Layered Network Domain Resource Management in Multi-domain 5G Slicing Environment

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***Abstract* – Multi-domain and end-to-end (E2E) capabilities are major objectives in 5G slicing. A split is needed of the multi-domain slice capabilities between several technological and/or administrative domains while still preserving their individual independency. Admission control is also necessary when a new multi-domain slice is requested by an user/tenant, i.e., during the slice preparation and instantiation phase or at run-time when slice instances scaling is needed. The above tasks are solved by the Management and Orchestration (M&O) system for services, slices and resources (physical or virtual). The M&O is performed at two scopes (global and local in each domain) and can be organized using several layers depending on the business model (actors) considered. This paper contribution consists in the proposal and analysis of several architectural solutions to organize the domain-level management for a network segment of a multi-domain slice. In particular, the functions splitting and interactions among the layers of the domain management are studied in the context of Network Function Virtualization (NFV) and Software Defined Networks (SDN), technologies used in the system architecture.**

Keywords — 5G slicing; Multi-domain; Management and Orchestration; Resource management; Software Defined Networking; Network Function Virtualization.

I. INTRODUCTION

The slicing concept applied to 5G networks (based on virtualization and softwarization) enables the system to serve in a dedicated way various verticals/use-cases. It also allows programmability and modularity for network resources provisioning, adapted to different vertical service requirements (in terms of bandwidth, latency, etc.) [1-9]. A *Network Slice* (NSL) is a managed logical group of subsets of resources, *Physical/Virtual network functions* (PNFs/VNFs) in the architectural Data Plane (DPl), Control Plane (CPl) and Management Plane (MPl) [1][2].

Network Function Virtualization [6-8][10-12] and Software Defined Networks [13] architectures are used in cooperation [14-16], to manage and control in a flexible and programmable way the 5G sliced environment. Note that the general topics of the NFV framework and SDN are not detailed in this study; they are just used here in the 5G slicing architecture.

The layered structure of the M&O 5G sliced systems depends on the definition of business model and actors. Several business models aim to support multi-tenant, multi-domain end-to-end (E2E) and multi-operator capabilities. A basic and flexible model (see A. Galis, [9]) can be composed of four main actors:

Infrastructure Provider (InP) – owns and manages the physical infrastructure (network/cloud/data centre). It could lease its infrastructure (as it is) to a slice provider, or it can itself construct slices and then lease the infrastructure in network slicing fashion. An InP may include several technological domains (e.g., Radio Access Network (RAN), Core network, Transport network) and could be represented by a single Administrative domain.

Network Slice Provider (NSLP) – can be typically a telecommunication service provider. It could be the owner or tenant of the infrastructures from which network slices can be constructed. Generally, the NSLP can construct multi-domain slices, on top of infrastructures offered by different InPs. It should also support multiple tenants.

Slice Tenant (SLT) – is the generic user of a specific slice, including network/cloud/data centres, hosting customized services. The SLTs can request from a NSLP creation of new slices. The SLT can lease virtual resources from one or more NSLPs in the form of a virtual network, where the tenant can realize, manage and provide *Network Services* (NS) to its individual end users. A network service is a composition of Network Functions (NFs); it is defined in terms of the individual NFs and the mechanism used to connect them. A single tenant may have one or several slices in its domain.

End User (EU) - consumes (part of) the services supplied by the tenant, without providing them to other business actors.

The business model is recursive (see Ordonez et. al., [3]), i.e., a tenant can, in turn, offer parts of its sliced resources to other tenants. Other variants of business models are presented in [9].

The actual running slices are *Network Slice Instance*(s) (NSLI), i.e., specific, logically isolated, but full virtual networks created by the NSLP (based on NSL templates) at the request of an SLT or at NSLP's initiative. A *blueprint/template* is a logical representation of NFs and the resource requirements. It describes the structure, configuration and work flows for instantiating and controlling a NSLI. It includes particular network characteristics (e.g., bandwidth, latency, reliability) and refers to the required physical or logical resources and the sub-networks. A NSLI may be dedicated or shared across multiple *Service Instances*.

The 5G sliced networks M&O sub-system is usually organized in a hierarchical fashion on several layers [7]. The management can include the traditional functions; the orchestration consists in a coordinated set of activities to automatically select and control multiple resources, services and systems [14].

The *Life-Cycle Management* (LCM) of a NSLI comprises several phases performed by the Slice Provider: (1) *instantiation, configuration* and *activation*, (2) *run-time* and (3) *decommissioning* [6]. Actually, the LCM is preceded by a *preparation phase* (0) of the network for the future instantiation and support of a NSLI. Phase (1) is split into the instantiation/configuration sub-phase (the necessary shared/dedicated resources, including NFs, are configured and instantiated but not yet used) and the activation sub-phase (the NSLI handles traffic). The run-time phase focuses on data traffic transport, reporting the network service performance and possible NSLI re-configurations or scaling, if dynamic conditions impose that. Phase (3) includes the deactivation and termination of the NSLI and release of the allocated resources.

The specific contribution of this paper is the proposal and analysis of several architectural solutions, to organize the domain-level (InP) management for a network segment (controlled in SDN style) of a multi-domain slice (see Section IV). In particular, the function splitting and interactions among the SDN controller with an upper management layer (Virtual Infrastructure Manager – VIM or Wide area Infrastructure Manager – WIM) of the domain management are studied. The business model adopted will influence these interactions.

The paper structure is described below. Sections II and III are preliminary. They serve to introduce and clarify the 5G management and control framework, where the solutions of the main Section IV will be applied, in the context of NFV-SDN technologies. In particular, Section II presents a few relevant examples of related architectural work to emphasize the M&O elements for resources, slices and services in multi-domain context. Section III details the slice creation phase M&O interactions. Section IV proposes and compares several architectural variants for the interface between the domain controller (SDN-IC) and higher layer manager (V/WIM). This interface determines how the mapping can be done of the required slice segment resources upon the network domain owned by the InP. The work is still preliminary - at architectural level. Section V presents conclusions and a future work outline.

II. 5G MULTI-DOMAIN SLICING ARCHITECTURES

This section presents a few examples of relevant 5G slicing architectures, in order to outline the M&O entities roles in a multi-domain environment and *locate the individual domain levels as a zone of interest for this study.* Many studies, projects, pilots, define variants of 5G slicing multi-domain architectures in various contexts [4][6][7][14 - 17][18]. In all of them, the M&O functions are crucial for coordination of the components.

The document (The European Telecommunications Standards Institute (ETSI) NFV Evolution and Ecosystem (EVE) 012 [6]) and The 3rd Generation Partnership Project (3GPP) Technical Report (TR) 28.801 document [7] consider the ETSI NFV framework to which they added three new management functional blocks dedicated for slice management: *Communication Service Management Function* (CSMF) - to translate the service requirements into NSL ones; *Network Slice Management Function* (NSMF) - to manage (including lifecycle) the NSLIs (it derives network slice subnet requirements from the network slice related requirements); *Network Slice Subnet Management Function* (NSSMF) - to manage the *Network Slice Subnet Instances* NSLSIs. These three elements interact with the upper entity of the NFV *Management and Orchestration* (MANO), i.e., with NFV *Orchestration of the NFV* (NFVO).

The 5G Infrastructure Public Private Partnership (5GPPP) Working Group details the architecture by defining four planes [1]: *Service*, *M&O*, *Control* and *Data* planes. The architecture also includes a *Multi-Domain Network Operating System* containing different adaptors and network abstractions above the networks and clouds heterogeneous fabrics. It is responsible for allocation of (virtual) network resources and maintains network state to ensure network reliability in a multi domain environment.

The *Service* plane comprises the *Business Support Systems* (BSSs) and business-level Policy and Decision functions as well as applications and services operated by the tenant. This plane includes an *end-to-end orchestration* system.

The *M&O* plane includes a general *Service Management,* the *Software-Defined Mobile Network Orchestrator* (SDMO) and the ETSI NFV lower level managers (i.e., *VNF Manager* - VNFM and *Virtualized Infrastructure Manager* - VIM). The SDMO is composed of a *domain specific application management*, an *Inter-slice Resource Broker* and *NFV-NFVO*. The SDMO performs the E2E management of network services; it can set up slices by using the network slice templates and merge them properly at the described multiplexing point. The Service Management intermediates between the upper service layer and the Inter-slice Broker; it transforms consumer-facing service descriptions into resource-facing service descriptions and vice versa. The Inter-slice Broker handles cross-slice resource allocation. The domain-specific application management functions could be, e.g., for 3GPP: Element Managers (EM) and Network Management (NM) functions, including Network (Sub-) Slice Management Function.

The *Control* plane is “horizontally” separated in two parts: intra and inter-slice control functions. “Vertically”, it is organized in SDN style, i.e., with three planes: *Control applications* (inter and intra-slice); *SDN controllers*; SDN nodes (these are actually slicing control function blocks realized as PNF/VNFs. Note here the flexibility of the SDN-NFV cooperation: some slicing control functions are seen and realized as SDN nodes. The SDN controllers are two types: *Software-Defined Mobile Network Coordinator* (SDM-X) and *Software-Defined Mobile Network Controller* (SDM-C). The SDM-C and SDM-X take care of dedicated

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and shared NFs, respectively; following the SDN principles, they translate decisions of the control applications into commands to SDN nodes, i.e., VNFs and PNFs. Note that also SDM-X and SDM-C, as well as other possible control applications could be implemented as VNFs or PNFs.

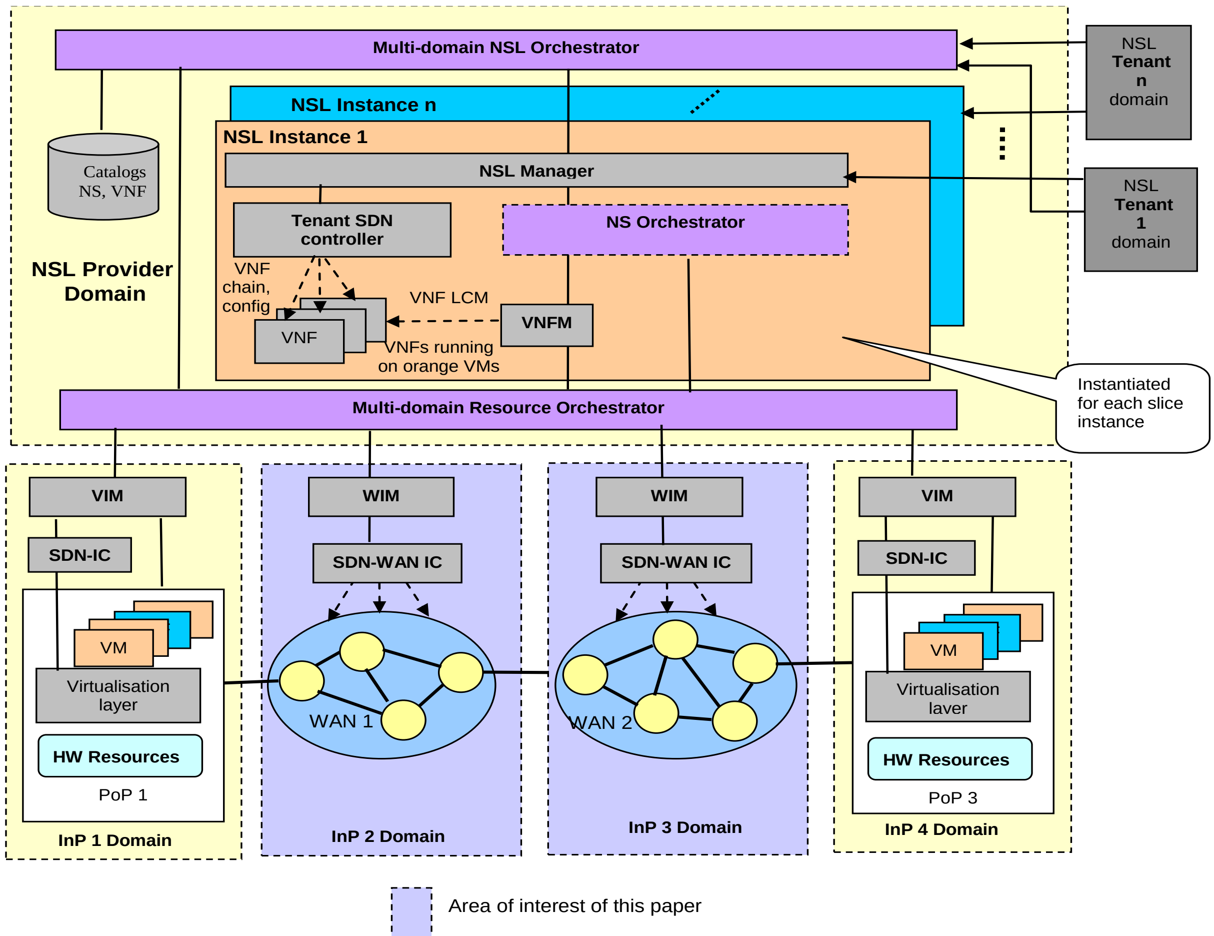

Figure 1. Run-time image of a multi-domain slicing architecture - example 1 (adapted from ETSI GR NFV-EVE 012 [6] and Ordonez-Lucena [3][18])

NS – Network Service; NSL - Network Slice; VNF – Virtualized Network Function; VNFM – VNF Manager; SDN Software Defined Networking; LCM – Life Cycle Management; VIM – Virtual Infrastructure Manager; WIM – WAN Infrastructure Manager; SDN-IC- Infrastructure SDN controller; HW-Hardware; WAN – Wide Area Network

The *Data plane* comprises the VNFs and PNFs needed to carry and process the user data traffic.

A relevant multi-domain slicing architecture, viewed at run-time phase, is presented in Figure 1 (adapted from ETSI GR NFV-EVE 012 [6] and J.Ordonez-Lucena et. al. [3][18]).

The specific contribution of this paper (Section IV) will be focused on the lower functional parts of such an architecture or a similar one.

A multi-domain slice instance can span several InPs and/or administrative or technological domains belonging to different providers. Figure 1 shows several domains upon which multi-domain slices can be constructed. Note also that this architectural picture focuses on the transport and core network domains, omitting the RAN domain.

The NSLP rents infrastructure resources owned by the underlying InPs to construct NSL instances. The *Resource Orchestration* (RO) manages the set of resources offered by different INPs (the resources are supplied under the control of the underlying VIMs/WIMs), and optimally dispatches them to the NSLIs aiming to satisfy their requirements but preserving their logical isolation. The RO *should have information on resource availability in each domain* whose resources will enter the multi-domain NSLI. To construct a multi-domain slice, some inter-domain interactions are also necessary.

The highest layer *NSL Orchestrator* (NSLO) has a main role in the *creation* phase of slices and also in the *run-time* phase. In the creation phase, NSLO receives the order to deploy a NSLI for a tenant (or the NSLP decides to construct a slice). The NSLO should have enough information (including on multi-domain resource availability) in order to check the feasibility of the order. To accomplish this, it interacts with RO (which aggregates resource information from several domains (InPs)), and also accesses the VNF and

NS catalogues. These catalogues contain VNF and NS descriptors, exposing the capabilities of all the VNFs and NSs that an NSL provider can select for the NSLs. If the slice is feasible, then NSLO triggers its instantiation.

At run-time, the NSLO performs policy-based inter-slice operations, e.g., it analyzes the performance and fault management data received from the operative NSLIs to check the fulfilment of their *Service Level Agreements* (SLAs). In case of SLA violations, the NSLO decides which NSLIs need to be modified and, if this is possible, sends corrective management actions (e.g., scaling, healing, etc.) to some specific NSL Managers.

Each NSLI has its own management plane (to get slice isolation) composed of: *NSL Manager*, *NS Orchestrator (NSO)*, *Tenant SDN Controller* and *VNF Manager (VNFM).* The VNFM(s) and the NSO perform the life cycle operations (e.g., instantiation, scaling, termination, etc.) over the instances of the VNFs and NS(s), respectively. Interactions between these functional blocks and the RO are necessary. The NSL Manager coordinates the operations on management data obtained from Tenant SDN Controller and the NS Orchestrator, to perform the fault, configuration, accounting, performance, and security management within the NSLI. Each tenant operates its NSLI instance (within the limits agreed with the NSL provider) through the NSL Manager.

Both in the preparation phase and at run-time the RO should interact with each domain management entities (e.g., VIM or WIM) in order to apply *Admission Control* (AC) before deciding on a new NSLI construction or later, on NSLI possible modification. Naturally, each domain should decide upon its resources availability. The specific contributions of this paper are focused on a domain resource management.

An SDN control is supposed to exist at domain level. The *SDN - Infrastructure Controller* (SDN-IC) manages and controls connectivity in its domain, under the directives of the corresponding VIM/WIM. The VIMs and WIMs can act as SDN applications, delegating the tasks related to the management of networking resources to their underlying ICs.

III. NETWORK SLICE CREATION

This section summarizes the general slice creation steps in order to clearly identify the scope and role of the management actions proposed in Section IV.

Before slice instantiation, preparation activities are necessary. Catalogues of available services and resources must be constructed in advance, usable by the tenants in order to select a slice model fitted to their needs.

The general typical set of steps coordinated by the NSLO and RO (see Figure 1) for a slice instance creation are [7][17][18]: a. Service ordering; b. Network slice resource description; c. Admission control; d. Optimization and Resource Reservation; e. Network slice preparation.

Service ordering: the NSLP should construct a *Service Catalogue* (business-driven), containing service offering (*service templates*). The catalogue contains NSLs specifications, optimized for different usage scenarios, like: enhanced Mobile Broadband (eMBB), massive Machine Type Communications (mMTC), ultra Reliable Low Latency Communications (uRLLC), or other vertical-specific applications. A service template includes all the information required to drive the NSL deployment, e.g., the NSL topology (technology-agnostic), NSL requirements (functional, performance, security), temporal, geo-location and other operational requirements [18]. The NSL provider offers application programming interfaces (APIs) to tenants, giving them access to the Service Catalogue, where the tenant can select the service template that best matches its requirements. Some parameters and attributes can be customized by the tenant. The result of this dialogue is a catalogue-driven NSL *service order* containing information to be mapped on technological segments (Radio Access Network (RAN), transport, and core network) and also over several administrative domains. The NSLO should process such information.

Network Slice Resource Description: this step creates a resource-centric view of the ordered NSL. For a higher flexibility and better adaptation to the tenant needs, different *Levels of Implementations* (NSL-IL) can be defined [18]. The NSLO extracts the relevant content from a resource viewpoint (e.g., the NSL topology, network requirements, etc.) and constructs an NSL-IL for the NSL instance. The NSL topology serves to identify which NS(s) need to be deployed for the NSL, retrieving the corresponding NS descriptor(s) from the NS Catalogue; the deployment option is selected for each descriptor (*NS descriptor ID, NS FlavorID, NS-IL ID*), that best matches the features and the performance level required for the NSL; an NSL-IL is constructed by referencing the selected triplet(s).

Admission Control (AC): the target NSL-IL specifies the resources needed for the tenant's demands. Now, the AC will be enforced on the ordered NSL-IL, from a resource viewpoint, to decide acceptance/rejection for deployment. Several types of information are needed in this process:

(1) NSLI resource requirements (resources to be allocated for each VNF instance and virtual link, affinity/anti-affinity rules applicable between VNF instances, reliability requirements for each VNF instance and virtual link);

(2) geographical region(s) where each VNF is needed;

(3) time intervals for activation of the NSL instance;

(4) information of the Points of Presence (PoPs) (and the WAN network(s) connecting them) to which the NSLP is subscribed. Such information is partially available at the NSLO and partially at RO; therefore, these two functional blocks need to interact within the AC actions.

Note that AC should be actually enforced at several levels: at a global multi-domain level and at each domain management level. This last aspect will be further analysed in Section IV.

Optimization and *Resource Reservation*: if several variants of NSL-ILs are found feasible by the AC, then RO can run an algorithm to select an optimal solution (note that this is a multi-criteria optimization problem). Afterwards, RO may proceed with resource reservation; it sends resource reservation requests to the underlying VIM(s)/WIM(s). The hard/soft nature of this reservation depends on the use case and NSL provider's policies.

Network Slice Preparation: it consists of setting up all that is required to manage the NSLI throughout its life cycle, i.e., from commissioning (instantiation, configuration, and activation) to decommissioning (de-activation and termination) (see for details, 3GPP TS 28.801 V.15.1.0 [7]). The preparation comprises: a. preparation of the network environment and b. designing and on-boarding the NSL descriptor.

For the step a., the NSLO (see Figure 1) performs the following tasks:

- negotiation with RO a priority level for the NSLI (this allows the RO to manage the cases when several NSLIs compete for the same resources, or to manage the case of resources shortage);
- instantiation of a NSLI specific management plane (NSL Manager, Tenant SDN Controller, NS Orchestrator, VNFM(s)); it configures these functional blocks, making them ready for the run-time phase.

In parallel to the network environment preparation, the NSLO builds up the NSL descriptor, which is a deployment template used by the NSL Manager to operate the NSLI during its life cycle. This descriptor includes the following parts: a set of policy-based workflows; the set of NSL-ILs available for use, constructed in the Network Slice Resource Description phase; VNF configuration primitives at application level and VNF chaining management instructions; information about management data, used for performance management.

IV. Resource management at domain level

This section contains the specific contribution of the paper. The focus will be on network segments of a multi-domain NSL (e.g., InP2 and InP3 domains in Figure 1). However, the framework proposed could be applied also (with some modifications) for cloud-like segments like PoP1 or PoP3. The business model considered here will be flexible. The domain manager and controller (here it will be the SDN-IC) and the Virtual Infrastructure Manager (VIM/WIM) could belong to the same administrative entity of a domain. In this case, there is a clear separation between administrative domains and the InP could offer virtualized resources due to VIM/WIM capabilities. However, is it possible that an InP keeps the classical functions as equipment/infrastructure provider while virtualization tasks and management could be delegated to a third-party provider.

A. Function splitting between VIM/WIM and SDN-IC

An important architectural choice related to the slice mapping onto network resources in a network domain is the functional split among SDN-IC and WIM and consequently the interface/relationship between WIM and SDN-IC with respect to:

(1) the style used by SDN-IC to upload information to VIM/WIM, about its available resources: *on demand* (OD) or in *proactive* (P) style (at SDN-IC initiative);

(2) the amount and depth of information uploaded by SDN-IC on the network resources (graph, capacities, etc.). Table I presents the resulting *architectural variants* of the functional split and WIM/SDN-IC interface and Figure 2 presents *architectural variants* for mapping a slice on InP domain network resources.

It is assumed that the network domain resources can be represented by topology and Resource Availability Matrix information, collected by the SDN-IC from the domain network (e.g., ingress and egress points/routers, available paths and network resources per path, supported traffic classes to allow Quality of Services (QoS) enabled transport, etc.).

Note that for each variant, and depending on monitoring information at network level, a Resource Availability Matrix RAM can be uploaded to VIM/WIM and also adjusted by SDN-IC to improve the traffic engineering performances.

In turn, the VIM/WIM can express the requirements for this network domain in the form of a *Service order* (or, equivalent, *Server Level Specification* - SLS) request. The generation of this request is actually done by the RO (wanting to construct a new slice), after splitting the multi-domain slice requirements in sets of requirements for participating domains to the multi-domain slice. The details of such a split at RO level is out of scope of this paper. An example of connectivity set of requirements known by the VIM/WIM (to be mapped onto domain resources) is a matrix of *Traffic Trunks* (TT). Each VIM/WIM may have an abstract view of its network and output links towards neighbors in a form of a set of virtual pipes (called TTs). A set of such pipes can belong to a given QoS class; so, this approach allows a given multiple domain slice to belong to a specific QoS class.

To simplify the notation, in the following, only the WIM notation will be used.

Several variants of interactions and function splitting between WIM and SDN-IC are proposed and discussed below in terms of pros, cons and trade-off.

Proactive style: at the initiative of the SDN-IC, (periodically or event triggered) the information that is uploaded to WIM is: the Resource Availability Matrix (RAM), i.e., full connectivity graph and capacities, or only a summary called Overlay Network Topology – ONT [19].

- *Pros*: the SDN-IC is the most qualified to know when to deliver network information to WIM, e.g., every time when network re-dimensioning is performed; WIM has at every moment all the information about network resources.
- *Cons*: WIM can be overloaded with information that it does not really need at a given time; it may keep or discard some information, depending on its local policy at WIM level; signaling overhead appears.

On demand style: WIM asks the domain RAM from the SDN-IC when needed, in order to answer appropriately to service order requests.

- *Pros*: the WIM decides when it wants RAM information; this could lead to a better usage of WIM Data Base space; SDN-IC doesn't need to systematically inform the WIM anymore.

- *Cons*: higher delay in servicing the RO requests, because WIM should first acquire RAM in order to respond appropriately to RO, based on updated RAM information.

High WIM role (HR): SDN-IC uploads to WIM its full connectivity graph.

- *Pros:* WIM has deep control on the network resources. It becomes in this way a major factor in assuring efficient allocation and exploitation of network resources in the future slice; more seamless deployment, given the fact that mapping of the slice onto network resources is outsourced to WIM; therefore, not many changes have to be done in the traditional networking SDN-IC functionalities;SDN-IC is released of AC and mapping functions.
- *Cons:* overload at WIM level: it should make both *mapping* of the slice requested resources onto network nodes and perform AC*;* less clean architecture: actual network related tasks are moved at WIM layer.

Medium WIM role (MR): SDN-IC uploads to WIM an overlay RAM based on traffic trunks (similar to ONT):

- *Pros:* WIM has medium degree of control on the network resources; it is still capable to apply optimization techniques; routing tasks and mapping real-paths to TTs are done at network level (natural choice), where local SDN-IC policies can be considered; clean architecture – WIM works at overlay level only, making AC, thus being compliant with abstraction principles.
- *Cons:* AC is performed at WIM level; it is more difficult to consider the current status of the network load; optimization at WIM level is not "the best".

Low WIM role (LR): SDN-IC does not upload/disclose any topology and resources to WIM but only ingress-egress points IDs and answer Yes/No to an SLS request:

- *Pros:* WIM has simpler task to only download the SLS parameters to SDN-IC and then ask SDN-IC about the result; sophisticated optimization techniques could be applied at SDN-IC level, considering local policies and current network status; routing tasks and mapping real-paths to TTs are done at network level (natural choice), where local SDN-IC policies can be considered; clean architecture – WIM works at overlay level only, thus being compliant with abstraction principles.
- *Cons:* all mapping and local AC is performed at SDN-IC network level; SDN-IC is overloaded with additional functions.

In practice, one of the six variants can be selected, depending on the overall design objectives of the slicing system, general set of requirements and business model adopted.

TABLE I. VARIANTS OF COOPERATION BETWEEN WIM AND SDN-IC

		Amount of available information (on CND resources) from SDN-IC for V/WIM		
		High WIM role (HR): SDN-IC uploads to WIM its full connectivity graph	Medium WIM role (MR): SDN-IC uploads only an overlay availability matrix (similar to Overlay Network Topology -ONT)	Low WIM role (LR): SDN-IC does not upload/disclose any topology and resources to WIM but only ingress-egress points Ids and answer Yes/No to an SLS request
SDN-IC style to upload info to WIM about its available resources	Proactive (P) style	P-HR	P-MR	P-LR
	(OD) on demand from WIM	OD-HR	OD-MR	OD-LR

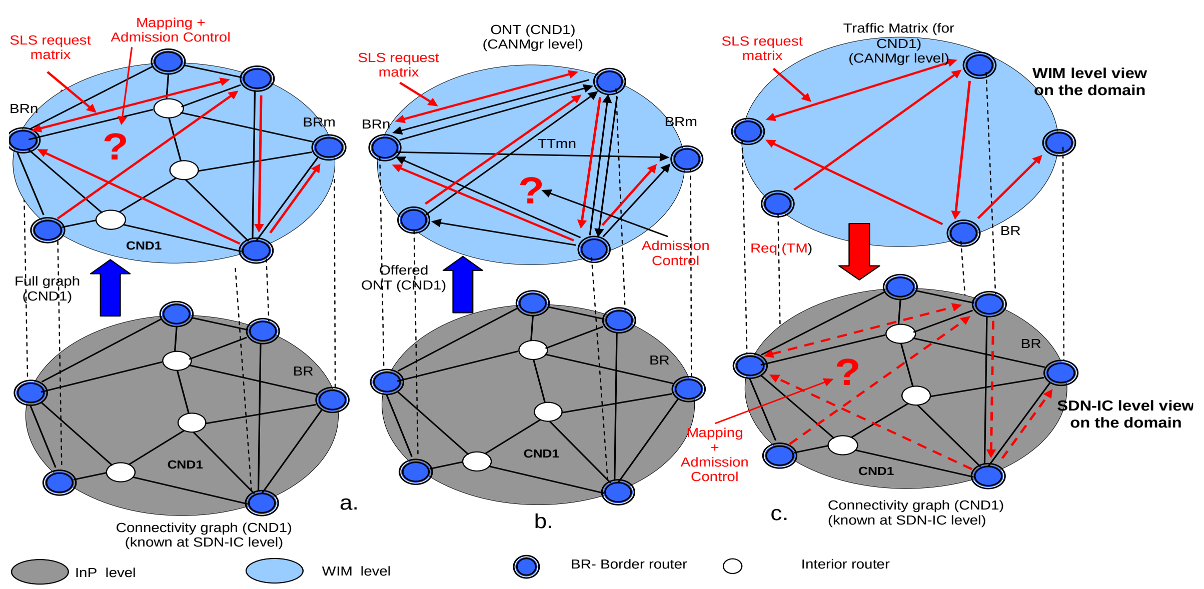

Figure 2. Architectural variants for mapping of a slice on InP domain network resources (WIM role: High, Medium, Low)
CND1-Connectivity Domain1; TM - Traffic Matrix; ONT – Overlay Network Topology

B. Local Resources Mapping

A design choice should be which entity has to perform the mapping of the RO requested resources (for the slice segment realized by this domain): WIM or SDN-IC? Two variants are proposed below.

WIM determines the mapping of SLS requested resources on the network resource matrix uploaded by the SDN-IC:

- *Pros*: SDN-IC does not need to run mapping algorithms but only to dimension its network conforming local policies; this way, a stronger control on mapping optimality is kept at the WIM level.
- *Cons*: more complexity at the level of WIM (AC for different levels of QoS guarantees are necessary); periodic or event-triggered updates are necessary to update the WIM vision on the network resources matrix, for the domain to which it is associated.

SDN-IC determines the mapping of SLS requested resources on its network resource matrix:

- *Pros*: SDN-IC has full knowledge on the network resource matrix, so the mapping can be optimized in a refined solution; SDN-IC will not disclose to the WIM any intra-domain topology; AC is enforced by SDN-IC, which decides upon the actual mapping.
- *Cons*: overloads the SDN-IC with additional functions.

C. Local Negotiation

An advanced solution could include a negotiation in the functionality of the WIM - SDN-IC interface. A negotiation protocol will be necessary here. The WIM could play the client role and SDN-IC the server role. Several variants can be considered and are discussed below in a comparative way:

Basic two-step negotiation session: "proposal followed by yes/no answer", started with a client proposal and then server accepting or rejecting it:

- *Pros*: simplest and fastest solution.
- *Cons*: non-optimal usage of resources; higher probability of negotiation failure.

Multi-step negotiation session: initial proposal from the client, revisions returned by the server, another proposal from the client and so on, up to the termination of the negotiation:

- *Pros*: higher probability of success for large network slices (several possibilities of SLS variants).
- *Cons*: lower speed wireless router two-step negotiation; medium complexity solution.

Optional enhanced negotiation based on several variants (alternatives) of negotiated objects values and selective acceptance or rejection of different alternatives:

- *Pros*: most refined way to negotiate due to selectivity of acceptance.
- *Cons*: high complexity and overhead; lowest speed.

V. CONCLUSIONS AND FUTURE WORK

This paper considered a 5G slicing system architecture based on NFV and SDN cooperation and selected some relevant layered examples, from those proposed in several standards and projects. The general architectural framework was described in Sections I-III.

Section IV developed the specific contribution, which was on studying the domain-level management for a network segment of a multi-domain slice.

The main management and control entities associated to an administrative domain were an SDN-Infrastructure Controller (SDN-IC) (playing also the role of an intra-domain network manager) and a Virtual Infrastructure Manager (VIM) (playing the role defined in ETSI-NFV MANO framework, plus some slice-specific new functions). Six variants of splitting the resource management functions (related to mapping of the virtual requested resources on the network domain ones) between two entities above, were proposed in the paper and comparatively analyzed with pros and cons comments. It has been shown that an additional flexibility can be added to the above cooperation if negotiations (related to resource availability) are introduced between VIM and SDN-IC.

Future work would be a continuation of this study, for a quantitative evaluation of the six variants in terms of complexity, performance, response time and seamless deployment capabilities. Also, refining the hierarchies and scope of admission control actions among the multi-domain Resource Orchestrator (higher level), VIM (middle level) and SDN-IC (lower level) is still an open research topic.

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