5G Slicing Management and Orchestration Architectures - Any Convergence?

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Abstract **— Management and Orchestration (M&O) are essential activities in 5G slicing systems. Essentially, the integrated M&O based on The European Telecommunications Standards Institute (ETSI) Management and Orchestration (MANO) is the basis, but enriched, in order to cope with slicing. In particular, supporting technologies like Network Function Virtualization (NFV) and Software Defined Networks (SDN) are considered, to deliver functional components for 5G slicing M&O. The multi-tenant, multi-domain, multi-operator, end-to-end (E2E) features of the 5G slicing determine a high complexity for M&O. Consequently, many different architectural variants have been already proposed, studied and developed in recent studies, standards and projects. The study in this paper is useful because, despite many efforts, (spent in the last five years) much heterogeneity and different solutions still exist, even at the M&O architectural level. This paper analyzes the existing common parts and differences between several 5G slicing architectures, in an attempt to identify a degree of "convergence", while considering the MANO as a base architecture.**

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

I. INTRODUCTION

The emergent 5G mobile network technologies offer powerful features, in terms of capacity, speed, flexibility and services, to answer the increasing demand and challenges addressed to communication systems and Internet [1][2]. 5G can provide specific types of services to satisfy simultaneously various customer/tenant demands in a multi-x fashion (the notation –x stands for: tenant, domain, operator and provider).

The 5G network slicing concept (based on virtualization and softwarization) enables programmability and modularity for network resources provisioning, adapted to different vertical service requirements (in terms of bandwidth, latency, mobility, etc.) [2]-[6]. In a general view, a *Network Slice* (NSL) is a managed logical group of subsets of resources, Physical/Virtual network functions (PNFs/VNFs), placed in the architectural Data Plane (DPl), Control Plane (CPl) and Management Plane (MPl). The slice is programmable and has the ability to expose its capabilities to the users.

Network Function Virtualization [7]-[9] and Software Defined Networks can cooperate [10] to manage and control the 5G sliced environment, in a flexible and programmable way.

Management and Orchestration (M&O) is a crucial subsystem in 5G. Such topics constitute the object of standardization organizations and forums among which The 3rd Generation Partnership Project (3GPP), The 5G Infrastructure Public Private Partnership (5GPPP), and ETSI are representative [11]-[16]. They cooperate in order to harmonize their specifications. For instance, the 3GPP-defined management system interacts with ETSI's NFV MANO system to enable the resource management for virtualized Core Network (CN), virtualized Radio Access Network (RAN) and network slicing. ETSI collaboration with 3GPP – especially the Service and System Aspects Fifth (SA5) Working Group – is a key throughout the specification work of both ETSI NFV Releases 2 and 3, to ensure interoperability between management systems.

ETSI NFV has recently designed new features to support 5G networks. 5G resource M&O aspects were added on top of the NFV Release 2 framework. New NFV Release 3 [9] topics related to 5G include: "Support for network slicing in NFV", "Management over multi-administrative domains", and "Multi-site network connectivity". These features are essential to address the variety of applications expected to run on top of a 5G system, whether using distributed resources over multiple sites, centralized or a combination of both.

However, it is recently recognized that a complete understanding of the relationship of an M&O system and a slicing system is still missing [2]. Even more, it is not yet a general/common agreement on the slice itself; several definitions exist, having major impacts and relationships to the M&O.

In the simplest view, a slice is a service with resource guarantees. Here, the slicing system and the orchestration system are identical. At the other end of approaches, a slice is a complex entity, i.e., a collection of resources (computing, networking, storage) – that constitute a virtual logical network (and customizable), embedded in some physical networking infrastructure. Inside such a slice, the slice owner/tenant has partial or even full freedom to enforce its own management and control (M&C) policies and actions. Many studies and standards adopted the slice complex definition; this is also considered in this work, given the high flexibility that it can offer to the tenants. On the other hand, the complex structure of such a slice induces M&O complexity and leads to a large variety of possible architectural approaches.

Given the rather large variety of architectural proposals, there is an interest to evaluate in what degree they have similar approaches of the main "core" architectural functional set of blocks. This similarity level will be called here "convergence", although this word has usually a richer semantic. The focus of this paper is on management and orchestration sub-systems. Due to space limitation, this text cannot afford to offer detailed explanations about the architectures presented; the objective is to identify the major point of similarity of different approaches.

Therefore, this paper is mainly an overview type. Its structure is described below. Section II outlines the stakeholder roles, given that such definitions determine essentially the overall architecture. Section III evaluates whether a unified view exists at architectural level, expressed in so-called *meta-architecture*. Section IV performs an analysis of some factors that lead to non-convergent refined M&O architectures. Section V uses some examples extracted from various studies and projects to illustrate the heterogeneity of solutions. Section VI summarizes conclusions and future work.

II. STAKEHOLDER ROLES

The layered structure of the 5G slicing M&O strongly depends on the definition of stakeholder roles (also called *business model*). Different business models aim to support multi-tenant, multi-domain end-to-end (E2E) and multi-operator capabilities. A basic model (see A. Galis, [17]) defines four roles:

Infrastructure Provider (InP) – owns and manages the physical infrastructure (network/cloud/data center). 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.

Network Slice Provider (NSLP) – can be typically a telecommunication service provider (owner or tenant of the infrastructures from which network slices are constructed). The NSLP can construct multi-tenant, multi-domain slices, on top of infrastructures offered by one or several InPs.

Slice Tenant (SLT) – is the generic user of a specific slice, including network/cloud/data centres, which can host customized services. The SLTs can request from a NSLP to create a new slice instance. The SLT can lease virtual resources from one or more NSLP in the form of a virtual network, where the tenant can realize, manage and provide *Network Services* (NS) to its individual end users. A NS is a composition of *Network Functions (NFs)*, 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 slice tenant, without providing them to other business actors.

The above business model is recursive (see Ordonez et al., [3]), i.e., a tenant can at its turn to offer parts of its sliced resources to other tenants. Other variants of business models are presented in [17].

Several recent Public Private Partnership (PPP) Phase I/II collaborative research are running, having as objectives 5G technologies [17]. Some of them extended the list of role definitions to allow various possible customer-provider relationships between verticals, operators, and other stakeholders. In [2] one can find a more refined business model:

Service Customer (SC): uses services offered by a Service Provider (SP). The vertical industries are considered as typical examples of SCs.

Service Provider (SP): generic role**,** comprising three possible sub-roles, depending on the service offered to the SC: *Communication SP* offers traditional telecom services; *Digital SP* offers digital services (e.g., enhanced mobile broadband and IoT to various verticals); *Network Slice as a Service* (NSaaS) *Provider* offers an NSL and its services. The SPs have to design, build and operate services using aggregated network services.

Network Operator (NOP): orchestrates resources, potentially from multiple *virtualized infrastructure providers* (VISP). The NOP uses aggregated virtualized infrastructure services to design, build, and operate network services that are offered to SPs.

Virtualization Infrastructure SP (VISP): offers virtualized infrastructure services and designs, builds, and operates virtualization infrastructure(s) (networking and computing resources). Sometimes a VISP offers access to a variety of resources by aggregating multiple technology domains and making them accessible through a single Application Programming Interface (API).

Data Centre SP (DCSP): designs, builds, operates and offers data center services. A DCSP differs from a VISP by offering "raw" resources (i.e., host servers) in rather centralized locations and simple services for consumption of these raw resources.

The hierarchy of this model (in the top-down sense of a layered architecture) is: SC, SP, NOP, VISP, DCSP. Note that, in practice, a single organization can play one or more roles of the above list.

III. A GENERIC 5G MANAGEMENT META-ARCHITECTURE

The analysis of the convergence degree between many architectural proposals (in 5G and in particular, in 5G slicing) leads to the question: *is there any high-level consensus architecture?* Recently, the document [2], authored by 5G PPP Architecture Working Group has identified a set of requirements for a consensus/meta 5G high-level architecture (collecting some M&O fundamental functionalities). The identified features are general for 5G and in particular applicable also to the slicing approach. This architecture should be able to support:

a. individual control of NFs (their distribution/placement, number of instances, deployment of an execution environment, management of the instances' states, start/stop the instances).

b. individual NFs chaining into services (NF graphs) facilitated by different control mechanisms at network level (e.g., the NFs chaining can be SDN -controlled).

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c. different underlying execution environments: various virtualization techniques (virtual machines (VM), containers, or plain processes) in clusters of different sizes (from a CPU board to an entire large-scale data center) over different, specialized “technological domains” - i.e., from some simple hardware, up to complex networking environments (wireless, optics, cable).

d. working across different “organizational”, or administrative domains, i.e., owned by network operators or companies and using various business models (e.g., network operators can be separated from cloud infrastructure operators).

e. a large range of applications with different specific requirements (in terms of resource, deployment, orchestration and optimization goals);

f. subdivision of the infrastructure in logical separated and isolated slices – while offering different levels of guaranteed performance to their tenants.

Note that slicing capabilities – can be seen as part of a M&O system. However, there is no general consensus on this inclusion. There are proposals to position a slicing system underneath or above a MANO system.

Several core roles have emerged from the above requirements: end user, function developer, application developer, validation and verification entity, tenant (owner of applications), operator (not necessarily encompassing slicing operator) infrastructure provider (network, cloud), etc., [2]. These can be mapped onto the roles described in Section II. Overlaps can exist between some of the above. Also, the mapping of the above roles on real organizations roles is flexible.

The requirements listed above actually drive the definition of the M&O meta-architecture, in the sense that no matter the solution will be, the six functionalities should be included. These define a general level of convergence from architectural point of view. A particular architecture will be a refinement of the meta-one.

Another general aspect is related to the different time scales of different operations. One can distinguish between *“orchestration”* and *“control”* actions. The first are mid-long-time scales operations, relatively heavy-weight (e.g., optimization of the overall structure of a service, group of services, or slices). The second class comprises short time scales operations (e.g., light-weight operations, flow routing, etc.). We defend here the idea that such a logical separation should exist (it is natural) between functional elements performing the orchestration w.r.t. those dedicated to control; however, in different refinements of the meta-architecture this separation is not quite obvious; this, again, leads to heterogeneity of approaches.

The basic framework for a high-level meta-architecture is offered by ETSI NFV (Figure 1). The main M&O blocks are: the NFV Orchestration (NFVO), VNF Manager (VNFM) and Virtual Infrastructure Manager (VIM). If the principle of separation between the orchestration and control is applied, then the specific network configuration tasks (e.g., connectivity - related) can be outsourced to a separate SDN controller, working under command of the NFVO. An alternative could be, to split the NFVO into two parts – orchestrator and controller.

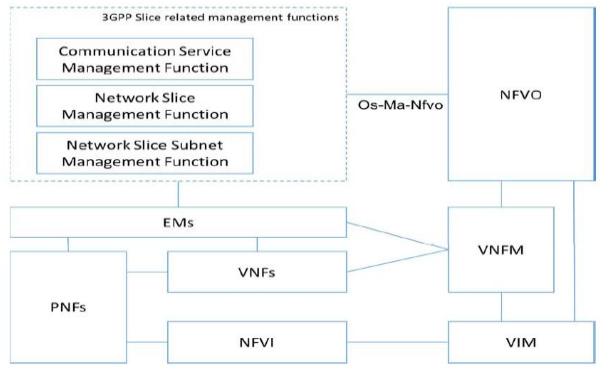

Figure 1. Network slice management in an NFV framework (ETSI GR NFV-EVE 012 V3.1.1, [14])

NFV -Network Function Virtualization; EM - Element Manager; MANO - Management and Orchestration (NFVO – NFV Orchestration; VNFM – VNF Manager; VIM Virtual Infrastructure Manager); VNF/PNF – Virtual/Physical Network Function; NFVI -NFV Infrastructure; NS-Network Service; OSS-Operations Support System.

The slicing support feature (i.e., yes/no) introduces significant differentiation between particular architectures. The slice management can be included into the NFVO (because a network slice instance (NSLI) can be actually seen as a guaranteed network service), or a separate slice manager exists (controlled by NFVO). The service management can be defined as separated from resource management, or they can be treated together. A cleaner architecture is resulting in the former case.

In multiple domain cases, the NFVOs should federate in some form with peer NFVOs, placed in a single or in multiple organizations. In some approaches, a hierarchy of service management instances is developed, having on top a multi-domain manager (working at abstract level) and then single-domain managers. The latter should perform also peer interactions.

A typical set of functional M&O blocks for a single-domain meta-architecture is [2] (top-down ordered levels): [Service management, Orchestrator, (MANO controller, SDN controller), VIM, Resources]. In a multi-domain environment, each domain should have the previous set and above all a multi-domain service manager should exist. Note that inter-domain (horizontal) peer interactions must exist between peers (e.g., Orchestrator_X <---> Orchestrator_Y).

The basic 5G slicing high level architecture proposed by ETSI [14] (Figure 1), can be considered as a meta-architecture comprising the six features exposed above. To the original ETSI NFV architecture [7][8], several new functional blocks have been added in order to support the network slicing (ETSI-NFV EVE 012 [14]).

The 3GPP TR 28.801 document [15] defines three new management functions: *Communication Service Management Function* (CSMF) – it translates the communication service requirements to NSL requirements;

Network Slice Management Function (NSMF) - responsible for the management (including instances lifecycle) of NSLIs (it derives network slice subnet requirements from the network slice related requirements); *Network Slice Subnet Management Function* (NSSMF) - responsible for the management (including lifecycle) of *Network Slice Subnet Instances* (NSSIs).

An interface is defined, i.e., Os-Ma-NFVO Reference Point (RP) with ETSI NFV-MANO. To interact in an appropriate way with NFV-MANO, the NSMF and/or NSSMF need to determine the type of NS or set of NSs, VNF and PNF that can support the resource requirements for a NSLI or NSSI, and whether new instances of these NSs, VNFs, and the connectivity to the PNFs, need to be created, or existing instances can be re-used.

Starting from the above basic architecture and considering different visions (shortly presented in the Introduction section), several groups developed a large set of variants of refined architectures [17]. Some of them are substantially different from each other. Currently there is a high heterogeneity seen in this area. The question analyzed in this paper is: *how much convergence/similarity* and how much *mutual compliancy* exists among them?

IV. Where Does the Heterogeneity Come From?

This section will summarise the factors leading to heterogeneity in the area of particular architectures. Note that, given the topics complexity, this analysis cannot be exhaustive. Some aspects are not touched, or only briefly mentioned, such as: abstraction aspects, slice isolation and security, slice composition, monitoring issues and slice optimization, details on multi-domain interactions, technological details and so on.

The *services deployment* is inherently heterogeneous, depending on applications to be supported. An example is the traffic locality property (at the edge of the network/slice or crossing the core part). An orchestrator should be aware of such traffic properties and, if necessary, deploy the corresponding network functions at the mobile edge. The orchestrator needs to have enough topology information of slices in order to be able to install appropriate functions at right places.

The *execution environments* at the infrastructure level could also be heterogeneous. The infrastructure should provide an interface to the orchestrator, via which different functions execution can be started, stopped, paused, or migrated; the interface also provides means to influence the transport of data. Variants can exist:

- The infrastructure hides (to MANO) its information on the type of execution elements available. The infrastructure management chooses the right (i.e., "functionally possible") realization of a function (virtual machine (VM) or container, etc.). This abstraction simplifies the MANO tasks, but makes difficult for the infrastructure manager to decide what is "performance-optimal" in the absence of information about the performance requirements of an entire service, and the relationships to other services.
- The infrastructure provides to the MANO information on available types of execution resources (quantity, locations, etc.). So, the MANO has enough information to optimize the execution environment. The price paid is a higher burden for MANO. Note that such an approach should consider the degree of trust between the infrastructure provider and MANO entity, especially in multi-domain environment.

The *hardware heterogeneity* at infrastructure level can also determine many variants, e.g., virtualization methods and other factors (e.g., Field programmable gate arrays (FPGA), Graphics processing unit (GPU) implementations, hardware accelerators, etc.).

The classical principle of *vertical separation of services* in *network-related* (i.e., connectivity–oriented) and *application-level services* (e.g., caching, video transcoding, content-oriented, web server, etc.) could be preserved or not. The separation will require one orchestrator vs. separate network/service orchestrators. One can speak about segregated or integrated orchestration, respectively. Concerning slicing, one can define some slices offering essentially connectivity services and other dedicated to high-level applications. The clear separation of areas of responsibility over resources could be an advantage for operational stability (e.g., a segregated RAN orchestrator could still maintain basic RAN services even if an application-oriented orchestrator fails). On the other hand, the integrated orchestration could be attractive, in particular for operators, if both kinds of services could be orchestrated in the same fashion (and possibly even with the same orchestration infrastructure). These two options also determine heterogeneity at M&O architectural level.

Segregated orchestrators lead to a more complex overall architecture. One must assign areas of responsibilities from a resource perspective (which orchestrator controls - what resources); one should identify services pertaining to each orchestrator. The split of service is also a problem, i.e., the service description should define the "network" and "application-facing" parts of the service. Aligning the control decisions taken by these two kinds of orchestrators in a consistent way is also not trivial. In an integrated orchestration approach, all these problems disappear. However, an integrated orchestrator might be very complex if required to treat substantially different services (a one-size-fits-all orchestration approach is rather not the best choice). An integrated orchestrator is a more challenging piece of software (from both dependability and performance perspectives) but would result in a simpler overall architecture.

Considering the above rationale, we defend the idea that from the slicing point of view, a segregate orchestrator is a better choice.

However, in practice, both approaches have been pursued in different projects. Currently, a final verdict commonly agreed, on segregated versus integrated orchestration is not yet available. Apparently, there is no need to standardize this option, as long as both of them could be realized inside a meta-architecture. So, for the time being, we can state that M&O heterogeneity, from this point of view, will last.

Another architectural choice is on "*flat"* or *"hierarchical"* orchestration. In the flat solution, a single instance of a particular orchestrator type is in charge of all assigned resources. In the hierarchical solution, there are multiple orchestrators (a "hierarchical" model is needed, when orchestrators know to talk to each other). Note that a hierarchical orchestrator is *not necessarily* a segregated one, because all hierarchy members could deal with the same type of services.

In many projects and studies, the hierarchical M&O option is chosen [6][17]-[20]. However, several issues should be solved in each of the two solutions [2]:

- The *number of hierarchy levels* and each member responsibility area could be fixed or adaptive (upon load changes the responsibility areas can be split/merged; new hierarchy levels can be added/removed and new orchestrator instances can be started or some old ones can be stopped). However, the adaptive option is highly complex, given the inherent dynamicity capability required.
- *North/south vertical interfaces* between the orchestrators must be defined. In a flat model, the service requests are received by an orchestrator's northbound interface (NBI). At its south bound the orchestrator communicates with NBI of the abstracted infrastructure (VIM). These two NBIs are structurally different. In a hierarchical model, an orchestrator should be able to communicate with a lower level orchestrator through a different interface than for VIM. So, an orchestrator should be able to use different NBIs (NBI of a VIM, or NBI of a lower-level orchestrator). It is still in study to create uniform interfaces; the advantage would be that from the perspective of a higher-level orchestrator, it always talks to a VIM-style interface. The recursive orchestration could be much easier implemented.
- *Horizontal interfaces* (east/west) should be defined between peer orchestrators (those who are on the same level), if they are allowed to negotiate directly with each other (for resources). Such interfaces are naturally to exist in cross-domain slicing scenarios.
- *Multi-domain scenarios* create new problems (e.g., in the case of a multi-domain "federated" slice) [6][18]. In a flat model, each orchestrator of a domain is actually multi-orchestration capable, i.e., it can discuss/negotiate with other domains' orchestrators. In the hierarchical model, a higher-level orchestrator could exist, in charge of harmonizing multiple organizations cooperation. However, several issues are not fully solved today: which entity would run that multi-domain orchestrator, trust issues, preservation of domains independency, assuring the fairness, etc.
- *Mapping* of the *orchestration entities* (and their areas of responsibility) onto *"domains"* (in a very general sense of the word) is still an open research issue and it is also a factor of heterogeneity of the refined M&O architectures. For instance, one could have separate orchestrators for different technological domains (e.g., computational resources, optical networking infrastructure, wireless edge, etc.). However, the word "domain" can be associated to organizations/companies boundaries. Such domains have overlap with the technological ones. A third semantic is that a "domain" could be a subdivision of a larger infrastructure into an edge domain, a core domain, etc. (each one spanning multiple technologies, possibly dealing with all kinds of services in a non- segregated way).
- *Relationship* of the *M&O system* and a *slicing system* is another factor of architectural variability, depending on what the definition of a slice is. A largely agreed solution is to have a general orchestrator (configured offline), capable to trigger the construction of a new slice and then to install in this new slice its own dedicated orchestrator (before the slice run-time). To still assure the basic services outside any slice (e.g., packet forwarding at network level) one can construct an additional special orchestrator installed outside of all slices. Currently, many combinations have been proposed, and there is still no consensus on such matters. The convergence of solutions will be determined probably by the adoption of a more unique definition of a slice – which could assure better inter-operability.

V. EXAMPLES OF SLICED 5G MANAGEMNT AND ORCHESTRATION ARCHITECTURES

This section will provide some examples to illustrate the major M&O options and also the heterogeneity of the refined architectures. Given the limited dimension of this paper, the examples are included mainly for illustrative purposes, i.e. this text cannot cover a large set of refined architectures.

The 5GPPP Working Group details a 5G multi-domain 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. The *M&O* plane comprises a general *Service Management,* the *Software-Defined Mobile Network Orchestrator* (SDMO) and the ETSI NFV lower level managers (i.e., VNFM and 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. Note the definition of a separated Control Plane. It 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 also the flexibility of 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).

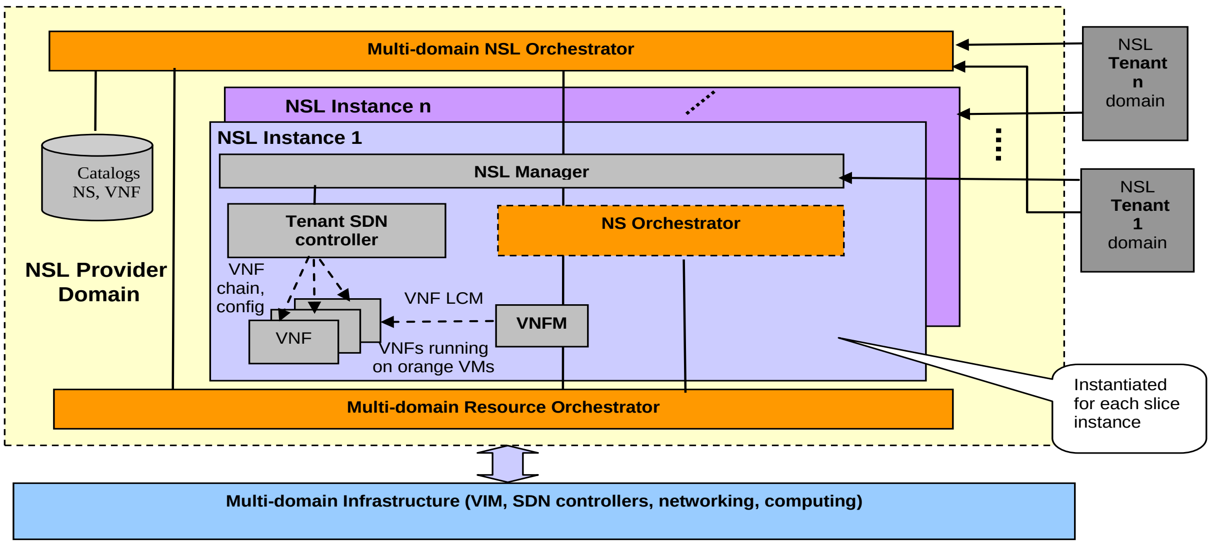

Figure 2. Run-time view of a multi-domain slicing hierarchical architecture example 1
(adapted from ETSI GR NFV-EVE 012 [14] and Ordonez-Lucena [3][19])

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

In Figure 2, a multi-domain hierarchical slicing architecture (viewed at run-time phase) is presented according to the proposal from ETSI GR NFV-EVE 012 [14] and J.Ordonez-Lucena et al. [3][19]. The main M&O entity is the *Network Slice Provider (NSLP).* Note the multiple levels of orchestrators and separation between service and resource management. Inside NSLP, a highest layer *NSL Orchestrator* (NSLO) (configured offline) 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 itself 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 a lower level *Resource Orchestrator* (RO) (which aggregates resource information from several domains (InPs)), and also accesses the VNF and NS catalogues.

The NSL provider plays a role of an infrastructure tenant; it rents the infrastructure resources owned by the underlying infrastructure providers, and uses them to provision the NSL instances. The RO uses the set of resources supplied by the underlying VIMs/WIMs and optimally dispatches them to the NSL instances. All the NSL instances are simultaneously provided with the needed resources to satisfy their requirements and preserve their performance isolation. Note that in this high-level architecture proposal it is not detailed how the multi-domain capable RO is implemented in order to assure inter-domain independence.

For each network slice instance (NSLI), individual M&O entities are dynamically created. 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).

Taleb et al. [6] recently proposed a multi-domain slicing hierarchical, complex orchestration architecture (see Figure 3). It is structured into four major strata: *Multi-domain Service Conductor, Domain-specific Fully-Fledged Orchestration, Sub-Domain Management and Orchestration (MANO) and Connectivity, and Logical Multidomain Slice Instance* stratum. The architecture introduces (at top level) a novel architectural plane - *Service Broker* (SB), to handle incoming slice requests from verticals, for instance *Mobile Virtual Network Operators* (MVNO), and application providers. The main SB operations are: NS admission control and negotiation, considering service aspects; management of slice user/owner relationship enabling a direct tenant interface with the MSC plane; billing and charging; NSLI scheduling, i.e., start and termination instant of time, related with slice composition and decommission.

Below the SB, a *Multi-domain Service Conductor* (MSC) plane is defined, to perform service management across *federated domains*. The MSC stratum analyzes and maps the service requirements of incoming multi-domain slice requests onto the respective administrative domains. It also maintains the desired service performance throughout the entire service life-cycle. Inside MSC, a *Service Conductor (SC)* is placed on top; the SC analyses and maps the service requirements of incoming slice requests onto appropriate administrative domains and maintains the desired service performance during service lifecycle. Below SC, a *Cross-domain Slice Coordinator* is defined for each slice, which aligns cloud and networking resources across federated domains and carries out the Life Cycle Management (LCM)

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operations of a multi-domain slice. It also establishes and controls inter-domain transport layer connectivity, assuring the desired performance. A multi-domain NSLI can combine several *Fully-Fledged NSLIs* that belong to distinct administrative domains, to get an E2E multi-domain (i.e., federated NSLI).

For each domain a *Fully-fledged NetSlice Orchestration Plane* is constructed, dealing with specific operations associated to slices instance in that domain (such as service management and slice lifecycle management). The lower layers of this specific orchestration plane comprise NFV MANO functionalities (NFVO, VNFM and VIM). Low level connectivity tasks between VNF/PNFs are performed by an SDN controller.

The 5G-MoNArch H2020 project [20] develops a hierarchical architecture consisting of four layers: *Service, M&O, Controller and Network* layer (similar to that proposed in [1] by 5GPPP). The overall functional architecture is presented in Figure 4. The Service layer comprises *Business Support Systems (BSS)*, business-level *Policy and Decision* functions, and further applications and services operated by a tenant or other external entities.

The M&O layer contains M&O functions from different network, technology, and administration domains (e.g., 3GPP public mobile network management, ETSI NFV MANO, ETSI Multi-access Edge Computing functions [ETSI MEC16], management functions of transport network or enterprise networks. The M&O layer is divided into an End-to-End (E2E) service M&O sublayer and an additional sublayer containing domain-specific management functions. An E2E network slice is composed of *Network Slice Subnet Instances (NSSIs)*, typically each from a different network domain, including subnets from radio access network (RAN), transport, and core network domains, or private networks. The M&O layer performs cross-domain coordination actions.

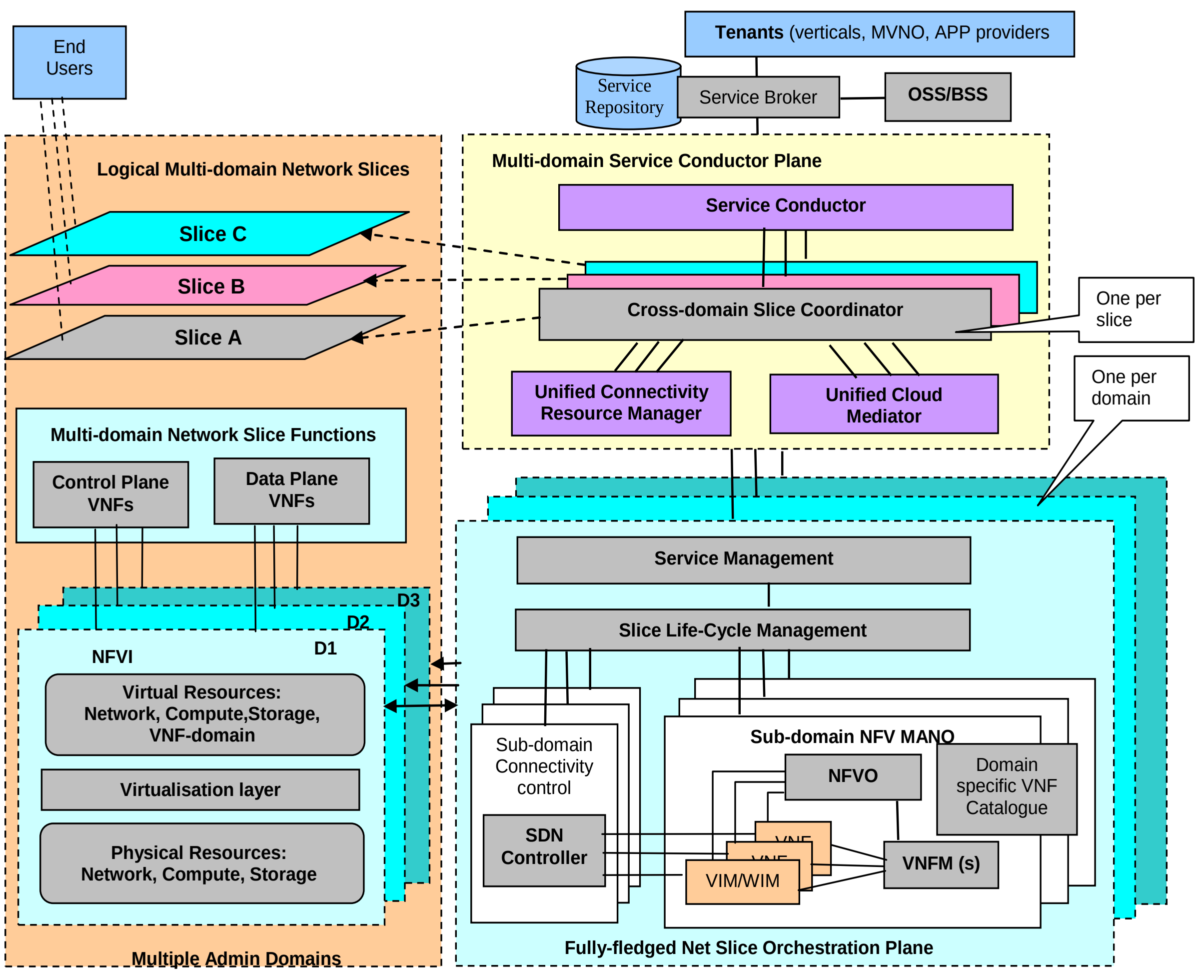

Figure 3. Multi-domain multi-tenant slicing architecture example 2 (adapted from [6])

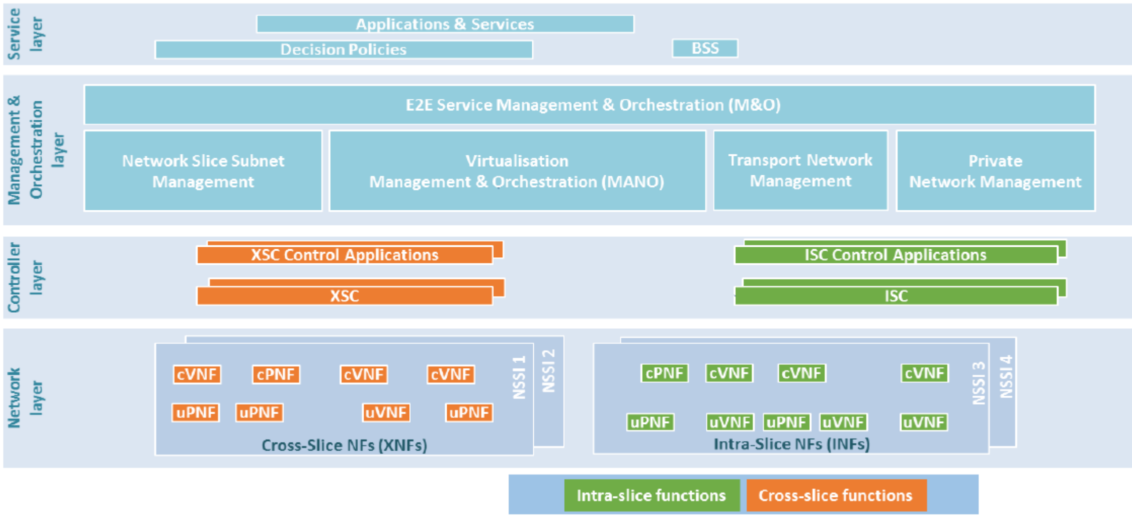

Figure 4. 5G-MoNArch high-level structure of the overall functional architecture (Source: [20])

Note again the architectural separation between the management and control. The Controller layer comprises two types of controllers- cross-slice and the intra-slice (XSC and ISC, respectively). On top of the controllers, there are *Control Applications*; together they realise the network programmability in SDN style. Each network domain has a dedicated controller that is aware of the domain technology and implementation characteristics.

Other architectures are proposed and developed in different research projects [17]. Again, all of them satisfy the characteristics of the meta-architecture described in Section III. However, different specific developments are present in their refined version.

VI. Conclusions and Future Work

This is an overview-type paper; it analyzed different M&O architectures for 5G slicing, in order to evaluate the degree of their similarity/convergence, given the large variety of proposals existing in various studies, standards and projects.

It has been shown that business model definitions (actors) and their roles (Section II) have an important impact on the high-level definition of the architectural assembly. Actually, the variety of business models is a primary factor of architectural heterogeneity, given the different definition of actors and roles, adopted mainly from business reasons and only secondly from technical ones. Also, the definition of a slice itself is still not globally agreed upon and this naturally leads to different architectures.

However, a unifying meta-architecture has been defined (see Section III), answering to some basic requirements for 5G systems and, in particular, for 5G M&O slicing. It has been derived from ETSI MANO work complemented with additional functionalities slice-oriented. The most relevant architecture examples found in literature and developments are essentially compliant with the basic meta-architecture. It is important to note that, all relevant architectures proposed in different studies, standards and projects generally try to achieve the main meta-architecture capabilities.

On the other hand, many factors are inducing heterogeneity of the refined architecture variants, such as: multi-domain, multi-tenant, multi-operator, multi-technology

Future work can go further to consider more deeply the multi-x aspects, implementation and performance. Future work can concentrate on M&O issues such as: an appropriate cooperation between slice-specific management functional blocks. Policies need to be captured in a way that they can be automatically validated. This automation enables slice-specific functional blocks to be authorized to perform the corresponding management and configuration actions in a timely manner.

Designing computationally efficient resource allocation algorithms and conflict resolution mechanisms at each abstraction layer is also a way to flexibly assign resource on-the-fly to slices.

Lastly, one should mention new approaches for 5G slicing M&O architectures: usage of artificial intelligence and in particular, machine learning techniques in order to provide more M&O automation and capabilities of dealing with big volumes of data [21]-[24]. This domain is only at its beginning, so is an open field for further studies.

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