Small cEllS coordinAtion for Multi-tenancy and Edge services

2nd White Paper

SESAME: An innovative multi-operator enabled Small Cell based infrastructure that integrates a virtualised execution platform for deploying Virtual Network Functions

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SESAME: An Innovative Business Model

In a constantly changing telecom environment characterised by the softwarization of networks and the provision of ultra high speeds, 5G networks are expected to play a pivotal role. New players such as network function developers and facility managers will enter the market, while the role of existing ones will change. Traditional telecom operators will be transformed in order to compete with Over-The-Top (OTT) players. New market opportunities will arise, due to lower barriers to entry. Moreover, new advanced applications and services with demanding requirements will be provided, mainly by vertical industries. Charging schemes are expected to evolve due to the use of virtualization, revealing more dynamic characteristics.

With the ever-increasing demand for capacity, the deployment of small cells is predicted to rise rapidly[1]. However, the deployment and maintenance of equipment from multiple network operators in a densely populated area will be both costly for network operators due to the proliferation of radio equipment and IT resources. Sharing radio and backhaul resources “seem” to be a solution to these challenges.

Combining this with the increasing need by network operators to efficiently manage their networks -whilst adding value/revenue to their operation- is driving special services to be provided at the network edge, such as augmented reality provided through local or co-located resources at the edge.

Within this emerging 5G landscape, the SESAME H2020 project (GA No.671596) focused on the development and demonstration of an innovative architecture, capable of providing Small Cell (SC) coverage to multiple virtual operators “as-a-Service”. To that end, SESAME envisages the virtualisation and partitioning of Small Cell capacity while, *at the same time*, supporting enhanced edge cloud services by enriching a Small Cell network with co-located compute resources based on a micro-server architecture.

Operators may provide the network’s edge to third party partners, enabling the rapid on-demand deployment of cutting-edge network services in the form of Virtual Network Functions (VNFs) – such as data processors, security appliances, proxies, media transcoders, Machine-to-Machine (M2M) gateways, close to the end-users. Locating virtual service processing nodes closer to end-users reduces latency, improves throughput, and reduces traffic in the core network.

SESAME innovations focus on the novel concepts of virtualising Small Cell networks by leveraging the paradigms of a multi-operator (multi-tenancy) enabling framework, coupled with an edge-*based*, virtualised execution environment. SESAME falls in the scope of these two principles and promotes the adoption of Small Cell multi-tenancy, i.e., multiple network operators will be able to use the SESAME platform, each one using his own network “slice”.

SESAME will improve the QoS (Quality of Service) and QoE (Quality of Experience) of end-users. Users will be able to enjoy advanced services that are expected to meliorate the quality of their lives through better medical care, transportation, human wellbeing, entertainment, etc. The increased capacity, low deployment time, caching and clustering capabilities provided by SESAME will facilitate the support of rescue missions, crowd events, HD live streaming and provide connectivity to areas without -or with limited- network coverage.

[1] SCF Market status report, *June 2017*.

On the other hand, for a Virtual Network Operator (VNO), the SESAME approach will facilitate the use of edge-*based* cloud capabilities and "enable" accelerated services, content and applications due to the increased network responsiveness, thus offering service differentiation to the VNOs customers. Operators may provide the network's edge to third party partners, allowing the rapid deployment of cutting-edge services to the VNO's users and enterprises, translating this to an "added value" and creating opportunities for vendors, service providers and operators.

Table 1: SESAME Value Proposition

SESAME result	Feature	Value	Beneficiary
CESC (Cloud Enabled Small Cell) platform	Flexible design and the associated management layers promote a shared virtualised infrastructure, i.e., a cloud environment, right at the network's edge	• Reduce the average service creation time	VNOs
CESC cluster	Provide access to a geographical area with one or more operators.	• Reduce rural/urban divide • Increased Capacity	VNOs, users
Edge computing capabilities	Acceleration, optimization, virtualization, caching, "Self-X" features	• Reduce energy consumption • Improve QoS and QoE • Improve network performance • Automate operation • Reduce OPEX	VNOs, users
Multi-tenancy	Infrastructure sharing mainly through slicing / virtualisation	• Reduce CAPEX	VNOs
Virtualised execution environment (Light DC)	VNFs chaining to "meet" a requested Network Service by a tenant	• Reduce CAPEX / OPEX	VNOs

Small Cell Network Operators (SCNOs) are assumed to be the main players in the SESAME ecosystem, as the target to adopt the proposed solutions and tools. Involved market "players"/actors are divided according to their type and then categorized into target groups, depending on their relevance to the SESAME ecosystem. These include: end-users and subscribers; IT Equipment vendors; Small Cell vendors; Network equipment vendors; CPE and IoT devices vendors; OTT and e-Service providers; content providers and content aggregators; Network Function Providers (NFPs) and software houses (application providers); Facility and Equipment managers; Virtual Small Cell Network Operators (VSCNOs); Small Cell Network Operator (SCNO); Mobile operators; network providers; vertical industries, spectrum owners; regulators; distributors; advertising agencies, *and*; brokers. The value proposition along with SESAME results and features are illustrated in Table 1.

The next step is to define the relationships between the players in modern SESAME environment. The related model involves many different players and a complex value network. This reference model is described with all the participating players, relationship interfaces, revenue streams and cost drivers in Figure 1.

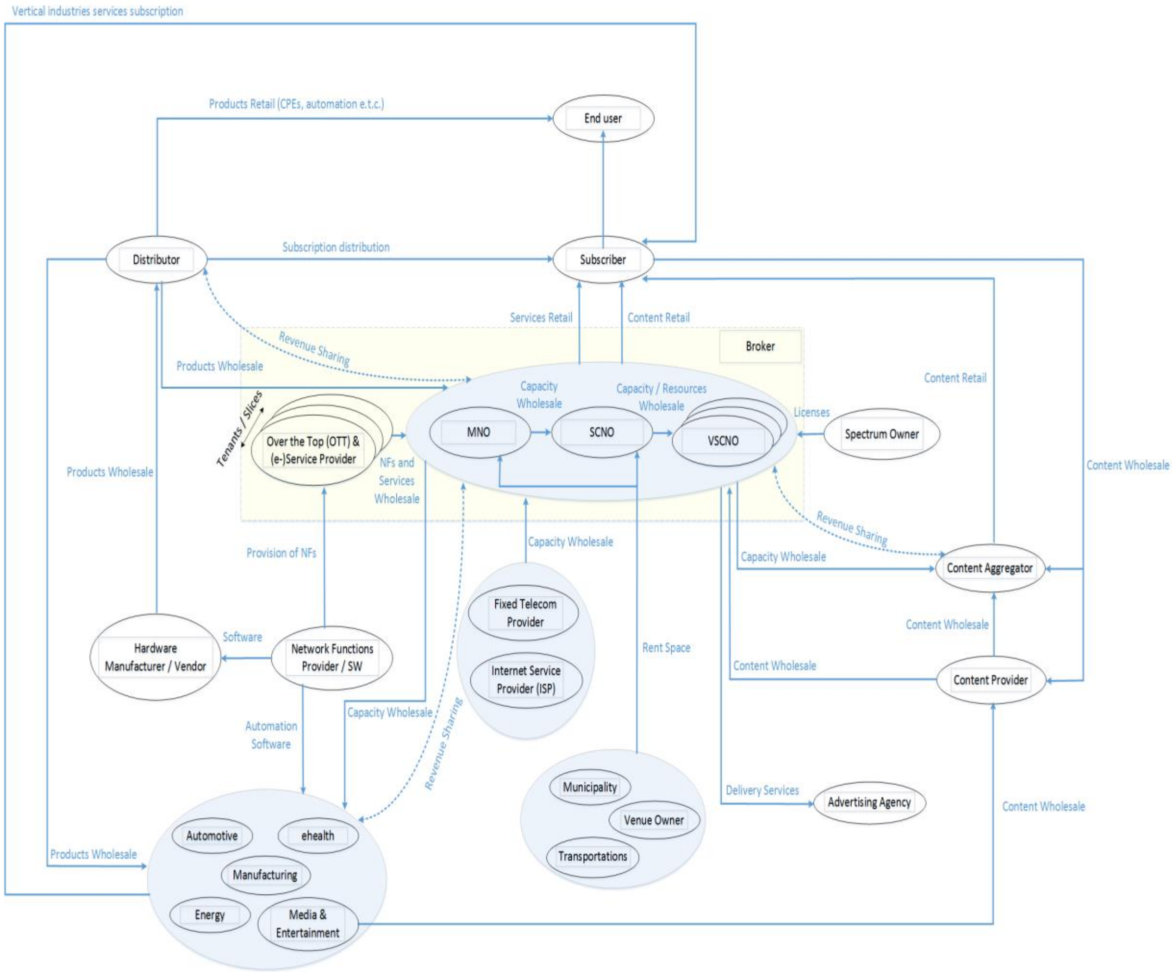

Figure 1: SESAME Reference Model

The SCNOs are assumed to be the main SESAME players while, *in general*, operators/providers "act" as the main responsible players towards the subscriber by providing telecom services (like voice and video telephony, broadband access, etc.). In this model, the following type of service level agreement (SLA) is assumed to exist between SCNOs and VSCNOs: A VSCNO enters into a contract or service level agreement with the SCNO for the usage of services and/or resources. The contract can be of two types: either basic or advanced, with the latter incorporating more potential for service chaining.

Brokers and verticals are expected to play a significant role towards 5G success, while the role of end-users are anticipated to be bilateral; meaning that they will be both consumers and producers of content.

A major observation for the SESAME ecosystem with regards to business models is that control over the value network is distributed among multiple players and not only to the traditional operators, even if the measurement of its degree of control is higher than the other players in the value chain.

Use Cases

Use Cases (UCs) are often a “useful tool” in order to test and validate a system along with its sub-systems and their functionalities. In order to demonstrate several among the actual SESAME features and capabilities, four (-4-) use cases were selected. Each of these UCs “touches” a limited sector inside the overall SESAME scope. The use cases that will be demonstrated by the SESAME Project during its duration are as follows:

SESAME Use Case1:
Sporadic Crowd Event Service Function Chaining (SFC) in Multi-tenant environment

This use case is focused upon the automatic deployment of a few selected VNFs for two Virtual Small Cell Network Operators (VSCNOs). It is presupposed that the CESC infrastructure supporting multi-tenancy exists in an area, like a stadium or a shopping mall.

Two VSCNOs wish to exploit this infrastructure, in order to provide their services to end-users. A few selected VNFs for VSCNO1 and some others for VSCNO2 will be dynamically deployed.

SESAME Use Case2:
Managing inter-tenant traffic classification & Multimedia services at the edge

This use case will demonstrate a dynamic environment, where the total bandwidth of the CESC will be divided between the two VSCNOs. We consider two sub-cases.

The first one is focused on the *network resources*. A video traffic reaches the User Equipments (UEs) of VSCNO1. We will inject data traffic in the S1 link of VSCNO1 and the total traffic in VSCNO1 increases above a limit. An alarm will be created and sent to the CESCM (CESC Manager) /TeNOR[2], as well as to the operator. Based on the availability of resources, a command will be sent to Network Operators (Nos) to re-arrange the bandwidth sharing between the two VSCNOs.

The second one is focused upon the *IT resources*. A vVA (virtual Video Analytics) is instantiated at the CESC (i.e., at the edge of network). As the number of video streams fed to vVA will be increased, so does the latency for video analysis. Similarly to the previous case, an alarm will be created and be sent to TeNOR, and a new vVA will be instantiated in the CESC, in order to “handle” the excess video streams, so that latency will be decreased.

SESAME Use Case 3:
Service Function Chaining (SFC) in multi-tenant and multi-provider network

This use case focuses upon the orchestration and automatic deployment of virtual network functions into the SESAME cloud infrastructure, and upon providing a Software Defined Network (SDN)- enabled Service Function Chaining between network services involving both, Could-*based* and Telco-*based* VNFs.

The demonstration will orchestrate and compose, end-to-end (E2E) a service that delivers optimized and tailored video to an end-user through their UE (i.e., a mobile device). Since

[2] See: https://github.com/T-NOVA/TeNOR

in principle the SFC concept, as the configuration of data flow between VMs (Virtual Machines) /VNFs, is not dependent to the hardware platform and/or the VNF nature, we will verify it over a well-accepted solution.

However, in case of availability of new hardware platforms (e.g. NXP platform visible to OpenStack) we intend to investigate the possibility of moving the proof-of-concept so that to include such platforms.

SESAME Use Case 4:

Optimized Radio Network Capacity Planning and Operation mechanisms of the Small Cell Network Operator

The objective of this demonstration will be to illustrate the behavior of the Artificial Intelligence (AI)-*based* framework for knowledge discovery that can be used to support the optimization decisions made by "Self-X" functions. This demonstration will take as input monitoring data collected during a certain period of time by the Network Orchestration System (NOS) in the form of Performance Management (PM) reports.

The collected PM reports will be pre-processed and passed to the Rapidminer tool[3] where illustrative AI-*based* algorithms will be executed, in order to extract knowledge models that characterize the behavior of the network.

[3] RapidMiner Studio, http://www.rapidminer.com

SESAME Architecture

Architecture Overview

The SESAME concept is to enhance the deployment of Small Cells with some virtualized functions running on an attached micro-server through appropriate fronthaul technology. The micro-server is based on a non-x86 architecture using 64-bit ARMv8 technology. Together with the SC, they form the Cloud- Enabled Small Cell (CESC) and a number of CESCs form the "CESC cluster", capable of providing access to a geographical area with one -or more- virtual operator(s).

The overall SESAME system architecture is illustrated in Figure 2. The SESAME architecture foresees the functional split of the Small Cell into physical functions (Small Cell – Physical Network Function / SC-PNF) and virtualised functions (SC-VNF), based on the Multi-Operator Core Network (MOCN) feature defined by 3GPPP[4][5] and associated Radio Resource Manager (RRM) and Operations and Management (OAM) features that need to be supported. Further design decisions have led to the introduction of a new functional entity, namely the Small Cell Common VNF (SC-C-VNF). The SC-C-VNF is defined as an element in the SESAME architecture that resides between the SC-PNF and the different SC-VNFs. This allows a unique SC-C-VNF per CESC, which performs control-plane multiplexing and coordination functions from the SC-PNF to the virtualised world. Each SC-VNF supports a single Virtual Small Cell Network Operator and maintains its own control and user plane connections to the VSCNO's core network.

The design also enables a flexible functional split for the Small Cell. Depending on different parameters (e.g., fronthaul capacity, processing power, business decisions), one SC could implement a higher-level functional split, while others could go for a lower level functional split.

SESAME Light DC

Moreover, the SESAME project proposes a micro-scale virtualized execution infrastructure in the form of a Light Data Centre (Light DC) to enhance the virtualization capabilities of the Small Cell deployment, providing high processing power at the network edge. The Light DC concept, which encompasses the micro-servers of the different CESCs in a cluster, provides a high manageable architecture optimized to reduce power consumption, cabling, space and cost. To achieve these requirements, it relies on an infrastructure that aggregates and enables sharing of computing, networking and storage resources available in each micro-server belonging to the CESC cluster.

[4] 3GPP, "TS 23.251, Technical Specification Group Services and System Aspects; Network Sharing;Architecture and functional description". 3GPP, Sept., 2012.

[5] 3GPP, "TS 23.236 V11.0.0, Technical Specification Group Services and System Aspects; Intra-domain connection of Radio Access Network (RAN)". 3GPP, Dec., 2012.

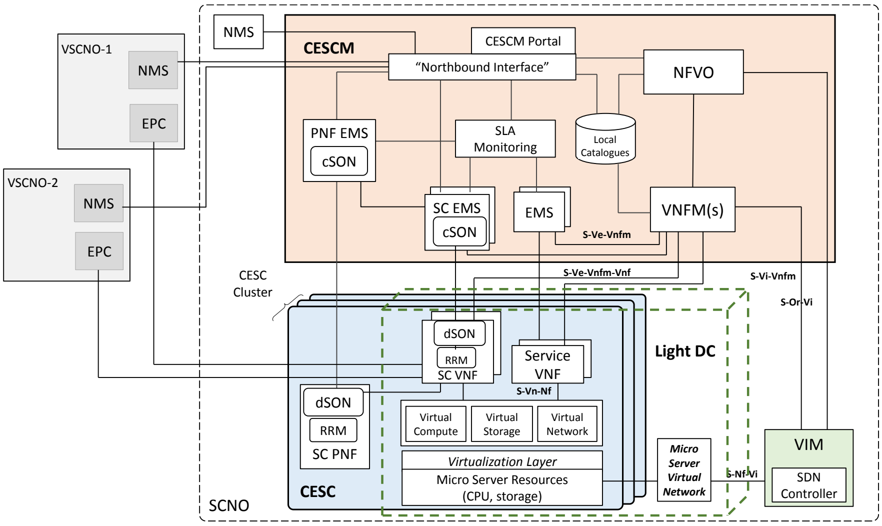

Figure 2: SESAME architecture and components' interactions

The Light DC infrastructure also provides the backhaul and fronthaul resources for guaranteeing the requirements for connectivity, in case of multi-operator (multi-tenancy) scenarios. The hypervisor computing virtualization extensions enable access of Virtual Machines (VMs) to the HW accelerators, for providing an execution platform that can support the deployment of VNFs. Different types of VNFs can be deployed through the Virtual Infrastructure Manager (VIM), for carrying out the virtualization of the Small Cell, for running the cognitive/"Self-X" management operations and for supporting computing needs for the mobile edge applications of the end-users.

The combination of the proposed architecture allows achieving an adequate level of flexibility and scalability in the edge cloud infrastructure.

SESAME CESC Manager

Finally, the CESC Manager (CESCM) is a component with an overall knowledge of the virtual and physical resources, responsible for the proper deployment, monitoring, configuration and orchestration of the Light DC cloud environment as well as of the various radio access functionalities, over a single/multiple CESC cluster(s), with a minimum cluster size of one CESC.

The main challenge to "address" is to design a uniform platform where the radio access management task (e.g. transmission power control, packet scheduling, handover and cell reselection thresholds, etc.) and Network Function Virtualization (NFV) management responsibilities (e.g. VNF/service instantiation, lifecycle management, policy management) can be handled in an orchestrated way.

Self-X features

The efficient management of the multi-tenant Cloud Enabled Small Cell network considered in the SESAME EU-funded project, is facilitated by the introduction of Self-Organizing Networks (SON) functionalities, also denoted as "Self-X" functions. The term "Self-X" covers a range of autonomous features that include self-configuration, self-optimisation and self-healing. For small cells, self-configuration may involve the selection of parameters dealing with factors such as transmit parameter selection (for example TX power), automatic neighbour relations (ANR) and load capping based on backhaul capacity and quality. Self-optimisation deals with the ability of the system to optimise its performance in response to events such as changes in load, changes in the radio environment or simply fine-tuning over a meaningful time-period. In other words, these include a set of functions for reducing -or even removing- the need for manual network optimisation tasks, so that operating costs can be reduced as well as revenue can be protected by minimizing human errors. Self-healing is relevant to the automation of the processes related to fault management (i.e., fault detection, diagnosis, compensation and correction), usually associated to hardware and/or software problems, in order to "keep" the network operational, while awaiting a more permanent solution to fix it and/or prevent disruptive problems from arising.

With the introduction of "Self-X" features classical manual planning, deployment, optimisation and maintenance activities of the network can be replaced -and/or supported- by more autonomous and automated processes, thus making network operations simpler and faster.

SON features are generally classified into one of the three following groups:

- Distributed SON (dSON) features are normally implemented in close proximity to the small cell. Processing is local to the small cell and typically considers a single small cell at a time. A typical dSON feature would be a small cell's ability to select its own transmit parameters.
- Centralised SON (cSON) features are normally implemented in a central location (such as the operator's EMS (Element Management System) or radio planning system) and typically operate over a larger area, optimising the performance of a group of cells such as those covering a defined geographic area. A classic cSON feature would be a radio planning exercise conducted across a defined area to optimise coverage and interference, taking into account the location and transmission parameters or every cell in the area.
- Hybrid SON (hSON) features comprise a combination of the two approaches with some decisions taken locally and others centrally. For example, central planning might be used to define the target coverage of each cell in an area based on their locations, whilst the selection of transmit parameters required to deliver this coverage might be performed locally at each cell and optimised periodically.

Figure 2 presents the SESAME architecture including explicitly the "Self-X" functionalities. The Element Management Systems EMSs for the SC-PNF and VNF include the centralised "Self-X" functions (cSON) and the centralised components of the hybrid SON functions. In turn, the dSON functions - or the decentralised components of the hybrid functions - reside at the CESCs. Concerning the dSON

functions, they can be implemented as a PNF or, if proper open control interfaces with the element (e.g. the RRM (radio resources management) function) controlled by the "Self-X" function are established, they can also be implemented as a VNF running at the Light DC.

SESAME has developed, analysed and evaluated some selected "Self-X" functions to support the automatic operation of certain planning and optimisation tasks in multi-tenant small cell networks. A summary of the main outcomes is provided in the following:

- The impact of Multi-Operator Core Network on some "Self-X" functionalities like the transmit frequency and power selection or automatic neighbour relations (ANR) was analysed. A small cell supporting MOCN will need to handover to neighbours from multiple network operators. Therefore, the goal of automatic frequency and power selection is to attempt selection of a cell radius that encompasses at least one neighbour supporting each configured PLMN (Public Land Mobile Network) rather than simply minimising interference with its closest neighbours. As for ANR, a small cell that supports MOCN will have to scan a potentially much larger set of frequencies to identify potential neighbour cells, and it will have to decode all of the PLMNs broadcast by each neighbour to discover those that they support. The neighbour ranking algorithm must be modified to provide a fair representation to each PLMN in the neighbour lists of the small cell.
- **Self-planning of multi-tenant small cell networks:** A functional architecture has been proposed for a cSON self-planning function that contains two functions, namely the multi-tenant management entity, which translates the SLA capacity terminology into detailed planning specifications, *and*; the self-planning entity, which checks whether -or not- the deployed capacity "fits" the tenants' demand and identifies the required changes in the network layout and channel allocation. The proposed approach was illustrated in a use case where a new tenant is added to the network. Results have shown that capacity overprovisioning can be minimized by reducing uncertainties about the spatial and temporal correlations between the new tenant's traffic and the actual traffic in the network.
- **Self-optimisation of Admission Control in multi-tenant scenarios:** An Admission Control algorithm has been proposed for controlling the share of radio resources between tenants, based on a cell-level capacity check and a per-tenant capacity share check. The tenant-specific threshold of this second check is adjusted by means of a hybrid SON technique, that accounts for unused capacity left by the tenants and that copes with heterogeneities in the spatial traffic distribution across different cells. Figure 3 illustrates the functional architecture of the proposed approach. The simulation results have shown that the self-optimisation approach is able to increase the aggregate throughput of a cell in up to 106% with respect to the case in which the tenant specific threshold is set to a fixed value.

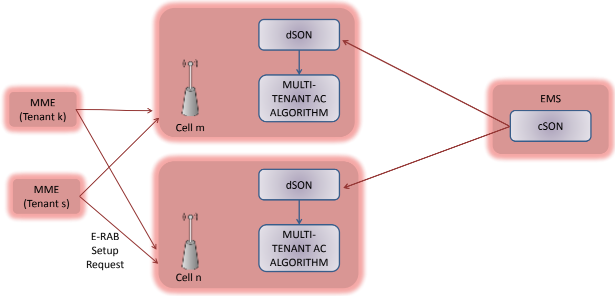

Figure 3: Functional architecture of the Self-Optimisation for AC

- **Mobility Load Balancing (MLB) and User association:** A novel approach has been investigated for dense small cell scenarios based on the Knapsack Optimisation. Results have demonstrated that the proposed approach achieves four fold improvements in blocking ratios with respect to the case where no MLB strategy is applied. Besides, it outperforms other techniques relying on Cell Range Expansion and Almost Blank Subframes.
- **Packet scheduling problem in conjunction with InterCell Interference Coordination (ICIC):** A two-level scheduler of downlink packets has been proposed. One level takes decision in the time domain every TTI (Transmission Time-Interval), and the other takes decisions in the spatial domain every radio frame. Both centralised and distributed solutions for the spatial domain scheduler have been analysed, modelling the coverage probability through stochastic geometry. Presented results show that the decentralised approach performs better than the centralised one. The reason is that the global decision made by the centralised approach in terms of utilising the available resources is not as optimal as the interference rejection from adjacent cells. Instead, the decentralised approach makes locally optimised decisions but still taking some advantage of Fractional Frequency Reuse.
- **Dynamic virtual resource allocation for multi-tenant networks:** A model to split the CPU (Central Processing Unit), memory and storage resources of the CESCs among the involved tenants has been analysed. The strategy is based on ensuring each tenant is allocated at least the resources indicated in the SLA while, *at the same time*, allowing more resources if the other tenants are not using them. The proposed dynamic strategy results in a higher resource utilisation than a static approach.
- **Virtualisation of the wireless backhaul to interconnect the different CESCs and the core network in a multi-tenant environment:** A software module has been developed that allows a per-tenant - *based* scheduling of data for up to 6 different virtual tenants. In this way, it is possible to set-up different mesh networks for different tenants on top of the same physical infrastructure. Via an API (Application Programming Interface), the percentage of the wireless resources between two -or more- physical devices (i.e. the wireless transceivers that form the bakchaul network) can be adjusted. Results have shown that the resource assignment performed by the scheduler module not only maintains the ratio of available resources for the tenant, but also adapts dynamically to varying resource usage/availability and number of active tenants.
- A user-centric knowledge discovery methodology for characterizing the QoS of individual users by exploiting the predictability of the user daily motifs was presented. It relies upon an agglomerative clustering technique that identifies these motifs

and characterizes them as state diagrams, identifying the QoS that is experienced in each state (e.g. depending on the day of the week or the time of the day). This enables a more detailed characterization of the user QoS at different levels, such as the overall QoS experienced by a specific user or the QoS that is experienced during certain days or during certain states. Results have shown that the user-centric approach allows the operator to better identify situations with poor user performance that could not be detected by classical network centric optimisation mechanisms relying on aggregate statistics for all the users of a cell.

It is envisaged that the extracted knowledge can have applicability in different “Self-X” functionalities to optimise the behaviour of the network following a user-centric perspective.

Prototyping Self-X features

When multiple tenants (VSCNOs) are taken into the mix, "Self-X" features must also consider and balance the needs of each of the tenants hosted by the physical small cell.

The desired coverage of the cell may vary from one tenant to another, based on the area where they wish to provide service and the location of neighbour cells supporting their PLMN. In this case, the SC PNF will be responsible for balancing the requirements of the tenants without compromising, for example, its target cell edge Signal to Interference and Noise Ratio (SINR).

Transmit power selection in SESAME is considered an hSON feature:

- The SC PNF supports a "FAP (Femtocell Access Point) Coverage Target" parameter which specifies the target path loss for the cell, measured in dB. This would typically be set by the EMS to a value representing the largest cell radius demanded by the tenants of the SC-PNF.
- The SC-PNF also supports a "Cell Edge SINR Target" parameter that specifies the target quality that is desired at the cell edge.
- Following a radio environment scan (performed on start-up and upon a configured schedule), the SESAME SC-PNF uses measurements of co-channel neighbours to compute the desired Reference Signal Power, required to achieve the specified coverage and quality.

Other self-configuration features include PRACH (Physical Random Access Channel) root sequence selection and PCI (Physical layer Cell ID) selection. In each case, the SC PNF is configured with a list of possible values and, following a radio environment scan, attempts to select a value that is not in use by detected neighbour cells.

Automatic Neighbour Relations is another area where the addition of multiple tenants changes the dSON processing implemented in the SC PNF. As part of a radio environment scan, the SC PNF must consider all of the PLMNs (not just the Home PLMN) served by each neighbour cell, and compare them against the PLMNs of its tenants. Any neighbour serving one or more PLMNs of its tenants may now be considered as a target for hand-over. This also introduces a potential problem in that the number of potential targets may increase significantly. Given that the size of a cell's broadcast neighbour list is limited and that the order in which neighbours appear affects the order in which a UE reports measurements relating to those neighbours, the SESAME SC-PNF provides the following behaviours for UEs in idle and connected mode:

- Neighbour cell information broadcast by a small cell in its System Information is used by UEs in Idle mode to determine when to re-select on to a neighbouring cell. A small cell serving a single PLMN might typically rank such neighbour according to quality with the best quality neighbours appearing earlier in the list. Given that the neighbours belonging to different operators may reside in different physical locations, this behaviour could favour one operator's neighbours over another because, *for example*, their cells are closer. In an extreme case, the neighbour cells belonging to distant operator could be pushed off the bottom of the SC PNF's neighbour list by the closer neighbours of another operator. In order to provide "fair representation" to each PLMN that it

serves, the SESAME SC PNF gives equal ranking to the neighbours of each PLMN that it serves such that, *for example*, the best quality neighbour cells of operators A, B and C occur in the first three neighbour list entries, regardless of their relative quality. The next best neighbours of each PLMN would occur in the next three slots, *and so on*.

- A UE entering connected mode may be configured with a set of measurement reports and associated criteria that the serving cell wishes it to perform. The SESAME SC PNF filters this configuration, so that the UE is only required to make measurements on frequencies supporting one -or more- neighbour(s) serving its Selected PLMN. This reduces the measurements that the UE needs to make and speeds up handover processing (thereby improving reliability).

In addition to neighbour cells detected by ANR, specific statically configured neighbour cells may be provided by each tenant. Small cells typically have neighbour lists containing a combination of cells detected by a radio environment scan and those explicitly configured by the network operator (i.e., known to be present but not necessarily detected). In the case where multiple tenants are stakeholders in the configuration of the SC-PNF, it is possible that each tenant may wish to specify a number of neighbours that are explicitly included in the PNF's configuration. In this case, the SC EMS may process each tenant's configuration to arrive at a fair representation configured on the SC-PNF.

In addition to the self-configuration features describe above, the SESAME system also provides "hooks" for self-optimisation:

The SESAME EMS implements an automated SLA monitoring feature that calculates Key Performance Indicators (KPIs) from performance management data reported by the SC VNF. Reported values are aggregated across the set of virtual cells specified by an SLA managed object and the resulting KPIs compared against configured thresholds. If a KPI threshold is crossed, an SLA breach is indicated and the EMS takes a configured action. The SLA managed objects may be configured with different geographic (i.e., the area covered by the SLA) and temporal (the time frame over which performance is assessed) scopes. Any number of such SLAs may be configured, providing a powerful means for assessing performance across the "network as a whole" or in specific defined regions. Currently, the only supported action is to raise an alarm, but future actions could include triggering an appropriate optimisation step.

Advanced RAN Functionalities

Within the SESAME scope, a particular attention has been put to explore “how to introduce advanced RAN functionalities into the CESC”. Such functionalities aim at providing better support for the multiple-tenants while, *at the same time*, optimizing the small cell available radio resources.

SESAME use cases also include dynamic scenarios, where the network should be set-up on a temporary basis. In this context, it is advisable to support mechanisms for making resources configuration suitably flexible and programmable, in order to allow orchestration and “Self-X” services’ support.

RAN sharing is one of the advanced RAN functionalities considered by SESAME, and it is used for slicing of radio resources between multiple services.

The work carried on in SESAME has explored how to exploit new approaches to RAN sharing at scheduler level, thus allowing two different tenants to access to the resources of same Small Cell, in an independent way. The resources are transparently assigned to the two tenants by the scheduler logic, creating two slices of the spectrum. Then, each of the two tenants can apply his own scheduler logic, for assigning the related spectrum to his own users.

With this approach, RAN resources are virtualized and made independently available to multiple operators. From his point of view, the operator is the only utilizer of the Small Cell and he can manage the assigned resources according to his own strategies.

Besides the advantage of accommodating multiple tenants’ requirements, the considered approach is useful also to cope with the fluctuating nature of the user’s traffic. Thus, with the support of with well-designed schedulers at different level, it is possible to cope with the variability of the spectrum utilization and so to increase the overall utilization of the RAN. Optimization of resources can also be enabled by functional split approaches. In SESAME, we studied solutions for practically implementing it by using a solution based on Software Defined Radio (SDR) and an open source LTE (Long Term Evolution) Stack. The split is performed at MAC-RLC (Medium Access Control/Radio Link Control) level, and allows dividing the protocol stack tasks between two units connected through the CESC network; namely a small cell Remote Radio Unit (RRU) and a Base Band Unit (BBU) placed at the LightDC. This approach requires not only a careful evaluation of the fronthaul available network resources, but also the optimization of the communication protocols between the two units, as well as of the task processing strategy within them. In SESAME, we studied both problems in order to make the solution feasible, in a realistic context. This step is essential for allowing the implementation of C-RAN (Cloud-Enabled RAN) centralized solutions, necessary to enable advanced services, such as interference management and optimization of computational and storage resources. A theoretical study on the dynamic functional split has been conducted, in order to analyse and optimize the placement of the CESCs protocol functions, so that to maximise the fronthaul resource and energy utilization. With this study, we lay the foundations of an adaptive approach to functional split, able to better support the scalabity and dynamicity requirements required by many use cases.

Light DC Implementation

One of the main Light DC design goals is to bring computational power at the network edge at low price in a limited space. These considerations were taken into account during the development of the *ST Barcelona board*[6]. However, for more demanding applications in terms of computing resources, the *NXP LS2085A*[7] (which has bigger form factor and higher power consumption, but offers high core density and disposes of hardware accelerators in the SoC (System on Chip) has been considered.

In case of high-workload scenarios and if space or power consumption restrictions are present at the CESC, the NXP LS2085A can be deployed as remote, auxiliary compute node with the ST Barcelona being "better suitable" for supporting the CESC. Without such restrictions, the NXP LS2085A can be directly employed as micro-server part of the CESC. Further on, the investigations on some wide-spread hardware accelerators, such as the GPU (Graphics Processing Unit), lead to the decision to include the NVIDIA GPU M4000 in the micro-server for supporting the computing requirements needed, in case of running video transcoding VNFs at the edge.

At the beginning of the SESAME project, the NVIDIA CUDA developer's toolkit[8] was supporting the software development on this device. The toolkit supported different operating systems (Linux, Mac OS (Operating System) and Windows), on different architectures. However, since version 7.5 NVIDIA[9] decided to stop supporting the vast majority of devices based on ARM architecture[10], which lead to the decision on including x86 based nodes in the Light DC, thus making the computing platform heterogeneous.

The Raspberry Pi 3 board[11] can act as a very low cost micro-server node and it is used for providing a development platform for testing lightweight virtualization solutions, especially for the case of virtualization of small cell-*related* functions.

The system proposed envisages four different nodes (Figure 4) acting as micro-servers (Table 2):

- STM board running a virtualization layer to host Common SC-VNF and SC-VNF (at least one).
- Raspberry Pi 3 board.
- NXP board running a virtualization layer to host SC-VNF, Service VNFs (SW only) and storage.
- INTEL node (Xeon v3) equipped with a NVIDIA GPU M4000 for VTU HW acceleration and storage.

[6] See: *http://www.st.com/en/evaluation-tools.html*

[7] *http://www.nxp.com/products/microcontrollers-and-processors/arm-processors:ARM-ARCHITECTURE*

[8] *https://developer.nvidia.com/cuda-downloads*

[9] See: *https://developer.nvidia.com/cuda-75-downloads-archive*

[10] See: *https://developer.arm.com/products/architecture*

[11] See: *https://www.raspberrypi.org/products/raspberry-pi-3-model-b/*

Table 2: Main Characteristics of Micro servers

Micro server	Architecture	Cores	RAM	Storage	PCI-e Acceleration
NXP LS2085A	ARMv8, A57	8	16 GB	500 GB	no
GOMA (FlexPAC)	Xeon E5-2630v3	8	64 GB	4+2 TB	GPU
STM board	ARMv8, A53	4+1	1 GB	xx GB (SATA disk)	no
Raspberry Pi 3	ARMv8, A53	4	1 GB	xx GB (microSD)	no

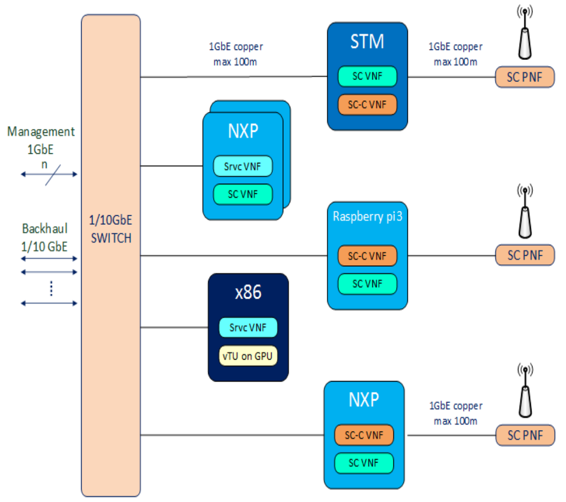

Figure 4: Light DC physical architecture

Testbed for preliminary integration and testing activities

The testbed environment shown in Figure 5 has been used to integrate and verify several aspects of the Light DC development:

- Hypervisor, Hardware acceleration layer and Accelerated Virtual networking (VOSYSwitch) integration on the NXP platform.
- OpenStack integration (the Kilo Release[12] was selected): Computing and networking managed by OpenStack controller in case of Hybrid node (Intel/ARM).
- VNFs deployment in compute node based on:
  - Intel, CPU-only
  - Intel, CPU+GPU
  - Arm, CPU-only
- VTU (Video Transcoding Unit) performance characterization in case of video transcoding service for CESCs.

[12] https://www.openstack.org/software/kilo/

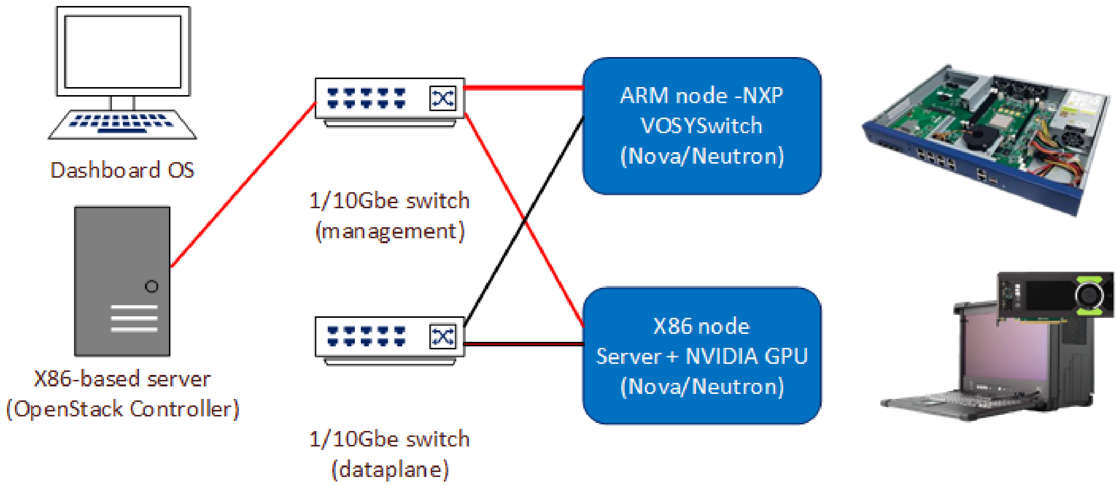

Figure 5: Light DC testbed

VTU porting on ARMv8 - steps done

- Porting of Linux using the NXP BSP/SDK (yocto[13], LS2085A SDK 2016 0304, poky[14]), kernel version: 4.1.8 (the KVM (Kernel-*based* Virtual Machine) hypervisor is natively integrated).
- Integration of QEMU (Quick Emulator), VOSYSwitch, Nova[15] and Neutron[16] agents for building the virtualization platform in the OpenStack environment. Several patches were needed to run the ARMv8-*based* compute node in OpenStack.
- Building of three different images:
  - Kernel image (AltArch CentOS 7.3 for ARM64, kernel 4.5.0);
  - Initrd image;
  - a raw image with linux file system.
- Porting of audio and video codecs inside the distribution, as they was not available natively (the FFmpeg package was chosen).

VTU performances

Figure 6 shows the results obtained with the VTU featuring the H.264 transcoding (expressed in frames per second) without HW acceleration (SW-only) and with HW acceleration (using a GPU). The processing implies decoding from the input format to the one required as output.

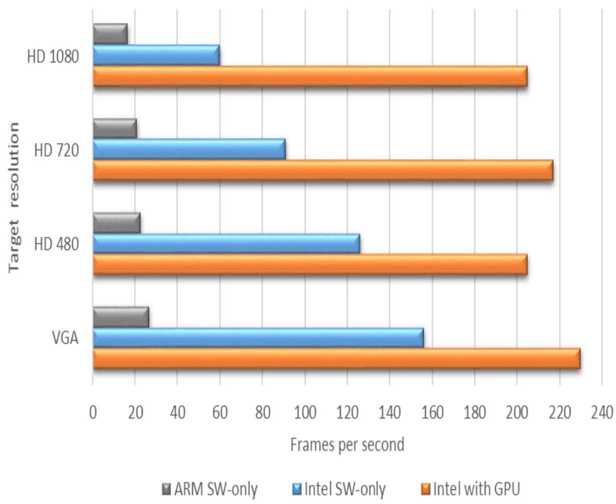

Figure 6: H.264 single session encoding performance

[13] https://www.yoctoproject.org/
[14] https://www.yoctoproject.org/tools-resources/projects/poky
[15] https://wiki.openstack.org/wiki/Nova
[16] https://wiki.openstack.org/wiki/Neutron

CESC and Virtual Infrastructure Managers

The new paradigm in virtualized clouds to deliver and operate a high level of innovative services at the lowest cost, enlarge the difficulties in the infrastructure management approach.

The CESC Manager (CESCM) is the “key component” for the creation and the coordination of complex virtual network scenarios based on end-to-end (E2E) virtualization management, evaluating the service assurance and SLA management in multi-tenancy scenarios. The solution has been implemented (Figure 7) so that to provide features such as a simplified infrastructure able to scale services without renouncing resiliency in internal operations and service quality.

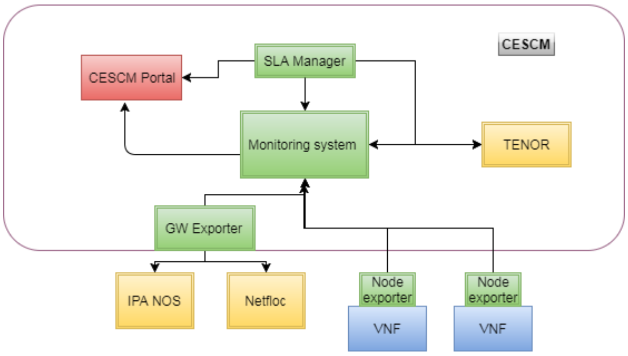

Figure 7: SESAME CESC Manager

CESCM portal

The CESCM portal is a control plane web GUI (graphics user interface) used as an “entry point” to SESAME services. The users of the infrastructure, (i.e.: SCNO and VSCNO), contract and manage the available VNFs through this portal. It also provides a dashboard that monitors and visualizes the status of the service instances.

In addition, anomaly detection of critical situations is supported with the system notifying users when a service failure is detected (i.e., identify bottleneck in a NFV deployment due to high CPU utilization), based on the rules defined in the SLA negotiation process.

SLA Manager

Service Level Agreements (SLAs) represent the contractual relationship between a consumer of the infrastructure and the provider of the available service(s). The SLA manager provides the mechanism to increase trust in providers, by encoding dependability commitments and ensuring that the level of the provided Quality of Service is maintained to an acceptable level. In the context of SESAME, performance monitoring allows to the identification that the infrastructure is reaching to a certain level, where the resources used by the tenants are close to the specific level where performance of the system can be affected.

The SLA Manager negotiates with the user the level of reliability based on the SLA requirements. The flavour name (i.e.: Gold, Silver and Bronze) is used to define the particular features, by means of QoS parameters that compose a network service.

The SLA Manager will align with business requirements and meet the expectations of the customers and users, in terms of service quality. This approach considers the revenue model for service and functions providers as a tool for accounting and billing processes.

Monitoring system

The monitoring system is an independent module for smart metric retrieval, for SLA Evaluation. This feature makes the SLA flexible enough to work with different monitoring systems. The smart monitoring system implemented is a real time-series database that sustains the ingestion of the metrics infrastructure in a pull-*based* mode, scraping real-time information of the VNFs composition in the Service Function Chain (i.e.: Network Services composed of several VNFs) to instrumented external services. This allows evaluating the

constraints and raising the appropriate violations of big amounts of data.

Gateway Exporter

This component is the ingress point to monitor external systems in the infrastructure. The Gateway Exporter exposes external metrics from the managed objects (i.e.: VNFs) to the endpoint in order to be scraped by the monitoring service. The IPA Network Orchestration System (IPA-NOS) exporter prepares the metrics produced by the radio system and exposes them as-a-service to be evaluated together with the cloud exporter so that to form the aggregated metrics of the infrastructure. The cloud exporter, depicted as node exporters, is the agent for monitoring real and virtual network element resources; it exposes metrics about disk I/O statistics, CPU load, memory usage and network statistics. This exporter is embedded together with the VNF in the process of instance deployment.

VNFs Orchestrator: From models to a Prototype

From an operator's perspective, evolution of mobile networks implies a continuous attempt to find a trade-off between capacity increase (i.e., higher bitrates, more coverage, etc.) and total cost of ownership (i.e., CAPEX and OPEX). A viable solution points to the concept of a flexible Radio Access Network with simplified deployment and management. Although today's RAN is able to provide a high level of configurability (e.g. support for a variety of transport network and baseband configurations), there is still plenty of room to exploit the potential synergies with concepts like Network Function Virtualization (NFV) and Software Define Networking (SDN). Joint radio-cloud architecture proposed by SESAME presents an effort to "place intelligence" at the network edge and to use virtualization technologies to build a cost-, spectrum-, and energy-efficient RAN, able to offer improved user experience.

In SESAME, we focus on a distributed Cloud-Enabled RAN architecture. As stated above, designing a multi-tenant C-RAN represents an effort of evolving commercial Small Cells towards a so-called Cloud Enabled Small Cell (CESC). This leads to the creation of a distributed data centre, denominated Light DC, aimed to enhance the virtualisation capabilities and processing power at the network's edge.

Migrating part of SC radio functionality to the Light DC in the form of Virtual Network Functions, permits "linking" of the radio data transmission to the cloud world. That is the lifecycle events of SC VNFs can be managed in a way similar to service VNFs which will offer the added-value Mobile Edge Services (MES) to the subscribers of tenant (SC operator).

Multiple independent instances of MES can operate over the shared Light DC environment. With the help of both authentication and authorization management (logical isolation), it is possible to serve more than one tenant over a single C-RAN infrastructure. By definition, this case is interpreted as "multi-tenancy" in the context of 5G.

The multi-tenant mixed radio-cloud environment poses extra challenges for service management and orchestration, especially on ensuring the Quality of Service per tenant. The logical C-RAN manager/orchestrator needs to simultaneously take into account both, the radio status (i.e., volume of traffic, geographical distribution of traffic, etc.) and the cloud capabilities (i.e., available IT resources, VM-to-VM communication requirements, etc.) for all the action related to the service lifecycle management. To do so, forming a feedback QoS ensuring loop is necessary. Such a loop consists of three main steps:

- Monitoring: A phase in which performance monitoring parameters are collected from the radio/cloud elements (e.g. SC physical network function, virtual machines, etc.) and handed over to the decision-making process. Depending on the nature of the resources, that is radio or cloud, QoS requirements, the available Service Level Agreement (SLA), etc., the monitoring parameters might vary from one use case to another.
- Decision-making: A phase in which performance metrics collected in the previous step are processed. Depending on the situation and the available resources, a decision will be taken to ensure the level of QoS (with the help of a dedicated algorithm). Besides available resources, in a

multi-tenant scenario, the decision-making process needs to take into account the status of other tenants (i.e., keeping a good level of QoS for one tenant should not cost the failure of others). In principle, the nature of such a decision-making algorithm can range from a greedy heuristic to a complex cognitive form.

- Reaction: Upon making a decision, the management/orchestration system needs to coordinate the interaction with the other lower level modules such as Element Management System (EMS), Virtual Network Function Manager (VNFM) and Virtual Infrastructure Manager (VIM), to react appropriately.

Ensuring QoS in the SESAME multi-tenant cloud-*enabled* RAN is the main focus of WP5 and WP6 of the project. The proposed solution to ensure the QoS in the joint radio cloud environment of SESAME is described as a pseudo-algorithm, where we proposed a performance evaluation of edge cloud services. The evaluation mechanisms are based on two types of actions:

i- **Preventive (proactive) action:** Foreseeing saturation levels that can potentially lead to QoS breaches, warning alerts are sent to the appropriate management module for it to consider performing corrective actions, e.g. VNF scaling, *and*;

ii- **Correction (reactive) action:** In case of breach in the QoS, violation alerts are reported to be analysed and corrected, *if possible*. Figure 8 depicts the SESAME proposed QoS insurance feedback solution.

Network Services in SESAME are composed of a SC-PNF, a SC-VNF and a chain of service VNFs, which are described in the Network Service Descriptor (NSD). Therefore, in the monitoring phase, the proposed solution (Figure 8), will retrieve metrics from both cloud and radio parameters. The Metric Aggregator (MA), as its name indicates, is the function responsible for combining and filtering the collected monitored parameters and associating them with the running services over the SESAME platform. The Metric Aggregator continuously processes the collected monitoring values for the QoS or SLA evaluation. Depending on the dedicated use case, the algorithm used for this purpose might be a simple threshold checking logic or a complex multi attribute decision-making process. Bearing in mind its fast processing time, we select the threshold checking procedure. To this end, a threshold (i.e., Warning Threshold - WT) is defined for each of the monitored metrics, aiming to detect the critical values per case and trigger a warning alert for the specific failure component. Note that, WTs are defined in a way that the multi-tenant capabilities of the system are taken into account. In this sense, the proposed solution is inflexible, that is values of WTs will not adapt dynamically according to the real-time needs of the system. Having said that, SESAME has targeted the introduction of a more complete solution.

In conjunction with a more complex data process, SESAME envisioned a module denoted as the Decision Support System (DSS), as shown in Figure 8. The main responsibility of DSS is to detect the level of severity on the QoS evaluation process done in MA and decide whether a reactive -or a proactive- action is needed. Basically, such a decision will be made based on the high level SLA agreements made with the VNOs. Such an agreement will indicate points such as at what PoP (point of presence) a VNO will be present, how much of overall IT resources are dedicated to a VNO, etc. With the help of DSS, the SESAME solution, in addition to the “per NS (Network Service) performance metrics”, will bring in the high level SLA agreements into calculations.

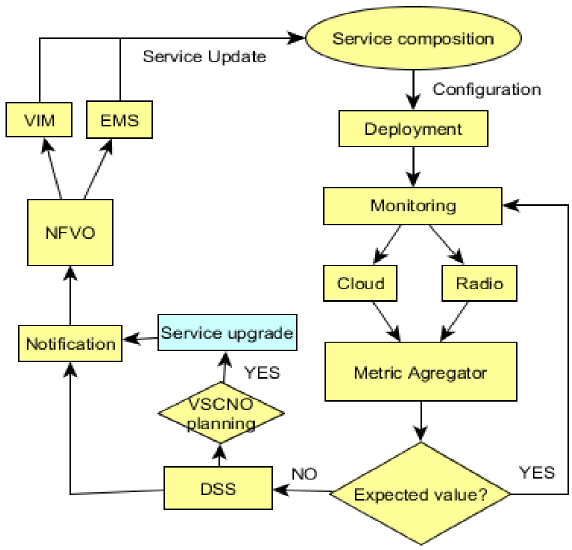

Figure 8: SESAME QoS insurance feedback loop

NFVO (Network Function Virtualisation Orchestrator) is the responsible module to perform the appropriate reaction, based on the analysis made in the previous steps. There are a set of possible reaction mechanisms, including:

- i- Reconfiguring the flow of data in a NS (i.e. changing the SDN rules),
- ii- migrating the NS within the point of presence (PoP) or from one PoP to another,
- iii- scaling up/down the whole NS (i.e. instantiation of a parallel service or terminating a running one),
- iv- scale in/out of VNF (i.e. adding more resources to a VNF).

Depending on the nature of requested process (proactive/reactive), nature of warning (radio/cloud), available resources, possibilities of VNFs indicated in the VNFD by developers, NS agreement with VNO depicted on NSD, the NFVO selects and applies a reaction mechanism. Figure 8, also depicts the workflow of the reaction process. That is, the NFVO has the possibility to interact with the EMS (thus managing the radio parameters of SC or SCs) and/or VIM (thus managing the cloud infrastructure – e.g., OpenStack). In this sense, EMS and VIM are the enablers' components for the adaptation service of the NFVO on cloud- and/or radio-domain. It is worth noting that, in a more advance scenario, EMS and VIM can also be enhanced with "Self-X" features, aiming to enable them so that to make local decisions for a CESC or a set of CESCs (sub set of Light DC).

From the infrastructure owner's perspective, besides the status of each provided service, the overall system performance is also highly relevant; therefore, MA is also able to "expose" general information about the system status. This information helps the infrastructure owner to perform a temporary capacity upgrade, if the expected use of resources does not "meet" planned terms (e.g., due to overloaded use of services / users). The data can be seen visually from the CESCM Portal through, *for example*, a customized dashboard.

The preliminary result of the integrated SESAME QoS solution has been presented on the SESAME EuCNC 2017 demo in Oulu, Finland. In addition, based on the SESAME consortium decisions, new showcases will be presented on the future SESAME demos, (e.g., on the final SESAME demo).

Spectrum Sharing and Security Issues

Spectrum Sharing

Shared spectrum solutions are receiving increased interest recently, due the extremely high cost and scarcity of dedicated licenced spectrum bands. It is expected that efficient use of spectrum in 5G networks will rely on sharing rather than exclusive licenses, to ease congestion in licensed bands and to increase capacity. Potential methods for mutually acceptable spectrum sharing strategies in SESAME, include looking up a central database with current location to find the permitted frequencies, RF power levels, etc. To ensure maximum density with least interference, a more complex approach involves measurement of building penetration loss plus terrain path-loss models which are both necessary to estimate interference accurately.

A reported spectrum sharing mechanism than can be implemented in SESAME is the so-called Co-primary Spectrum Sharing (CoPSS) where any operator is allowed to use shared spectrum. In CoPSS, primary license holders agree on the joint use of -or parts of- their licensed spectrum. This can be suitable for dense small cells, especially when base stations (BSs) have a limited coverage similar to that of WiFi access points and the frequency is dedicated to small cell use.

Inter-operator spectrum sharing and management strategies for SESAME are ideally implemented in a centralised way at the light DC to set the allocated frequency (-ies) and power levels for each small cell. The main factors needed to set a spectrum management methodology are: (i) The percentage of spectrum allowed to be shared for each operator, and; (ii) The locations of small cells to find and set permitted frequencies and RF power levels.

Security Issues

Security challenges of 5G networks are not only due to virtualisation, but also due to the different security requirements identified at different network domains. Therefore, an effective security management system is required to “address” these challenges. The security management system should be able to provide robust authentication and authorisation, to control any unauthorised access and abuse to the Northbound interface and controllers. The Northbound interface is an abstraction layer to the internal modules of the Network Function Virtualisation Orchestrator. To guarantee confidentiality, security and integrity in the multi-tenant environment, tenant isolation should be instigated at different network domains. To define security requirements for CESC, we concentrate on security requirements of the Northbound interface and the Orchestrator. Securing the Northbound interface means securing communication with the external elements, while securing the Orchestrator implicates for securing the entire management of the system.

The SESAME security requirement and security threats analyses have been carried out in two sub-sections. In the first part, the *SecTro (Security Tropos)* security modelling tool was used to identify the SESAME system architecture as well as to analyse the most important security requirements. The second part deals with the system potential security threats analysis using *STRIDE* threat modelling. The identified threats were then incorporated into the *SecTro* model for in-depth threat analysis and the security mitigations.

The *SecTro* is a security analysis modelling tool that allows user to model and analyse security requirements and objectives of a system. The main aim of

this methodology is to support capturing, analysing and identifying security requirements of a system at the early stage of the development process. It also allows system developers to analyse and identify potential security threats. An application can send commands to the controller through the Northbound Interface in order to control the network. To prevent security breaches in this interface, every call to the NFVO needs to be secured by having only authorised users and modules to execute such call. Threats can be identified using different methods.

The *STRIDE* threat modelling is used to identify potential security threat in the SESAME architecture. There are number of threat vectors related to the Northbound interface, which are categorised as: (i) Vulnerabilities and attacks against controllers and applications, *and*; (ii) Lack of mechanisms to ensure trust between the controller and management applications.

Integration and Demonstration

The individual components that need to be integrated to be able to test and validate the proposed use cases are the following:

- Light DC infrastructure
- VIM
- SDN Controller
- NFV Orchestrator
- Rest of CESCM components (such as EMS and SLA monitoring)

Light DC infrastructure

It is composed by the micro-servers of each CESC and creates the basis upon which SESAME services will be deployed. The platform will be made leveraging both traditional x86 CPU architectures with the more low-power oriented ARM architecture.

The key pieces to which the Light DC will be integrated are the VIM and the SDN Controller. The connectivity with the VIM will allow the correct deployment and management of VNFs, while the SDN Controller will define and establish the networking paths between them, so that to create the services. Once that integration is done, the CESMC, as the upper management layer, will be able to communicate with the VIM to orchestrate the Light DC virtual infrastructure *as a whole*.

VIM

OpenStack is used in SESAME as the Virtual Infrastructure Manager (VIM). The popularity as a *de facto* standard, its open source nature, the available documentation and community support and the prior experience of SESAME partners with it, have been the determining factors for this choice.

The VIM needs to integrate on one hand with the Light DC infrastructure, *as described above*, and with the CESCM. To be able to deploy services in the virtual infrastructure, the VIM needs to abstract to the CESCM and, *in particular*, to the NFVO, all the functionality required to manage the whole lifecycle of VNFs. OpenStack does this by exposing a REST API that can be used to perform any kind of action that could be realized by directly executing commands on a local terminal. This API is secured, which implies that the CESCM components need to be included in the authentication module to be granted the access.

Additionally, there is a required integration of this module with the SDN Controller to extend the OpenStack default functionality, in terms of networking and Service Function Chain (SFC) capabilities.

SDN Controller

The SDN Controller in SESAME is considered as an extension of the VIM that allows the definition, creation and management of virtual networks across VNFs in the Light DC. Therefore, it will require integration with the VIM to act as the main network controller and to obtain information from it, such as the status of the virtual appliances for example; and with the CESCM NFVO which will request the specific service chains that are needed for a service.

The software Netfloc[17] will be used for that purpose, thanks to the Service Function Chaining functionality it provides. It is an open source project that is being developed by one of the SESAME partners, making the integration process easier.

[17] *https://blog.zhaw.ch/icclab/gui-for-netfloc/*

NFVO

The SESAME NFVO is compliant with the ETSI NFV specification and includes the orchestration and VNFM functionality. To perform the lifecycle management of VNFs services, the NFVO will need to be integrated into the CESCM, with the VIM and the SDN Controller.

The base software upon which the NFVO is being built is TeNOR. The development of TeNOR exposes a REST API to perform every command in the NFVO, such as on boarding VNF descriptors, deploy VNFs and get the status of network services.

CESCM components

The CESCM is composed of several pieces, including the orchestrator that manages the use, performance and delivery of services as well as interfaces, EMSs; SLA monitoring and the CESCM Northbound Interface, with external components and the NFVO. Additionally, the connectivity of previous components with the VIM is also considered, in case further management options or data monitoring needs to be extracted from it.

The software that will be used as the basis for the PNF and SC EMS modules is the Network Orchestration System (NOS), a proprietary solution from IP.Access. The NOS is able to handle the PNF configuration of the CESC and will be extended to deal with the virtualized SC VNFs.

Integration, Testing and Demonstration methodology

Regarding the integration and testing phases, a two-phased approach will be applied in respect to the final demonstrations.

Integration methodology

In order to coordinate the integration effort, it is important to select a methodology that guides the process of building a functional architecture from a set of independent modules. For that purpose, an iterative process of incremental steps is to be used in SESAME. The concept of this strategy is based on performing small integration steps, starting from a basic implementation and, *subsequently*, adding pieces and functionality incrementally to the system. Thus, *as a general rule*, the priority for integration will be put in the pieces that build the Light DC and allow managing it, followed by the orchestration of services composed by VNFs and to finalize with the monitoring and SLA evaluation of those services.

By starting the integration before reaching the final version of each of the different pieces in the architecture, the complexity of integrating every module together once they are finished is split into easier steps, where the integration is reduced to smaller sets of instructions. Another benefit of the mentioned approach is that it allows identifying potential incompatibility issues at an earlier stage of the development, thud giving more flexibility to modify -or adapt- the modules. Additionally, in each integration step, the corresponding tests have to be performed to check the correct behaviour of the modules that are being brought together.

Testbed environment

SESAME includes several platforms provided by partners, where to deploy the software and to carry-out the integration and testing work.

Table 3 depicts the available testbeds in the SESAME project, along with their available hardware and software. Further enhancements of the testbeds below will be considered as the project continues.

Table 3: Testbeds in the SESAME project

Partner	Hardware	Software
OTE	3x Dell T310 PowerEdge 3x Dell 9020 NXP per case	Openstack Kilo with 5 nodes (to be upgraded) 1 Gateway 2 Controllers 2 Compute nodes
NCSRD	1 Intel-i5 @ 3.2 GHz 1 NXP Env. Board 2 Raspberry Pi 3	1 All-in-one Openstack Liberty Version
Italtel	2+1 NXP Env. Board FlexPac Industrial portable Workstation (Intel Xeon E5-2630v3) & NVIDIA QUADRO M4000 GPU DGS-1510-20: Gigabit Switch Managed - 20 ports DXS 1210-10TS 10 10GBE ports (8 10GBASE-T, 2 SFP+)	
Athonet	COTS	vEPCs (MOCN)
CNET	1 Dell blade server 6 Open small cells 2 Intel based micro servers	EmPOWER controller

Modules interfaces and interconnection

Due to their popularity and simplicity, most of the software that is being used as the basis for the components in SESAME exposes a REST API. Both OpenStack and TeNOR have a well-documented northbound API through which, prior to an authentication step, a client can access each component's functions. Therefore, to make the integration process easier, REST APIs are going to be used whenever possible in the remaining pieces. The only exception to this is the SC EMS, since the NOS software that is used as the basis implements the standard 3GPP SOAP interface for the configuration of the Small Cell. A simple solution to solve the incompatibility of SOAP and REST interfaces is to develop a proxy that is able to intercept the traffic from one of the sources and translate it to the other, although other possible solutions will be explored.

As an example, Figure 9 below shows a screen of TeNOR software where the OpenStack API endpoint can be specified to be used as the VIM. Under the "configuration" dropdown, there is an option to introduce a Point-of-Present (PoP) which corresponds to a VIM for TeNOR (it is worth noting that, *in general*, TeNOR is able to manage more than one VIM simultaneously). By clicking on the PoP, the dialog below will appear.

The most important item on the dialog is the OpenStack IP which determines where OpenStack is located. TeNOR supports

Openstack Juno version[18] -or higher- and both Keystone[19] v2.0 and v3.0. After the introducing the OpenStack, TeNOR will assign a PoP ID to it. Since for the SESAME prototype only one VIM is considered, the assigned ID will represent the PoP where all services of all tenants (VSCNOs) will be instantiated (i.e., the Light DC).

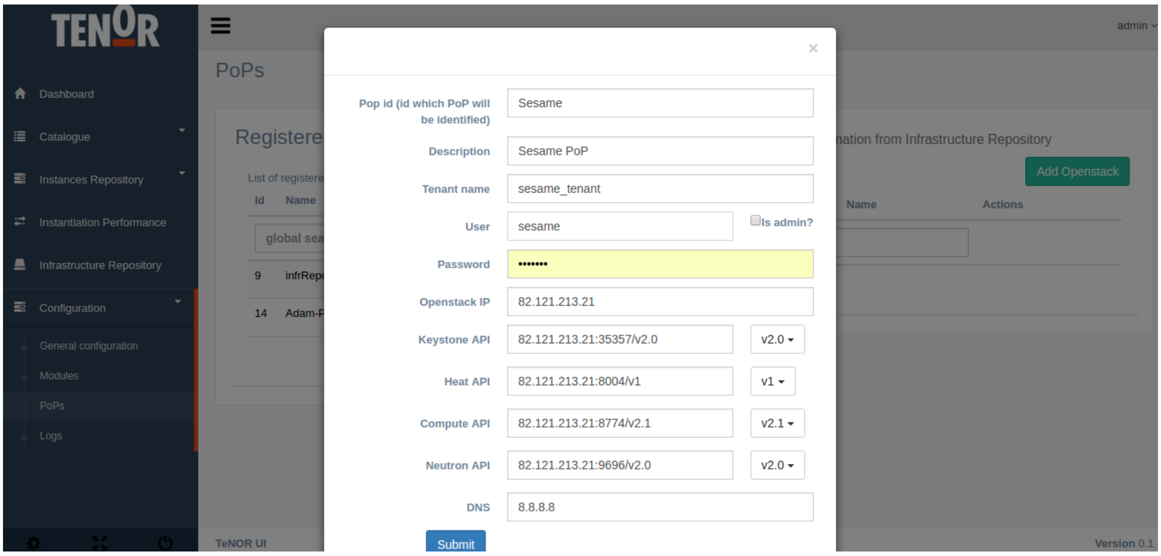

Figure 9: How to make TeNOR communicate with OpenStack

SESAME NFVO

TeNOR GUI has included a "configuration" dropdown which makes the configuration process easy and user-friendly. Besides introducing OpenStack to TeNOR (as explain above), it is possible to assign credentials and access right to the TeNOR users (in SESAME, both SCNO and VSCNO). In the context of SESAME, this is an important configuration step, since the view of SCNO and VSCNOs are different. While SCNO has an overview of all available resources and running services, a VSCNO should have access only on its own services. TeNOR perfectly is able to carry out such separation/isolation.

Light DC

The Light DC is deployed at the edge of the SESAME infrastructure. It is composed of micro-servers that might be attached to a SC PNF, thus forming a CESC. All micro-servers are connected to a common edge network. In this way, they are able to communicate with the SESAME network core, to share resources and enable VNFs running on different hosts to form SFCs. Each micro-server is pre-installed with a software baseline capable of supporting virtualization, accelerated virtual networking, virtualization of hardware accelerators (when those are available on the platform) and set of agents that allow the VIM (OpenStack in the case of SESAME) to manage the node as part of the SESAME NFVI.

The configuration of the node consists of setting up a management network interface and configuring the OpenStack agents according to selected parameters of the infrastructure.

[18] https://releases.openstack.org/juno/

[19] https://wiki.openstack.org/wiki/Keystone

Roadmap to SESAME Success

Due to 5G networks innovative nature, several challenges should be addressed prior to their deployment and successful adoption. These challenges are multi-dimensional, including not only technical aspects but also societal and economic parameters. Thus, the assessment of these multi-disciplinary factors necessitates a clear technology and business roadmap.

The first step towards this direction is to identify and prioritize the factors that will affect the market adoption and evolution of SESAME, through a survey based on the AHP (Analytic Hierarchy Process) methodology.

All partners of SESAME project were invited to participate in the roadmapping thus ensuring a balanced mixture of experts between industry, research institutes and academia. The derived hierarchy, including the main criteria and sub-criteria, is shown in Figure 10.

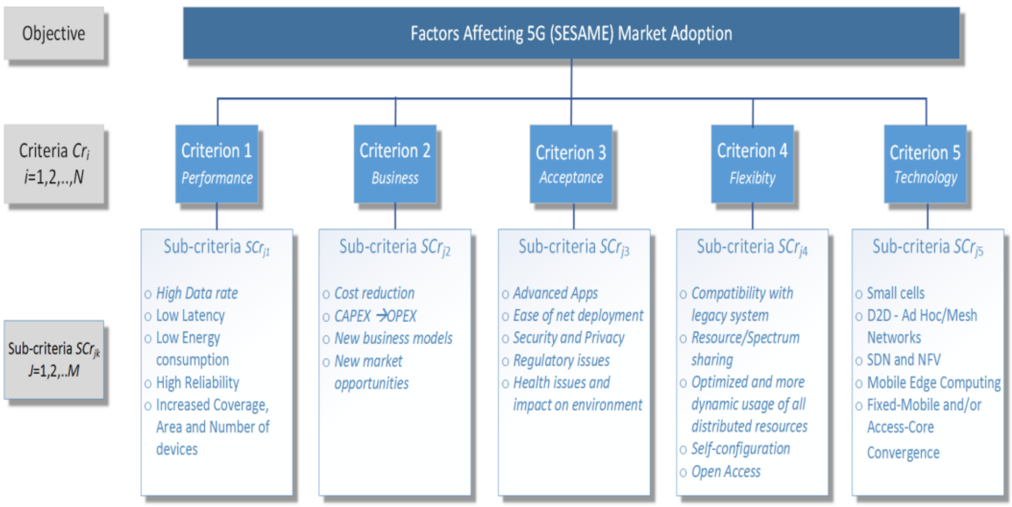

Figure 10: Multi-level hierarchy of interrelated criteria and sub-criteria

According to the opinion of the experts (survey results), business criterion is the most important factor to take into account as its weight reaches 0.31 (or 31%) emphasizing the need for cost-effectiveness as well as opportunities for new entrants. On the one hand, reducing the cost (especially the CAPEX) will greatly affect the business perspectives of 5G networking. A portion of deployment cost reduction is expected to pass to retail prices too. This will further enhance the penetration of 5G technologies, since nowadays people are used to pay reasonable amounts of money for telecom services. Business criteria are very important in any decision making process for telecom products.

Adding new advanced services does not guarantee a market potential, since this must come at the right price. On the other hand, in recent years, the telecoms market seems to have been constantly shrinking and, *therefore*, needs to be rejuvenated and refreshed. In this context, 5G networking is expected to be important in lowering the barriers to entry and helping new players to enter the market.

The performance criterion has the second largest weight (0.26 or 26%). This is also a confirmation of the fact that previous networking paradigms have reached a limit in their performance. Thus, experts are waiting for a new paradigm in order to

support advanced services and applications with increased requirements.

By investigating the global ranking of sub-criteria, the most important factors affecting the adoption and evolution of SESAME -and 5G networks in general- are cost reduction, low latency, optimized and more dynamic usage of all distributed resources, high reliability and new market opportunities. Essential sub-criteria constitute furthermore CAPEX transforming to OPEX, as well as new business models. This purely suggests that 5G should be designed in order to fulfil a number of diverse sub-criteria.

The high ranking of cost reduction is not surprising, as the cost of deployment is very important since it will influence service prices leading to increased -or decreased- penetration. In addition, the experts seem more concerned about low latency in view of the many new advanced applications and services, where latency requirements are very tight and crucial. In addition, verticals such as e-health and automotive are expecting low latency, in order to support their particular use cases.

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