On Heterogeneity of Management and Orchestration Functional Architectures in 5G Slicing

Eugen Borcoci, Cosmin Contu, Andra Ciobanu
University POLITEHNICA of Bucharest - UPB
Bucharest, Romania
Emails: eugen.borcoci@elcom.pub.ro, cosmin.contu@elcom.pub.ro, andraciobanu90@yahoo.com

Abstract — **Management and orchestration functionalities are crucial activities in 5G slicing systems. Essentially, the basis is the integrated framework Management and Orchestration (MANO), of The European Telecommunications Standards Institute but enriched, in order to cope with slicing. In particular, supporting technologies like Network Function Virtualization and Software Defined Networks are considered, to deliver functional components, cooperating for 5G slicing management and orchestration. The multi-tenant, multi-domain, multi-operator, end-to-end features of the 5G slicing determine a high complexity for management and orchestration. Consequently, many different architectural variants have been already proposed, studied and developed in recent studies, standards and projects. This study is useful because, despite many efforts (spent in the last five years), much heterogeneity and different solutions still exist, even at the management and orchestration architectural level. However, the MANO is considered as a base starting point architecture. This paper is an extension of a previous study. It analyzes in more depth the existing common parts, differences and heterogeneity of several management and orchestration 5G slicing architectures, identifying the similar functionalities and also the factors leading to heterogeneity.**

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

I. INTRODUCTION

This paper is an extension of a previous paper published at IARIA AFIN Conference, 2019 [1], dealing with management and orchestration of 5G sliced systems.

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 [2][3]. 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.) [3]-[7]. 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 (NFV) [8]-[10] *and Software Defined Networks (SDN)* are two powerful technologies, which offer the basis for softwarization and virtualization. They are considered as cooperating tools [11] to manage and control the 5G sliced environment, in a flexible and programmable way.

Management and Orchestration (M&O) is a crucial subsystem in NFV framework and also 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 (5G PPP), and European Telecommunications Standards Institute (ETSI) are representative [12]-[17]. Given the complexity of 5G systems, the above organizations 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 [10] topics related to 5G includes: "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 and services expected to run on top of a 5G system, while using in a distributed way resources over single or multiple sites, or in centralized or a combination of both.

However, it is recently recognized that a complete understanding of the relationship of a M&O system and a slicing system is still missing [3]. Even more, there is not yet a general/common agreement on the slice definition 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. In such a case, the slicing system and the orchestration system are identical. At the other end of the spectrum, a slice is a complex entity, i.e., a collection of resources (computing, networking, storage) – that constitute a virtual logical network (customizable), working on top of a 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. Consequently, each slice will have its own M&O. Many studies and standards adopted the above complex definition of a slice; *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 many architectural proposals, there is an interest to evaluate in what degree they have similar approaches of the main "core" architectural functional set of blocks and what are the factors that induce heterogeneity. The similarity degree of different architectures could be named "convergence", although this word has usually a richer semantic.

Among many architectural aspects, the focus of this paper is on M&O sub-systems. Due to space limitation, this text cannot afford to offer detailed explanations about the architectures presented; the objective here is to identify the major point of similarity and heterogeneity of different approaches.

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

II. Business Model and Stakeholder Roles

The layered structure of the 5G slicing M&O strongly depends on the definition of the *business model (BM),* which defines the stakeholder/actors roles and their interactions. Different BMs aim to support multi-tenant, multi-domain end-to-end (E2E) and multi-operator capabilities. A basic model (see A. Galis, [18]) defines four roles:

Infrastructure Provider (InP): owns and manages the physical infrastructure (network/cloud/data center). It could lease to a slice provider its infrastructure (connectivity, computing and storage resources) as they are, or it can itself construct slices and then lease the infrastructure in a 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 centers, which can host customized services. An SLT can request from a NSLP to create a new customized slice instance. The SLT can lease virtual resources from one or more NSLP in the form of a virtual network, where the tenant can assemble, manage and then provide *Network Services* (NS) to its individual end users. A NS is a composition of *Network Functions (NFs*), physical or virtual, 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 InP, NSLP and SLT have, each one, a specific role in M&O activities. A powerful feature of the above business model is the recursivity (see Ordonez et al., [4]), i.e., a tenant can become itself a new slice provider; at its turn it can offer parts of its sliced resources to other tenants. Other variants of business models are presented in [18].

Several recent Public Private Partnership (PPP) Phase I/II collaborative research projects are running, having as objectives 5G technologies [18]. Some of them extended the list of role definitions to allow various possible customer-provider relationships between verticals, operators, and other stakeholders. The 5G PPP Architecture Working Group, "View on 5G Architecture", Version 3.0, June 2019, [3] has defined a more refined business model (Figure 1):

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 services) to various verticals; *Network Slice as a Service* (NSaaS) *Provider* offers an NSL and its services. The SPs have to design, build and operate high-level services, by using aggregated network services.

Network Operator (NOP): orchestrates resources, potentially coming 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 Center 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.

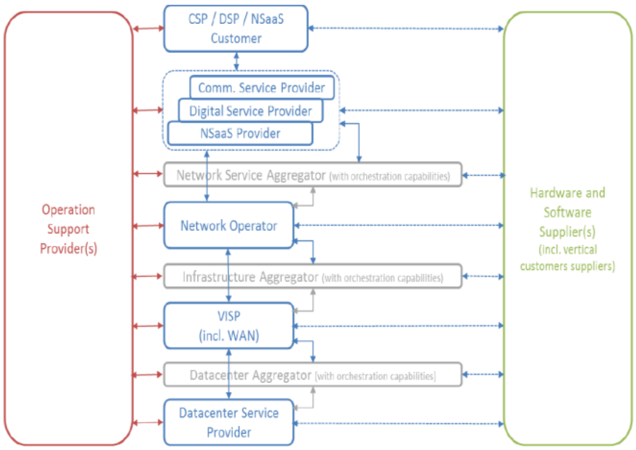

Figure 1. 5G PPP Business model [3]

III. A GENERIC 5G MANAGEMENT META-ARCHITECTURE

The analysis of many architectural proposals (in 5G and in particular, in 5G slicing) leads to the question: *is there any high-level consensus core architecture?* Recently, the document [3], 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 M&O architecture should be able to support:

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

b. chaining of individual NFs into services (NF graphs, see [8]) facilitated by different control mechanisms at network level (e.g., the NFs chaining can be SDN – controlled - where the NFs are treated by the SDN controller like SDN forwarding nodes).

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). Multiple operators and multi-domains operation are also a target, in order to provide services at vast geographic ranges.

e. a large range of applications with different specific requirements (in terms of resources, 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 – could be seen as part of a M&O system. However, there is no general consensus on this inclusion. There are also proposals to position a slicing system underneath or above a MANO system.

Several core roles of the involved entities 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., [3]. 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 so-called M&O *meta-architecture*, in the sense that no matter how the particular architectural solution will be chosen, the six functionalities should be included. These define a general level of convergence from an 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 2) [8]. This has been defined as a general framework, before the 5G slicing concepts emerged. However, NFV Management and orchestration (NFV MANO) has been soon considered, by the standardization organizations, operators and research groups, as being appropriate to further develop M&O for 5G sliced systems.

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.

We recall shortly the roles of the basic NFV functional blocks [9]:

NFV Orchestrator (NFVO) has two main responsibilities:

- the lifecycle management of Network Services (NS); thus, it fulfills the *Network Service Orchestration* functions;
- the orchestration of NFVI resources across multiple VIMs; thus, it fulfills the *Resource Orchestration (RO)* tasks.

VNF Manager (VNFM) is responsible for the lifecycle management (LCM) of VNF instances;

Virtualized Infrastructure Manager (VIM) is responsible for managing and controlling the NFVI resources, i.e., compute, storage and network resources.

To provide a more complete architectural assembly the following functional blocks may also be considered:

Operation/Business System Support (OSS/BSS) represents the combination of the operator's other operations and business support functions that are not otherwise explicitly captured in the architectural diagram. An Element Manager (EM) is responsible for traditional management functionality (fault detection, configuration, accounting, performance, security- FCAPS) for a VNF.

The NFVI represents all the hardware (e.g., compute, storage, and networking) and software (e.g., hypervisors) components that together provide the infrastructure resources where VNFs are deployed.

The NFV framework is added with new functions in order to support slicing (see Figure 2). The slicing support feature introduces significant differentiation between particular architectures. The slice management:

- could be included into the NFVO (because a network slice instance (NSLI) can be seen, in a simpler approach, as a guaranteed network service);
- or, a separate slice manager exists (controlled by NFVO). Note that the service management can be defined as separated from resource management (this option provides a cleaner architecture), or they can be treated together.

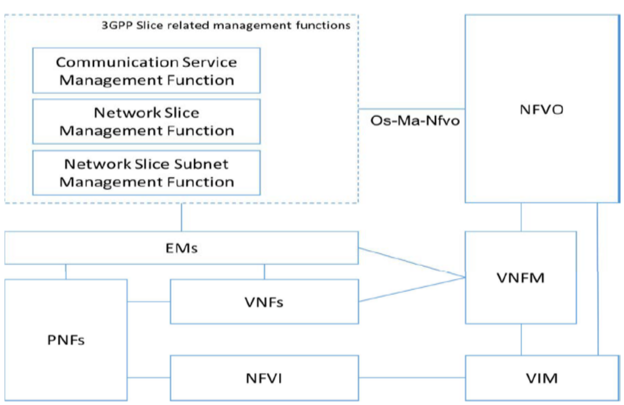

Figure 2. Network slice management in an NFV framework (ETSI GR NFV-EVE 012 V3.1.1, [15])

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.

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 single-domain managers at lower level. The latter should perform also peer interactions.

A typical set of functional M&O blocks for a single-domain meta-architecture is [3] (the levels are top-down ordered): [Service management, Orchestrator, (MANO controller, SDN controller), VIM, Resources]. In a multi-domain environment, each domain should have the previous set and on top of them 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 [15] (Figure 2), can be considered as a meta-architecture comprising the six features exposed above. To the original ETSI NFV architecture [8][9], several new functional blocks have been added in order to support the network slicing (ETSI-NFV EVE 012 [15]).

The 3GPP TR 28.801 document [16] 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 lifecycle of instances) 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 network service or set of network services, the VNFs and PNFs that can support the resource requirements for a NSLI or NSSI. Consequently, one should determine 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 research groups and/or projects developed a large set of variants of refined architectures (see examples in A. Galis [18], [19]). 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?

Despite the fact that many architectures essentially satisfy the requirements of the meta-architecture presented in Section III, significant heterogeneity can inherently appear in different proposals. This section will summarise the factors leading to heterogeneity in the area of particular architectures. Note that, given the topic's complexity and this limited paper space, the 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 and implementation details and so on.

A. Services deployment

This 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.

B. Assigning tasks to the edge or core network

Some tasks may be executed either in edge network or in the core. So, there are options how to share such burdens between edge and core network. Two options can be identified:

- to keep some administrative control functions (e.g., call management) in the core and only move data plane media-related functions to the edge;
- to move to the edge all relevant VNFs and services in both data, management and control plane.

Trade-offs are between: operational complexity, the need to run multiple instances of the same services, reduced tunneling overhead, and others. Content delivery services in mission-critical environments may require similar decisions.

C. Execution environments

At the infrastructure level, the e*xecution environments* could 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. Two variants are mentioned below:

- 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", given its lack 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 will have some additional issues: it should consider the degree of trust between the infrastructure provider and MANO entity, especially in multi-domain environment.

D. Hardware heterogeneity

At infrastructure level, the hardware heterogeneity 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.).

E. Vertical separation of services

The classical principle of separation in *network-related services* (i.e., connectivity–oriented) and *application-level services* (e.g., caching, video transcoding, content-oriented, web server, etc.) could be preserved or not. One can respectively speak about, segregated or integrated orchestration. . The separation will require one service orchestrator and separate network/service orchestrators.

Concerning slicing, one can define some slices offering essentially connectivity services and other dedicated to high-level services and 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 (i.e., the high level and respectively the connectivity-oriented 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 approach leads to a more complex overall architecture. One must assign areas of responsibilities from a resource perspective (i.e, which orchestrator controls - what resources); one should identify services pertaining to each orchestrator. The split of a 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 (an orchestration of type "one-size-fits-all" 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 more compact overall architecture.

Considering the above rationale, we defend the idea that from the slicing point of view, a segregate orchestrator approach is a better choice in the sense that it provides s more clear separation of orchestration tasks.

Note that in practice, both approaches have been pursued in different projects. *Currently, a final verdict on segregated* *versus integrated orchestration, commonly agreed by many communities is not yet available.* Apparently, there is no evident need to standardize such an 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.

F. *"Flat" or "Hierarchical" orchestration*

In the flat solution, a single instance of a particular orchestrator type is in charge to orchestrate 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 [7][18]-[22]. However, several issues should be solved in each of the two solutions [3]:

- 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 how 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. In such a case, 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 "domain") 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 as well, to organizations/companies boundaries. Such domains have overlap with the technological ones. A third possible 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).

G. *Relationship of the M&O system and the slicing system*

This 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 a 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.

H. *Different abstraction mappings applied between hiearchical levels*

In a multi-level hierarchy levels of orchestrators, abstractions will be used between adjacent layers, to hide to the upper levels the details of the lower ones. However, it is not clear what the best mapping is, in order to produce a simplified view of a lower level to the upper one. Violations could appear when mapping high level services onto the resources of a lower level [3]. So, different mapping methods can lead to heterogeneity.

I. *Conflict resolution*

In 5G complex systems there will exist inherently conflicts between participating entities given the basic idea of resource sharing. Different specific choices to solve them will lead to heterogeneity of solutions. A few examples are given below.

Resource conflicts for shared resources: they can appear due to incorrect admission control or overly aggressive oversubscription. Architectural refinements are necessary to solve them.

Conflicting rules: e.g., when composing a service out of functions that specify mutually incompatible packet forwarding behavior (this can happen both in NFV context or in SDN context).

Feature interaction conflicts: this is a classical issue in systems offering complex multi-feature services and being dynamically configurable as in the case of updating slices.

The conflicts need to be avoided or detected and resolved. Pre-fixed policies (limited approach), either for a platform, or for a service in particular, can help. More research effort points towards conflict resolution actions from inside an operational network is necessary.

J. Time scales (short vs. long-term actions)

It makes sense to separate short-term actions (e.g., actions on a flow level) from long-term planning actions (e.g., decision where to run which function). The refined functional architecture can reflect this separation, e.g., by splitting the MANO system into separate subsystems, each one responsible for different types of actions. A typical terminology would be: "control" for short-time scale operations vs. "orchestration" for operations on longer time scales. This separation is attractive from a software development and maintenance perspective (e.g., a SDN controller becomes a separated piece of software); however, this separation does introduce additional interfaces and operational dependency into an already complex architecture model. The decision on which actions are short-term and which are long-term can produce heterogeneity.

K. Traffic load variations

Some traffic spikes can happen which cannot be simply dealt by the short-term control system. Hence, the long-term orchestrator needs to be also able to deal with short-term changes (this is related with the control/orchestration separation). The MANO system's architecture should have the ability to bring up additional instances. The cloud computing can solve this (Function as a Service –concept (FaaS)) by bringing up functions on an as-needed, load-adaptive basis. However, this requires that the realized code is indeed a function, hence, stateless – there is no state maintained inside a function and it is not possible to move state between function instances.

V. Examples of Sliced 5G Management and Orchestration Functional Architectures

This section will provide a few relevant examples to illustrate the major management and orchestration (M&O) options and also the heterogeneity of the refined architectures. Given the limited dimension of this paper, the depth of discussion on them is also limited to the essential aspects illustrating the main characteristics and heterogeneity factors.

A. Example 1

The 5G PPP Working Group [2] and NORMA European Project [20] have proposed a 5G multi-domain architecture by defining four planes: *Service, M&O, Control* and *Data* planes (Figure 3). Note that in [2] the above are called "layers"; however, we believe that the correct semantics is rather "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 *Service plane* comprises *Business Support Systems* (BSSs) and business-level Policy and Decision functions as well as applications and services operated by the tenant. This includes the end-to-end orchestration system (not detailed in this architecture).

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 *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 *Inter-slice Broker* handles cross-slice resource allocation and interacts with the *Service Management* (SM) function. The SM is an intermediary function between the service layer and the *Inter-slice Broker*. It transforms consumer-facing service descriptions into resource-facing service descriptions and vice versa. The SDMO has a complete knowledge of the network managing the resources needed by all the slices of all tenants. This enables the SDMO to perform the required optimal configuration in order to adjust the amount of used resources. The MANO accommodates domain-specific application management functions (e.g., in 3GPP, this comprises *Element Managers* (EM) and *Network Management* (NM) functions, including Network (Sub-) Slice Management Function (N(S)SMF). Those functions would also implement ETSI NFV MANO interfaces to the VNF Manager and the NFVO.

The *Control Plane (CPl)* 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 physical or virtual network functions 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). Following the SDN principles, SDM-X and SDM-C translate decisions of the control applications into commands to VNFs and PNFs. Each network slice has an SDM-C, to manage the network slice resources and building the paths to join the NFs taking into account the received requirements and constraints. The SDM-C and SDM-X take care of dedicated and shared Network Functions (NFs), respectively. SDM-X and SDM-C as well as other control applications can be executed as VNFs or PNFs themselves; this shows the flexibility of SDN/NFV cooperation.

The *Data plane* (DPl) comprises the VNFs and PNFs executing different tasks to carry and process the user data traffic. Following the NRFV principles VNF/PNF graphs are defined and configured in DPl.

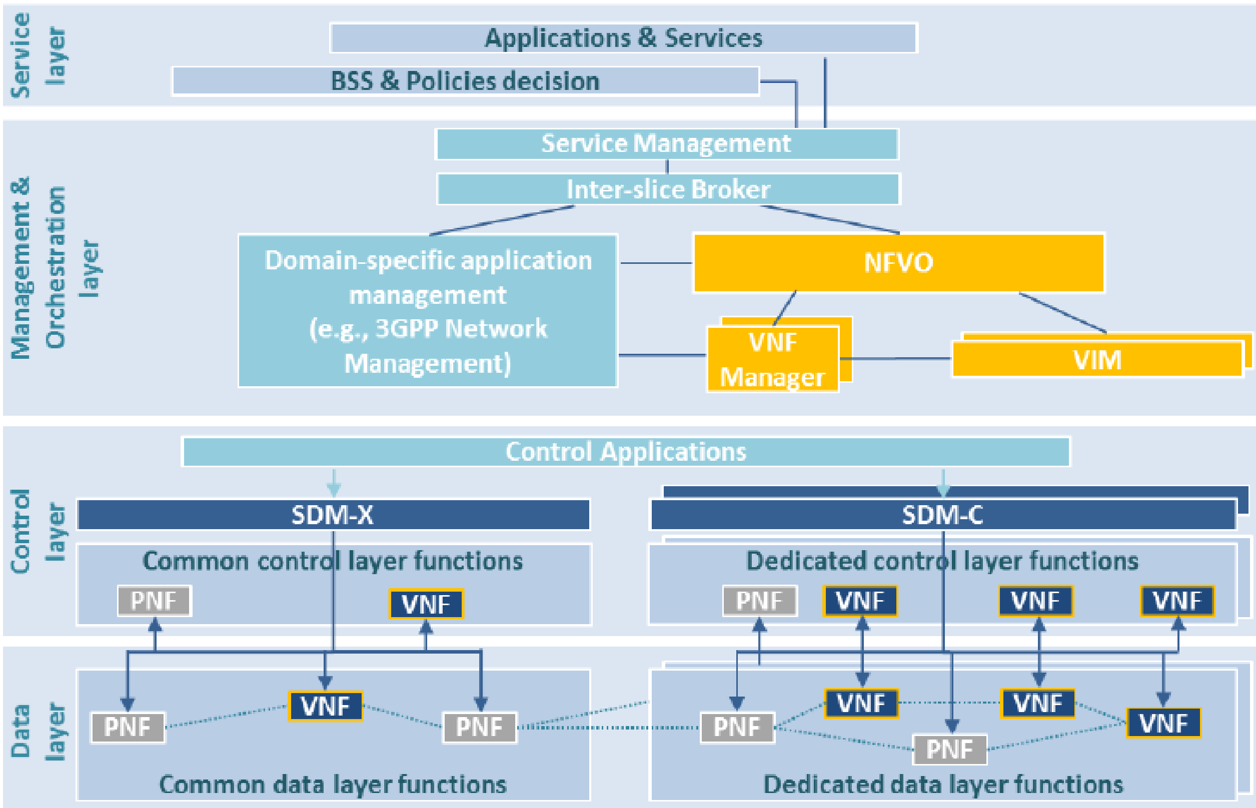

Figure 3. 5G PPP and NORMA project - proposed functional 5G slicing architecture (source: [2][20])

The *Multi-Domain Network Operating System* Facilities (not represented in Figure 3) is an additional subsystem which includes different adaptors and network abstractions above the networks and clouds heterogeneous fabrics. It allocates the (virtual) network resources and maintains network state; it also ensures network reliability in a multi domain environment.

Horizontally, the architecture should cover all segments: RAN (radio and edge), core and transport. 3GPP has defined [2] the 5G System (5GS) comprising a core network (CN) and one or more access networks, e.g., a RAN. The CN consists of NFs, NF services and the interaction between NFs to support data connectivity and other services. It is needed to provide infrastructure connectivity from the Access Points (APs) to the CN, also referred to as transport network connectivity. Transport networks are the foundation of 5GS as they provide the network fabric interconnecting NFs, CN and RAN and the units of RAN.

The architecture presented in Figure 3 is only high level defined. With respect to the meta-architecture capabilities exposed in Section III, it is evident that 5G PPP/NORMA architecture can generally satisfy the requirements a., b., e. and partially f. However, several options could be considered for c., d., f., if wanting to develop further refinements regarding:

c. Different execution environments

The architecture (Figure 3) does not functionally define the virtual infrastructure, neither in data plane nor in the management and control planes, except mentioning the usage of graphs of PNF/VNFs. Therefore, one of several refinement options can be selected.

d. *Working across different "organizational" or administrative domains*

Figure 3 does not define a mapping on a business models containing different actors. While a multi-domain feature is desired, the functional split between different actors is not yet defined. In [2] it is proposed the Mobile Network Service Provider as a main entity capable to serve several tenants with dedicated slices, based on the infrastructure offered by one ore more infrastructure providers, but without detailing the precise framework for resource management. Concerning the multi-domain capabilities one can assume that Inter-slice Broker can manage slices covering several domains [2] but it is not decided how such an Inter-slice Broker is mapped in flat style or hierarchical one onto business actors.

f. Subdivision of the infrastructure in logical separated and isolated slices.

The Figure 3 architecture shows the split of the control and data plane in two regions: common (shared) and respectively dedicated functions. However, the choice on how to separate the slices from point of view performance (observed in the data plane) and security for both data and control plane) can lead to different options for solutions.

Therefore, different or heterogeneous refinements (see Section IV and [2] for several possible solutions) can be selected for such matters.

B. *Example 2*

A multi-domain, multi-tenant hierarchized slicing architecture (viewed at run-time phase, i.e., after a slice instance has been created and activated) is presented in Figure 4, adapted from the proposal ETSI GR NFV-EVE 012 [15] and J. Ordonez-Lucena et al. [4][21]. We state that in comparison with *Example 1*, this architecture presents a more clear hierarchization of M&O functions and also a clear mapping onto a business model. It is adopted a solution with multiple levels of orchestrators and the principle of clear separation between service management versus resource management.

A multi-domain slice instance can span several InPs and/or administrative or technological domains belonging to different providers. Figure 4 shows several domains upon which multi-domain slices can be constructed. (the picture focuses on the transport and core network domains, omitting the RAN domain).

The main M&O entity is the *Network Slice Provider (NSLP)*. Inside NSLP, a highest layer multi-domain *NSL Orchestrator* (NSLO) (configured offline) has a main role, both in the *creation* phase of slices and also in the *run-time* phase. In the creation phase, NSLO receives from a tenant the order to deploy a NSLI (or the NSLP decides itself to construct a slice by provisioning actions). 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.

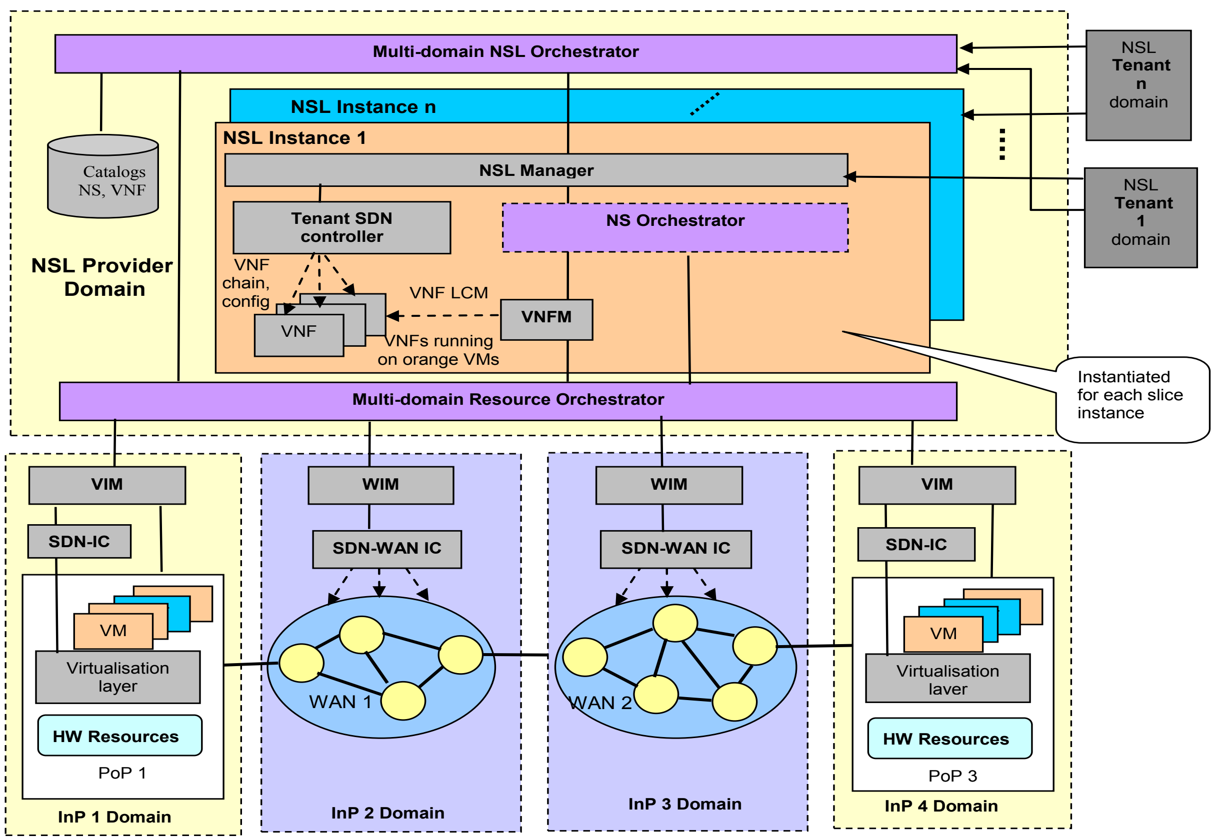

Figure 4. Run-time view of a multi-domain slicing hierarchical architecture example 2
(adapted from ETSI GR NFV-EVE 012 [15] and Ordonez-Lucena [4][21])
NS – Network Service; NSL - Network Slice; VNF – Virtualized Network Function; VNFM – VNF Manager; SDN - Software Defined Networking; LCM – Life Cycle Management; VIM – Virtual Infrastructure Manager; WIM- Widea Area Infrastructure Manager; SDN-IC- Infrastructure SDN controller; HW- Hardware; WAN – Wide Area Network; InP - Infrastructure Provider

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 two important objectives: harmonizing the resource assignments per slice and per-domain and also to preserve the inter-domain independence in terms of management and control.

For each new network slice instance (NSLI), an individual set of M&O entities is dynamically created and installed when the new slice instance is created. Each NSLI has its own M&O and control planes (this assures the slice isolation capability) composed of: NSL Manager, Network Service Orchestrator (NSO), Tenant SDN Controller and VNF Manager (VNFM).

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, inter-domain interactions are also necessary.

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.

Does the above architecture satisfy the requirements of a meta-architecture (see Section III)? The answer is "yes", i.e.:

a. The individual control of NFs (their placement, LCM, etc.) can be realized due to existence of the pair- manager VNFM and tenant SDN Controller (at M&Olevel) and by the pair VIM and SDN-IC.

b. The chaining of individual NFs into services (NF graphs) can be assured by the same M&O blocks as above.

c. Different underlying execution environments: various virtualization techniques (virtual machines (VM), containers, or plain processes) can refine the architecture. Such details are not visible at this high level but are naturally possible to be embedded in each domain.

d. Working across different "organizational", or administrative domains, i.e., owned by network operators or companies and using various business models- is already emphasized in Figure 4.

e. A large range of applications with different specific requirements (in terms of resource, deployment, orchestration and optimization goals) can be supported given that a tenant has interfaces to NSLs, allowing it to express its requirements.

f. Subdivision of the infrastructure in logical separated and isolated slices with levels of guaranteed performance is possible to be achieved, given the mapping from services to the resources orchestrated by the RO.

Refinements of the above high-level architectures are possible [4][15][21], following different paths to go further towards the system design. Examples could be:

- how to split the RO functionalities between different operators' domains in the case of E2E multi-domain slices;
- 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.).

The above example illustrates the inherent heterogeneity of particular refined architectures, while all starting from a "tree root" defined by the meta-architecture requirements.

C. *Example 3*

T. Taleb et al. [7] recently proposed a multi-domain slicing hierarchical, complex management and orchestration architecture (Figure 5). They use a powerful definition of a slice, i.e., "a set of network functions, and resources to run these network functions, forming a complete instantiated logical network to meet certain network characteristics required by the Service Instance(s)". An E2E NSL can be deployed across multiple networks, stretching across the RAN, transport and core network segments; belonging to the same or different administrative domains.

A NSLI typically consists of multiple Network Slice Subnet Instances (NSSIs) that represent a group of network function instances and/or logical connectivity. As an example, a *Fully-Fledged NSLI*, can consists of several NSSIs, each belonging to a different technology domain, e.g., Radio Access Network (RAN), transport and core. The RAN and core NSSIs are composed of VNF(s) interconnected over logical transport links.

The proposed architecture is structured into four major strata: *Multi-domain Service Conductor (MSC); Domain-specific Fully-Fledged Orchestration, Sub-Domain Management and Orchestration (MANO) and Connectivity, Logical Multi-domain Slice Instances.*

The architecture introduces (at top level) a novel architectural plane named *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: Network Service (NS) admission control and negotiation, considering service aspects; management of slice user/owner relationship enabling a direct tenant interface with the *Multi-domain Service Conductor* (MSC) plane; billing and charging; NSLI scheduling, i.e., start and termination instant of time, related with slice composition and decommission.

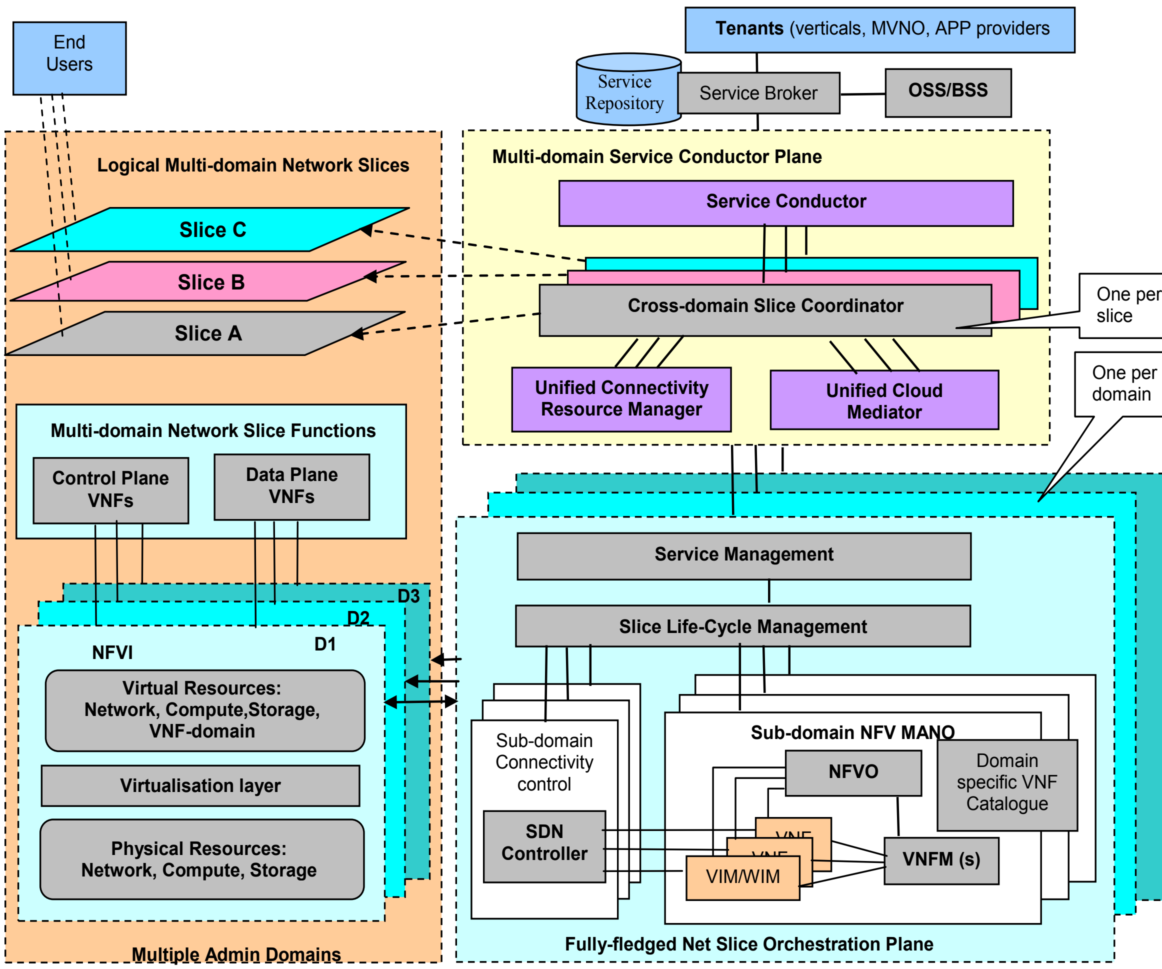

Figure 5 Multi-domain multi-tenant 5G slicing architecture example 2 (adapted from [7])

The *Multi-domain Service Conductor* is (functionally) placed under Service Broker and performs service management across *federated domains*. The MSC stratum analyzes and maps the service requirements of incoming multi-domain slice requests onto the one or several administrative domains. It also maintains the desired service performance throughout the entire service lifecycle. Inside MSC, a *Service Conductor (SC)* entity 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)* 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., a federated NSLI).

A coordinated management system is required to facilitate an effective LCM of a Fully-Fledge NSLI. At minimum, the following management, orchestration and control M&O&C entities are necessary: _ *Network Slice Manager* for the configuration and operation of a mobile network service to a Fully-Fledge NSLI; _ NFV MANO to instantiate and orchestrate the requested VNFs considering the supported availability; SDN Controller that connects together VNFs forming service function chains and controls the transport layer connectivity.

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; this is a similar solution as in Example 2.

The above complex architecture *can satisfy all of a…f.* general requirements of the meta-architecture. Many specific refinements can be added to satisfy the A..K (Section IV) as presented in the work [7].

D. Example 4

The 5G-MoNArch H2020 project [22] develops a hierarchical architecture consisting of four layers: *Service, M&O, Controller and Network* layer (similar to that proposed in [2] by 5GPPP).

The main design goals of the 5G-MoNArch architecture design [22] has been among those defined by the meta-architecture described in Section III:

(1) Support for E2E network slicing: one can combine different options of slicing support across M&O and network layers for each slice instance. Several options are possible: a. slice-specific functions (i.e., dedicated/ customised functions that are not shared with others); b. functions (or function instances) that are shared by multiple slices and have the capability to address requirements from multiple slices in parallel).

(2) Split of control and user/data plane throughout all network domains, including RAN, Core Network and Transport Network.

(3) Flexible architecture customisation: this is performed by the management system which can modify the architecture and functionality used in existing slices. For example, this can include further deployment, management, orchestration, and control instructions for specialised NFs [22].

The overall functional architecture is presented in Figure 6. 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 management and orchestration 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, 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.

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.

Generally, the MoNArch architecture satisfies the requirements of the meta-architecture described in Section III. However, many (heterogeneous) refinements should be added in order to cover the A..K (Section IV) needs.

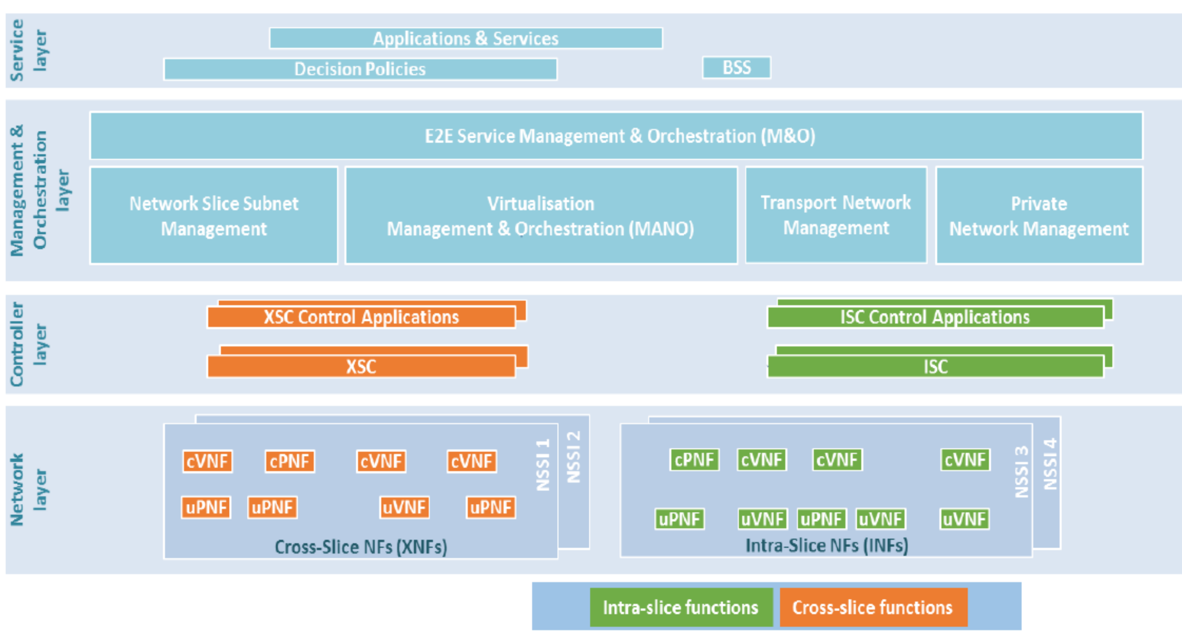

Figure 6. 5G-MoNArch high-level overall functional architecture (Source: [22])

Other variants f architectures are proposed and developed in different research projects [18]. 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, firstly adopted mainly from business reasons and only secondly from technical ones. *Also, the definition of a slice itself is still not yet globally agreed and this situation 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, optimization and capabilities of dealing with big volumes of data [23]-[26]. This domain is only at its beginning, so it is an open field for further studies.

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