Enabling the SLA Management of Federated Network Services through Scaling Operations

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***Abstract*—Slices are deployed to continuously fulfill requirements from vertical industries. Thus, the management of service level agreements (SLAs) is fundamental. Composite network services (NSs), made up of multiple nested NSs, can be exploited to build slices. Generally, slices may span multiple domains and the different nested NSs may be deployed by different providers, in what is referred to as federated NS. Previous work focused on the architectural design and workflows for the functional deployment of federated services without considering the continuous SLA management. Herein, we cover this gap by presenting a complete workflow, the required interface extensions, and the operation profiling over an experimental testbed to automatically scale nested NSs deployed in a federated domain. Evaluation results show that such scale out/in operations can be performed in tens of seconds (39/31 s, respectively), where the allocation/release of underlying resources account for most of the profiled scaling time (more than 80%).**

***Index Terms*—Network Service Federation, SLA Management, (Auto)Scaling, NFV/SDN, Experimental evaluation**

I. Introduction

5G networks exploit the flexibility, dynamicity, and programmability provided by Software Defined Networking (SDN), Network Function Virtualization (NFV), and Network Slicing paradigms to open the door to vertical industries' transformation. NFV network services (NSs) instantiating slices are designed and deployed to fulfill the variety of requirements demanded by vertical services. Composite NSs, made of multiple constituent elements called nested NSs, can be exploited to build the targeted end-to-end (E2E) slices. The deployment of such slices may involve multiple administrative domains (ADs). That is, several nested NSs are offered by different providers and are grouped to attain a federated NS deployment. Furthermore, some of these nested NSs may become network slice subnet instances that are shared by multiple slices (e.g., a core network serving multiple slices).

The slicing concept is tightly linked with E2E service level agreement (SLA) compliance. However, the management of SLAs for complex composite NSs deployments over multi-AD scenarios has mostly been explored at a high architectural level. This is one of the aims of the EU 5G-ROUTES [1] and 5Growth (5Gr) projects, which evolve the 5G SDN/NFV-based service platform developed in the EU 5G-Transformer (5GT) project [3]. The 5Gr platform architecture consists of four main building blocks. The Vertical Slicer (5Gr-VS) is the entry point for vertical industries to request the creation and management of network slice instances, which are mapped to NSs. The Service Orchestrator (5Gr-SO) oversees the E2E lifecycle management of these NSs in single and multi-AD scenarios. Besides vertical requirements, the 5Gr-SO operation is based on the available resources (compute, storage and network) advertised by the underlying infrastructure manager, the Resource Layer (5Gr-RL). The Vertical-oriented Monitoring System (5Gr-VoMS) provides metrics to the mentioned building blocks of the 5Gr platform (e.g., status of deployed NSs and corresponding VNFs, status of the infrastructure). With them, the platform can take decisions to adapt the NS deployments according to their demands and the infrastructure conditions, hence complying with the SLAs embedded in the NS descriptor (NSD) without needing the NS redeployment, hence reducing the service discontinuity.

This work focuses on the evolution of the 5Gr-SO to support these decisions by enabling the orchestration of scaling operations for composite NSs, including also those deployments involving multiple ADs that leverage the network service federation (NSF) concept [4]. Scaling operations for such kind of NS deployments are scarcely investigated in the literature, mostly focused on simple (i.e., non-composite) NS deployments. Only the work in [5] presents high-level architectural considerations for this problem but only from a service orchestration perspective and limited to the scaling of the whole composite NS deployment, not considering the independent scaling of its constituent nested NSs. Additionally, it disregards the resource orchestration aspects related to the inter-nested, inter-AD connectivity, which are essential to achieve real deployments in practice. Our work herein is the first one covering these gaps and contributes with i) a detailed operative workflow and the interface between ADs, ii) its validation in a real multi-AD experimental testbed, and iii) a time profiling of the scaling operation of a real composite NS deployment entailing NSF.

The rest of the paper is structured as follows. Section II presents relevant approaches to the NSF problem and SLA management available in the literature. Section III makes an overview of how the 5Gr-SO handles NSF and the possible options when considering the scaling of composite NS deployments, involving also multiple ADs. Then, we focus on the case of the auto-scaling of a nested NS part of a composite NS deployed between peering ADs. We present a detailed workflow handling this situation and the required interface

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extension between peering ADs to handle such process, which is not covered in the literature. Section IV presents a performance evaluation of the proposed scaling procedure done in the scenario built with the available multi-domain experimental testbed. Section V concludes this work.

II. Background and Related Work

In last years, literature works (e.g., [5]–[8]) related to orchestration involving NSF exclusively considered high-level architectural aspects of the instantiation phase. However, these approaches lack of resource orchestration aspects (e.g., solving addressing and conflicts on virtual networking resources identifiers to attach the created VNFs) related to the dynamic inter-nested/inter-AD connectivity management. These operations are essential to make such deployments operative in practice, and have been considered in more recent works (e.g., [9], [4]). In [9], the authors rely on a centralised approach where a top controller performs service orchestration and interconnection of nested NSs deployed in different ADs. Our previous work in [4] proposes a flat peer-to-peer approach between MANO components to perform NSF, which may fit better with current business models between network service providers.

Nevertheless, most of these previous works do not consider SLA-related management aspects, such as service scaling capabilities to dynamically adapt composite NS deployments (involving or not NSF) upon fluctuating service demands. These scaling actions may be triggered by either manual (human intervention) or automated decisions based on monitored NS performance metrics. For the latter, we can find examples of threshold-based solutions (e.g., [10]–[12]) or more recently, based on the use of Artificial Intelligence/Machine Learning techniques (e.g. [12], [13]), but both only for single NS deployments. Actually, the same principles could be applied in federated NS deployments that may require the scaling of any of the nested NSs part of a composite NS. This consideration, tackled within this work, broadens the scope of ETSI NFV-IFA028 [5], which is the sole work presenting high-level considerations regarding the scaling of composite NSs. However, as for the instantiation case, this is only from a service orchestration perspective and restricted to the composite NS level. Additionally, our work digs into the nested NS level an considers the essential resource orchestration perspective handling the update of the inter-nested connectivity at the involved ADs after scaling (out/in) operations.

III. Network Service Federation Scaling

Fig. 1 depicts the 5Gr-SO architecture and its interactions with the other building blocks of the 5Growth platform. A detailed description of the 5Gr-SO baseline architecture is found in [14] and its code is released as open source under Apache 2.0 licence [15]. The highlighted modules are the parent Service Orchestration Engine (SOEp) and the Composite Resource Orchestrator Engine (CROOE), which take over the NSF process [4]. The SOEp orchestrates all the operations in case of a composite NS, relying on the child SOE (SOEc) to perform the instantiation of the different nested NSs forming the composite NS as if they were a single NS [14]. The CROOE, triggered by the SOEp, is in charge of determining the inter-nested NS connections. In this work, the logic of these modules has been extensively evolved to handle the multiple scaling scenarios possible for composite NS deployments. The operations conducted during the scaling process depend on i) how the composite NS has been deployed (i.e., whether multiple ADs are involved and/or whether an already deployed single NS is shared by a/multiple composite NSs), and ii) the destination of the scaling request (i.e., the whole composite NS, the shared single NS or a nested NS triggering an auto-scaling operation). From the previous cases, the following subsection considers the case of a nested NS deployed in a federated AD triggering an auto-scaling operation as a consequence of an SLA violation, hence implying NSF. This case, not covered in the literature, requires a more complete coordination and interaction between involved ADs to change part of the composite NS deployment to react in front of changes in the service demands.

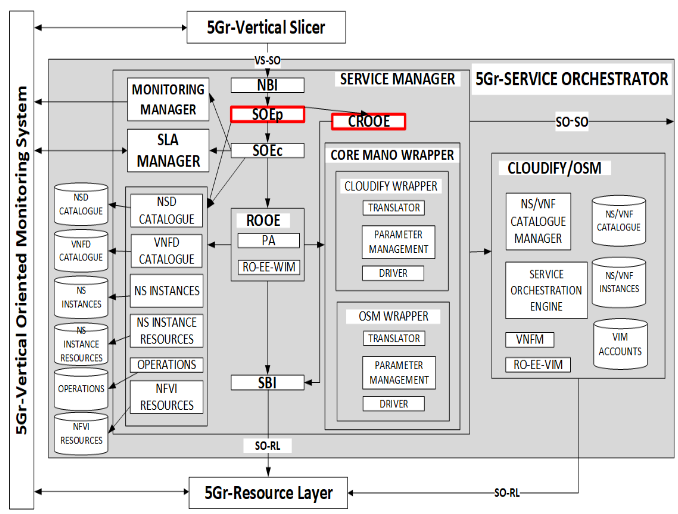

Fig. 1. 5Growth Service Orchestrator Architecture

A. Federated Nested NS auto-scaling workflow

Prior to describing the intended workflow, regarding the terminology, we refer to the consumer domain (CD) as the one coordinating the instantiation process of the composite NS. The provider domain/s (PD) is/are the one/s satisfying the nested NS instantiation requests issued by the CD during the composite NS deployment involving NSF. The proposed workflow, depicted in Fig. 2, is as follows:

1. The PD NorthBound interface (NBI) receives a scaling request triggered by the PD SLA Manager for the already deployed nested NS. This 5Gr-SO module processes the alerts derived from monitored metrics and triggers the corresponding lifecycle management operations (e.g., scaling) as expressed in the nested NSD. This operation may imply a change in the instantiation level (IL) of the nested NS, modifying its structure (i.e., scale out, scale in operations).

2. The PD SOEp creates an operation identifier (ID). Upon processing the scaling request, the PD SOEp spawns a parallel process, where the PD SOEc handles the scaling operation of

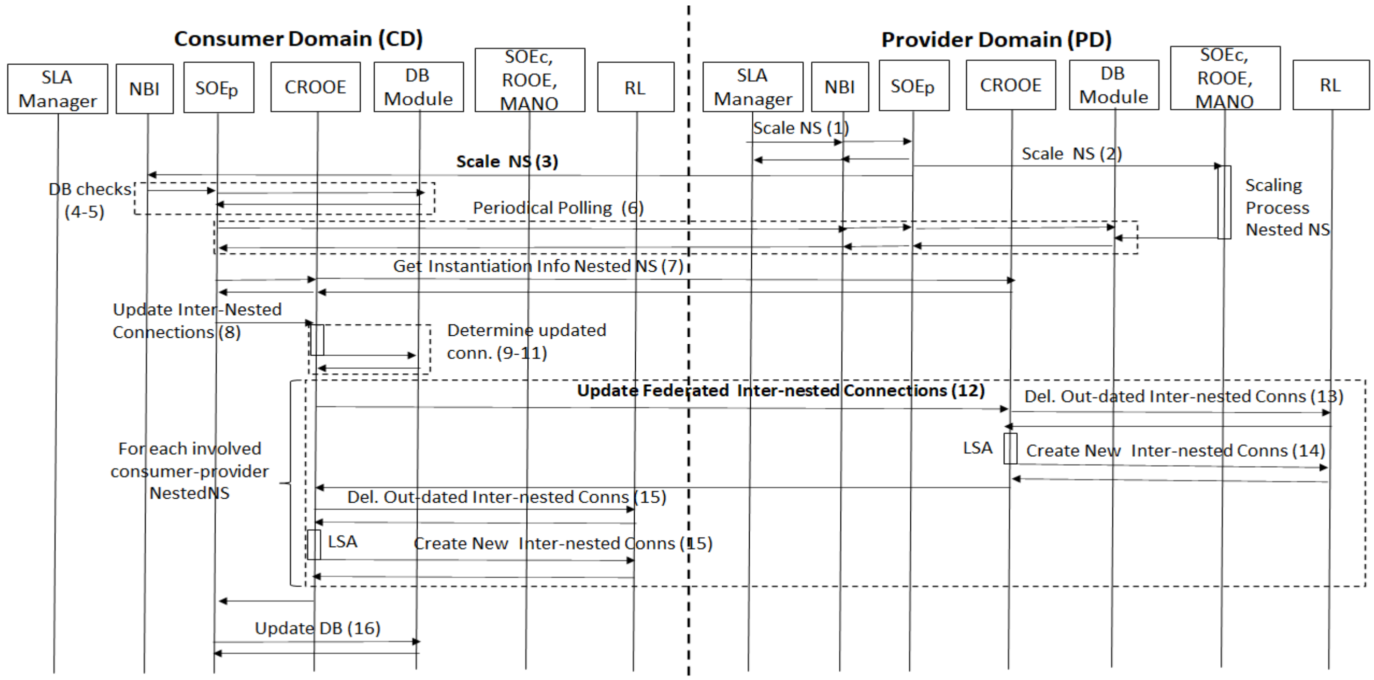

Fig. 2. 5Gr-SO Federated Nested NS auto-scaling workflow

the requested NS, as explained in [11].
3. In the main process, the PD SOEp realises that the scaling request refers to a nested NS that is part of a composite NS. This issues a scaling operation to the CD informing of the scaling process at the PD. This request includes the nested NS ID, the new IL and the operation ID at the PD.
4. The 5Gr-SO NBI at the CD receives the scaling request from the PD. Then, the SOEp verifies with the *NS Instance DB* the validity of the request. It checks that the nested NS instance exists in the DB as part of a composite NS entry and that the composite NSD includes the new requested nested IL.
5. Once validated, the SOEp sets the status of the composite NS to "Scaling" state.
6. The SOEp polls periodically the PD to check the status of the nested NS at the PD using the received operation ID. This is a required synchronization point between ADs before continuing with the update of the composite NS deployment.
7. After successfully validating the scaling operation at the PD, the SOEp requests the CROOE to contact the PD CROOE to retrieve the updated instantiation information of the nested NS after the scaling operation (new/terminated VNF instances) and updates the composite NS entry at the *NS Instance DB*.
8. Then, the SOEp proceeds with the update of the interconnections between nested NSs. To perform this operation, the SOEp contacts the CROOE.
9. For each combination of deployed consumer-provider nested NSs, the CROOE determines the inter-nested connections between CD and PD based on the corresponding NSDs and the instantiation information available in DBs.
10. The CROOE compares the new set of inter-nested connections with those stored in the *NS Instance DB* to determine those connections that need to be established and those that need to be deleted at each AD due to the scaling operation.
11. Then, the CROOE updates the associated DB entry with the *new* set of inter-nested connections to take them into account for possible subsequent scaling operations.
12. The CROOE contacts with the corresponding PD CROOE to update the requested inter-nested connections between ADs.
13. The PD CROOE processes the request, removing first the specified inter-nested connections (if any) by contacting with its associated 5Gr-Resource Layer (5Gr-RL). The 5Gr-RL, acting as infrastructure manager, configures the corresponding forwarding elements (FEs) at the underlying transport network.
14. Then, the PD CROOE runs the Link Selection Algorithm (LSA) to select the appropriate inter-AD links (from PD to CD) serving the new inter-nested connections between ADs and contacts its 5Gr-RL to establish them. The LSA chooses among the logical links connecting the NFVI-PoPs at involved ADs the one fulfilling the inter-nested connection requirements in terms of bandwidth and latency and having the less available bandwidth. Once finished, the PD CROOE reports the CD CROOE about the successful operation.
15. The CD CROOE deletes the required inter-nested connections, runs the the LSA to determine the appropriate inter-AD links (from CD to PD) mapping the new inter-nested connections, and contacts its 5Gr-RL to establish them.
16. After repeating steps 12 to 15 for each combination of involved consumer-provider nested NSs, the SOEp updates its DBs, declaring the composite NS in "Instantiated" status.

B. Extended NSF Interface

As with the instantiation operation [4], all the messages exchanged during the scaling operation between SOEp and CROOE modules of respective ADs are performed through the available *SO-SO* interface depicted in Fig. 1. Messages exchanged between peering SOEp modules relate to lifecycle management operations and follow the ETSI NFV IFA030/013 specifications [16]. In this work, we added the support of the *Scale NS* operation in the 5Gr-SO between peering ADs. A particular explored case is the use of this operation at the PD to inform the CD that an auto-scaling operation is being held in a nested NS deployed using NSF, as explained in step 3 of the proposed workflow. Our work contributes with this interaction, which expands the logic initially considered for this operation in the mentioned specifications [16], restricted only to communications issued from the CD to the PD. When issuing this message, the PD, besides informing the CD of the new nested NS IL in the *scaleNsData* parameter, also includes as an *additionalParamForNs* attribute, the scaling *operationID* at the PD, so the CD can poll the status of the operation before continuing with the scaling process (step 6).

The messages exchanged between CROOE modules are related to the resource orchestration operations associated to the creation of virtual network resources and the configuration of the required interconnections between VNFs of nested NSs in different ADs. These operations and the associated messages are not present in the state-of-the-art work, covering them in our previous work [4]. Herein, we present the required extension of this interface to update the inter-nested connections (either create/remove) during the scaling operation. It is worth noting that the scaling of a NS may imply the simultaneous creation/deletion of multiple new VNF instances (i.e., scale out/scale in) and thus, of its associated inter-connections. The format of the *Update Federated Inter-nested Connections* (step 12) operation is detailed in Listing 1. In this query from the CD to the PD, a list of the *"new"* pairs of VNFs to be connected (PD-CD) as a consequence of a possible scale out operation, and a list of *"old"* pairs of VNFs whose connection needs to be deleted due to a possible scale in operation are included. This message also includes the requirements of the shared inter-nested virtual links (VLs) in terms of bandwidth and latency used as inputs to the LSA. The query URL contains the NS ID in the PD. The body of the query contains the NSD ID in the PD to verify that the NS ID in the URL corresponds to an NS instance using the requested NSD. The PD replies *"OK"* or *"KO"* to the CD.

```
Request: Consumer domain
URL = "http://provider_domain:port/5gt/v1/
ns/{nsId}/update-fed-internested-connections"
body:{
  "nsdId": "NS descriptor identifier in the PD"
  "connectedVNFs_add": {
    "internested_VL1": [VNF3p-VNF1c,...]
    "internested_VL2": [VNF3p-VNF2c,...]},
  "connectedVNFs_del": {
    "internested_VL1": [VNF4p-VNF2c,...]
    "internested_VL2": [VNF2p-VNF3c,...]},
  "linkChar":{
    "internested_VL1": {
      "latency": latency_vl1,
      "bw": bandwidth_vl1},
    "internested_VL2": {
      "latency": latency_vl2
      "bw": bandwidth_vl2}  }  }
Reply: Provider domain
body:{
  "pathEstablishment": {"OK"/"KO"}  }
```

Listing 1: Update Federated Inter-nested Connections

IV. Experimental evaluation

This section validates and assesses the proposed workflow and interface extension in an experimental multi-AD testbed. To the best of our knowledge, this is the first realistic deployment and evaluation considering the auto-scaling of a nested NS part of a composite NS and also involving NSF.

A. Experimental Testbed Setup

Fig. 3 presents the experimental setup split among thirteen commercial off-the-shelf equipment (Intel Core i7, 32GB RAM, 1TB HDD), where each AD presents an instance of the 5Gr stack. The 5Gr-SO at the different ADs uses Open Source MANO (OSM) as Core MANO platform; namely, AD1 uses OSM Release 6 whilst AD2 uses OSM Release 7. Different OSM releases are considered in the setup to validate the backward compatibility of the 5Gr platform with external components along with increasing its heterogeneity. AD1 hosts three NFVI-PoPs, which are managed by dedicated Virtual Infrastructure Managers (VIMs) based on Devstack Queens release. These NFVI-PoPs are interconnected by a GNS3 [17] emulated transport network topology of 14 packet-switch nodes and 22 bidirectional links managed by an ONOS SDN controller instance acting as the Wide Area Network Infrastructure Manager (WIM). AD2 has two NFVI-PoPs, also managed by its own VIM (i.e., Devstack Queens release) instances, which are interconnected by a GNS3 emulated transport network featuring 5 packet-switch nodes and 8 bidirectional links. Like in AD1, the transport network infrastructure is managed by an ONOS SDN controller. At the data plane level, AD1 and AD2 are linked through a VPN connection implementing the Inter-AD Link depicted in Fig. 3. The use of the GNS3 network emulator allows considering arbitrary and scalable network topologies of SDN-controlled software switches (OpenVSwitch), which can be connected to the physical network interface cards available at the host running the GNS3 emulation to interact with the NFVI managers (VIM/WIM) available in the 5Gr platform.

B. Profiling the Federated Scaling operation

This subsection presents the time profiling of the main operations involved during the scaling of a composite NS deployed in the experimental setup of Fig. 3 when one of its constituent nested NS detects an SLA violation and, thus, triggers an auto-scaling operation.

The composite NS under evaluation, shown at the bottom part of Fig. 3, is defined in the context of the Industry 4.0 use case of the 5Growth project. This composite NS has two inter-connected nested NSs with multiple ILs (depicted with dashed components). The definition of multiple ILs allows either the manual or the automatic triggering of the scaling operation at the different levels mentioned in Section III. Hence, the NS structure can be adapted to satisfy the requested SLAs in front of dynamic service demands or network conditions. The first nested NS emulates a standalone Non-Public Network (NPN) [18] vEPC NS consisting of five VNFs, namely SEC-GW, MME, HSS, S-GW and P-GW. The second nested NS

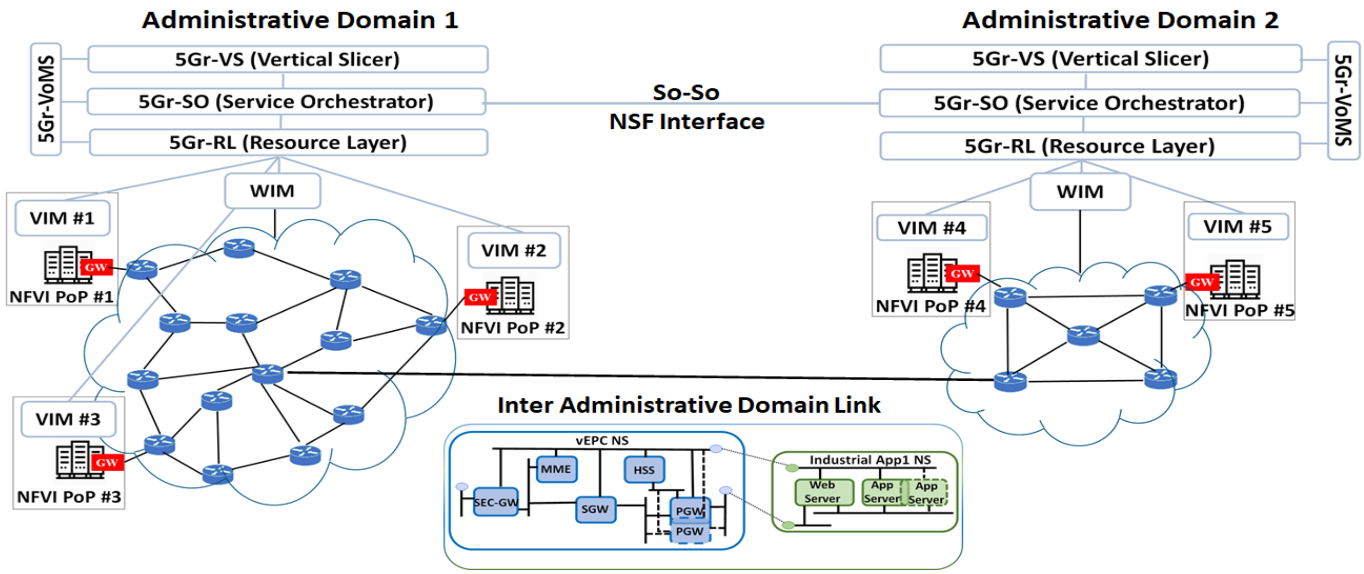

Fig. 3. Experimental multi-administrative domain testbed setup

emulates an Industrial App NS, which initially consists of two VNFs: a webserver and an application processing server.

Fig. 4 compares the average time of an auto-scaling request triggered by the nested Industrial App NS to react to an SLA violation produced by the increase of the processing needs (e.g., a change in the IL to scale out and add a new application server VNF). In this comparison, the composite NS is deployed between two different NFVI-PoPs of a single AD (labelled as *Composite Multi-Pop*) and between two different NFVI-PoPs managed by different ADs (labelled as *Federation*). In both cases, the NPN vEPC nested NS is deployed in NFVI-PoP#1 of AD1, and the Industrial App nested NS is rolled out in NFVI-PoP#2 and NFVI-PoP#4 of Fig. 3, respectively. The experiments are repeated ten times.

Fig. 4 shows that the average scale out time of the *Federation* case is of 38.5 s. This value is in line with those presented in [10], [11] for the scaling of a similar single NS deployment in a less complex experimental setup. This confirms the reduced time impact of the processing associated to federation-related operations and the latency in the communication between peering orchestrators. The different steps of the proposed workflow in Section III-A are grouped into three main groups. First, the 5Gr-SOEp time accounts for the time spent at the SOEp module of the different ADs to process the corresponding scaling requests, retrieve and update information at the DBs, and the time associated to the periodical polling operation the CD makes to the PD to check that the nested NS is successfully scaled. This polling operation is the main contributor to the 5Gr-SOEp time. The other mentioned components of the 5Gr-SOEp time are in the order of milliseconds. Indeed, the 5Gr-SOEp presents a value of several seconds because the interval of this polling operation is set to 10 s in this evaluation. This value was chosen to keep a reduced amount of interactions between ADs because the time required to create/remove a VNF instance is in the order of tens of seconds.

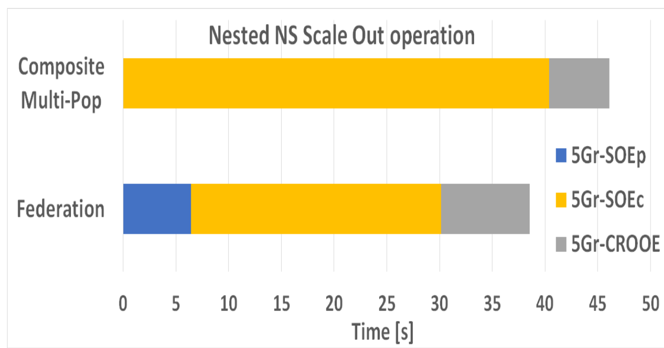

Fig. 4. Nested NS Scale Out Profiling

Next, the 5Gr-SOEc time accounts for the time required by the SOEc to coordinate the scaling operation of the nested NS with the rest of sub-modules of the 5Gr-SO. Actually, the most time consuming operation (85% of the 5Gr-SOEc time) is the interaction between the Core MANO platform and the VIM to create the virtual machine (VM) for the new instance of the application server VNF. The 5Gr-SOEc represents around the 62% out of the total time of the scale out process.

Lastly, the 5Gr-CROOE value represents the 22% of the total time. It accounts for the determination of the new inter-nested connections and its configuration at the different ADs after triggering the LSA execution and interacting with the corresponding 5Gr-RL modules. Out of the total value of the 5Gr-CROOE time of the *Federation* case, 72% corresponds to the time to update the inter-nested connections at the different AD1 forwarding elements (FEs). This reflects the higher complexity of the AD1 transport network compared to the one of AD2. This sub-component of the 5Gr-CROOE time in the *Federation* case is similar to the one experienced in the *Composite Multi-PoP*. This is due to the similar amount of FEs to configure between NFVI-PoP#1 and the Inter-AD Link and between NFVI-PoP#1 and NFVI-PoP#2 of AD1, respectively.

Surprisingly, the scale out operation at the *Federation* case required less time than at the *Composite Multi-Pop* case although performing the polling operation and configuring new inter-nested connections at both ADs. This is explained due to the different performance of the used Core MANO software releases. Additional tests revealed that OSM Release 7 at AD2 provided faster VM creation time than OSM Release 6 at AD1. Finally, mention that the impact of the 5Gr-SOEp time in the *Composite Multi-Pop* case is minimal (in the order of tens of ms) because it is mainly devoted to check the content of the scaling request and update the corresponding DB entries.

Fig. 5 compares the scale in operation, when the nested Industrial App NS can return to its original structure after a decrease in the processing loads, as described in the NSD. The average value of this operation in the *Federation* case is of 30.4 s. Scale in operation is performed faster than scale out, hence confirming the trend presented in [10], [11] for single NS with respect to allocation/de-allocation operation behaviour. As expected, the *Federation* case presented a higher value than the *Composite Multi-Pop* case. Mostly, the time difference comes from the polling operation time done in the CD and included in the 5Gr-SOEp value, which represents around 18% of the average experienced value. More noticeable differences in the overall time between considered deployments could be experienced as a contribution of the 5Gr-CROOE component if AD2 presented a more complex transport topology. Finally, in this case, both Core MANO platforms versions at the different ADs attained similar performance when terminating the VM associated to the previously added application server VNF.

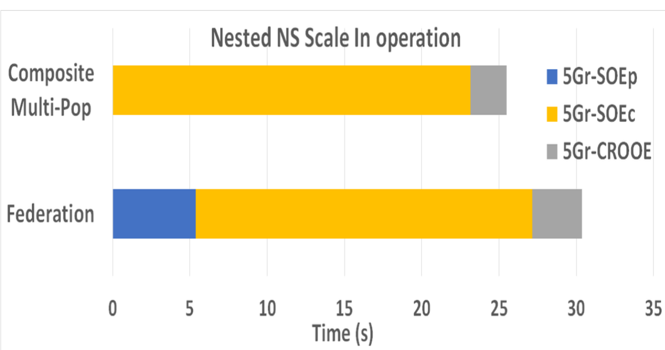

Fig. 5. Nested NS Scale In Profiling

V. Summary and Conclusions

The deployment of end-to-end network slices requires continuous orchestration actions during their lifecycle to fulfill their SLAs. The complexity of SLA management scaling actions increases when considering the different deployment options of composite NSs constituting the slice instances over multiple administrative domains (ADs). This work delves into the SLA management in such complex multi-AD scenarios contributing with a complete design of the workflow and interface supporting the scaling of federated NS deployments. More specifically, it focuses on the auto-scaling of a nested NS (representing a network slice subnet instance) in a provider (federated) AD. The rest of the composite NS is deployed in the consumer (local) AD.

The proposed approach is profiled in a real multi-domain experimental testbed, being, to the best of our knowledge, the first work realising and evaluating a complete scaling procedure involving NS federation. The conducted experimentation shows that scaling (out/in) operations involving a nested NS of a composite NS deployed in a federated AD can be accomplished on the order of tens of seconds (39/31 s., respectively), like for single NS deployments. The impact of the processing associated to federated-related operation is limited, being operations related to the allocation/release of the required underlying resources (i.e., VMs and network connections) the most time consuming. Multiple aspects may impact on these resource oriented operations for the continuous SLA management of slices: the used hardware, the virtualization technique of computing resources (VM), or the complexity of the transport infrastructure (both at control and data plane level) connecting remote NFVI-PoPs and ADs. Additionally, different releases of a same open source MANO platform (e.g., OSM) may also perform differently.

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