A Comprehensive Survey on the E2E 5G Network Slicing Model

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A Comprehensive Survey on the E2E 5G Network Slicing Model

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***Abstract*—Today, the Network Slicing technology is massively addressed by the research community. However, Network Slice (NS) modelling details from Standards Developing Organizations (SDOs) are not yet well considered for End-to-End (E2E) NS implementations. In addition, each SDO develops standards targeting only a specific part of the NS architecture. Therefore, based on a profound analysis of the major existing works, this paper explains first (i) a general architecture that clarifies the basic E2E network slicing functionality before diving deep into domain-specific visions. Then, (ii) it focuses at providing a survey stitching together the NS modelling works in Radio Access Networks (RAN), Core Networks (CN) and also Transport Networks (TN). The end goal is to clarify the E2E Network Slicing process from the service order request to the NS deployment and life-cycle management. Last, as there is no consensus on a specific information model in the Transport network domains (iii) we provide our vision on how several data models, developed by IETF working groups, can be integrated together in the context of the ACTN architecture in order to provision and manage Transport NSs.**

***Index Terms*—Network Slice, Network Slice Information Model, Network Slicing model, Network Slice Architecture, Network Management, SDN, NFV, Orchestration.**

I. Introduction

The NGMN has developed 25 prominent mobile broadband use cases categorized in 8 families with highly diversified requirements in order to support its vision for the 5G architecture [2]. "Remote surgery" is an example of a customer use case that requires ultra-high reliability and at the same time ultra-low latency communications.

Because of the high variety of new emerging services, their conflicting and their extremely diversified requirements, the traditional "one-size-fits-all" network approach is no longer efficiently feasible. In this context, network slicing is proposed as a key feature that allows multiple dedicated virtual networks, called network slices (NSs) to operate on a common physical network infrastructure. In fact, a network slice (NS) is nothing but a logically isolated network over multi-domain, multi-technology physical networks that provides resource guarantees. Built on top of emerging technologies such as software defined networking (SDN) and network function virtualisation (NFV), network slicing should select the appropriate compute, storage and network resources and manage them such as to meet the customer service requirements [3].

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Network slicing is an ongoing standardization work performed by different Standards Developing Organizations (SDOs) targeting each a specific part of the network slicing architecture. E2E NS implementations have to be aligned with the SDOs' standards particularly with the NS information models. These models describe all the NS management entities as well as their relationships from the perspective of operators and service providers. Currently, an E2E network slicing model is not yet explicitly provided but need to be derived based on an exhaustive analysis of all the SDOs' contributions particularly their proposed NS information/data models to this day. In our previous work [54] we observed that the issued contributions may potentially be unified and represented in a common architecture and terminologies. Today, we go beyond this simplified vision. To the best of our knowledge, we are the first to provide by this work a comprehensive survey stitching together the different NS modeling works in radio access network (RAN), core network (CN) and transport network (TN) domains in order to bring forth an up-to-date E2E network slicing model. Prior works [4] [5] [6] [7] [8] addressed the network slicing concept in an abstract manner providing the research community with a general understanding on the topic. Instead, our paper will provide researchers and developers with an in-depth technology-independent NS definition necessary to build their complete NS solutions.

Our paper is organised as follows. Section II provides a common and general vision of network slicing among the leading SDOs. It serves as a stepping-stone to set the primary NS foundations in terms of actors, architectures, functions and workflows. Section III, introduces the NS template in order to request NS services. In section IV, we present a domain-specific vision of network slicing diving deep into the NS modeling details of each of the RAN, the CN and the TN domains. Then, our vision on the use of the available transport network data models for achieving network slicing in the TN domains is explained in section V. We address also in this section some of the open standardization issues as well as future research directions. Section VI concludes the paper.

II. Network slicing: A general vision

This section provides the main NS workflows, functions, interfaces and the managed objects that are supposed to be common, to a large extent, to different SDOs, administrative

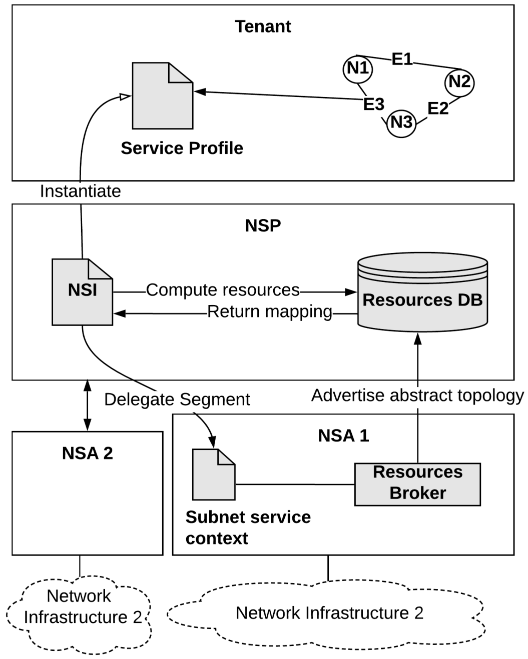

Fig. 1. ETSI NGP NS Framework. Introduction of the NS managed objects, NS workflows and functions in the NS architecture.

and technology domains. The goal is to provide a general architecture that clarifies the basic E2E network slicing functionality before diving deep into domain-specific visions. The need for such a general vision was first identified by ETSI NGP workgroup and then led to the adoption of the reference network slicing architecture [9] depicted in Figure 1. This architecture comprises three actors:

- Tenants that consume the service supported by a NS. The service can itself be a NS, commonly known by the term NS as a Service (NSaaS).
- NS Providers (NSPs) that provide access to the NS instances.
- NS Agents (NSAs) that have the complete view and control of their own network domain.

Firstly, a tenant prepares a *service profile* that describes its desired NS. It comprises a *service graph* and some additional service attributes such as the service type, service profile identifier and the service subscribing entity. The *service graph*, represents the tenant's view of the NS so that on the one hand it describes the nodes in terms of compute, storage and service instance type, e.g., firewall and load balancer. On the other hand it defines the edges as the slice constraints, also called slice characteristics such as link bandwidth and packet loss. *Service endpoints* are additional attributes of the service profile that describe the entry and termination point of a service. The tenant uses then that service profile to order the creation of a NS.

Within the NSP, the *resource database* (DB) aggregates the exposed topological information from several domains in the underlying infrastructure along with their constraints and their belonging domain as shown in figure 1. Therefore, the resources DB provides the NSP with the full view of the abstracted underlying physical infrastructure from many NSAs. At the NSA level, a *resources broker* is in charge of gathering the domain-specific topology information (links, nodes) along with the constraints such as links cost, bandwidth, and latency. Then, for security reason these topological data are abstracted and exported to the resources DB at the NSP domain. This is done through the *subnet discovery* function located in each NSA.

The NSP creates the *NS Instance (NSI)* as an instantiation of the service profile once received from the tenant. The new created object will represents the NSP's own view of the NS. In fact, the aim of the NSI is to compute the mappings of the service profile to the abstracted infrastructure elements stored in the resources DB taking into consideration the tenant constraints. This is done using the following two functions defined in the ETSI slicing architecture: the *resources computation* and *NS mapping* functions. Table I overviews the high level network functions performed by NSP and NSA of this architecture.

TABLE I
NS FUNCTIONS

NS functions	*Brief description*
Subnet Discovery	Exports an abstracted topology of the NSA domain to the resource DB.
Resource Computation	Determines the adequate resources for a specific service graph.
NS Mapping	Associates infrastructure elements with the logical ones.
NS delegation	Delegates segments to NSAs for mapping, encapsulation and segment interconnection.
Report aggregation	Monitor characteristics from different slice subnets for accounting and performance for business model.
Service assurance	Monitors each flow in a NS by NSP and takes decisions in order to provide service assurance.
Subnet augment	Allows the tenant to request an increase or a decrease of its allocated resources.

The bindings of the service graph to the physical resources are then stored in the *runtime service context object* within the NSI. The usage of the term NSI here is relative to ETSI NGP and is not aligned with the other SDOs. To clear up this confusion, it is necessary here to differentiate the term NS from NSI. The former is a definition of a logical network in terms of a managed set of resources and network functions. An NSI is an activated NS, a set of resources and network functions forming a deployed logical network that satisfies the tenant's service requirements [10].

After computation and mapping functions are successful, the final step, at the NSP level, towards the deployment of the NS is to distribute the so-called *segments* (also called *subnets* by other SDOs) to NSAs. This is done through the NS *delegation function*. Providing that a NS may span across several NSA domains, a segment is the set of paths and nodes a NSI is allocating to a specific NSA. After a NSA receives the segment associated to a NS, it first computes the mapping of abstract to concrete resources from the subnet resource broker with the help of a *child path compute element (PCE)* and stores them on the *subnet service context run-time object*. NS segments are not meant to be deployed separately, they are all part of the same logical E2E NS. Hence, a *NS Gateway* is needed to perform segments interconnection. Also, its is exported as a node to the NSP during the discovery process with the next hop information pointing to the adjacent network domain.

The possible modes that describes the flow of tenant traffic within its assigned NS, as defined by the ETSI architecture, are threefold. First, *E2E encapsulation* where the tenant flow undergo the same encapsulation type such as MPLS, VXLAN, etc, along all the segments. Although, this mode appears to be simple, it does not promote the technology agnostic approach and leads to scale related issues. In contrast to the first mode, *segmented encapsulation* allow each NSA to independently choose its encapsulation technique. For example, the same tenant flow is encapsulated using VXLAN in some segment and MPLS in another one thanks to some of the NS Gateway functions [11].

Once a segment on a NSA's domain is successfully deployed, the resource broker inside the NSA updates the NSP information using the *subnet discovery function*. Furthermore, service characteristics should be collected at each segment throughout the slice life-cycle, and then reported to the NSP. Collecting statistics and aggregating performance metrics about both the slice subnets and also the flows in the context of a NSI is the role of the report aggregation and the service assurance functions respectively. They provide a complete E2E monitoring framework for accounting, performance, QoS of the business model and service assurance.

Network slicing includes also exposing the capability to the tenant in order to scale up or down its allocated resources at run-time. This resources augmentation is performed by the *subnet augment function*. A tenant *augment request* may be a change on the latency constraint from 10 ms to 5 ms for instance. This may lead to some additional operations that could affect the system stability. In particular, if the current path does not support the new latency constraint, the operations include setting up a new path to meet the new requirements, then moving flows from the older path to the new one and finally deprovisioning of the participating nodes in the abandoned path.

The subnet augment function requires a set of operations and corresponding interface to the underlying infrastructure. These are covered by the *tenant operated network service function*. For example, the tenant uses the "augment" operation to modify its constraints associated with a path or a node in the service graph.

To conclude, the ETSI network slicing architecture, following the NGMN conceptual outline [12], includes three layers: a service layer where the service graph is built, then the NS instance layer where the service graph to abstract resources mappings happens and lastly the resource layer where segments are delegated and deployed on the underlying infrastructure. Concerning the NS life-cycle, we can refer to the 3GPP specification that considers 4 phases: Preparation phase including design and pre-provisioning, an "instantiation, configuration and activation" phase, a run-time phase including supervision and reporting, as well as upgrade, reconfiguration and scaling, and a decommissioning phase. These phases are similar for all the SDOs.

III. Ordering a NS: Service graph or NS Template ?

In the ETSI NGP architecture, the tenant is not necessarily an end customer, it may play the role of a service provider that offer its own services on top of the ordered NS instance (NSaaS model). This explains why the tenant is ordering a NS and playing in some sort the same role as the NSP. However, an end Customer is rather interested in the fulfilment of a service whether it is supported by a NS in the underlying infrastructure or not. While the ETSI NGP uses a *service graph* to order a NS, GSMA has entirely a different vision. GSMA is investigating all the potential service attributes, also called *NS characteristics*, from several enterprises and vertical industries, and gathering them in a template called *Generic Slice Template (GST)*. The goal is to define a template (see table II) that helps both the NS customer (NSC) and NSP to identify a NS [13]. The GST will be used as a reference by vendors, operators, providers and customers in order to deploy a NS that accommodate a certain use case. Thereafter, to order the deployment of a NS, a NSC needs to fill some or all the GST template attributes with its desired values and/or ranges depending on the NS use case. The obtained template is then called *NEST (NS Type)*.

TABLE II
GSMA's NS templates

NS templates	***Brief description***
GST	A template containing a set of attributes that characterize any slice.
NEST	A GST filled with values to define and identify slices.
S-NEST	A NEST template that defines a standardized slice.
P-NEST	Operator-specific NEST created based on negotiation between an operator and its customers.

In fact, the GSMA approach has several advantages. First, it gives the mean for a NSC to express its NS service requirements and at the same time allows operators and providers to fulfill any possible use case. Second, *Standardized slice types (SSTs)* are defined for the most popular use cases in standard NEST templates (S-NEST) and diffused to all operators around the world. Third, service capabilities offered to a user inside its home operator are conserved when it roams to a visited network. This could simply happens by exporting the NEST templates from the home network to the visited one. That is, NEST is a generic template that aims at describing the service requirements of a use case that will later help an operator to select an appropriate *NS template (NST)* [13] [14] also referred to as NS blueprint in [12]. The NST contains the network functions, their interconnections and the necessary configurations to meet the service requirements described in the NEST. As it is depicted in figure 2, a NST may correspond to one or multiple NESTs and is further instantiated to realize a NSI. The detailed list of all the GST attributes as well as their explanations are provided in [15].

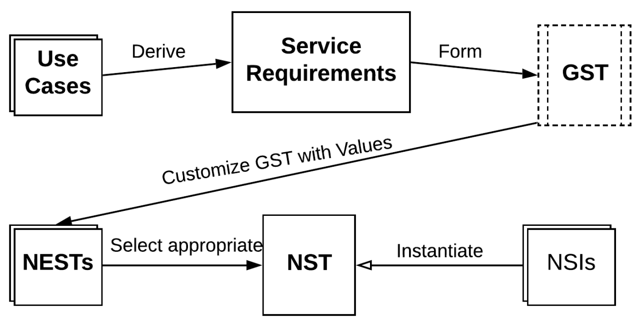

Fig. 2. Involving the GSMA GST/NEST in the instantiation phase of a NS.

After this introduction of the network slicing general vision and how ordering a NS can be done with the use of the service graph or the NS template. The next section, will provide an in-depth exploration of the E2E network slicing information models within the RAN, CN and TN specific domains.

IV. Network slicing: A domain-specific vision

For a given 5G customer service, an E2E NS that spans across the RAN, the CN and the TN needs to be established. Following the set up of the RAN and core sub-slices (subnets) by the 3GPP orchestration system, one or many transport NSs (TNS) has or have to be provisioned within the TNS provider as a set of connections with Service Level Agreements (SLAs) that connects together RAN and core sub-slices [17].

A. RAN and CN

RAN and CN slicing is still under standardization by 3GPP. In fact, 3GPP is tremendously contributing to the NS standardization work through several working groups particularly SA1 (service requirements), SA2 (Architecture), SA3 (Security), SA5 (Network Management). In order to get deeper insights on NSs, their implementation and life-cycle management we focus in this section on the 3GPP NS information model [16]. The SA5 group has defined the entities that compose a NS and the way they interact with each other using the information model depicted on figure 3.

Communication service is the term used by 3GPP to refer to the customer ordered service. In general, It is carried to the service provider as a set of service requirements that serve a certain business purpose. Based on those requirements the service provider derives the NS related requirements and orders the creation of the NS to the network operator. As indicated in the information model, the NS object supports a list of service profiles, each of them corresponds to a communication service and maintains the derived NS related requirements. The NS also makes reference to its constituents subnets (this term is interchangeable with segments) which may recursively be composed of other subnets. Likewise,

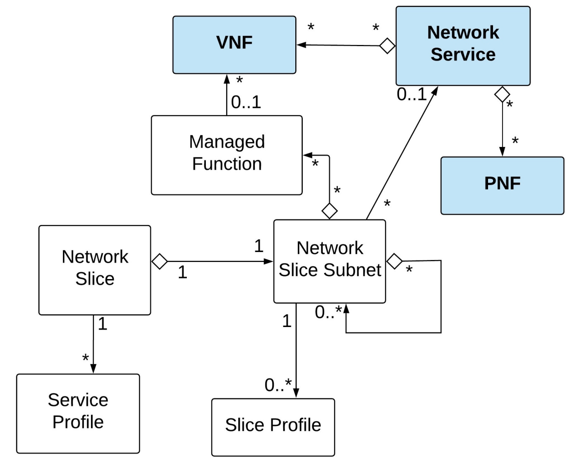

Fig. 3. 3GPP NS Information Model

several slice profiles are associated to each subnet. The reason behind the modelling of a NS/NS subnet supporting multiple service/slice profiles is that multiple communication services may share the same NS. The data model describing all the entities in figure 3 except the ones in dark color are given in yang data modeling language in 3GPP TS 28.541 [16]. The service profile has many common attributes with the slice profile, some of them have reference in GSMA GST such as User Equipment (UE) mobility level.

A NS subnet, that aggregates a list of managed functions, is supported by at most one network service. A managed function is realized by one or many virtualized network functions (VNFs). A network service is a composition of the subnet's VNFs and PNFs (physical network functions) according to one or many forwarding graphs. The entities network service, VNF and PNF are out of the scope of 3GPP working groups. Thus, their descriptions are delegated to ETSI NFV-IFA VNF and network service information models [17] [18].

The 3GPP NS information model's entities are consumed, managed and provided by different actors. Each actor may play more than one role depending on the NS management use case. 3GPP has defined three main NS management roles (see table III): Communication Service Customer (CSC), Communication Service Provider (CSP) and Network Operator (NOP). There are other business roles defined by 3GPP in [3] such as hardware supplier, NFVI supplier, network equipment provider, data center service provider, and virtualization infrastructure service provider.

A business agreement must be created between two actors in order to interact with each other. Commonly, real NS management use cases includes actors having multiple roles, therefore reducing the number of needed mutual relationships. For example an actor ”NS Tenant” may simultaneously plays both the role of a Communication Service Customer (CSC) and a Communication Service provider (CSP).

The deployment and management of a NS in a NOP's infrastructure based on the customer's SLA are performed by three main 3GPP functions as illustrated in Figure 4. First the *Customer Service Management Function (CSMF)* receives the

TABLE III
NS MANAGEMENT ROLES AND ACTORS [3]

Actor	*Role*	*Description*
Basic customer	Communication Service Customer	Consumes a Communication Service but does not use CSMF.
Advanced customer	Communication Service Customer	Consumes a Communication Service. It has some capabilities limited by the CSP to manage the Communication Service via the CSMF.
NS Provider	Network Operator	Provides a NS and Consumes NS Subnet(s).
NS tenant	Communication Service Customer and Communication Service Provider	Consumes and manages a Communication Service and also NS(s) via the *NS Management Function (NSMF)*.
NS Subnet Provider	Network Operator	Provides a NS Subnet.
Communication Network Provider	Communication Service Provider and Network Operator	Provides Communication Service NS(s) and NS Subnet(s).
Network-as-a-service Provider	Network Operator	Provides NS and NS Subnet(s).

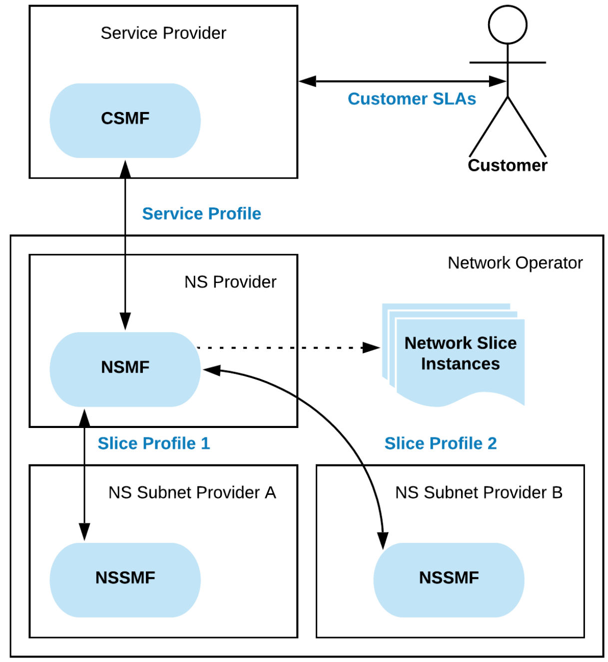

Fig. 4. 3GPP NS Management Functions

communication service related requirements from the CSC. Those requirements are converted to NS related requirements *(Service profile)* and then provided to the *NS Management Function (NSMF)*. Indeed, the CSMF manages the Communication Services provided by the Network Operator.

The NSMF creates and manages the NSIs based on the received NSs related requirements. Then, it derives the NS subnets related requirements *(Slice Profile)* and provides them to the *NS Subnet Management Function (NSSMF)* so that the NS subnet management is delegated to the NSSMF.

NS Subnets instances (NSSIs) are separated units associated to a NS instance (NSI). They can also be used (shared) simultaneously by another NSI if needed. Terminating a NSI doesn't necessarily affect those units, they are still existing and running but disassociated to the terminated NSI. This separation of the NSSMF from the NSMF offer a NSSI life-cycle management independent from the NSI life-cycle. Lastly, the NSSMF creates and manages the NSSIs based on the received NS Subnets related requirements.

NSs and NS Subnets are always provided by the NOP. Hence, the NSMF and the NSSMF are located inside it. Particularly, a NS is defined within a Public Land Mobile Network (PLMN). This is to say that a NSI is defined in one operator while its constituents NSSIs may be associated from different ones. Communication Services are generally managed by a CSP but might also be managed by the customer or the NOP so that there is a direct communication interface between them. Therefore, the CSMF might be placed at each of the CSP, the customer or the NOP depending respectively on the previously mentioned options.

The 3GPP NS information model defined in [16] lists all the attributes defining NSs . In the following of this section, we introduce the most relevant attributes for the understanding of the 3GPP network slicing vision. In the 3GPP data model, a NSI refers to a unique NSSI through the *NetworkSliceSubnetRef* attribute instead of multiples NSSIs. This is due to the modelling of each of the NS and the NS Subnet entities. As shown in figure 3, a NS is modelled as being composed of a unique NS Subnet.

A NSI may be well deployed and working but administratively configured by the operator to not serve any user [19]. Therefore the state of a NSI/NSSI is described by two attributes, the *operational state* and the *administrative state*.

A NS Subnet refers to its constituents subnets and supported managed functions respectively through the *NetworkSliceSubnetRef* and *ManagedFunctionRef* attributes.

The *NSInfo* attribute provides real-time information of a NSI that corresponds to a NSSI. This attribute contains many information such as the reference to the flavour of the *network service descriptor (NSD)* used to instantiate the network service and the reference to all information on network service's constituents VNFs and PNFs. An exhaustive definition of all the information provided by the NSInfo attribute is given by ETSI GS NFV-IFA 013 [20].

A same NS service may be provided by different operators so a user may roams from its home PLMN to one or multiple serving PLMNs without any service interruption. The PLMNs that support a NS or a NS subnet are identified respectively in each of the service profile and the slice profile as *PLMNIdList*.

The service profile includes the attributes of the slice profile in addition to the the *SST* and the *NS availability* attributes. The SST refers to the expected NS behaviour in terms of features and services [21]. 3GPP defines three standardized SSTs as described by table IV: eMBB (Enhanced Mobile Broadband), URLLC (Ultra Reliable Low Latency Communication) and mIoT (massive Internet of Things). At the time of writing, standardized mIoT characteristics are not yet included in the 3GPP slicing data model published in TS 28.541 [16].

TABLE IV
STANDARDISED SST VALUES

SST	*SST Value*	*Bref Description*
eMBB	1	Slice suitable for the handling of 5G enhanced Mobile Broadband.
URLLC	2	Slice suitable for the handling of ultra-reliable low latency communications.
mIoT	3	Slice suitable for the handling of massive IoT.

The identification of NSs in control plane is done using the *Network Single-Slice Selection Assistance Information* (S-NSSAIs). It is based on the SST and an optional complementary information, called *Slice Differentiator* (SD), that allows the definition of different NSs types around the same SST value.

3GPP distinguishes three options for the definition of a S-NSSAI that is comprised of:

- A standardized SST value and no SD.
- A standardized SST value and a SD.
- A non-standardized SST value and no SD.

The service and slice profiles are comprised of a collection of S-NSSAIs values also referred to as a NSSAI. The later indicates the different NS behaviours that can be accommodated by the NS/NS subnet. An NSSAI may be configured, requested or allowed.

A given user can have at most eight S-NSSAIs. During the registration procedure, the UE includes an NSSAI in its request to the PLMN. The later verifies the requested NSSAI against the subscription information. If the match is successful, the UE obtains the allowed NSSAI from the PLMN which may include one or many S-NSSAIs. In addition, the latter can be used simultaneously by the UE. Finally, a NS and a NSI can now be selected for that UE. Also a service/slice profile includes a list of performance requirements that are defined for each standardized SST value (e.g., low latency and high reliability) [22]. In addition, they comprises other characteristics that can be considered as NS/Subnet-level attributes such as Maximum Number of UEs, UE mobility level, latency [23].

B. Transport Network Slicing

1) Definition: A transport NS provides a set of connections between a group of VNFs or/and PNFs from both the RAN and the CN. Each connection has its own deterministic SLAs and is implemented in the underlying transport network (TN) using any technology type (IP, optics, microwave, etc), any tunnel type such as IP/MPLS and any Layer service type (L0, L1, L2, L3).

Depending on the RAN deployment, there might be multiple transport sub-slices per a single E2E NS:

- In the case of the distributed RAN deployment, in addition to the TN connecting together the RAN and the CN, another TN (i.e., Internet) connects the users' mobile applications to the CN. This is a common deployment in 4G and 5G networks.
- An additional transport network is introduced in the case of the centralized RAN (C-RAN) between the RAN's two functional units, the base-band unit (BBU) and the radio unit (RU), called Front-haul network. The BBU is further divided in the case of cloud RAN to include two separated units called the centralized and the distributed units (CU and DU). The former is hosted in the cloud while the later remains close to the antenna. An additional transport network is then introduced in this case called Mid-haul in order to connect the DU to the CU.

In total, there might be a maximum of four transport sub-slices (Figure 5) per an E2E NS depending on the aforementioned deployment options [25].

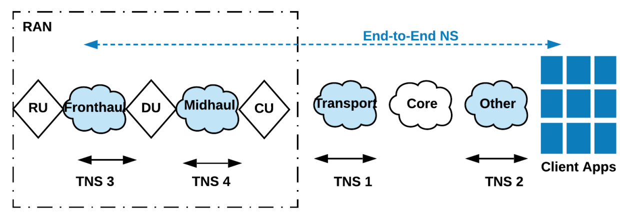

Fig. 5. The 4 types of a Transport NS: Fronthaul, Midhaul, Transport and an other Network separating the core to client applications.

Network slicing standardization in the transport domain is under the IETF realm. Actually, continuous efforts are being made to model the network slicing technology and consequently to define a standardized architecture in the TN domains. In fact there are multiple mechanisms and data models covering different parts of the transport domain architecture that may be applied to the network slicing use case. However, there is no consensus within IETF on the use of this model or that one. In addition, it is not clear how they can be applied to network slicing. In the remaining of this section, we will list in a technology-independent manner all the candidate works within IETF that have the potential to accommodate network slicing in the the TN domain. Then, in the next section we will present our vision in this context.

2) ACTN Architecture: The most likely candidate architecture to accommodate network slicing is the one of the Abstraction and Control of Traffic Engineered (TE) Networks (ACTN) defined by the IETF TEAS (Traffic Engineering Architecture and Signaling) workgroup in [26]. ACTN is a set of management and control functions that facilitates the presentation of virtual networks built from abstractions [27] of the underlying TE networks to customers. TE networks or TE topologies mechanisms are key enablers of network slicing since they allow the dynamic provisioning of the E2E connectivity. The TE topology (or TE Network) model will be further discussed in this section.

The ACTN architecture (Figure 6) includes three controllers: the Customer Network Controller (CNC), the Multi-Domain Service Coordinator (MDSC) and the Provisioning Network Controller (PNC). Three interfaces are then introduced by this three-tier architecture: CNC-MDSC interface (CMI), MDSC-PNC interface (MPI) and Southbound interface (SBI). The information exchanged in each of the cited interfaces are governed by a set of data models [28] structured by IETF into yang language modules. These models are classified in general to 4 categories: *Customer service model (CSM), service delivery model (SDM), network configuration model (NCM) and device configuration model (DevCM)* [29] [30]. DevCMs are located in the SBI and are technology specific. While in this paper the network slicing concept is surveyed in a technology-independent way, those models will not be covered in the following of this section. However, we will address all the other data models that we consider as enablers of the network slicing technology located in either the CMI or the MPI. Then, in section V we will explain our vision on how they may relate to each other in order to instantiate and manage NSs.

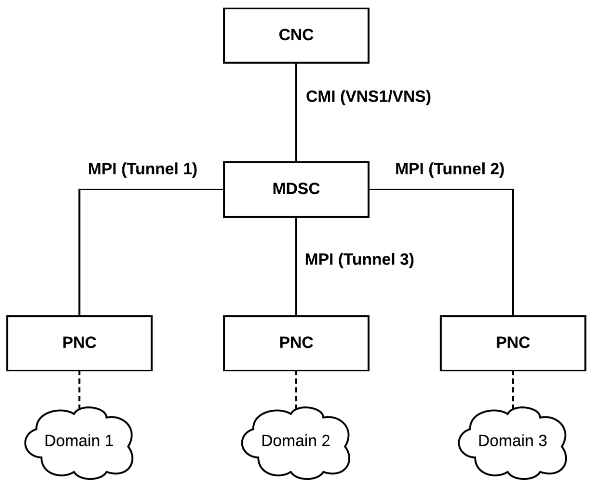

Fig. 6. The ACTN Architecture: CNC, MDSCs and PNCs.

The CNC request the instantiation of a VNS to the MDSC via the CMI interface. The MDSC is at the core of the ACTN model obviating the need of the underlying technologies for network and service control while helping the E2E NS consumer to express the desired TNS by the mean of SLAs. This is achieved in the MDSC by the implementation of network-related functions such as multi-domain coordination, abstraction and service-related functions like service mapping/translation and virtual network service coordination.

From a bottom-up perspective, each PNC exposes an abstracted topology to the MDSC. The MDSC merges then all the advertised topologies at the MPI into its native network topology. Therefore, the MDSC provides an abstracted topology based on its view to the customer. It is worth mentioning that a hierarchy of MDSCs is very likely to be envisaged in real world deployments. In that case lower-level MDSCs (MDSC-Ls) are connected to higher-level ones (MDSC-Hs) using the MPI interface. Likewise, each MDSC-L advertises an abstract topology to the MDSC-H. The PNC may be implemented as an SDN controller, e.g., an active PCE-based or P4 controller to dynamically manage a domain network. We note that the ACTN Framework resumes most of the NS functions defined in section I by ETSI NGP with more focus and details on the abstraction functions.

3) TE topology model [36]: The TE topology model describes the provider's data store of abstract TE topologies provided to customers independently to any specific underlying technology. Indeed, a TE topology may be hierarchical so each network element of an overly topology is mapped to the next underlay topology until reaching the provider's native one. Within the data store, a TE topology comes with a set of TE information related to nodes and links that are used for the selection of a TE path. Certain TE information along with the provider's policy or a negotiated customer-provider policy (bandwidth, shortest path, etc) are given as inputs to the abstraction process in order to produce selective information representing the potential ability to connect across the domain [27].

4) The VN model [37]: In the ACTN architecture, a type 1 and type 2 Customer VNSs allow respectively the creation of type 1 and type 2 VNs defined by the VN model. A type 1 VN is a set of edge-to-edge abstract links (also called VN members) modelled as an abstract node along with a set of Virtual Network Access Points (VNAPs). In a type 2 VN, the provider disclose a detailed abstract topology as an underlay to the one abstract node, allowing customers to configure explicit path for some of the VN members.

5) The COMS data model [38]: An other data model outside the IETF TEAS working group called COMS [43] [44] is proposed for the technology-independent management of NSs.

Similar to the TE topology model, COMS augments also the data model for network topologies [45] but with the essential entities facilitating configuration of QoS, reporting of statistics, QoS threshold monitoring, services instances, and description of compute and storage resources. Figure 7 shows our vision of the IETF NS data model with the augmenting entities (dark color).

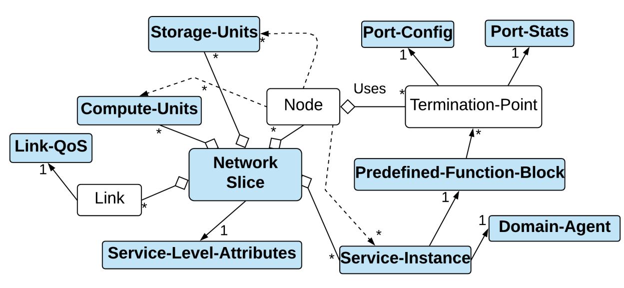

Fig. 7. IETF COMS Information Model

As a result of the last augmentation, a node will make references to a list of compute units, storage units and service instances (e.g., firewall and load-balancer). This is illustrated in figure 7 with dashed arrows. Also, a *termination-poin* entity is described with configuration and statistic attributes. Lastly, a link is augmented with QoS attributes. The content of the augmenting entities is listed in table V.

TABLE V
NS AUGMENTING ENTITIES

NS Entities	*NS characteristics*
Port-Config	packet-rate, packet-loss-probability, packet loss threshold.
Port-Stats	received packets, sent packets.
Link-QoS	link bandwidth agreement, link throughput, link throughput threshold, link-latency agreement, link-latency, link-jitter agreement, link-jitter, link-jitter threshold, path restrictions: list of mandatory nodes, list of mandatory links, list of excluded nodes, list of excluded links.
Compute-Unit	compute unit ID, number of Cores, ram, access mode, location, unit type.
Storage-Unit	storage unit ID, size, access rate, access mode, read-write mode type, redundancy type, location.
Service-Instance	service instance ID, Pre-defined Function Block: Domain-agent name, southbound(sb) IP address, sb port, northbound (nb) IP address, nb port, Function Id, Function name, IP address, port, list of termination points.
Slice-Level-Attributes	service time start, service time end, life-cycle status, reliability level, resource reservation level, availability, availability-threshold, Access-control: match, action, priority, counter.

6) The NS stitching data model [39]: Furthermore, the COMS model is augmented to show up NS subnets and their interconnections within the E2E transport NSs. The new model will not only isolate the management of subnets but also will allow the description of the interconnection instances (implemented as gateways in the data plane) to the upper layers for management operations such as subnet sharing or substituting. The model introduces the mechanism of anchor node and anchor termination point in which all open-ended links within a subnet are linked to an anchor node at a anchor termination point (Figure 8). A similar mechanism is used in TE networks to identify adjacent domains while merging multiple provider TE topologies into the client native one by the help of the *inter-connect plug id* attribute. However, this mechanism is specific to providers' domains interconnection and does not serve the objectives of subnet interconnection instances.

7) The TE tunnel data model [40]: Categorized as a network configuration model, it describes the PNC's TE tunnel data store as it is seen and influenced by the MDSC. The later computes a VNS against the abstract view provided by the PNC then request the instantiaion of the computed TE links as TE tunnels in the PNC's domain.

8) The Performance Telemetry data model (PTISA) [41]: The transport NS consumer may want to subscribe to the monitoring of a set of KPIs of its interest at the NS level (VN 1 type). For this aim the PTISA model can be used. Performance Telemetry data in the PTISA is divided into VN-level and tunnel-level data. Hence, The VN and the tunnel models are separately augmented with KPI telemetry data.

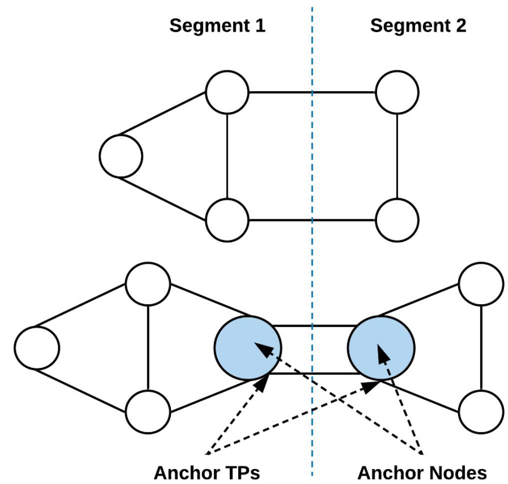

Fig. 8. The NS Subnet Stitching Mechanism

9) The ACTN Common Interfaces Information Model (ACTN C2IM) [42]: Finally, the ACTN C2IM models the CMI and MPI by providing respectively their required VN and TE tunnel primitives.

V. Challenges and Future Research Directions

In this section, we look at the aforementioned studies described in section IV-B as foundations of the network slicing technology in the transport domains. Therefore, we provide our vision on the network slicing architecture in the TN domain by analysing and explaining, in a technology-independent manner, how the different models and techniques work together within the ACTN framework in order to provide TNS services. Then, we discuss some open issues such as the standardization of the TNS customer service model, the enhancing of the GSMA GST template and the unification of NS standardization efforts. Finally, the security and isolation problem brought by the Network Slicing technology was highlighted.

A. Enable Network Slicing within the ACTN Framework

Figure 9 depicts our vision. The customer in our case is the 3GPP system orchestrator (the operator). Therefore the CNC hosts the aforementionned 3GPP NSMF. By analogy to the RAN and the CN, the CNC sends the TNS related requirement over the CMI. At the later, a service customer model encompasses the technology-agnostic TNS profile and the 3GPP RAN and CN access points. At the time of writing this article, neither a TNS profile nor a clear NS customer service model are defined within the IETF. Examples of customer service models include L2SM [31] and L3SM [32] which allow respectively the presentation of L2VPN [33] and L3VPN [34] services to a customer by an operator.

In alignment with the service model architecture provided in the context of SDN in [30], we adopt the functional split

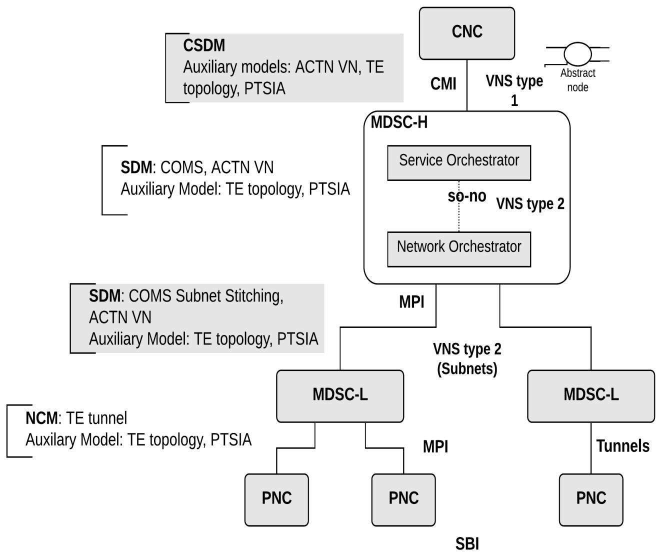

Fig. 9. Enabling network slicing within the ACTN architecture

of the MDSC between a service orchestrator (SO) and a network orchestrator (NO). In this implementation option, the SO and the NO realize respectively the service-related and the network-related functions. As a result, a new interface (SO-NO) is exposed within the ACTN architecture controlled by a new data model type called the service delivery model.

Customer service models and service delivery models are sub-types of the service model. In general, the later describes the service in a technology-agnostic way so that the customer has no knowledge of how the service is engineered in the underlying technologies. However, the level of service abstraction at the SO-NO interface is lower in comparison to the CMI. Particularly, a service delivery model is network centric and may be aware of many features such as topology, technology and operator policy [30].

The service orchestrator communicates the computed TNS (based on its abstract view) to the network orchestrator as a virtual network (VN) over the SO-NO interface. Recursively, the network orchestrator segments the virtual network service received on its northbound interface then requests the instantiation of the resulting virtual services to the concerned PNCs over the MPI. This is done using network configurations models. The PNC configures and manages the resources under its control domain. It establishes the tunnels in the network infrastructure as part of the virtual service segment received at the MPI.

It is important to note that the transport slice service received by the MDSC at the CMI is progressively mapped and translated at each layer until its realization as connectivity tunnels in the underlying infrastructure. The multi-layer/multi-domain service mapping function addressed here is an essential brick of the network and service automation architecture [35]. Indeed, the later is to be bound to the ACTN framework for the sake of network slicing fulfillment.

The data models needed to support the ACTN architecture in order to enable network slicing can be as follows:

1) The yang data model for TE topologies [36] to support the ACTN abstraction function.
2) The yang data model for VN operation to request the instantiation of the TNS and its constituent subnets [37].
3) The technology independent information model for common operation and management of network slicing (COMS) [38].
4) The NS Subnet stitching data model [39].
5) The yang data model for TE tunnels and interfaces [40].
6) The yang data models for VN and TE-tunnel performance telemetry and scaling intent autonomics (PTSIA) [41].
7) The ACTN common interfaces information model (ACTN C2IM) [42].

In the context of network slicing, the TE topology model is used at MPIs, the SO-NO interface as well as the CMI. We consider the TE topology as an auxiliary model for the service delivery and the customer service models.

According to both 3GPP and GSMA, the NSP orders a NS service using a set of Service Level Specifications (SLSs), also called *NS related requirements*, without specifying any service graph. It comes to the NOP to map those SLSs, using the NSMF, to RAN/CN/TN slice profiles. The NSSMF of each domain is then the responsible for translating those profiles to topology and network service models to be instantiated in the underlying infrastructure.

Following the same modeling, a transport slice profile should be defined in terms of a set of parameters, metrics and thresholds, along with the customer (operator) access points of the transport slice service. Therefore we believe that there is no need for a *service graph* in the customer service model but a type 1 VN. This is referred to as a type 1 virtual network service (VNS) in the ACTN framework.

A type 1 VN is the easiest way for customers to express E2E connectivity so they do not deal with service graphs or any technical detail. Consequently, in addition to the slice profile, the customer service model has to refer to an abstract node with the different VNAPs along with a connectivity matrix. The use of the VN model in the ACTN is addressed only at the CMI. However, we propose to use it also at the SO-NO interface allowing the service orchestrator to request the instantiation of a VN to the network orchestrator. In addition, the VN model needs to be used in an eventual implementation of layered MDSCs at the MPI interface between a MDSC-H and MDSC-Ls in order to segment the VNS to NS subnets. Clearly, the VNS used outside the CMI is of type 2 (more concrete that Type 1). We consider the VN model as a service delivery model. Indeed, it relies on the TE topology model to refer to a VN abstract topology. This is achieved in the yang module using the attributes: *vn-topology-id* and *abstract-node*.

Since we categorize the COMS data model as service delivery model, it becomes necessary to explain the specificities of this model in comparison with the VN and the TE topology ones. We show in figure 10 how all of them can be integrated together in the whole network slicing process. The COMS model comes with a new data store which provides a complete and unified view of NSs. Without COMS, a NS is stored in the TE topology data store and there is no way to recognize

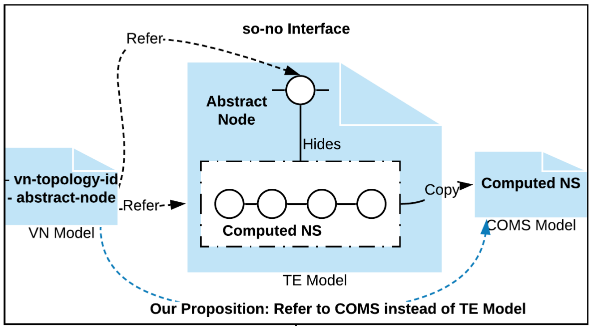

Fig. 10. Integration of VN, TE and COMS models

it as slice only through the VN data store. However, the VN model provides only a mechanism for VN instantiation and does not include NS provisioning and management operations. Furthermore, managing a NS as TE topology is a heavy task because of its numerous contained TE information necessary to compute a NS but useless for its maintenance and life-cycle management.

Another strong point about COMS is its integration with the ETSI NFV MANO (management and orchestration) framework so that it describes compute, storage and network resources relayed on by the VNFs purchased with a NS [43] [44].

For all these reasons, we propose to use the TE topology model only for the provider's domain abstractions and the computation of a NS based on the received customer service model. The TE computed network can be then stored in the COMS data store with the aforementioned augmenting entities as a NS. This how the COMS service delivery model is derived from the customer service one. In the network slicing case, instead of pointing out to a TE topology, the VN model refers to the COMS topology network at the SO-NO interface for the provisioning and management of a NS.

In this context, an ongoing project is recently lunched under the opensource Open Network Operating System (ONOS) controller in partnership with several telecom operators (e.g., Huawei and SK Telecom) [1]. It aims at the implementation of the ACTN framework. Since the project is not intended in a first place for TNS implementation it is actually involving only the TE topology and the TE tunnel yang data models. Nevertheless, the framework if extended by a NS engine and an implementation of the COMS and the VN models, can serve as a reference plateform for the TNS experimentation.

Afterwards, the VNS (type 2) received by each low level MDSC is mapped to the tunnel network configuration model [46] so that one or multiple tunnels are sent to the concerned PNCs in order to be deployed in the underlying domains.

Finally, the MDSC-H requests the subscription for subnets level (VN 2 type) telemetry data from multiple MDSC-Ls. Recursively, the MDSC-L maps the received VN KPI telemetry subscription request to multiple tunnel KPI telemetry subscription requests sent to one or many concerned PNCs. Besides, tunnel telemetry data is derived from low-level data collected via performance monitoring counters in network elements and pulled up to the PNC using the device configuration model. Moreover, the PTISA model provides a mechanism for the CNC, the MDSC-H and the MDSC-L to respectively configure automatic scale-in and scale-out of a NS (VN type 1), a NS subnet (VN type 2) and a TE tunnel.

B. TNS Customer Service Model

Section IV rises an important question about the customer service model that should be used to order NSs: Does it carry a service graph as stated by ETSI NGP or rather a NS template as affirmed by GSMA? This is the major difference between SDOs' vision. 3GPP is aligned with the GSMA vision and is already considering many of the GST attributes in the definition of its service/slice profile. Table VI lists those commonly used attributes and their reference to GSMA GST fields.

TABLE VI
3GPP AND GSMA COMMUN NS CHARACTERISTICS

3GPP field	*Value*	*Equivalent GSMA attribute*
Connection Density	Integer (UE/sq km)	Terminal Density
E2E Latency	integer (ms)	slice quality of service parameters
UE Mobility Level	Enumeration (stationary, nomadic, restricted mobility, fully mobility)	Supported device velocity
Resources Sharing Level	Enumeration (shared, non shared)	Simultaneous use of the network slice
Reliability	Float	Reliability
Communication Service Availability	Float	Availability
UE Speed	integer (Km/h)	Supported device velocity

Nevertheless, the GSMA GST template extends the 3GPP service/slice profile with standardized slice characteristics.

As for IETF, it is not yet clear if the customer service model supports a service graph or a transport slice profile following the same modelling of 3GPP within the RAN and CN. In fact, authors in [25] proposed an initial version of the NS customer service model at the CMI interface also called Transport Slice Connectivity Interface (TSCI) information model. This model supports the vision of the ETSI NGP and represents a NS service as a set of transport networks (subnets) including nodes and their interconnection links. The nodes may represent either the endpoints of the transport slice connections (RAN and CN network functions) or the endpoints of the transport service (border routers). This in progress work claims to be flexible in that matter.

Another transport slice data model is proposed in [47] in order to support network slicing as a service between a customer and a provider. The later augments the data model of network topologies. Truly, after the request of a NS service and that later is implemented in the underlying network infrastructure, the TNS provider is required to expose the NSI management capability to the customer for operational state retrieval and any augmentation in the NSI resources. The transport slice data model provide the means to serve that goal. The model operates at the CMI, and may be considered as service customer model to be activated after the creation of the NSI for management capability exposure purposes.

Furthermore, an analysis was performed on the GST's 35 attributes in order to decide on their impact on the transport network since some of them target either the RAN or the CN [48]. The end goal is to define the functionality required on the northbound interface of the MDSC (CMI). As result, GSMA GST attributes were categorized as directly impactive, indirectly impactive and non-impactive attributes. This work is definitely an important step toward the definition of a NS customer model. We believe that the TNS provisioning request at the CMI is an abstract intent-based request following the same modeling of 3GPP in the provisioning of RAN and CN sub-slices. Thus, the NS customer service model would be based on GST SLAs, most likely the ones with direct impact on the transport network, along with customer endpoints as explained in section IV-B. Further, this model may be augmented with the TE service mapping model [49] as proposed in [50]. The goal is to record the mapping between a requested NS service and its instantiation in the underlying infrastructure in terms of either a VN, a TE topology or tunnels. This will allow to view the NS service instantiations outside the MDSC from either an operator for diagnostics purposes or to give an idea to customers on how their services are instantiated in the transport domains.

Another point, we propose to use the TE topology model only for the provider's domain abstractions and the computation of a NS based on the received customer service model. The TE computed network can be then stored in the COMS data store with the augmenting entities resumed in section IV-B5 as a NS. This how the COMS service delivery model is derived from the customer service one. In the network slicing case, instead of pointing out to a TE topology, the VN model refers to the COMS topology network at the SO-NO interface for the provisioning and management of a NS.

Finally, the discussion on the TNS provision model is an open topic within IETF and requires more feedback and reviews from standardization bodies and vertical customers. Currently, three NS provision models are envisaged: The SaaS-like, the PaaS-like and the IaaS-like models [51]. The former is the model adopted by GSMA and 3GPP to respectively request and provide a NS service. In the PaaS-like model the tenant's request carries a representation of the NS as a set of nodes, their interconnections along with connectivity configurations. This is aligned with the ETSI NGP vision. Tenants in the IaaS-like model have direct control over the underlying infrastructure so they order NSs with concrete resource configurations. The latter model is not aligned with the common network slicing vision. Yet, no use case was cited in the related work in order to prove its usefulness. Table VII summarizes the aforementioned similarities and differences between the different SDOs'visions.

Regarding the service order management, the REST open API specification provided by the TM Forum can be used to place an order at each of the CMI as well as the interface between the E2E NSC and the NSP (operator) [52]. Also, authors in [53] have provided a specification of Connectivity Provisioning Negotiation Protocol (CPNP) which is meant for exchanging and negotiating dynamically connectivity provisioning parameters between a customer and a provider (or only between providers). By comparison to the TM Forum REST API, this protocol introduces the concept of "Offer" that allows the service provider to accommodate received orders beyond monolithic yes/no answers. CPNP can also be used at the aforementioned interfaces to order a NS service.

C. *Towards a Unified Network Slicing Model*

We have observed that the issued standards are generally completing each other and may potentially be unified as presented in our previous work [54]. Also, in another previous work [55] we have provided a framework for NS subnet management based on an exhaustive list of requirements derived from the network slicing standardization community. In this context, ETSI ZSM workgroup is building an E2E NS federated solution [56] by making use of all the aforementioned outputs from ETSI, 3GPP, IETF and GSMA and stitching them to the ZSM architecture [57]. For instance, 3GPP has introduced interesting concepts for the RAN and the CN that could be mapped and applied to the transport network such as NSMF/NSSMF, service/slice profile, NSI/NSSI.

All those terminologies could be mapped to the TN so that we define the transport-NSSMF, transport slice profile, and transport NSSI as illustrated in figure 11. Besides, the NS

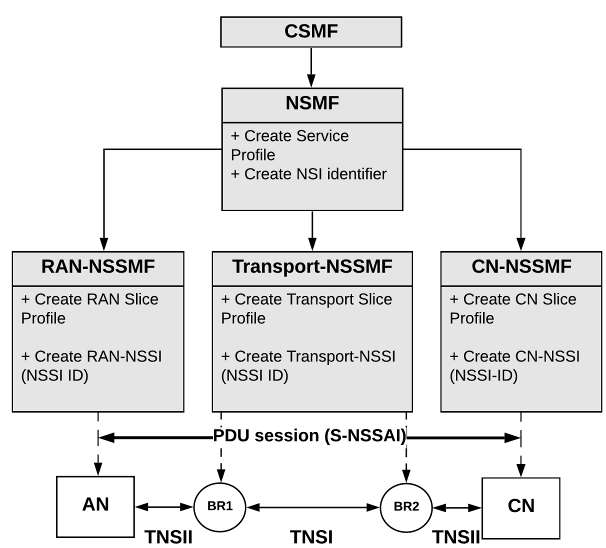

Fig. 11. Mapping of 3GPP NS functions to the Transport Network

functions provided by ETSI NGP in table I are all included in the 3GPP NSMF/NSSMF [3]. As described in [58], the

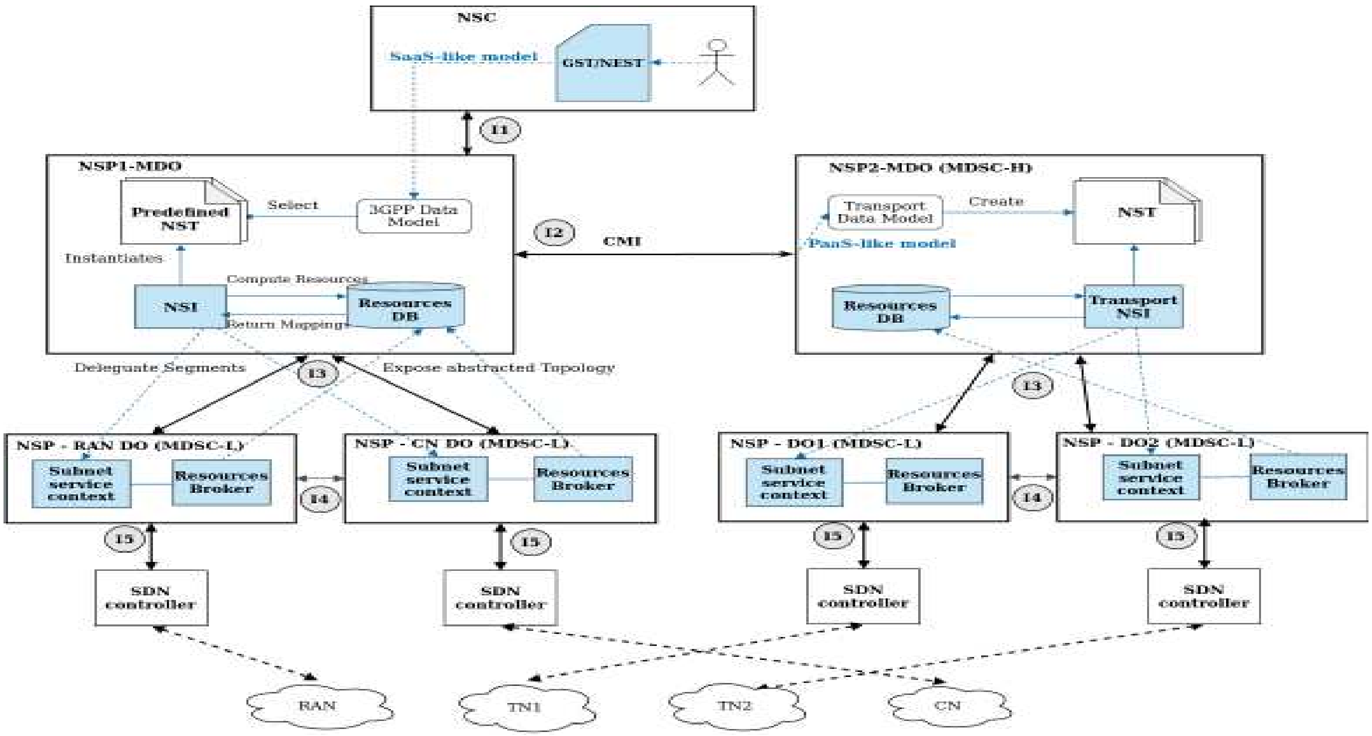

Fig. 12. Mapping of the ETSI NGP NS information model objects, the 3GPP NS data model, the GST/NEST and the ACTN Framework on the End-to-End Management and Orchestration reference architecture (MANO)

mapping of 3GPP network slicing to the transport network happens in each of the management plane, the control plane and the data plane. In the former, a binding between the NSI with the Transport-NSSI is maintained in each of the Transport-NSSMF and the NSMF. In the control plane, the S-NSSAI is used during the UE registration and the PDU session setup to identify a NS from the UE perspective thus the selection of a NSI. However, there is no explicit mapping of the S-NSSAI to the TN. The S-NSSAI is normally mapped to the NSI in the management plane and this will help in the selection of the Transport-NSSI. Regarding the data plane, the Transport Network Slice Interworking Identifier (TNSII) and the Transport Network Slice Identifier (TNSI) are proposed [58] to respectively identify transport NSs in the operator wide network and locally in the transport domain. The mapping between the TNSII and the TNSI is maintained within the transport network border nodes (br1 and br2). The mapping between the S-NSSAI or the NSI/Transport-NSSI and the TNSII is maintained in the AN/CN nodes so that packets of an uplink flow going to the transport network from the AN/CN is encapsulated with TNSII.

Finally, a NS life-cycle management REST API [59] is developed by the 5G riders on the storm catalyst [60] and provided as a proposal to the TM Forum (API-1284). The later binds together the data model work from 3GPP SA5, a JSON version of the GST and TM Forum API guidelines. Since orchestration is a key enabler of Network Slicing, we map the the major SDOs'aforementioned contributions to the End-to-End Management and Orchestration reference architecture (MANO) [62], proposed in the context of the 5G Exchange project, as depicted in Figure 12. The architecture introduces multi-domain orchestrators (MDO) and domain orchestrators (DO).

D. Enhancing the GST

The 5G riders on the storm catalyst project promoted by the TM Forum [60] have a different vision on how the GST should be structured based on its ongoing demonstrations as well as the Huawei's operational experience with NS management. The project focuses on an operational NS use case that support emergency services provided to first responders during extreme weather events such as flooding or storms. As a result a reviewed GST [61] is proposed that includes the following contributions:

1) Preparing the flat GST to automation and programmatic use by transforming it to a JSON template validated by a JSON schema.
2) Making the GST customer facing by separating the Customer Facing Service (CFS) attributes from Resource Facing Service (RFS) ones so that most customers (non-technicals) deal only with what/where/when questions.
3) Many of the GST attributes are ignored in the reviewed template on the pretext that their values can be derived from other populated parameters. After comparison of the two templates, we notice that the following GST attributes are missing: Downlink throughput per network slice, Energy efficiency, Isolation level, Location based message delivery, Maximum supported packet size, NB-IoT Support, Uplink throughput per UE.

4) The catalyst is also enhancing the GST with new attributes from NGMN and 3GPP such as the use case type and activity factor.
5) All the GST attributes are reorganized into profiles.

E. NS Security And Isolation

Nevertheless, the network slicing concept brings new security issues. In particular, providing and demonstrating the adequate NS isolation level is one of the biggest challenges faced by the 5G operators [63]. In fact, 3GPP architecture demonstrates a requirement for authenticating users of network slice resources. There is however a need for separate per-slice security policies, e.g. having different authentication requirements between IoT and broadband. Inter-operation between NSs is a major issue related to VNFs isolation at L2 or L3 levels. Moreover, the IETF COMS model already presented in details in Section IV.B includes a set of isolation attributes covering the following areas:traffic, bandwidth, processing, storage. However, COMS is not a customer-facing model. According to GSMA, a NS instance may be fully or partly, logically and/or physically, isolated from another network slice instance. These properties are included in the GSMA GST under the "isolation level" attribute. Finally, the NSP has to assure the NSC with evidence that confirms the NS isolation existence. This should be achieved by the measurements of the isolation properties in the operator's infrastructure as well as NS orchestration functions such as the report aggregation and service assurance functions proposed by ETSI NGP. The IETF PTSIA model may also be used to verify NS isolation since it allows a NSC (operator) to subscribe to transport NSs and NS subnets telemetry data. This is an interesting and complicated research direction that should be coupled with the frameworks designs in the future.

VI. Conclusion

In this survey, current NS modellings works in RAN, CN and transport network domains were bound together in order to bring forth the implicitly expressed 5G E2E network slicing model from the SDOs' technical specifications.

We started by introducing the network slicing general vision and how ordering a NS can be done with the use of the service graph. An in-depth exploration of the E2E network slicing information models within the RAN, CN and TN specific domains is then provided. We have analyzed and resumed most important models, their attributes and functions that are required for maintaining NSs at all its possible lifecycle phases. We tried to simplify the comprehension of all the complicated operations and the relationship between the elements of different layers or different domains via tables, figures and diagrams accompanied by brief descriptions. Our vision on how all these models and frameworks can be merged, completed and augmented together for an efficient E2E network slicing management has been proposed that is the real benefit of this work.

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TABLE VII
SUMMARY ON THE SIMILARITIES AND THE DIFFERENCES BETWEEN SDOS' VISIONS

SDOs modelling aspects	**Provision models [51]**			**NS Service request**			**Network domain**				**Main contribution**
	SaaS-like	PaaS-like	IaaS-like	Service graph	Service/ Slice profile	VN Type (1,2)	RAN	Core	Transport	General	
ETSI NGP		✓		✓						✓	Generalized NS architecture and its associated workflows.
3GPP	✓				✓		✓	✓			Information/data model for NS provisioning and management on RAN and Core network.
GSMA	✓				✓		✓	✓	✓		GST/NEST
IETF		✓				✓			✓		The ACTN architecture and several data models(cited in section IV-B).
Proposed vision		✓			✓	✓ VN type 1 + TNS profile			✓		Enable Network Slicing within the ACTN architecture by integrating together multiple IETF data models.

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