of the core project's KPIs. Furthermore, the Light DC is utilized so as to offer a platform for running VNFs, *per tenant.*

Requirements extracted from the UC

- The multitenant small cells must support at least two mobile operators.
- Each operator must be able to deploy VNFs separately.

5.1.11. Use case 11: Multimedia services at the mobile edge and inter-operator edge caching

Overall description

An SCNO is supporting two distinct VSCNOs within its infrastructure (i.e.: VSCNO1 and VSCNO2).
In case of flash events, utilization of resources needs to be maximized in order to offer the best possible service to an elevated number of users.

The CESC is decentralized and offers edge-services with low latency for end-users. Users of both VSCNO1 and VSCNO2 access the same content (e.g., video stream) repeatedly (e.g., at a sport event, recordings of previous records of an athlete). A distributed storage cache is implemented at the level of the CESC (cluster) and can be accessed by both VSCNOs to look for content (so the storage cache is inter-operator).

After user U1 of VSCNO1 has accessed content C1, user U2 of VSCNO2 tries to retrieve the same resource.
VSCNO2 looks-up the shared distributed cache and finds a valid reference to C1.
VSCNO2 offers C1 to U2 with high bandwidth and low latency over a local link (U2 request is terminated at the CESC).

U1 does not need to cache C1 locally for future accesses, as the content is available at the CESC (edge network) with a similar QoS than local cache.
The EUs can benefit of the edge computing architecture to offload resource-intense tasks, reducing mobile terminal power consumption (increase of battery lifetime) and increasing QoE also in case of high demanding compute applications.

Actors involved

- Small Cell Network Operator: The owner of the infrastructure that the VSCNOs use to serve their end-users; this legal entity has available a storage system with a distributed caching functionality that can be accessed by multiple tenants while preserving privacy requirements.
- Virtual Small Cell Network Operator: The users of the infrastructure owned by the SCNO; they benefit from the storage system that the SCNO has installed in his infrastructure and that enables distributed caching functionality.
- End Users: The use the networking service offered by the VSCNO and experience low latency when accessing content that had been cached.

Deployment topology

A proposed topology for the respective use case is illustrated in ***Figure 22.***

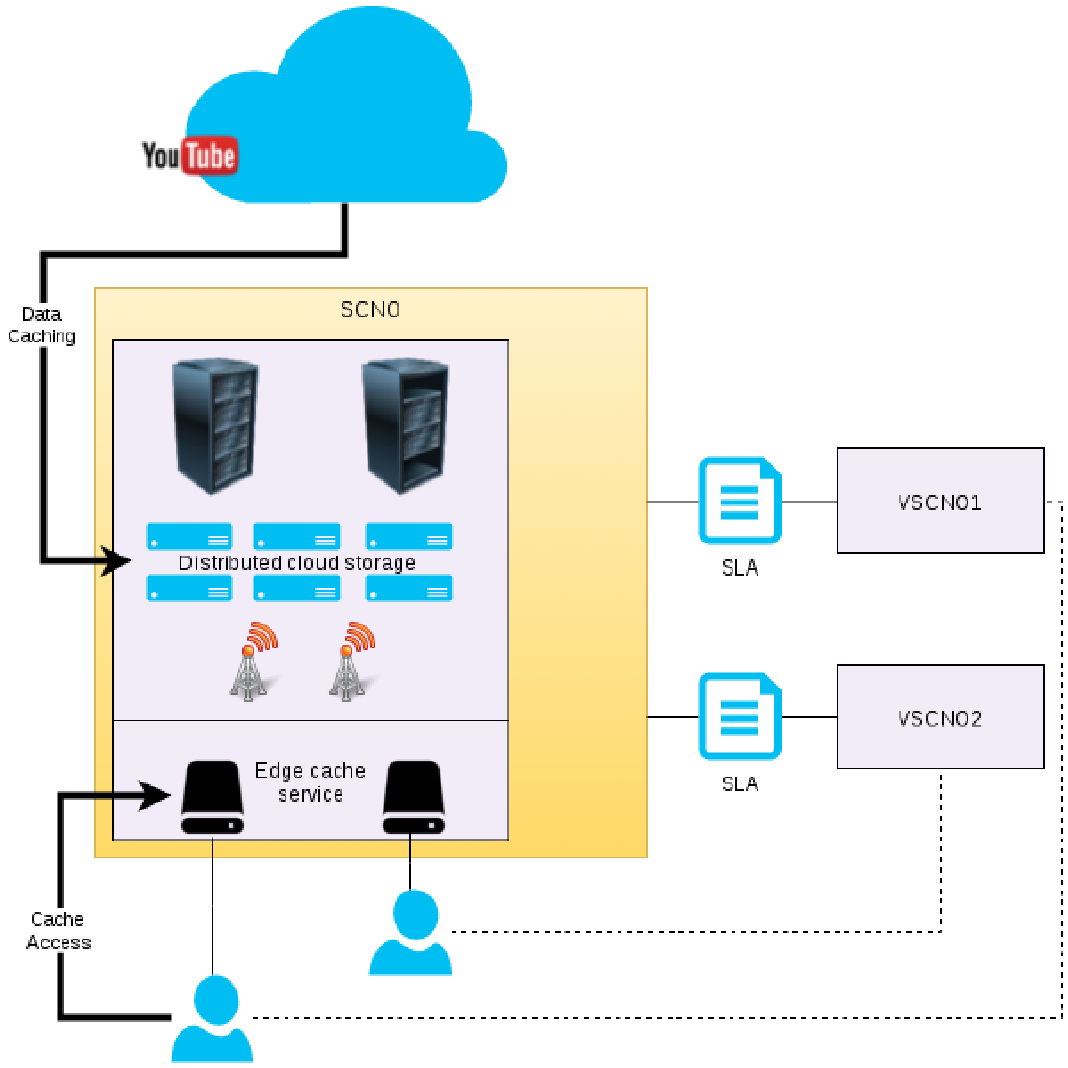

Figure 22: Multimedia services at the mobile edge and inter-operator edge caching - Example

Evaluation

The evaluation of the scenario requires the deployment of a CESC infrastructure with a distributed storage system that can easily enable the implementation of the cache functionality. Caching can be deployed as a VNF supported by the APIs of the storage infrastructure. The caching functionality can be served with a high degree of automation by analyzing the network flows and determining the presence of the requested content in the cache. At least two VSCNOs should use the CESC (or CESC cluster).

This use case can be evaluated if the following key elements are demonstrated:

- Low-latency content provisioning from the cache with edge-services.
- Improved QoS for EUs accessing content that was recently accessed by other EUs, possibly of other VSCNOs.
- Improved bandwidth allocation to guarantee low latency.
- Improved battery lifetime on mobile devices due to less power consumed (watt per transcoding channel).

For the business validation of the use case, it must be considered that, for privacy reasons and user agreements, individual VSCNOs may prefer their caches to be isolated from those of other VSCNOs. This scenario, however, does not affect the general validity of the use case and just imply a statistical

reduction in the cache hits rate. The benefit of edge caching would still be observable for the QoS perceived by the end-users.

Relevance to SESAME

Multiple VSCNOs can take advantage of a common shared infrastructure that is available in SESAME. In conjunction with edge services, this model allows VSCNOs to save resources and provide their users an elevated QoS. The control over the physical and virtual infrastructure enables SESAME components to perform DPI operations on the incoming traffic and identify content that can be served by VNFs running at the edge of the network. This use case demonstrates *how sharing a single infrastructure (CESC) to multiple network operators can bring advantages to both the operators and their users* thanks to the application of edge computing features.

In SESAME, CESCs are deployed at the edge of the network to take advantage of edge-computing mechanisms. A distributed (in case of CESC clusters) edge cache can be implemented as a VNF and managed by the CESCM (placement, access control, …). The use case combines advantages coming both from the physical architecture of SESAME (distributed, edge components) and its cloud operations (monitoring, components placement, SDN).

Moving computation and data at the edge will also bring energy savings both for the user equipments and the network components, additionally, terminating users' requests at the network edge will also increase mobile data volume per geographical area (at the operational level) as network communications will be confined between the user and the CESC. An efficient workload mapping with smart VNFs allocation through VIM will reduce latency and improve the overall QoE for EUs.

SESAME includes hardware-accelerated features at the micro-servers, which will be leveraged by the edge-computing requirement of this use case, through the virtualization API that will allow access to the specialized hardware from the VIM.

Related to *SESAME Scenario 1*, *SESAME Scenario 3* (*multi-tenancy, edge caching, DPI to serve cached content*), ETSI NFV Use Case #1 NFV Infrastructure as a Service (NFVIaaS).

Requirements extracted from the use case

- The CESC must provide a cloud-*based* storage system acting as cache and deployable as an NFV within the domain of VSCNOs
- The distributed cache must be available at the edge of the network.
- The distributed cache must be accessible by different VSCNOs with proper security/privacy requirements.
- EUs packets must undergo a process of DPI to determine matches in cached content.
- The CESCM must provide APIs to support inter-VSCNOs lookup requests into the distributed cache.
- The LightDC must support virtualized HW accelerators in order to guarantee the required computing performance to VNFs offloading the terminals' CPU.
- The transcoding VNF executed on the CESC must run on the micro-server including the specific accelerator (VIM will manage the right allocation of VNFs inside the CESC cluster – workload mapping).

5.2. SESAME KPIs

The use of key performance indicators (KPI) has become a recognized practice in measuring performance. In this section, an effort has been made to identify KPIs coming from SESAME use cases.

5.2.1. Multitenancy

Description

Multitenancy is a key requirement for SESAME. The whole architecture has to support the operation of different tenants (e.g. VSCNO) sharing the same infrastructure.

KPI

Number of supported tenants in both CESCs and CESCM.

Relevant use cases

- Elastic operator SLAs enforcement in multi-operator CESC with edge monitoring and control.
- Indoor Small Cells.
- Managing inter-tenant smart traffic classification and network optimization and intra-tenant service-aware routing based on QoS differentiation.
- Service Function Chaining (SFC) in multitenant and multi-provider network.
- Blind Spots.
- Sporadic Crowd Event.
- Multimedia services at the mobile edge and inter-operator edge caching.
- Optimized radio network capacity planning and operation mechanisms of the Small Cell Network Operator.

5.2.2. Component interoperability

Description

Elements in the SESAME architecture have to expose appropriate interfaces to allow component interoperability.
Components that are affected by this requirement are the CESCM, which has to provide an external API for tenants to access the offered functionality; the CESCs, to allow the management of the micro-server (e.g. VNF management) and the radio parameters (e.g. radio slicing); and the VIM, as the intermediary element between the CESCM and the CESCs in charge of managing the VNFI e.g. VNF interconnection).

KPI

Accessible information and functionality of SESAME components (i.e.: CESCM, VIM, CESC).

Relevant use cases

- All use cases previously identified.

5.2.3. Resource monitoring

Description

Monitoring information of both physical (e.g. CESC, network links) and virtual (e.g. VNFs) resources is required. By gathering operative and performance measurements of the architecture components, resource optimization algorithms can be applied to achieve a better overall performance. Monitoring metrics for each tenant are also needed to determine the compliance of agreed SLAs.

KPI

Amount of different retrievable information from CESCs and networks, on *a per VSCNO* basis.

Relevant use cases

- All use cases previously identified.

5.2.4. “Self-x” radio configuration

Description

“Self-x” configuration mechanisms developed within SESAME have to allow the dynamic reconfiguration of radio parameters of the CESC to achieve an optimized distribution of radio resources among tenants.

KPI

Time to reach an optimized CESC configuration.

Relevant use cases

- Elastic operator SLAs enforcement in multi-operator CESC with edge monitoring and control.
- Optimized radio network capacity planning and operation mechanisms of the Small Cell Network Operator.
- Blind spots.
- Wireless critical lifeline communication.

5.2.5. Dynamic configuration of virtual resources

Description

SESAME virtualization management components have to support the dynamic configuration and scaling of virtual resources. Elements such as the NFVO, the VNFM, the VIM and the SDN controller, need to have the capacity of modifying the amount of VNFs, adjust their configuration parameters and update virtual links stablished between them in a non-static manner.

KPI

Time to reconfigure the deployment of VNFs.

Relevant use cases

- Elastic operator SLAs enforcement in multi-operator CESC with edge monitoring and control.
- Managing inter-tenant smart traffic classification and network optimization and intra-tenant service-aware routing based on QoS differentiation.
- Sporadic Crowd Event.
- SESAME platform deployed for a moving hotspot.
- Service Function Chaining (SFC) in multitenant and multi-provider network.

5.2.6. Hardware and network acceleration

Description

State-of-the-art mechanisms to improve the VNF performance by means of both hardware and network accelerators are required. These include the use of a heterogeneous hardware architecture based on ARMv8 64-bit processors[23], GPUs, DSPs and FPGAs.

KPI

VNF performance in terms of processing speed and resource consumption.

Relevant use cases

- Elastic operator SLAs enforcement in multi-operator CESC with edge monitoring and control.
- Indoor Small Cells.
- Managing inter-tenant smart traffic classification and network optimization and intra-tenant service--aware routing based on QoS differentiation.
- Service Function Chaining (SFC) in multitenant and multi-provider network.
- Multimedia services at the mobile edge and inter-operator edge caching.

5.2.7. Service function chaining

Description

The CESCM and element has to allow Service Function Chaining between VNFs through the use of virtual links via SDN controller. Those VNFs can be placed inside a single CESC or spread among CESCs of the same cluster. This requirement also includes the capabilities to orchestrate the different services that can be offered, composed by either one or several VNFs.

KPI

Number of VNFs within a chain that can be supported without impacting negatively on the performance (e.g. network delay).
Number of available services.

Relevant use cases

- Indoor Small Cells.
- Managing inter-tenant smart traffic classification and network optimization and intra-tenant service-*aware* routing based on QoS differentiation.
- Service Function Chaining (SFC) in multitenant and multi-provider network.
- Multimedia services at the mobile edge and inter-operator edge caching.

5.2.8. VNFs at the networks edge

[23] The ARMv8 architecture introduces 64-bit support to the ARM architecture with a focus on power-efficient implementation while maintaining compatibility with existing 32-bit software. By adopting a clean approach ARMv8-A processors extend the performance range available while maintaining the low power consumption characteristics of the ARM processors that will power tomorrow's most innovative and efficient devices. Most related information can be found at: http://www.arm.com/products/processors/armv8-architecture.php.

Description

The Light DC platform, created by the micro-servers installed on each CESC inside a cluster, has to allow the deployment of VNFs leveraging the CESC virtualization capabilities. This aspect covers a key feature of SESAME, creating a platform capable of moving VNFs from the core to the edge of the network.

KPI

Number of available VNFs in the SESAME's catalog.

Relevant use cases

- All use cases previously identified.

5.2.9. Security and privacy

Description

Secure access to all SESAME components has to be provided as well as guaranteeing data privacy *per tenant* and *per slice*.

KPI

Amount of security and privacy violation issues.

Relevant use cases

- All use cases previously identified.

All technical requirements have been gathered and summarized at ***Table 8***, as it appears below.

Use case	Multitenancy	Component interoperability	Resource monitoring	"Self-x" radio configuration	Dynamic configuration of virtual resources	Hardware and network accelera-tors	Service Function Chaining	VNFs at the network's edge	Security and privacy
Elastic operator SLAs enforcement in multi-operator CESC with edge monitoring and control	x	x	x	x	x	x		x	x
Indoor Small Cells	x	x	x			x	x	x	x
Managing inter-tenant smart traffic classification and network optimization and intra-tenant service-aware routing based on QoS differentiation	x	x	x		x	x	x	x	x
Service Function Chaining (SFC) in multi-tenant and multi-provider network	x	x	x		x	x	x	x	x
Optimized Radio Network Capacity Planning and Operation mechanisms of the Small Cell Network Operator	x	x	x	x				x	x
Blind Spots	x	x	x	x				x	x
Communications in High Density Areas		x	x					x	x
SESAME Platform Deployed for a moving hotspot		x	x		x			x	x

Wireless Critical lifeline communication		x	x	x				x	x
Sporadic Crowd Event	x	x	x		x			x	x
Multimedia services at the mobile edge and inter-operator edge caching	x	x	x			x	x	x	x

Table 8: Mapping of requirements to SESAME objectives

5.2.10. Summary of use cases requirements

In the following table (***Table 9***), a summary of the requirements, extracted from all use cases, can be found.

Name	Requirement Description	Technical domain to which the requirement belongs	Justification of Requirement	Use case	Category
Transcoding VNF placement	The transcoding VNF executed on the CESC **MUST** run on the micro-server including the specific accelerator (VIM will manage the right allocation of VNFs inside the CESC cluster – workload mapping)	Multitenancy, Management & Orchestration, VNF execution at the edge, Service Function Chaining (SFC), Resiliency, Operability		Multimedia services at the mobile edge and inter-operator edge caching	Non-functional
DPI over packets for content matching	The Light DC must support virtualized HW accelerators in order to guarantee the required computing performance to VNFs offloading the terminals' CPU	VNF execution at the edge Service Function Chaining (SFC) Security, Resiliency Operability		Multimedia services at the mobile edge and inter-operator edge caching	Functional
API support for inter-VSCNOs lookup requests	The CESCM **MUST** provide APIs to support inter-VSCNOs lookup requests into the distributed cache	Multitenancy, Management & Orchestration, VNF execution at the edge, Operability		Multimedia services at the mobile edge and inter-operator edge caching	Functional
Secure cache access	The distributed cache **MUST** be accessible by different VSCNOs with proper security/privacy requirements	Multitenancy, Management & Orchestration, VNF execution at the edge, Security Dynamic Coordination of light Dc		Multimedia services at the mobile edge and inter-operator edge caching	Functional

		clusters			
Cloud-based storage system	The CESC **MUST** provide a cloud-based storage system acting as cache and deployable as an NFV within the domain of VSCNOs	Multitenancy Management & Orchestration VNF execution at the edge Service Function Chaining (SFC) Resiliency, Operability		Multimedia services at the mobile edge and inter-operator edge caching	Functional
Distributed cache at the edge of network	The distributed cache **MUST** be available at the edge of the network	Multitenancy Management & Orchestration VNF execution at the edge, Operability	Moving computation and data at the edge will reduce latency and improve the overall QoE for EUs, bring energy savings both for the user equipments and the network components, additionally, terminating users' requests at the network edge will also increase mobile data volume per geographical area.	Multimedia services at the mobile edge and inter-operator edge caching	Functional
Multitenant CESCs	The CESC **MUST** be able to serve to more than one MOs.	Multitenancy Management & Orchestration Resiliency Operability		Sporadic Crowd Event	Functional
VNF deployment per tenant	Each MO **MUST** be able to deploy a VNF separately from other MOs.	Multitenancy Management & Orchestration VNF execution at the		Sporadic Crowd Event	Functional

		edge Resiliency Operability			
Reconfigurable Parameters	The CESCM shall be aware of the radio parameters of the CESCs that can be dynamically reconfigurable through self-optimization functionalities.	“Self-x” features	The self-optimization functions are dependent on the reconfigurability capabilities offered by the CESCs.	Optimized Radio Network Capacity Planning and Operation mechanisms of the Small Cell Network Operator	Functional
Measurements Collection	The CESCM shall collect operative and performance measurements from the CESCs and the User Equipments on a per VSCNO basis.	“Self-x” features	The collected operative and performance measurements constitute the input used by the AI-based framework to extract the knowledge that will drive “self-x” functions. In order to properly optimize the network ensuring that the QoS requirements of each VSCNO are fulfilled, the measurements collected by the CESCM should differentiate between the SCNOs.	Optimized Radio Network Capacity Planning and Operation mechanisms of the Small Cell Network Operator	Functional
Reconfigurability Capabilities	CESCs shall have the capability of reconfiguring radio parameters, within specific time constraints,	“Self-x” features	The proper operation of the self-x functionalities requires that the reconfiguration orders are implemented within	Optimized Radio Network Capacity Planning and Operation mechanisms of the Small Cell Network Operator	Functional

	as a result of the decisions made by "self-x" functionalities.		specific time bounds that will be dependent on each specific function.		
VIM interfaces for VNFs interconnection with Service Function Chaining	The VIM offers interfaces to administrate the interconnection between VNFs with Service Function Chaining	Multitenancy Management & Orchestration VNF execution at the edge Dynamic coordination of LightDC clusters Service Function Chaining (SFC) Operability	In order to be able to administrate interconnection between VNFs, the VIM SHALL provide ways to configure Service Function Chaining.	Service Function Chaining (SFC) in multi-tenant and multi-provider network *(ZHAW and VOSYS SESAME partners)*	Functional
SDN controller support for configuration of individual VNFs	The SDN controller SHALL support the configuration of individual VNFs	Multitenancy Management & Orchestration VNF execution at the edge Operability	VNFs must be administrated via the SDN.	Service Function Chaining (SFC) in multi-tenant and multi-provider network *(ZHAW and VOSYS SESAEM partners)*	Functional
SFC support in SDN controller	SDN controller SHALL support Service Function Chaining	Multitenancy Management & Orchestration VNF execution at the edge Service Function Chaining (SFC) Operability	When configuring VNFs, the SDN controller must be able to setup SFC networks.	Service Function Chaining (SFC) in multi-tenant and multi-provider network *(ZHAW and VOSYS SESAME partners)*	Functional
Software switch on micro-server	Software switch SHALL be executed on micro-server	Multitenancy Management & Orchestration VNF execution at the edge	A software switch running on the micro-server is necessary to interconnect virtual machines, executing	Service Function Chaining (SFC) in multi-tenant and multi-provider network (*ZHAW and VOSYS SESAME*	Functional

		Service Function Chaining (SFC) Operability	VNFs on the same or on different hosts and assure Service Function Chaining.	*partners)*	
Accelerated VNFs	Hypervisor SHALL provide capability accelerate VNFs performance in respect to networking (VM to VM, VM to network) and computing (accelerators).	VNF execution at the edge Service Function Chaining (SFC) Operability	The SESAME hypervisor should provide carrier grade performance, minimizing the VMs I/O overhead and maximizing guests' performance by offloading the CPU by using accelerators.	Service Function Chaining (SFC) in multi-tenant and multi-provider network *(ZHAW and VOSYS SESAME partners)*	Functional
Resources utilization monitoring	The CESCM must be able to monitor the current utilization of each network operator relying on the CESC	Multitenancy Dynamic coordination of Light DC clusters "Self-x" features	In order to administer the CESC cluster(s), the CESCM needs to acquire information about the status of the resources it manages.	Elastic operator SLAs enforcement in multi-operator CESC with edge monitoring and control	Functional
Determination of SLA compliance	The CESCM must be able to determine the compliance of the supported VSCNOs with respect to their SLA (VSCNO to SCNO agreement)	Multitenancy Management & Orchestration Dynamic coordination of Light DC clusters Self-X features	Acquired information about the CESC cluster can be used by the CESCM to determine the compliance of the VSCNOs to their SLAs with the CESC operator.	Elastic operator SLAs enforcement in multi-operator CESC with edge monitoring and control	Functional
Radio slicing control	The RRM **must** expose interfaces to the CESCM to allow for a dynamic control of radio slicing across tenants (e.g., assign maximum capacity	Multitenancy VNF execution at the edge Dynamic coordination of LightDC clusters Self-X features	In the multi-tenant environment of the CESC, dynamic radio slicing can enable an efficient allocation of available resources to	Elastic operator SLAs enforcement in multi-operator CESC with edge monitoring and control	Functional

	to tenants to obtain a target data rate)		maximize the cell utilization.		
VNF scale-out	The VIM **must** support fast, dynamic scale-out of virtual resources assigned to tenants	Multitenancy Management & Orchestration VNF execution at the edge	VSCNOs may need additional VNFs in different configurations to continue supporting their operations. The VIM must support the scale-out of such resources.	Elastic operator SLAs enforcement in multi-operator CESC with edge monitoring and control	Functional
Fast reconfiguration of VNFs	The CESC **must** support fast reconfiguration of the VNFs (a KPI of 5-10 minutes can be supported in case of complete re-deployment of VNFs)	Management & Orchestration VNF execution at the edge	Services may require VNFs to be reconfigured or respawned. This requirement should be supported and achieved within a target time KPI.	Elastic operator SLAs enforcement in multi-operator CESC with edge monitoring and control	Functional
SDN components in LightDC	The LightDC executes SDN components that are integrated with the VIM	Multitenancy Service Function Chaining (SFC) Operability	SDN will be essential to support traffic classification and QoS for this use case.	Managing inter-tenant smart traffic classification and network optimization and intra-tenant service--aware routing based on QoS differentiation	Functional
CESCM APIs to provide CESC status information	The SDN controller accesses SLA information and CESC status from the CESCM	Multitenancy Management & Orchestration Service Function Chaining (SFC) Operability	Service-aware routing is based on information that can be retrieved by components placed inside the VIM and made available by the CESCM. The SDN controller uses	Managing inter-tenant smart traffic classification and network optimization and intra-tenant service--aware routing based on QoS differentiation	Functional

			this information to control traffic flows.		
SDN for VNF placement	The SDN controller controls VNF placement decisions by communicating with the VIM	Management & Orchestration VNF execution at the edge Service Function Chaining (SFC) Operability	The SDN controller acquires information on traffic flows and can feed it back to the VIM to influence VNF placement decisions.	Managing inter-tenant smart traffic classification and network optimization and intra-tenant service-*aware* routing based on QoS differentiation	Functional

Table 9: High level technical requirements

6. Conclusions

In this deliverable an effort has been made to define specific use-cases based on the SESAME scenarios described in DoW, and embody the practical realization of the SESAME vision for Small Cell networks.

SESAME defines actors with specific roles and interactions in the overall operation of the system. Their roles have been particularly checked and represented in the proposed use cases and will be accordingly embedded in the system features from the architecture to the specific functionalities to be developed in the project.

Since SESAME applies a specific targeted methodology for introducing and developing the novel concepts edge virtualization, the consortium has initially developed 11 architectural use cases deriving from the scenarios described in the DoW and which do constitute general stories of interesting situations and topics where the synergy of Small Cells and Virtualization at the Edge is described and is also appropriately highlighted.

The current results of the SESAME methodology revealed several Key Performance Indicators used for the categorization of use cases and aiming to provide hands-on evaluation criteria in order to measure the practical performance of possible simulation results and the trials later on, as described in the description of work.

The proposed use cases have been processed and refined to “fit” the SESAME objectives and methodology, so as to be able to give realizations of the synergy in network environments and situations that need to be addressed via SESAME system.
The range of the technical issues contained in the discussed use cases can be considered as broad, especially when observing the situations they are applicable to and/or when evaluating the functionalities that are necessary for their proper implementation/realization.

The SESAME Concept is presented and orchestrated in such way so as to constitute improvement of the current networks. The analysis performed in this deliverable, has indicated specific requirements for improvements and has opened up the next steps for development of SESAME architecture and work on specific technical areas planned in the project.

So, in the frame of and with respect to the analysis performed in the scope of SESAME in this deliverable, the consortium will evaluate the suggested use cases and will select the appropriate ones, which after the necessary modifications will be realized in trial cases, in order to validate SESAME architecture and concept.

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