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On Implementing RRM/SON in Virtualized Multi-Tenant Small Cell Networks

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Abstract—**This paper addresses the implementation of Radio Resource Management (RRM) and Self-Organizing Networks (SON) functions in virtualized multi-tenant small cell networks. In this context, the deployment and operation of RRM/SON functions as virtualized services facilitates the customization of the Radio Access Network (RAN) on a per-tenant basis. Specifically, this paper develops the architectural and functional framework for virtualizing RRM/SON functions, together with the illustration of some examples assessing the orders of magnitude of the requirements of the involved Virtual Network Functions (VNF).**

Keywords—Multi-tenancy; Small Cells; Radio Resource Management; Self-X; Virtual Network Functions

I. INTRODUCTION

Multi-tenant Radio Access Networks (RAN), in which a wireless network infrastructure is shared among multiple service providers, are envisaged to be beneficial in high traffic localised scenarios where dedicated operator deployments become impractical. The deployment of multi-tenant RANs in future Fifth Generation (5G) systems is expected to be fuelled by the inherent flexibility associated to the introduction of Network Function Virtualization (NFV) technologies in the RAN through the software implementation of network functions running on general purpose computing/storage resources [1]. The advent of the NFV paradigm provides an inherent capability to add new functionalities, extend, upgrade or evolve existing functionalities and to customize the RAN on a per-tenant basis. Given that 5G systems are envisaged to support a wide range of business models and vertical markets with very diverse performance and functional requirements [2], RAN customization arises as an essential capability for 5G.

The customization of a RAN on a per-tenant basis requires the implementation of "network slicing" mechanisms, which enable the deployment and operation of multiple logical networks over a common physical network infrastructure [2][3]. By ensuring isolation among "network slices" (i.e., one tenant's traffic do not affect the performance observed by another tenant) [3], customisation to best serve the needs of specific applications (e.g. mobile broadband, Internet of Things applications) and/or tenants (e.g. enterprises, service providers, content providers, etc., across different sectors such as public safety, utilities, smart city, automotive, etc.) is greatly facilitated [4].

RAN customisation is strongly related to Radio Resource Management (RRM) and Self-Organizing Network (SON) functions [4][5]. A given set of RRM/SON algorithms implements and enforces a set of pre-established policies (e.g. mobility policies, service usage policies) and operational constraints (e.g. capacity limitations).

In this context, the design and implementation of RRM/SON solutions for 5G face radical changes compared to the legacy 3G/4G *status quo*. On the one hand, a shared radio interface among multiple users from diverse tenants requires advanced RRM/SON algorithms able to ensure a fair and efficient usage of the radio resources. On the other hand, RRM/SON functions can be implemented in a highly flexible and customizable way by exploiting the NFV paradigm, opening the door for more open markets where third-parties could provide RRM/SON solutions that can be flexibly implemented in the network. Therefore, there is the opportunity for substantial innovation in the way that RRM/SON functions are conceived and brought to the market.

The provision of RRM/SON as virtualized functions for small cell networks is identified as one of the possible use cases by the Small Cell Forum [6]. In [7], virtualization of RRM/SON functions is considered in the context of a cloud-RAN, emphasizing the benefits of centralization, while [8] presents some considerations in relation to the implications of the functional split between virtualized and physical functions with respect to some RRM functions. Overall, [6]-[8] reflect industrial interest and fuel further work in this direction, particularly in the area of multi-tenant networks, where no tangible and publicly available outcomes have been produced to date.

Based on the above, the contributions of this paper are (i) to propose a framework for implementing virtualized RRM/SON functions in multi-tenant small cell networks and (ii) to illustrate this framework with specific examples, assessing the orders of magnitude of the requirements of the involved Virtual Network Functions (VNFs). The paper takes as a reference the architecture considered in the Small cEllS coordinAtion for Multi-tenancy and Edge services (SESAME) project [9], which intends the provision of multi-tenant Small Cells as a Service (SCaaS) and relies on a virtualized execution environment at the network edge.

The rest of the paper is organized as follows. Section II describes the architecture of the SESAME project. Section III presents the framework for virtualizing RRM/SON functions in multi-tenant small cells. Section IV discusses some illustrative RRM/SON functions that can be virtualized. Finally Section V summarizes the conclusions.

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II. SESAME ARCHITECTURE

Fig. 1 depicts the main components of the SESAME architecture for provisioning SCaaS with Mobile Edge Computing (MEC) capabilities in multi-tenant environments [9]. In general terms, SESAME scenarios assume a certain venue (e.g. a mall, a stadium, an enterprise, etc.) where a Small Cell Network Operator (SCNO) has deployed a number of small cells (SC) to provide wireless access to end users of different tenants through a SCaaS model.

The architecture of Fig. 1 relies on the Cloud Enabled Small Cell (CESC) concept, a new multi-operator enabled small cell that integrates a virtualized execution platform for executing novel applications and services inside the access network infrastructure. A CESC consists of a Small Cell Physical Network Function (SC PNF) unit, where a subset of the SC functionality is implemented via tightly coupled software and hardware, and a micro server that supports the execution of VNFs, which provide the rest of the SC functionality together with other added-value services.

The CESCs support the Multi-Operator Core Network (MOCN) sharing model of 3GPP [10], which allows them to offer access over shared radio channels to multiple operators' core networks. Accordingly, each CESC is connected with the Evolved Packet Core (EPC) of each tenant through an S1 interface.

The physical aggregation of a set of CESCs, denoted as a CESC cluster, gives the possibility to jointly operate the computational, storage and networking resources of the micro servers as a single virtualised execution infrastructure, denoted as Light Data Centre (Light DC). To compose the Light DC, the different CESCs are connected to a centralized Ethernet switch.

In the specific SESAME prototyping environment, a micro server consists of an Advanced Reduced instruction set computer Machine (ARM)-based System-on-Chip (SoC) including a multicore 64-bit ARM Central Processing Unit (CPU) with integrated HardWare (HW) accelerators and integrated fabric for Input/Output (I/O) communication. Then, the main capabilities of each micro server are defined by the number of CPU cores N_C and their operating frequency F(GHz) as well as by the total available memory M(GB). For example, the NXP Freescale LS2085A [11] has N_c=8 cores at F=1.8 GHz and M=16 GB. Similarly, the ST Barcelona board [11] has N_c=4 cores at F=1.3 GHz and M=8 GB.

A number of VNFs can be executed in the Network Function Virtualisation Infrastructure (NFVI) constituted by the Light DC. The functionalities of a VNF are implemented in software modules that run on one or more Virtual Machines (VMs) - or containers-. The VMs are instantiated on the physical CPUs of the Light DC through a hypervisor that partitions and abstracts the underlying physical resources. The use of VM allows hiding the HW infrastructure while offering the same sort of resources (processor, memory/storage, interfaces/ports) of a physical server to SoftWare (SW) developers.

The subset of the SC functionality that is embedded in the SC PNF and the subset that is run externally as VNFs depend on the selected functional split. Different functional splits are discussed in [6] following the layering architecture of the radio interface protocol stack. Each micro server allows the execution of the VNFs with the SC functionality associated with the locally attached SC PNF as well as other VNFs devoted to provide virtualised service-level functions within the CESC cluster (e.g. deep packet inspection, caching, etc.).

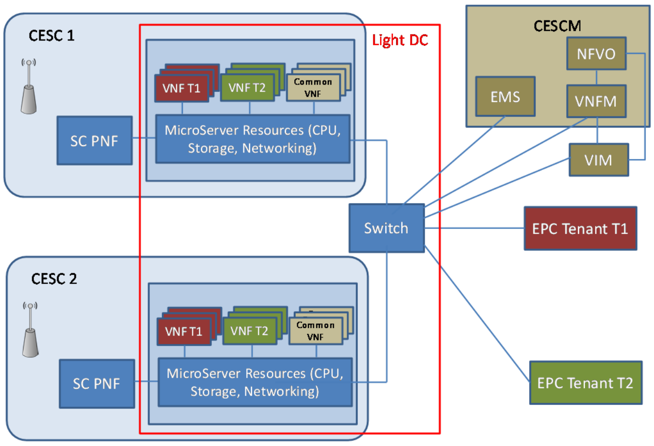

Fig. 1. SESAME architecture components

As illustrated in Fig. 1 with different colours, the VNFs running in the Light DC can be tenant-specific, i.e. they only handle traffic from a single tenant, or they can be common, meaning that they handle traffic and/or support procedures that are common to all the tenants. The communication among the different VNFs running in a micro server and among these VNFs and the local SC PNF is performed by means of a virtual switch running in the micro server (e.g. based on OpenVSwitch [12]).

The CESC Manager (CESCM) is the central service management component in the architecture that integrates the traditional 3GPP network management elements and the novel functional blocks of the NFV-MANO (Network Function Virtualization Management and Orchestration) framework. Configuration, Fault and Performance management of the SC PNFs and VNFs is performed through the Element Management System (EMS). In turn, the lifecycle management of the VNFs is carried out by the VNF Manager (VNFM), while the Network Functions Virtualization Orchestrator (NFVO) composes service chains constituted by one or more VNFs running in one or several CESCs and manages the deployment of VNFs over the Light DC with the support of the Virtualized Infrastructure Manager (VIM).

The VIM creates an abstraction layer to the CESCM of all the physical resources in the Light DC, managing the lifecycle of VMs and providing the virtual links among VMs and VNFs. The VIM includes a Software Defined Network (SDN) controller in charge of setting up the virtual networks on the physical infrastructure, configuring the virtual switches in the micro server so that the different VNFs can communicate. SESAME uses OpenStack as the VIM platform [9].

The mapping between VMs and VNFs is performed by the VIM. For this purpose, the process has to take into account the requirements of each VNF, expressed in terms of the CPU requirements C_{VNF}(GHz) and the memory/storage requirements M_{VNF}(GB) and the capabilities of the instantiated VMs.

III. RRM/SON FUNCTIONS IN VIRTUALIZED MULTI-TENANT SMALL CELLS

The dynamic management of the radio resources in a cellular network is carried out by a set of Radio Resource Management (RRM) functions aimed to ensure the efficient use of the resources while at the same time meeting the Quality of Service (QoS) requirements of the services provided to the users. Examples of these functionalities include the Admission Control (AC), Mobility Control (i.e. handover), Congestion Control, Packet Scheduling (PS), etc. Each RRM function is implemented as a decision-making logic. Traditionally, RRM algorithms are vendor-specific.

The parameters of each RRM function should be properly configured to achieve an efficient operation of this function. This configuration can be static, e.g. specified by the EMS when the radio network is activated, or it can be dynamically and automatically modified at runtime by means of a Self-Organizing Network (SON) function. In general, SON refers to a set of features and capabilities for automating the operation of a network [5]. SON functions can automatically tune global operational settings of the radio cells (e.g., maximum transmit power, channel bandwidth, electrical antenna tilt) as well as parameters corresponding to RRM functions (e.g., admission control threshold, handover offsets, etc.).

From an architectural perspective, SON functions can be: (i) centralized SON (cSON), meaning that the SON algorithm is executed at the network management level (e.g. at the EMS); (ii) distributed (dSON), meaning that the SON algorithm resides at the small cells; or (iii) hybrid SON, meaning that part of the functions are distributed and part are centralized.

Given that RRM/SON mechanisms have a strong and direct impact on the RAN performance, the development of RRM/SON algorithms adds an important value to the vendor equipment.

A. *Virtualized RRM/SON functions*

The introduction of virtualization technologies enables the possibility of implementing RRM/SON functions as virtualized services [6]. Virtualizing RRM/SON functions in scenarios like those of SESAME has multiple potential benefits, such as (i) scalability and flexibility in how RRM/SON functions are deployed within a CESC cluster, thanks to the capability of adding/removing the services as required, where and when needed and to upgrade them without hardware/firmware changes of the radio equipment; (ii) ease of integration of RRM/SON solutions from multiple vendors if common interfaces are adopted, which facilitates a more open market where third-parties could provide RRM/SON components to be flexibly plugged into the network; (iii) higher efficiency in power consumption by centralizing functions in some micro servers of the Light DC; (iv) more flexibility in accommodating variable computation requirements of the RRM/SON functions by scaling up/down the amount of resources allocated to them across the LightDC micro servers.

B. *Radio Network Information Service (RNIS)*

The implementation of RRM/SON functions as VNFs requires that radio network related information available within the small cells be accessed by these functions. In order to avoid separate access to the same information from multiple deployed RRM/SON functions, a common VNF to interact with the different components embedding the SC functionality is considered. In this way, this common VNF handles the acquisition, processing and collection of different measurements to monitor the status of the RAN and the User Equipment (UE) and exposes them to the RRM/SON functions. The exposed information could contain a wide range of metrics such as measurements and statistics information related to the user plane, information related to UEs served by the cells, cell load, throughput measurements, etc., delivered at the relevant granularity (e.g. per UE, per cell, per period of time). Moreover, the radio network information could be profiled according to the specific needs of each RRM/SON function.

In general, most of the measurements to be collected for RRM/SON functions are Layer 2 measurements [14]. Therefore, within the prototyping framework in SESAME project, which assumes a functional split at the S1 interface so that the SC PNF includes the whole radio protocol stack, these measurements are performed within the SC PNF. Therefore, these measurements can be obtained in SESAME from the SC PNF by means of Performance Management (PM) reports in the form of eXtensible Markup Language (XML) files including the measurements specified in [15] through a management interface such as the TR-069 [16]. The PM file upload is controlled by the parameters defined in [17], which allow specifying the destination (e.g. the address of the common VNF for measurements collection) and the periodicity of the file upload. On the other hand, while the interaction between the common VNF and the SC PNF could be conditioned by vendor specific implementation of the SC PNF management interface, the approach for the common VNF to expose the radio network information is the adoption of open interfaces, in line with the on-going work in European Telecommunications Standardization Institute (ETSI) about the Radio Network Information Service (RNIS) defined in [13] for MEC applications. Based on this, in the following we adopt the terminology RNIS to refer to the abovementioned common VNF.

In a multi-tenant scenario, the RNIS should in general provide both an aggregated view of a cell, composed of measurements aggregated for all the tenants, and an individual tenant view, composed of measurements that are split on a per-tenant basis and characterize the performance associated to the UEs of a single tenant.

C. *Multi-tenant virtualized RRM/SON functions*

Beyond the general benefits of virtualization mentioned in Section II.A, the design and implementation of virtualized RRM/SON functions in multi-tenant scenarios provides additional degrees of flexibility by facilitating the capability of customizing the RAN on a per-tenant basis depending on which RRM/SON functions are instantiated for each tenant.

An RRM/SON function can be instantiated on a per-tenant basis as long as isolation mechanisms are in place with respect to the resources/parameters managed by that specific function [4]. Isolation means that the decisions taken by a tenant's RRM/SON function do not impact on the performance observed by other tenants. If isolation is not ensured, a common RRM/SON solution is necessary for all the tenants.

For example, let us consider a Coverage and Capacity

Optimization (CCO) SON function that dynamically adjusts the tilt of a cell. Since a change in the tilt will impact on all the users in the cell regardless of the tenant they belong to, this function must be common to all tenants. In this case, this function will typically be implemented in a *tenant-agnostic* way, meaning that only aggregated measurements (e.g., power measurements received from all the UEs in a cell regardless of the tenant they belong to) from the RNIS will be used as inputs.

Instead, let us consider an Admission Control (AC) function that decides to accept or reject the Radio Access Bearers (RABs) of the UEs of the different tenants. If the radio resources used by the different tenants are isolated (i.e., each tenant uses a different orthogonal set of time/frequency resources), it is possible to instantiate different tenant-specific AC functions, so that each tenant can apply its own admission criteria. In this case, the AC will get a *tenant-specific* view of the measurements provided by the RNIS (e.g., amount of free physical resources in relation to the total set of resources allocated to this tenant).

As an additional example, let us consider a Packet Scheduling (PS) function that manages a set of time/frequency resources that are shared among several tenants. The PS decision making logic must be a common function, although the implementation of the function will typically be *tenant-aware* (i.e., it will be based on both aggregated and per-tenant measurements), so that the assignment of physical resources to a specific UE will take into account both how many resources are available as well as how many resources have already been occupied by other UEs from the same tenant.

Through the above examples, Fig. 2 illustrates a particularisation of the general architecture of Fig. 1 focusing on the VNFs that compose the RRM/SON services. The figure depicts the tenant-specific RRM/SON VNFs in different colours for tenant T1 and T2, while the common RRM/SON VNFs are depicted in brown. Furthermore, Fig. 2 illustrates that the RNIS will provide the necessary measurements to the different VNFs.

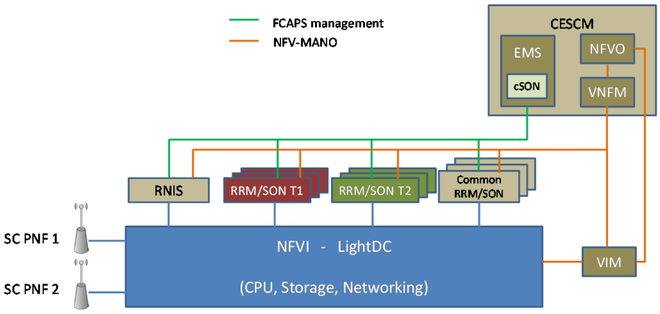

Fig. 2. Virtualized RRM/SON functions in a multi-tenant environment

D. *Management of Virtualized RRM/SON functions*

The management of the RNIS VNF and the RRM/SON VNFs depicted in Fig. 2 involves two different frameworks, namely the Fault, Configuration, Accounting, Performance and Security (FCAPS) management and the NFV-MANO.

The FCAPS management is performed by the EMS and includes a set of functions for configuration and re-configuration of the operational parameters of the RNIS VNF and the different RRM/SON functions (e.g. adjusting parameters and thresholds of the AC, handover, etc.) or for the collection of PM measurements characterizing the operation of these functions (e.g. number of successfully established RABs, etc.).

The NFV-MANO involves the management functionalities provided by the NFVO, VNFM and VIM to support the lifecycle management of these VNFs (e.g. instantiation, scaling, termination) as well as of the entire Network Services (NS) in which the VNFs are chained as components across the Light DC.

NFV-MANO uses different templates to describe the components and the connectivity of a NS [1]. The Network Service Descriptor (NSD) template is used by the NFVO and describes the NS topology (constituent VNFs, virtual links between VNFs and VNF forwarding graphs) and the NS characteristics (e.g. functional scripts and workflows for initializing, terminating and scaling the NS. For example, in the framework of Fig. 2 the NSD for implementing a RRM/SON function as a virtualized NS can involve the SC-PNF, the RNIS VNF and one RRM/SON VNF. Each one of these VNFs will be defined by means of a VNF Descriptor (VNFD), a template that specifies the deployment and operational behaviour requirements of the VNF and includes the functional scripts for lifecycle events of this VNF (initialization, termination, scaling). Similarly, the SC-PNF will be defined by means of a PNF Descriptor (PNFD).

The topology of the NS is defined by the VNF Forwarding Graph (VNFFG) that specifies how the different VNFs and PNFs are interconnected. A VNFFG is specified through its corresponding VNFFG Descriptor (VNFFGD). Finally, each of the connections in the VNFFG requires a virtual link (VL) defined by means of the Virtual Link Descriptor (VLD), a template that specifies the connectivity, interface and requirements of these virtual links.

In the context of SESAME prototyping framework, which has adopted the TeNOR orchestrator and OpenStack as VIM [9], the abovementioned NSD, VNFD, PNFD, VNFFGD and VLD descriptors are defined as Heat OpenStack Templates (HOT), in order to be forwarded to the OpenStack VIM.

When a NS has to be created, the NFVO translates the descriptors into HOT templates that are sent to the VIM and the VNFM. The VIM manages the NFVI to map the different NS components into the actual hardware (i.e. it creates the VMs, decides the mapping between VNFs and VMs and sets up the virtual links to connect the VNFs). Once completed, the VIM notifies the VNFM so that it can take care of the VNF lifecycle management. At this stage, the VNFM will instantiate the VNFs and will monitor their behaviour based on collecting performance measurements from the VNFs and from the VMs used by these VNFs. The process is illustrated in Fig. 3.

IV. EXAMPLES OF RRM/SON USE CASES

This section intends to illustrate the implementation-related aspects of specific RRM/SON functions under the framework described previously in sections II and III.

A. *Admission Control*

The considered AC function (described in [18]) runs at each CESC as a common RRM/SON VNF and makes the acceptance/rejection decisions of the RAB establishments of the different tenants. This allows keeping the SC PNF functionality as tenant-agnostic with respect to the admission of RABs. Such AC involves two different checks: (i) a capacity check at cell-level, to evaluate the aggregated number of Physical Resource Blocks (PRB) used by all the tenants in a cell after accepting the new RAB request and ensure that the cell has sufficient physical resources for serving the new RAB and, (ii) the per-tenant capacity share check, to establish an upper bound in the PRB usage by the RABs of a tenant in accordance with the capacity contracted through the SLA. In order to adapt to different network conditions, the AC VNF includes a dSON function used to dynamically modify the thresholds used in the abovementioned checks. The adjustments made by the dSON are supported by a cSON function, which runs at the EMS and has an overall view encompassing multiple cells.

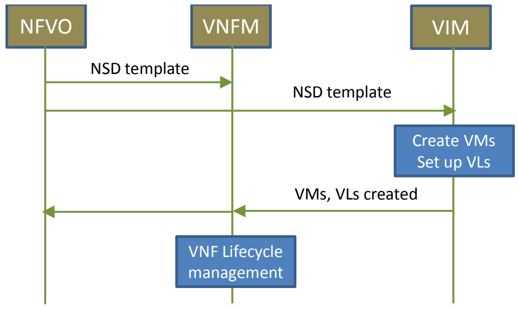

Fig. 3. NFV MANO process for creating a network service

The RNIS provides the common AC VNF with the average number of PRBs used by each tenant. This measurement can be obtained by extending the "PRB usage for traffic" measurement of [15] to include per-tenant measurements. Similarly, in order to estimate the amount of PRBs required by a new RAB with specific bit rate requirements, the RNIS provides an estimation of the average bit rate per PRB that can be obtained in the cell. This estimation can be obtained by dividing the aggregate IP throughput of the cell by the aggregate PRBs that have been allocated for transmission (see [18] for further details).

Table I illustrates the order of magnitude of the requirements associated to the VNFs of this example, i.e. the VNF implementing the AC decision making and the dSON and the VNF implementing the RNIS. Computations are based on the averaging window parameters defined in [18] for a scenario with 2 tenants. In particular, it is assumed that PRB usage measurements are provided by the RNIS in periods of 0.1s, while the dSON should store multiple samples and average them to makes adjustments of the thresholds every 300s. The computational requirements of the AC checks are dependent on the RAB arrival rate in a cell, for which a rate of 1 request/s has been considered for each tenant.

B. Coverage and Capacity Optimisation

CCO is a SON function that targets a continuous coverage and the provision of a sufficient achievable bit rate in the service area. This function operates by adjusting RF parameters of the cells, such as the downlink transmit power, the antenna tilt and the antenna azimuth. A typical operation of CCO consists in identifying specific symptoms such as coverage holes, cell overshoots or excessive cell overlaps and then to trigger an optimization process, e.g. by exploring different candidate configurations of the adjusted parameters through techniques like genetic algorithms or particle swarm [19].

Centralized implementations of this function are typically considered [20] since the optimization should be made jointly considering multiple cells in the service area. Therefore, the CCO would be implemented as a cSON function residing in the EMS, which in turn is part of the CESCM. Anyway, the CCO cSON function can benefit from the availability of the RNIS VNF running at the Light DC, which can provide local information about the coverage conditions in each cell.

In particular, the RNIS collects measurements from the SC-PNF (e.g. measurements performed by the RAN and UE reported measurements such as Reference Signal Received Power (RSRP), Reference Signal Received Quality (RSRQ) and Received Signal Strength Indication (RSSI)). This collection imposes requirements mainly in terms of memory and networking capabilities in the VL between the RNIS VNF and the SC PNF.

Table I provides an estimation of the RNIS requirements, assuming small cells with coverage radius of 100m and that the coverage is characterized in pixels of 5m x 5m. Besides, it is assumed that the RNIS provides storage capabilities to accumulate measurement reports for a period of 24h that are used in the coverage estimation per pixel. It is assumed that UEs provide an average of 1 RRC Measurement Report per second. As for the computational requirements, the RNIS will have to perform a high number of operations to process the measurements and characterize each pixel. However, given that the operation is in a long term basis, a relatively low computational complexity is envisaged and, in addition, the processing work can be scheduled during the times when the CPUs are less occupied. Similarly, the VL between the RNIS and the cSON does not pose tight requirements because, even if a large file characterizing all the pixels has to be provided to cSON, the transmission can be done without stringent delay constraints and only very sporadically when triggered by the cSON.

TABLE I. REQUIREMENTS OF THE VNFS INVOLVED IN THE CONSIDERED EXAMPLES

		Computation	Memory	Networking
AC	AC VNF (including dSON)	~ 100 ops/s	~ 10 KB	~ 200 b/s (RNIS-AC)
	RNIS	~100 ops/s	~ 10 KB	~ 1 kb/s (SC PNF - RNIS)
CCO	RNIS	~10^3 ops/s	~ 10 MB	~1 kb/s (SC PNF - RNIS and RNIS-cSON)
PS	PS VNF	~10^7 ops/s	~ 10 MB	~ 150 Mb/s (PS VNF - SC PNF)

C. Packet Scheduling

The PS function is responsible of assigning the PRBs of a cell among the different UEs served by that cell and to select the physical layer parameters used for each transmission (e.g.

modulation and coding scheme, antenna mapping in case of multi-antenna transmission). PS operates with a time granularity given by the Transmission Time Interval (TTI), which currently is 1 ms in Long Term Evolution (LTE).

The PS is executed at the Medium Access Control (MAC) layer. Therefore, since SESAME prototyping framework assumes a functional split at the S1 interface, the PS would be part of the SC PNF. Anyway, from a more general perspective, this sub-section assumes the possibility of using other functional splits. Specifically, the functional split between MAC and PHY enables a scenario in which a single SC PNF implementing the PHY layer with multi-carrier support can be logically partitioned into multiple instances, each one associated with one or several LTE carriers/RF chains, while the MAC and above layers for each of these instances are implemented as VNFs. In this case, each tenant can be allocated with a different SC PNF instance [21], thus providing isolation between tenants, while the VNFs can be made tenant-specific. This facilitates the implementation of tenant-specific PS VNFs, so that each tenant can customise the PS criteria for assigning PRBs to its own UEs. With this functional split, the interconnection of the PHY layer of one tenant with its corresponding VNFs is done through the network Functional Application Platform Interface (nFAPI) [22].

A tenant-specific PS VNF typically operates based on the instantaneous Channel Quality Indicators (CQI) reported by the UEs and on the information about the buffer status. Besides, the tenant-specific PS VNF should also deliver the scheduled data packets to the SC PNF. The transmission of this information across the nFAPI interface poses high networking requirements for the VL between the SC PNF and the tenant-specific PS VNF. For example, bandwidth requirements in the order of 150 Mb/s and latencies of 2 ms are mentioned in [6]. Storage requirements include both the UE data waiting for transmission in the buffers and the CQI reports of these UEs. Computational complexity in terms of number of operations will be highly dependent on the specific implemented algorithms, but the number of operations will increase in some orders of magnitude with respect to those required by simpler RRM functions like the AC. Besides, the execution of the PS every 1ms puts stronger requirements in terms of the number of operations/s. Table I summarizes some orders of magnitude of the envisaged requirements for the tenant-specific PS VNF.

V. CONCLUSIONS

This paper has proposed a framework for virtualizing RRM/SON functions in multi-tenant small cell networks as considered in the SESAME project. The paper has discussed the role of certain MEC services, such as the RNIS, to support different virtualized RRM/SON functions and has discussed the flexibility of the framework to customize the RAN on a per-tenant basis and adapt to different requirements of each tenant.

The paper has also illustrated the framework by presenting three different examples of RRM/SON functions, namely AC, CCO and PS, illustrating the order of magnitude of the computational, storage and networking requirements of the involved VNFs. Based on the analysis of these examples, it is observed that in most of the functions the computational and memory requirements are quite reduced in relation to the capabilities of the micro servers that compose an execution platform like the one of the SESAME project. This reflects the feasibility to implement packages encompassing multiple RRM/SON functions as a single VNF. Consequently, the virtualization of RRM/SON appears as a feasible option from an implementation point of view, which opens the door to substantial innovation in the way that RRM/SON functions are conceived and brought to the market. Specifically, it is envisaged that virtualization can facilitate more open markets where third-parties could provide RRM/SON solutions that can be easily plugged into the network thanks to the flexibility offered by the NFV-MANO framework.

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