Network Slicing as a Service: Enabling Enterprises' Own Software-Defined Cellular Networks

Xuan Zhou, Rongpeng Li, Tao Chen, and Honggang Zhang

The authors introduce the concept of hierarchical NSaaS, helping operators to offer customized end-to-end cellular networks as a service. Also, the service orchestration and service level agreement mapping for quality assurance are introduced to illustrate the architecture of service management across different levels of service models.

Abstract

With the blossoming of network functions virtualization and software-defined networks, networks are becoming more and more agile with features like resilience, programmability, and open interfaces, which help operators to launch a network or service with more flexibility and shorter time to market. Recently, the concept of network slicing has been proposed to facilitate the building of a dedicated and customized logical network with virtualized resources. In this article, we introduce the concept of hierarchical NSaaS, helping operators to offer customized end-to-end cellular networks as a service. Moreover, the service orchestration and service level agreement mapping for quality assurance are introduced to illustrate the architecture of service management across different levels of service models. Finally, we illustrate the process of network slicing as a service within operators by typical examples. With network slicing as a service, we believe that the supporting system will transform itself to a production system by merging the operation and business domains, and enabling operators to build network slices for vertical industries more agilely.

Introduction

Although the data traffic of mobile terminals is increasing rapidly, the consumer market of mobile broadband services is going to be saturated in North America, Europe, and East Asia [1]. Meanwhile, the growing popularity of machine type communication (MTC) terminals and applications of vertical enterprises poses an increasing demand for diverse services from mobile networks. However, legacy mobile networks are mostly designed to provide services for mobile broadband consumers, and merely consist of a few adjustable parameters like priority and quality of service (QoS) for dedicated services. Therefore, mobile operators find it difficult to get deeply into these emerging vertical services with different service requirements for network design and development. For example, the dedicated network for a railway company just involves the coverage along the railway with high-speed mobility management, but exhibits apparent difference from that of an electricity metering company, which only requires small-volume data transmission but massive connections at static positions. Some vehicle communication services are strictly delay-sensitive, while some video surveillance services require stable and immobile high bandwidth. Recently, network functions virtualization (NFV) technology has been proposed to decouple the software and hardware of network elements so as to simplify service development. A study by the European Telecommunications Standards Institute (ETSI) shows that NFV and software-defined networking (SDN) could shorten time to market and facilitate innovations in the technical field (e.g., saving maintenance cost, auto-scaling, enhancing system resilience) [2]. Nevertheless, currently the products and service types from operators are still limited. In order to enrich operators' products for vertical enterprises and provide service customization for emerging massive connections, as well as to give more control to enterprises and mobile virtual network operators (MVNOs), the concept of network slicing (NS) is proposed to allow the independent usage of a part of network resources by a group of mobile terminals with special requirements [3, 4].

NS aims to logically separate the set of network functions and resources within one network entity, according to specific technical or commercial demands. Although the concept of NS is still nascent, similar techniques already exist. Among them, IEEE 802.1Q, virtual local area networks (VLANs), which can be regarded as the ancestor of NS, provides a single broadcast domain to bring together a group of hosts possibly having no local and physical connectivity but sharing common interests. Moreover, in the field of fixed networks, Internet Engineering Task Force (IETF) RFC 4026, which is also known as virtual private network (VPN), is another form of NS, which could guarantee the QoS and security requirements for logically independent sessions [5]. However, in cellular networks, the realization of NS faces significant challenges, since more parameters such as mobility and authentication

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management in the control plane as well as session and charging management in the user plane need to be customized for a group of connections as a logical network. Fortunately, NFV and SDN can make NS a reality, with NS allowing operators to customize networks according to various requirements of mobile services, thus leading to a more cost-effective way to build dedicated networks. Therefore, NS is attracting significant interest from both industry and academia. For example, the Fifth Generation Infrastructure Public Private Partnership (5G-PPP) project 5GEx introduces a business model of NS among infrastructure owners, wholesale providers, retail providers, content providers, and end users [6]. The Third Generation Partnership Project (3GPP) also initiated a technical study into NS to specify service requirements and operational requirements [7]. Vendors such as Ericsson, Huawei, Nokia, and ZTE have also published white papers about NS to introduce the realization of NS into 5G [8]. In fixed networks, NS has been implemented to logically separate the networks, allowing slice owners to manage their own networks [9]. Another case is NS for emergency communications, which provides dedicated and priority resources to users for emergency communications, even in overwhelming scenarios [10]. However, due to the scattered service models across radio access networks (RANs), core networks (CNs), and transport networks, and complex protocols in tens of 3GPP interfaces, the realization of mobile NS seriously lags behind its counterpart in fixed networks. Specifically, there is still lacking an end-to-end service description of the mobile network for the northbound interface to deploy or manage a multi-vendor network slice across the domains with thousands of parameters. The study and standardization of NS are still at a rudimentary level, and give little insight into the mapping from business model and service operation [7]. In this article, following the operators' perspective provided by the Next Generation Mobile Network Alliance (NGMN) [3], we introduce the concept of network slicing as a service (NSaaS) with service models and management, and introduce how to technically realize the proposed business models.

This article is organized as follows. The next section introduces the concept and business models of NSaaS. We then propose the service models and service orchestration for NS as a bridge of business model and technical realization. After that we describe the management features of NSaaS such as auto-configuration, product management, and application programming interfaces (APIs). The final section concludes the article.

Network Slicing as a Service

Business Model of NSaaS

Recently, the information and communications technology industry is boldly embracing the concept of "something" as a service (XaaS), which refers to being able to call up reusable, fine-grained software components across a network. For example, Tarik Taleb *et al.* [11] studied the feasibility of on-demand creation of cloud-based elastic mobile CNs, along with their lifecycle management; Wanfu Ding *et al*. [12] presented the design of an open platform for service chain as a service, by using the tangible capabilities of SDN and NFV. In this article, we discuss how operators agilely provide a customized network slice for their customers as a service, which is called NSaaS. According to the relationships between service providers and consumers, the business models of NSaaS can be categorized into three classes as below.

Business to Business (B2B): Operators sell the network slice to a company who owns both the network and terminals, such as video surveillance networks for security companies and smart factory networks for manufacturing companies. In the B2B case, operators not only provide customized wireless connections to enterprises, but also release full control of terminals to the enterprise.

Business to Consumer (B2C): End consumers are able to purchase customized data pipes from operators for their terminals like smart home devices. In the B2C case, end customers could enjoy the slice once they put subscriber identification module (SIM) cards inside their devices. Generally, customers just use the customized network, but do not possess the network with service separation.

Business to Business to Consumer (B2B2C): The operator plays the role of wholesale provider; meanwhile, a broker like an MVNO helps operators to be engaged with end customers. In this case, operators just provide dedicated connections, called MVNO as a service, to the broker, without involving the business part. However, the broker could get more control of the network than traditional MVNOs, who could only get billing files from mobile network operators (MNOs).

From another perspective, there are three service scenarios of NSaaS, which have different life cycles, service objects, and slice scales:

- Industrial slice: Customers with the same network service requirements are registered with the same slice, which abstracts the common demands of users, such as high-bandwidth slice and low-latency slice.
- Monopolized slice: Anyone (usually an enterprise) who pays for the slice monopolizes and uses it as a private network.
- Event slice: A slice is launched for some events with relatively short life cycles, such as sports events, concerts, and even sales promotions inside shopping malls.

NSaaS also demonstrates some advantages to operators. First, confronted with prosperous over-the-top (OTT) services, operators could only provide less competitive OTT-like services and traditional services such as voice, SMS, and data. NSaaS makes a difference by facilitating operators to differentiate their data pipes with various QoS and providing additional promising services. Second, based on NSaaS, the design and configuration experience becomes a simple software reconstitution procedure and shortens the time to market of operators' products from months to hours. Assuming that infrastructure of network elements has already been virtualized and could be allocated as a simple reconstitution procedure of virtual machines, a

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The slice selection procedure is the same as that of RAN only, so UEs do not need to select the slice of CN once they have got access to the RAN part. The CN & RAN solution brings the advantages of both CN only and RAN only solutions, being able to program the functionalities of CN, as well as customize the air interfaces of RAN.

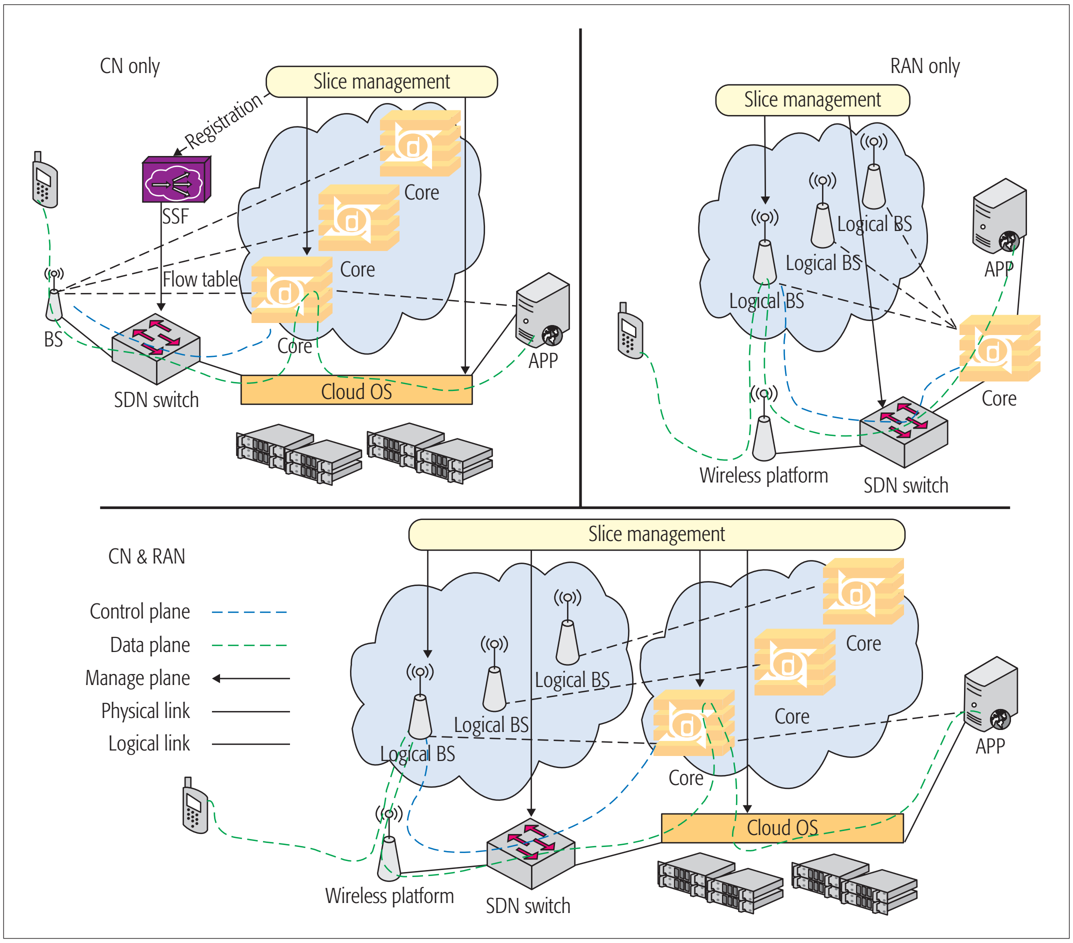

Figure 1. The architecture of three forms of NS.

component-based network could be described by configuration files as a service template and orchestrated by combining software packages from a library. Third, NSaaS enriches the products of operators so that operators could agilely offer dedicated network services to small and medium enterprises rather than build expensive dedicated networks case by case only for large enterprises. Moreover, software-based NSaaS facilitates the convergence of operators' operation support systems (OSSs) and business support systems (BSSs).

Architectures of Network Slicing

There are several implementations of NS, as illustrated in Fig. 1: CN only, RAN only, and CN and RAN.

CN Only: Tenant-level CNs are virtualized as network slices, with component-like functionalities to be programmable and auto-configurable, such as mobility management, session management, and authentication. The network slices only exist in CNs; therefore, neither the RAN nor the user equipments (UEs) need to be specially configured for the sliced CNs. All the interfaces and procedures remain unchanged except the case when the UEs initially attach to the networks, because the UEs should be assigned to the correct slice of the CNs. Here we propose to add a slice selection function (SSF) intervening at the interface between the control plane of the CN and RAN to notify the right slice to activate the bearers with the UEs. Another function of the SSF is to send flow tables to SDN switches to manage connections between the base stations (BSs) and the network slices, due to different coverage requirements of the slices.

RAN only: Different from CN only slicing, RAN slices run on the radio hardware and baseband resource pool, called a wireless platform, which exhibit less elasticity than the mature virtualized infrastructure in CNs. With several logical BSs, the slices of a RAN apply various parameters of the air interfaces (e.g., symbol length, sub-carrier spacing, cycle prefix length, and the parameters of hybrid automatic repeat request [HARQ]) to implement slices with different service models. Furthermore, other parameters like cell selection and handover threshold, as well as coordinated transmission policies can be defined for each slice in order to provide a featured wireless experience to the UEs.

CN and RAN: In this scenario, each slice of a RAN is connected to a core slice, so operators could offer an end-to-end logical network to clients. The slice selection procedure is the same as that of RAN only, so UEs do not need to select the slice of a CN once they have access to the RAN part. The CN and RAN solution brings the advantages of both the CN only and RAN only solutions, being able to program the functionalities of the CN, as well as customize the air interfaces of the RAN.

From NFV to NSaaS

The NFV technology contains general-purpose processor platform, cloud operating system, hypervisor, distributed computing, and the software of network elements, decouples software and hardware, and shields the hardware details for virtual network functions (VNFs). Based on NFV, NS realizes the service separation for multi-tenancy so as to virtually build an exclusive network for each tenancy. However, NSaaS is a more business-oriented concept than a technological one, with features of mapping service demands automatically from a customer to functionalities, topology, policies, and parameters of a network slice, as well as providing component-based and auto-configured network functionalities for operators to design and launch network services more conveniently. Table 1 lists the abstracted comparison of NFV, network slicing, and NSaaS.

An Example of NSaaS

Here we take an emergency communication slice as an example to further clarify NSaaS. Usually, an emergency communication slice offers two main functions in an emergency: alert broadcast and distress call. This slice is usually provided by a government to inhabitants for free with the B2B2C business model. Both the CN only and CN and RAN implementations are suitable for the emergency service, and provide dedicated communication resources of top priority when others are congested. The emergency slice could be available once launched without any hardware integration. Moreover, we can load new functions such as push-to-talk on demand just like installing a new software.

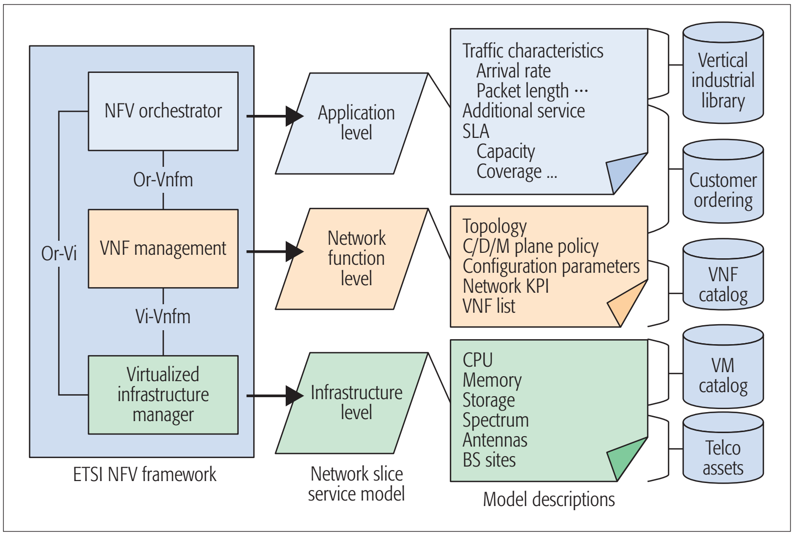

Figure 2. The proposed service models of network slicing.

Form	NFV	Network slicing	NSaaS
Features	Hardware/software decoupling [2]	Multi-network separation	Service auto-mapping
Managed object	Virtual machines	Virtual networks	Customized services
Value to operators	Better resource utilization	Tenancy separation	Agile product development
Value to consumers	None	Monopolized network	Customized service

Table 1. The comparison of NFV, network slicing and NSaaS.

Service Model and Orchestration

In the previous section, we point out that the key technology of NSaaS is service mapping, which translates service requirements into service models of operators and vendors. In this section, in order to better match network slices to various vertical applications, we propose to differentiate necessary service models of mobile network into three levels: application level, network function level, and infrastructure level. Figure 2 illustrates the summarized content of the service models mapped to the NFV architecture of ETSI, as well as the descriptor databases.

Application Level

At this level, we describe the traffic characteristics of the applications. In view of a single UE, the application requirements could be described by the metrics including arrival rate, average packet length, flow type (burst, periodic, and persistent streaming), download/upload ratio, and so on. Moreover, the application level also contains some additional services, such as location-based service, firewall, and service chain with third-party applications. The RAN part of network slices provides options about the wireless experience of an application, like the mobility of terminals, cell selection preference, and power-saving air interface. The application level service model should be easy to understand even for application developers without any telecommunication background. Therefore, this could be standardized as the application descriptors. In view of the entire network slice, another important description of the application requirements is the SLA, which defines some service-specific requirements including capacity, coverage area, QoS requirements, failure duration, network issues, denial of service, and scheduled maintenance, and so on.

The service level agreement (SLA) descriptions are usually included in the business contract, while the traffic characteristics with more technical details represent the operator's understanding of a vertical industry. Therefore, the traffic characteristics of this level come from a vertical industrial library built by operators, while the customized SLA requirements as well as additional services must be translated from customers' orders.

Network Function Level

The network function level shows how VNFs are interconnected and configured with non-vendor-specific descriptions. As we know, the topology of a network describes the connections among the sites of a RAN and network elements of a CN. In terms of the SLA of applications, all these RAN and CN nodes are associated by VLANs of control plane, data plane, and management plane. The other part of the service model at the network function level is the parameters defined by standards, like timers within 3GPP and IETF protocols. For example, the tracking area update timer is set to different values for immobile smart metering devices and high mobility vehicles, and

The control plane requires short latency to access the databases, while the data plane requires high throughput of forwarding modules, and the wireless part needs specific signal processing acceleration. Once a network slice starts to be instantiated, we need to find the suitable infrastructure as well as racks in data centers to bear it.

Functionalities	Metering	Video surveillance	Automobile	Emergency
Mobility management	Static, no handover	Static, no handover	High-speed	Low-speed
Session management	Light, no user plane	Standard	Multi-session	Broadcast
Access protocol	3GPP S1-C	3GPP S1 standard	3GPP S1 standard	3GPP MBMS
QoS policy	Bandwidth limitation	Bandwidth guarantee	Latency guarantee	Top priority
Security	N/A	Standard	Standard	N/A
Air interface feature	Power saving	Carrier aggregation	Small TTI	N/A
Band	800 MHz	6 GHz	900 MHz	450 MHz
Bandwidth	2 MHz	100 MHz	5 MHz	2 MHz
HARQ parameters	N + 14, no retransmission	N + 10, no retransmission	N + 3 + 3	N + 3 + 3
Topology	Centralized	Distributed gateway	Distributed gateway	Centralized
Auto-scaling	Enabled	Disabled	Enabled	Enabled
Additional service	Location-based service	Video compression	Push-to-talk	Distress call

Table 2. The functionalities and configurations of NSaaS for typical applications.

the radio resource control inactivity timer also differs between bursty instant messaging service and persistent video streaming.

Infrastructure Level

The infrastructure level of CN is maintained by IT engineers of operators who are responsible for ensuring all the virtual machines working properly to satisfy the demands of VNFs. Here, the wireless infrastructure consists of spectrum resource, antennas, BS sites, radio unit, and baseband resource pool, which is plotted as a wireless platform in Fig. 1. This level helps operators to define the resources of infrastructure with parameters like spectrums, CPU cores, memory, and storage. The control plane requires short latency to access the databases, while the data plane requires high throughput of forwarding modules, and the wireless part needs specific signal processing acceleration. Once a network slice starts to be instantiated, we need to find the suitable infrastructure as well as racks in data centers to bear it.

Service Orchestration

After describing the service models in three levels in terms of the requirements of the applications, we still need a service orchestrator to bridge the descriptions with an operational system with billing, monitoring, and vendor selection modules. According to the requirements of a customer, the orchestrator instantiates the network slice through assembling functionalities of vendors, such as VNF and BS selection, service chaining, subscriber management, as well as monitoring and billing. One of the most important features of NSaaS is the programmability of the network slice with the component-based network functions. Therefore, operators and slice customers could select different functions from vendors according to their own demands. Table 2 lists the examples of the selected functionalities for four typical applications, so that we can program a network slice conveniently according to the metrics.

To assemble functionalities, one challenge is to orchestrate service from different vendors' equipment. This challenge can be addressed in terms of three service levels as below.

Infrastructure Level: The differences between multi-vendor hardware servers are shielded by cloud operating systems including OpenStack, VMWare, and so on, and only need to expose the infrastructure level SLAs to the VNFs. Currently, products and solutions in the infrastructure level are so mature that they satisfy the compatibility requirements well and could be allocated in real time based on the demand of VNFs.

Network Function Level: Based on current NFV technology, we could inter-connect several VNFs at very large granularity without any interoperability and compatibility problems, such as mobility management entity (MME), serving gateway (S-GW), and IP multimedia subsystem (IMS). However, when we try to decompose VNFs into components as micro-services and integrate them on a service bus so that a network slice could be more customized, there appears to be arduous and cumbersome work to standardize functions and interfaces of the components, like mobility management, session management, and traffic detection. Some cellular system vendors have already provided an orchestrator with their NFV solutions inside the nonstandard domain (e.g., inside an MME), which not only offers customization capability of mobile service, but also maintains compatibility with other vendors through standard interfaces [13]. Furthermore, the life cycle management of VNFs and key performance indicator (KPI) data of vendors should be compatible with interfaces of operators' management systems. While ETSI allows operators to subscribe to element management systems (EMS) of vendors, AT&T proposes to standardize the Ve-Vnfm-vnf interface to control rich real-time data [14].

Application Level: According to general application services running on various VNFs of several vendors, there should be some VNF/component selection rules and mapping methods. In other words, operators should translate the requirements of an application into a language that can be understood by the orchestration interfaces of vendors, as studied in projects like Gohan from NTT [15] and OpenMANO from Telefonica. In this regard, the complicated standardization work of network slicing could be shifted to the development of a unified description language and thus interpreting by vendors.

Mapping of Function, SLA, and Vendor

In Fig. 2, the service and SLA of the application level is described in the language of slice consumers. However, in order to offer an eligible network slicing service with the right SLA, we have to map the service and SLA into network function level and infrastructure level, which could be executable for operators and vendors. As we know, a network slice could consist of multiple vendors with standard interfaces, although their supported functions and SLAs are different. Figure 3 illustrates how to map the service and SLA on the top level into lower levels, and how to find the matched functions from different vendors. In this figure, the service and SLA are mapped vertically, and the vendor is mapped horizontally. The application level service descriptions are mapped into both network function level and infrastructure level, and some of the application SLAs are mapped as low-level SLAs, while some of them are mapped as functions. All the components developed by vendors have to register their capabilities and functions with a VNF catalog of operators so that they can be selected according to application requirements. For example, an additional service named malicious website protection could be decomposed into VNFs like traffic detection, malicious database, firewall, and web redirection. It is worth mentioning that the inputs of the infrastructure-level SLA description come from the other two levels, as well as the components of vendors, because vendors have to propose the specifications of infrastructure for all the individual components.

NSaaS Management

In this section, the operation and process of NSaaS are discussed so that operators could provision the NSaaS with shorter time to market.

Automated Configuration

In previous sections, the service requirements have been translated to software packages by vendors' plug-ins so that VNF managers (VNFMs) are able to instantiate a network slice according to the order specification. However, there is still some remaining configuration work to do if the goal is to start the NSaaS automatically after obtaining orders from customers. The configurations of a newly instantiated network slice include:

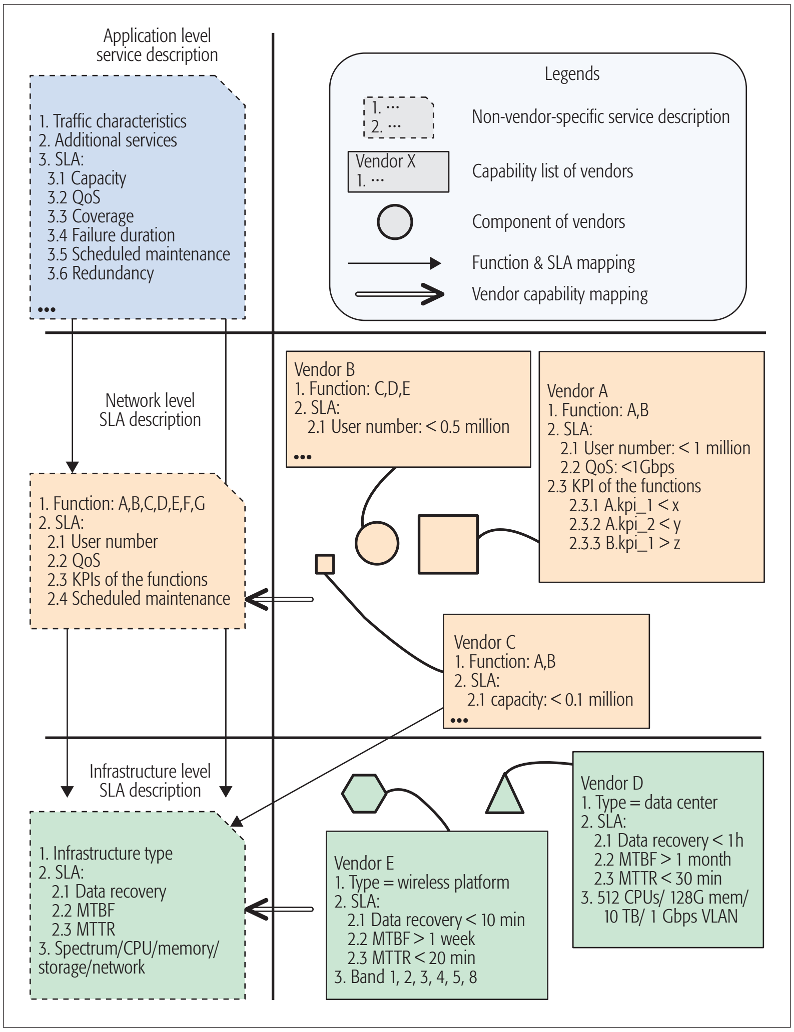

Figure 3. The SLA and vendor mapping of the service models of NSaaS.

- Infrastructure information: It contains the IP address pool of the control plane, data plane, and management plane of data centers, and the IP addresses and VLANs of BS lists.
- Service information: It describes basic entity identifiers and protocol interfaces, such as public land mobile network (PLMN) code, tracking area code, cell ID, domain name, network element name, access point name (APN), home subscriber server (HSS) address, as well as interface configurations of S1, S11, S6a, and so on.
- Subscription information: It contains the relationship between subscribers and network slices, while one subscriber may belong to several slices and different service chains.
- Slice registration: It connects the newly instantiated network slice to running cellular networks so that UEs can be redirected or assigned to it by SSF.
- Monitoring and billing interfaces: They tell where the KPI data and billing files should be sent.

All the configuration items above are also non-vendor-specific. Vendors are able to generate their scripts by exploiting the plug-ins of the network slicing orchestrator. Different from the

The supporting system will transform itself as a production system by providing a one-stop solution for future wireless connections and services. Particularly in the 5G era, with the merging of operation domain and business domain, operators will agilely build more and more customized network slices for vertical industries.

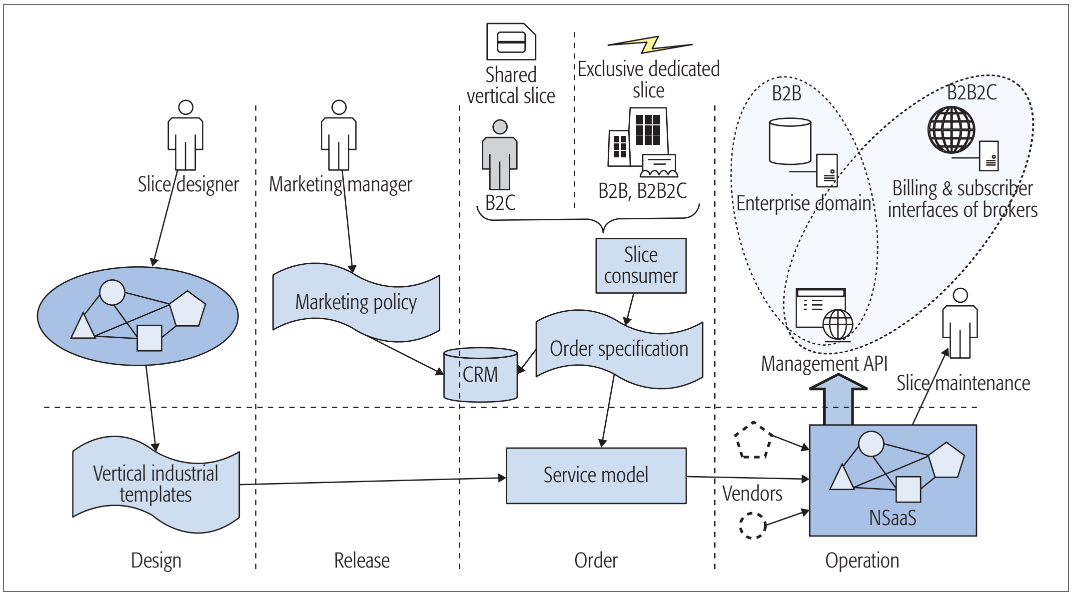

Figure 4. The lifecycle of NSaaS.

configuration of service models, all the parameters here are related to a real mobile network rather than application requirements. Hence, the most challenging part of automated configuration is to maintain the runtime environment information of the real mobile network, which requires operators to keep updating the environment information to reflect different levels of changes within their network happen (e.g., allocating an IP address or when a BS is offline).

Product Management

As a service or product for consumers and enterprises, the network slicing solution requires full life cycle management, spanning from design, release, order, and operation to disposal. Figure 4 describes the first four steps of product management of NSaaS. First, operators design a network slice for a general vertical enterprise according to the description of the service model, which could be named as the vertical industrial template. However, this general service model is not ready for instantiation, because it still lacks input information such as SLA from buyers. In order to sell the service online, operators need to price the slice service in terms of the subscriber number, QoS, SLA, additional service, and spectrum resources. Second, product managers from the marketing department of operators prepare the introduction and case studies of the slice service to help consumers to understand its value. After some internal review process, the slice service could be released onto the market shelf of operators. Third, customers order the slice service and input requirements to the vertical template, such as slice coverage, capacity, and SLA. Fourth, the network slice service is deployed and running, while both the operator and customer are able to monitor the status of the connections and service. Finally, if the slice service is not suitable to sell in the marketplace, operators would dispose it and end its life cycle.

Management APIs for Customers

Besides the product management and maintenance of operators, there is another kind of interface for slice customers, management APIs of NSaaS, which could be integrated with third-party systems or platforms. Slice customers could take advantage of this kind of management APIs to add or remove service and connections, as well as monitor the status of slices. For an MVNO retailing connections to its own clients, management APIs also provide an advanced charging policy and service package for each UE. Therefore, management APIs help operators to find new channels as a new type of broker to distribute their service, which is usually difficult for them to touch in traditional architectures. The broker orders a customized network slice just as an enterprise customer does, but with more capabilities like the integration of its own service platform with the slice (e.g., billing file interface and subscriber database) and user behavior data acquirement from OSS as well as components like traffic detection.

Conclusions

In this article, we introduce the concept of NSaaS to help operators to offer customized end-to-end cellular network as a service. Moreover, the service orchestration and SLA mapping for quality assurance are explained to illustrate the architecture of service management across three model levels. Finally, we illustrate the detailed process of NSaaS within operators by typical examples, including the configuration and product management of NSaaS and management APIs for customers.

With the growing maturity of NFV/SDN, we believe that the supporting system will transform itself as a production system by providing a one-stop solution for future wireless connections and services. Particularly in the 5G era, with the merging of the operation domain and business domain, operators will build more and more customized network slices for vertical industries in an agile way.

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