Self-X in SESAME

J. Perez-Romero[(1)], O. Sallent[(1)], C. Ruiz[(2)], A. Betzler[(2)], P. S. Khodashenas[(2)], S. Vahid[(3)], K. M. Nasr[(3)],
B. Abubakar[(4)], A. Whitehead[(5)], L. Goratti[(6)]

[(1)]Universitat Politècnica de Catalunya (UPC), Spain;   [(2)] i2Cat, Spain;   [(3)] University of Surrey, UK;
[(4)] University of Brighton, UK; [(5)] ip.access, UK; [(6)] CREATE-NET, Italy
Contact e-mail: jorperez@tsc.upc.edu

Abstract— **This paper addresses the use of Self-X functions to support Small Cell as a Service (SCaaS) provisioning in multi-tenant scenarios, as one of the main components of the SESAME project. After presenting the scenarios, requirements and architecture of the project, the paper discusses the implications of multi-tenancy on different Self-X functions and describes current studies that are being carried out in the project.**

Keywords—Small cell; SCaaS; multi-tenancy; 5G; Self-X; SON

I. INTRODUCTION

The deployment of small cells (SCs) has been considered as a means to effectively increase the available capacity in high traffic areas as well as locations with poor coverage conditions from outdoor macrocells. In this context, the so-called Small Cells as a Service (SCaaS) model is identified as an adequate solution [1] to facilitate a third-party provisioning of radio access capacity to mobile network operators (MNOs) in localised areas with capacity or coverage issues. The resulting densified network could serve multiple operators in scenarios where dedicated operator deployments are impractical. In that case, the multi-tenancy concept allows that the provisioned small cells are shared between multiple operators, denoted as "tenants", according to specific agreements between the SCaaS provider and each involved tenant.

SCaaS provision is one of the pillars of the Small cEllS coordinAtion for Multi-tenancy and Edge services (SESAME) project [2], which proposes the Cloud-Enabled Small Cell (CESC) concept, a new multi-operator enabled SC that integrates a virtualized execution platform for executing novel applications and services inside the access network infrastructure. 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) is the SCaaS provider that has deployed a number of CESCs that provide wireless access to end users of different operators, denoted as Virtual Small Cell Network Operators (VSCNOs), according to specific Service Level Agreements (SLAs). Radio Access Network (RAN) sharing in SESAME focuses on the Multi-Operator Core Network (MOCN) model [3], where the core networks of the VSCNOs are connected to the SCNO's RAN.

SCaaS provisioning under multi-tenancy is envisaged as a relevant component to fulfil the expected requirements of future 5G networks in highly densified scenarios. The successful delivery of SCaaS involves a number of challenges, such as the planning of the number, locations and configuration of the required SCs and their efficient management to ensure the desired performance goals. To face these challenges, the SCNO can benefit from the inclusion of the following key technologies relevant to SESAME:

- Network Function Virtualization (NFV) refers to the software implementation of network functions running on general purpose computing/storage resources [4]. Therefore, NFV brings the required flexibility to modify network configuration and/or topology in near real time and enables infrastructure sharing between multiple tenants (i.e. mobile operators) through multiple virtual networks (i.e. slices) running on top of the same infrastructure and satisfying the profile and requirements of each operator separately.

- Self-Organizing Networks (SON) refers to a set of features and capabilities, also denoted as Self-X functions, for managing a network designed to reduce or remove the need for manual planning, deployment, optimization and maintenance activities of the network, so that operating costs can be reduced as well as revenue can be protected by minimizing human errors [5]. This automatization will become fundamental to achieve an optimized operation of the SCs in future 5G scenarios, involving a high densification in the number of deployed SCs and stringent capacity, bit rate and delay requirements to be met.

- Mobile Edge Computing (MEC) is a new technology that provides an IT service environment and cloud-computing capabilities at the edge of the mobile network, within the RAN and in close proximity to mobile subscribers [6]. This environment is characterized by ultra-low latency and high bandwidth as well as real-time access to radio network information that can be leveraged by applications. In this way, operators can open their RAN edge to authorized third-parties, allowing them to flexibly and rapidly deploy innovative applications and services towards mobile subscribers, enterprises and vertical segments. Then, it can be envisaged that the management of small cell networks can be enhanced through the capabilities offered by MEC.

Under the above context, the main focus of this paper is on the Self-X functionalities in the framework of SESAME. In particular, the paper presents in Section II the SESAME scenarios and requirements from the perspective of Self-X. Then, Section III discusses how the SESAME architecture integrates the Self-X functions and Section IV discusses different Self-X functions when considered in a multi-tenant scenario. Section V describes on-going studies in SESAME. Finally, concluding remarks are summarized in Section V.

II. SELF-X IN SESAME'S SCENARIOS AND REQUIREMENTS

SESAME has identified in [7] different scenarios and use cases where Self-X features are relevant. The first scenario addresses the SCaaS provision of enterprise services in multi-tenant large business centres. A SCNO deploys an infrastructure of CESCs and enables enterprise users to access different services, optimizing service delivery through Self-X techniques. The second scenario focuses on the mobility of a reference end user generating high-definition real-time content across different CESCs clusters deployed in geographically adjacent areas, and uses Self-X features to seamlessly manage the handover process across neighbouring cells. Finally, the

third scenario considers the sudden concentration of people at a specific geographical location and time of the day, creating an unexpected hot spot zone in which a variety of different traffic types require proper management. In such a situation CESC cluster resources have to be provisioned to each tenant, and in order to efficiently handle the unexpectedly intense traffic generated by the users, Self-X techniques are required.

Based on the above scenarios, SESAME has identified a number of requirements. Requirements with a direct relation to Self-X are summarized in the following:

• Multitenancy: SESAME architecture has to support the operation of different tenants (e.g. VSCNO) sharing the same infrastructure. This means that Self-X functions need to be devised from a multi-tenant perspective and a distinction has to be made between those functions that must be tenant-specific (i.e., the configuration of parameters can differ from tenant to tenant) and those that are common to all tenants. Besides, the control of tenant-specific functions can be performed by the SCNO or it can be exposed to the tenant.

• Component interoperability: Elements in the SESAME architecture have to expose appropriate interfaces to allow component interoperability. In particular, an external API for tenants has to be provided to access the offered functionality and get a view of the portion of the network that they are able to manage (e.g. in the case of Self-X functions whose control is exposed to the tenant).

• Resource monitoring: Monitoring information of both physical and virtual resources is required. This information will be used by Self-X functions to assess the performance of the network and optimize the different parameters. Monitoring metrics for each tenant are also needed to determine the compliance of agreed SLAs.

• Self-X radio configuration: Automated configuration mechanisms in SESAME have to allow the dynamic reconfiguration of radio parameters of the CESC to achieve an optimized distribution of radio resources among tenants.

III. Self-X in SESAME's Architecture

The architecture of SESAME that addresses the evolution of the SC concept through the NFV, SON and MEC paradigms is presented in [8]. A simplified view is shown in Fig. 1, focusing on the components that are more related with Self-X functionalities. It consists of the following main entities:

• CESC: It consists of a complete SC with necessary modifications to the data model to allow Multi-Operator Core Network (MOCN) radio resource sharing. The CESC is composed by a Physical SC unit and a micro server. The physical aggregation of a set of CESCs (CESCs cluster) gives the possibility to share the IT resources of each micro-server belonging to the cluster and provides a virtualised execution infrastructure, denoted as Light Data Centre (Light DC), enhancing the virtualization capabilities and process power at the network edge. The functionalities of the SC are split between SC Physical Network Functions (PNFs) and SC Virtual Network Functions (VNFs). SC VNFs are hosted in the environment provided by the light DC.

• CESC Manager (CESCM): It 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 (Management and Orchestration) framework. Configuration, Fault and Performance management of the SC PNFs is performed

through the PNF Element Management System (EMS), while the management of the SC VNFs is carried out through the SC EMS. The EMSs provide performance measurements to the SLA Monitoring module that assesses the conformance with the agreed SLAs. EMSs are connected through the northbound interface with the Network Management Systems (NMS) of the SCNO and the VSCNOs, providing each VSCNO with a consolidated view of the portion of the network that they are able to manage. Finally, the CESCM includes a portal that constitutes the main graphical frontend to access the SESAME platform for both SCNO and VSCNOs.
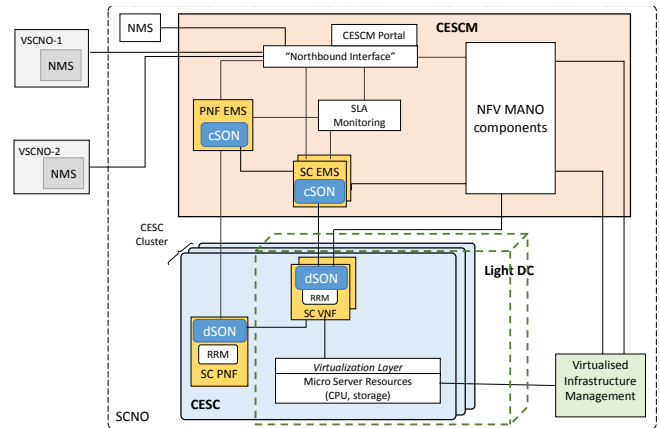

Fig. 1. SESAME architecture (simplified view).

Automated operation of CESCs is made possible by different Self-X functions that will tune global operational settings of the SC (e.g., transmit power, channel bandwidth, electrical antenna tilt) as well as specific parameters corresponding to Radio Resource Management (RRM) functions (e.g., admission control threshold, handover offsets, packet scheduling weights, etc.). Self-X functions can be implemented by following a centralised (cSON) approach (i.e. residing at the management systems), a distributed (dSON) approach (i.e. residing at the SCs) or hybrid approach (i.e. including some cSON components at the management systems and some dSON components at the small cells) [9]. Then, as shown in Fig. 1, the PNF EMS and SC EMS include the centralised Self-X functions and the centralised components of the hybrid functions. In turn, the decentralised Self-X functions or the decentralised components of the hybrid functions reside at the CESCs.

Furthermore, whatever Self-X function is considered of interest to be deployed, it can be implemented as a PNF or, if proper open control interfaces with the element controlled by the Self-X function are established, it can also be implemented as a VNF. The implementation as VNFs provides: (i) An inherent flexibility through easy instantiation, modification and termination procedures; (ii) an inherent efficiency in hardware utilization, since VNFs are executed on a pool of shared NFVI resources, and; (iii) an inherent capability to "add" new functionalities and/or extend/upgrade/evolve existing VNFs. In SESAME, this can be applied to distributed Self-X functions that would run as SC VNFs in the light DC.

IV. Self-X Functions in Relation to SESAME Architecture

In a multi-tenant scenario like the one considered in SESAME, it should be distinguished between those Self-X

functions that are tenant-specific (i.e., the configuration of parameters can differ from tenant to tenant) and those that are common to all tenants. In the following, the different Self-X functions are discussed from the perspective of multi-tenancy and its relation to the SESAME architecture.

A. Self-planning functions

Self-planning is the automatization of the process of deciding the need to roll out new network nodes in specific areas, identifying the adequate configurations and settings of these nodes, as well as proposing capacity extensions for already deployed nodes (e.g. by increasing channel bandwidths and/or adding new component carriers).

The planning of a new cell, which intends to automatically make the decision that a new SC has to be deployed in a certain area, specifying its geographical position as well, as well as the RF planning of this cell (i.e. to select transmit powers and antenna parameters) are inherent functions to the SCNO, who should plan the proper infrastructure to satisfy the capacity requirements of the VSCNOs.

The spectrum planning function specifies the amount of frequency bandwidth needed by a SC (either a new cell or an already deployed one), the type of spectrum (e.g. licensed/non-licensed, etc.) and carries out the dynamic assignment of spectrum to the SCs. This function can be tenant-specific if network slices associated to each tenant are implemented by assigning separate carriers to each tenant. Consequently, a carrier assigned to a tenant would only carry traffic from that tenant's User Equipments (UEs). In such case, the available set of licensed carriers would be split among the tenants, so the frequency planning in the scenario could also be tenant-specific (i.e., it could be implemented according to tenant's defined policies). Nevertheless, the spectrum planning may also be conducted globally for all the tenants in case that a given carrier assigned to a SC can carry traffic from various tenants. In that case, no tenant-specific policies could be applied and this functionality would be left at the expense of the SCNO.

B. Self-optimization functions

Once the network is in operational state, self-optimization includes the set of processes intended to improve or maintain the network performance in terms of coverage, capacity and service quality by tuning the different network settings.

The Coverage and Capacity Optimization (CCO) function intends to adjust RF parameters based on coverage and capacity targets. This has to be accomplished by the SCNO and cannot be left to a single tenant, because these parameters affect all tenants of a SC.

In turn, the Automatic Neighbor Relations (ANR) is responsible for automatically building the Neighbor Relation Table (NRT) of each cell. This is fundamental for mobility purposes because handovers can only be executed between neighbor cells. In a multi-tenant scenario, the NRT of each SC has to include the relations between the SCs of the SCNO and the cells of the tenant, to enable mobility between the two.

Mobility Robustness Optimization (MRO) aims at detecting and enabling correction of different handover (HO) problems, such as connection failures due to mobility (too late handover, too early handover, handover to wrong cell), unnecessary HO and ping pongs. This is done by properly setting the handover parameters (e.g. offset values, hysteresis values, time to trigger, thresholds, etc.). Since each tenant may have different performance requirements (e.g., call dropping rate), and since not all the tenants will have the same cell deployments in the area surrounding the SCs of the SCNO, a per-tenant MRO function is envisaged.

Mobility Load Balancing (MLB) addresses the problem of uneven traffic distribution in mobile networks. The main target of MLB and traffic steering algorithms is to enable overloaded cells to re-direct a percentage of their load to neighbouring less loaded cells hence alleviating congestion problems. The expected gains from MLB algorithms are highest when participating cells exhibit different usage patterns with respect to time. The resulting increased network efficiency using MLB, postpones the deployment of additional network capacity hence reducing capital costs (CAPEX). This is usually done through range-expansion [10], achieved by either cell coverage parameter adjustments or mobility parameter adjustments, However in 4G LTE networks, MLB is known to lead to network performance degradation due to the frequency reuse of one in this technology [11]. Re-allocating a user to a base station other than the one offering the highest signal level, as MLB sometimes does, often leads to increased interference levels. Suitable self-organizing MLB strategies automatically react to rapidly varying traffic and dynamic mobility patterns and should take into account multiple tenancy as neighbouring cells can generally belong to any tenant. In multi-tenant RAN deployments, where shared resources are allocated based on static or dynamic SLAs, the formulation of the "user-association" problem needs to take full account of multiple (and possibly conflicting) service types and requirements, as additional/new sets of constraints need to be met.

Admission and congestion control mechanisms are integral parts of any Quality of Service (QoS) design for networks that support integrated traffic. This is the case in SESAME where a variety of different applications are delivered to the tenants of a CESC. SESAME will utilise admission and congestion control algorithms to deliver, in an effective manner, the QoS that has been agreed with tenants. In traditional networks where the infrastructure is owned by a single tenant, admission and congestion control mechanisms utilise resources (e.g. multiservice packet traffic) that this tenant provides to its end-users. In SESAME, things become more challenging as we require the admission and congestion control mechanisms to take into account the particular features of the multi-environment to ensure that the contracted QoS characteristics are actually delivered. An effective way of designing such mechanisms is to take into account classes of SESAME tenants with different levels of QoS, adhering to multi-tenancy.

In frequency reuse-1 small cell networks, dealing with interference created to/from adjacent cells is of utmost importance. The problem has been addressed in several ways, including InterCell Interference Coordination (ICIC) and enhanced ICIC (eICIC) techniques. Typical ICIC techniques already defined by 3GPP include Almost Blank Subframes (ABS), Coordinated Multipoint Transmission/Reception (CoMP) and Time Domain Interference Coordination. In SESAME, ICIC techniques shall run as functions in the LightDC. Unlike conventional systems in which SCs can be managed by a SON server for centralized management, the SESAME orchestrator can deploy advanced virtual functions which are demanded to perform interference management, amongst other tasks. In addition, the peculiarities of the SESAME system include also the fact that CESCs are

organised in a CESC cluster. Within this environment, novel ICIC techniques can be devised to obtain global optimization of the interference environment.

Energy saving aims at reducing CO_2 emissions (protecting the environment and climate change) and OPEX costs by means of decreasing equipment power consumption. The contribution to energy saving in SESAME can be done by adapting network operation, in both terms of coverage (radio – Small Cell resources) and computation/storage services (IT – micro server resources), to traffic patterns over time. This means, taking advantage of the off-peak-traffic situations to switch off certain CESCs, while increasing the throughput of the neighboring ones as necessary to ensure QoS without degrading user experience. This procedure requires a high-degree of coordination between CESCs and an accurate real-time system resource usage overview, therefore, the Self-Energy Saving function should follow a centralized approach, residing on EMS elements of the SESAME architecture. The VNF placement/service mapping algorithms, which should consider dynamic resource allocation, are going to play a crucial role in the energy saving strategy success, while keeping compliancy with SLAs. In any case, Self-Energy Saving practice does not require specific parameter configuration for multi-tenant scenarios, it concerns mainly the SCNO and it should be common and transparent for all the operating VSCNOs.

C. Self-healing functions

This is the automation of the processes related to fault management and fault 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.

In SESAME the concept of cell outage can be extended to both the CESC and CESC cluster. Specifically, CESC outage occurs in case of failure of the small cells, the micro-server or VNFs. These failures might be caused by hardware/software failures as well as erroneous configuration of the VNFs or Network Services (NSs). Cell outage detection and compensation is essential to recover from possible CESC malfunctions. Cell outage detection is done first collecting information such as alarms, alerts, error messages and key performance indicators at both CESC and CESC cluster levels. Afterwards, cell outage detection can be done applying different methods, including data mining (e.g. for large small cells deployment) in order to identify possible misbehaviors. Once components of the CESC are detected to be faulty, cell outage compensation is applied, including reconfiguration of parameters and resources of the small cells, as well as the VNFs through the corresponding element management systems. In addition, within the CESC cluster, outage of a CESC can be detected and recovered whereby the cooperation between adjacent CESCs [12].

V. On-going Studies

This section briefly summarizes different studies related with Self-X addressed by SESAME.

a) Impact of MOCN requirements on SON: The main impact of MOCN in SESAME is in the area of ANR. For idle mode mobility, where the PNF of a CESC is configured to automatically detect neighbour cells and populate its intra-frequency and inter-frequency neighbour lists with discovered details, this population needs to consider candidates that support any of the PLMNs supported by the SESAME cell. By supporting multiple PLMNs, the number of candidate neighbour cells will probably be larger than a non-MOCN supporting cell. In extreme circumstances, this number could exceed the limits of what can realistically be broadcast in the SESAME cell's System Information Blocks and, where this is the case, only a sub-set of the detected cells is used "on-air". Internally, the SESAME cell maintains the full list of cells and may, if required, select different cells to be broadcast as a result of events such as a change in the list of its supported PLMNs. The SESAME cell attempts to ensure that each supported PLMN is represented fairly in the generated set of neighbour lists and that these lists are not dominated by a sub-set of supported PLMNs simply because they appear to provide the "best" signal. It also needs to ensure that there are not multiple neighbour list entries for the same MOCN capable neighbour. For connected mode mobility, the PNF of a SESAME cell configures each UE to perform measurements relating only to those neighbours that support its Selected PLMN. Thus, it does not waste time and power measuring neighbours to which it cannot hand over. The candidate cells for measurement configuration are selected from the SESAME cells internal list which may be a superset of those broadcast in its System Information.

b) Knowledge-based framework for supporting self-x: A general framework is being developed using different techniques from the Artificial Intelligence (AI) field to process available input data in order to come up with exploitable knowledge (i.e., knowledge that can be formalized in terms of models and/or structured metrics that represent the network and user behavior in a way that can be directly used to make smart network planning and optimization decisions). Considered techniques include classification, prediction and clustering tool. As some possible examples, in [13] the classification of time domain traffic patterns has been applied as a support in the spectrum planning and energy saving functions.

c) Self-optimizing resource allocation function for virtualized Small Cells: In shared virtualised computing and network environments, like the ones proposed in SESAME, dynamic changes in resources' and applications' quality requirements of different tenants can lead to poor resource utilisation when using existing static resource allocation mechanisms. Therefore, in presence of different, for each tenant, and dynamic requests for resources, such as computing, storage and communication, as it is the case in SESAME, there is an apparent need for proposing a dynamic resource allocation mechanism. The SESAME self-optimising resource allocation function for virtualised Small Cells will take into account resource allocations from two different perspectives; Per-Tenant and Per-Application. First, the Per-Tenant Resource Allocation aims at allocating resources to individual tenants based upon an agreed SLA and the available CESC resources. For the virtual system, an upper threshold, in terms of granted resources, should be set for each tenant based on its SLA and service demands. The resource allocation algorithm, in the NFV, should be continuously aware of the total available virtual resources and the tenants' threshold in order to allocate, at least, a minimum required amount resources to a tenant. Second, the Per-Application Resource Allocation deals with allocating resources to individual applications that can be used by more than one tenant. This type of allocation is done based on the application priority (e.g. real-time applications have

more priority than the non real-time applications).

d) MLB studies: This work will focus on novel formulations for multi-cell use-association, in multi-tenant deployments considering the on-demand networking use cases (of fixed and moving hotspots) identified in [14]. User association mechanisms in dense small cells deployments are currently being studied. This will enable the selection of the best neighbouring small cell for load balancing and traffic steering purposes. This work will be followed by studying the impact of user mobility patterns for the different SESAME use cases and scenarios described above.

e) Studies on ICIC: The particular setup of the CESC cluster allows prefiguring SC networks which behave as cluster centre for the UEs. Each SC can rely on its own computational facility at the edge, or micro-server. CESC within the same CESC cluster could potentially interfere, as well as be interfered by macrocell emissions or by other CESC clusters in vicinity. Such a spatial configuration requires novel ICIC techniques, including adaptive scheduling of resources. The basic starting point would require developing adequate stochastic models of the interference in order to reflect the spatially collocated clusters of users around small cells [15][16]. Based on such models, it is hence possible to optimize the behavior of the CESC cluster, including global power control algorithms, and algorithms which can perform load balancing taking interference as one constraint of the problem.

f) Studies on self-healing: One crucial aspect dealt within SESAME is the capability of automatically recovering from unexpected situations in which hardware software misbehaviors affect the correct execution of the CESC functions or even the CESC cluster as a whole. This is indeed the self-healing capability of the Self-x features of SESAME. In the virtualized environment this includes also taking the necessary actions to detect and recover from any misbehavior connected to the VNFs or NSs. If hardware problems would require human intervention, problems connected to an erroneous behavior of a VNF could be relieved by the NFV-MANO framework. The orchestrator, in conjunction with the VIM, can decide to rescale a VNF or a NS in terms of resources, or it could decide for a different selection of micro-servers where to deploy the network services. In other words a different VNF placement could be decided (i.e. different solution to the embedding problem). Part of the research work carried out in SESAME will look at determining proper configuration of the CESC cluster, including solving the network embedding problem, or determining optimum solutions for the network configuration when some CESC elements wear out.

g) Self-X features for the virtualized wireless backhaul: In a multi-tenant capable wireless backhaul, Self-X is an essential aspect, required for the backhaul to work correctly. In SESAME, a virtual wireless backhaul is deployed for each of the tenants. The virtual wireless backhauls are managed by an SDN controller that is responsible for assigning and managing the wireless backhaul resources, while applying Self-X features. As part of the self-planning, the wireless backhaul will be configured for an optimal performance, e.g. assigning combinations of radio channels to the wireless interfaces to minimize internal and external interference. Further, the required share of wireless backhaul resources per tenant will be determined according to the SLAs they established, but also on the availability of backhaul resources. On the other hand, self-optimization is applied constantly to the backhaul: the wireless backhaul resources are monitored (e.g. available and used bandwidth of the radio links) and they are assigned dynamically to different tenants. This is done taking into consideration the different requirements on the backhaul per tenant. Eventually, self-healing functions will address temporary issues, like peaks of congestion or link breaks that can affect the performance of the wireless backhaul, by applying mechanisms such as load balancing or fast rerouting.

VI. Conclusions

This paper has presented the current vision of Self-X functions for the provision of Small Cell as a Service in multi-tenant scenarios in the context of SESAME project. After presenting the scenarios, requirements and architecture of the project, the paper has discussed the implications of multi-tenancy on different Self-X functions and has described current studies that are being carried out in the project.

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