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Network slicing as enablers for 5G services: state of the art and challenges for mobile industry

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Abstract

The next generation of mobile communications, 5G, is expected to enable global economic output of USD 12.3 trillion by 2035. This would be achieved by applying 5G networks not only to mobile broadband, but also to diverse use cases such as machine-type communications and ultra-reliable low-latency communications. The diverse use cases and requirements are best handled by network slicing, which creates virtual networks over a single physical network. In this paper, we provide an overview of the standardization landscape of network slicing and identify major challenges for mobile operators such as end-to-end scope, roaming, interoperability, and migration. We conclude that the mobile industry and academia should focus on virtualizing base stations and sharing wireless spectrum resources, while selecting set verticals for which to create standardized slices and to formulate relevant requirements, where the GSM Association is a major player to be monitored. The industry should also provide a resolution to ensure the interoperability of network slicing, and study measures to ensure the stable and seamless migration from the physical to virtual networks. With the challenges resolved, mobile operators will be able to harness the full potential of network slicing in their mobile networks.

Keywords Network slicing · Standardization · Roaming · Interoperability · SDN · NFV

1 Introduction

Mobile communications have enjoyed a great success in recent decades, as demonstrated by the 7.5 billion connections worldwide in 2016 excluding cellular Machine-to-Machine (M2M) worldwide in 2016; this is almost 10 times the number of connections in 2000 according to GSMA intelligence. This, however, is not the end and mobile communications are expected to impact the society even further. 5G, the fifth generation of mobile networks, is expected to enable USD 12.3 trillion of global economic output, and the 5G value chain itself will generate USD 3.5 trillion in output and support 22 million jobs [1]. This projected economic growth is attributed to the potential applications of 5G, which will not be limited to broadband for consumers, but will extend to various industries such as automotive and smart metering.

In cost-effectively fulfilling the requirements of the new applications of 5G, network slicing technology is essential for the success of 5G. Network slicing is a technique that "enables the network elements and functions to be easily configured and reused in each network slice to meet a specific requirement" [2]. Each slice supports a specific requirement "with a specific way of handling the control and the user plane for this service" [3]. In short, network slicing creates virtual networks with "its own network architecture, engineering mechanism and network provisioning" [2] over a single physical network.

There have been many studies/whitepapers on network slicing including technical aspects (e.g., architecture and effective implementation) [4–6] and business aspects (e.g., use cases and cost implications) [7, 8]. However, the considerations of implications in the perspective of mobile network operators have been limited. In this context, this paper attempts to describe the major challenges for mobile network operators' adoption of network slicing including end-to-end (E2E) scope of network slicing, roaming, inter-

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operability and migration. It also provides future directions for academia and the mobile industry in studying network slicing.

This paper is structured as follows. This section provides an overview of the diverse 5G use cases and requirements to justify the necessity of network slicing. Section 2 describes the network slicing technology along with its constituents, Software Defined Networking (SDN) and Network Function Virtualization (NFV), and Sect. 3 illustrates the state-of-the-art landscape of network slicing standardization. Section 4 highlights the future challenges for mobile operators and Sect. 5 concludes the paper with future directions for the mobile community.

1.1 5G use cases and different requirements

5G is attracting global interest not because it is a future generation of network but because it would be able to cover use cases in addition to the traditional mobile broadband/communications. Namely, International Telecommunications Union—Radiocommunication Sector (ITU-R) has defined three major classes of use cases that 5G networks are to cover: enhanced mobile broadband (eMBB), massive machine type communications (MTC) and ultra-reliable low latency communications (URLLC). These use cases come with a variety of technical requirements [9].

The requirements become more complicated when one delves into each use case. For example, the requirements of MTC differ depending on the specific use case being considered. For instance, discrete automation requires very stringent E2E latency, whereas process automation is more relaxed on that particular requirement. Figure 1 shows differing requirements of selected MTC cases, as described in 3rd Generation Partnership Project (3GPP) Technical Specification (TS) 22.261 [10].

In light of the various requirements, it is essential that mobile operators have a method that is cost-effective and agile (i.e., fast time-to-market) to address the variety of requirements. Otherwise, mobile operators would have to deploy several networks to meet the needs of various customers including consumers using broadband and local factories that require mission-critical communications. Network slicing is a prospective candidate for addressing this challenge, as it allows a single physical network to create many virtual networks that are optimized for different use cases. The potential of network slicing is also prevalent in 3GPP's standardization activities, where network slicing is a vital feature of 5GC (5G Core). Network slicing is no longer a choice but rather an indispensable component to fully exploit the potential of 5G networks.

2 Technical overview of network slicing

Network slicing is a technique that creates network slices, where a network slice "supports the communication service of a particular connection type with a specific way of handling the control and user plane for this service." [3]. Network slicing is not a single technology, but rather a collection of innovative technologies, including cloud technologies. SDN and NFV, along with cloud technologies, are necessary to enable network slicing [2]. This section provides an overview of SDN, NFV and the resulting network slicing architecture for mobile networks as studied by 5G Infrastructure Public Private Partnership (5GPPP).

2.1 Software Defined Networking

SDN, in essence, separates the network control functions (control plane) the from network forwarding functions (data plane) [11, 12]. That is, whereas traditional switches contain both functions for decisions on forwarding data and data forwarding, SDN allows the separation of these two functions such that the network control can be *logically centralized* in a central controller and the data forwarding hardware can be simplified [12]. With this separation, SDN is able to provide five major benefits [11]. First, SDN delivers directly programmable network control, where administrators can easily program networks via programmable interfaces. Second, SDN is agile and responsive, where network can dynamically adjust to fluctuating demands in different places in the network. Additionally, as the network intelligence is logically centralized, the controllers maintain a coherent global view of the network and they appear to applications/policy engines as a single switch. Fourth, SDN provides a programmable configuration, where automated SDN programs can configure network resources. Lastly, SDN is standards-based and vendor-neutral, which streamlines the network design and operation. Figure 2 provides a high-level view of SDN technology, where the network operating systems are centralized for a global view and abstracted as a single switch for network applications to leverage. The network infrastructure consists of simple network forwarding devices and interacts with the network operating system via a southbound interface. The network applications interact with the network abstractions via a northbound interface [13].

2.2 Network Function Virtualization

In contrast to SDN, NFV abstracts the network functions (including the network forwarding and control functions) from the hardware [11]. That is, the functions of the traditionally dedicated network equipment (e.g., router, firewall and load balancers) can be provided as software functions running on virtual machines. NFV enables savings in both

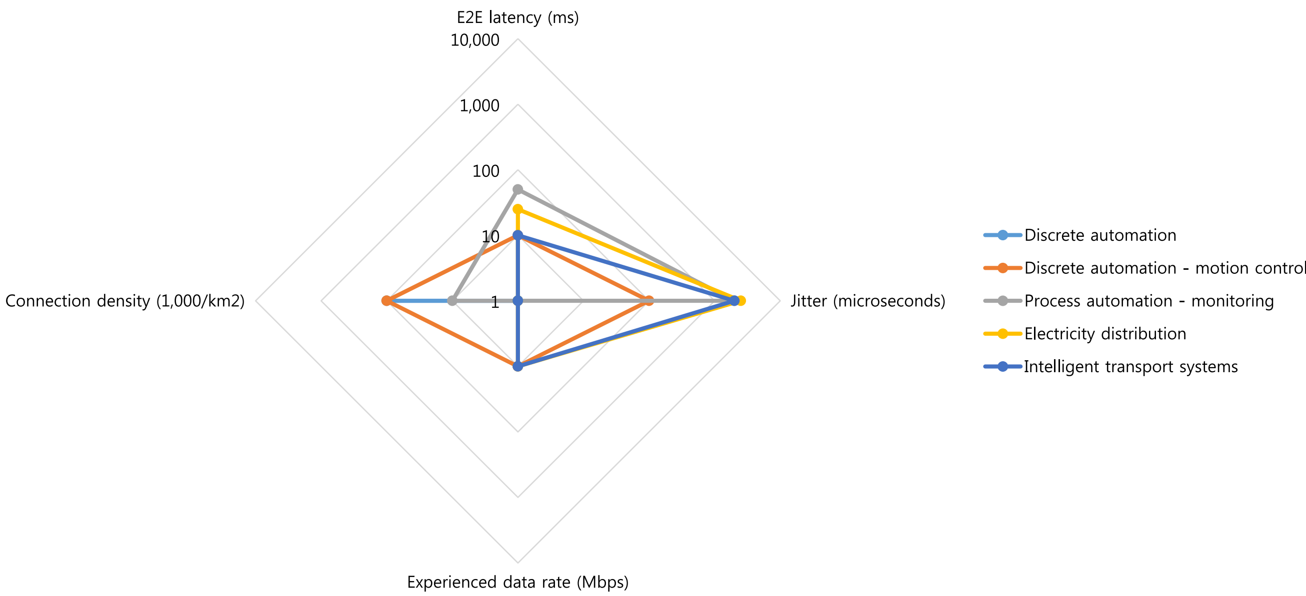


Fig. 1 Requirements of selected MTC cases (reconstructed from 3GPP TS 22.261) [10]

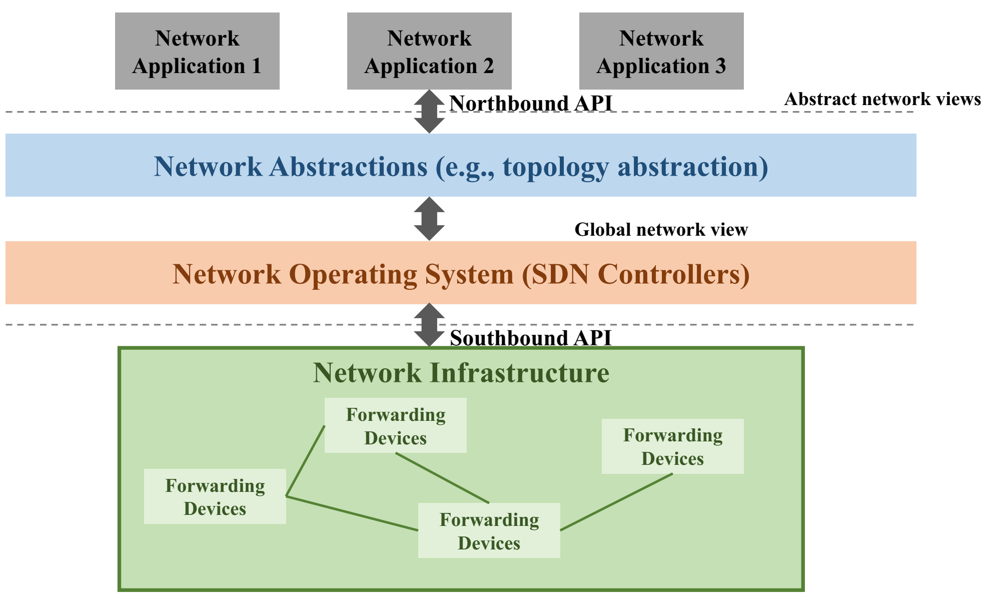


Fig. 2 High-level overview of SDN architecture (reconstructed from [13])

capital expenditures and operating expenses as dedicated hardware can run on standard commodity servers. Furthermore, there is no need to overprovision data or service centers as server capacity can be changed on demand through the software settings [11]. This is especially relevant for mobile networks, where there is a variety of proprietary hardware, which is expensive to operate on which it is challenging to launch new services [12]. Figure 3 illustrates a simplified high-level overview of NFV architecture as described in European Telecommunications Standards Institute (ETSI) Group Specification (GS) NFV 002 (along with some elaborations by other sources). Essentially, the hardware is virtualized and coupled with software capabilities to form NFV infrastructure (NFVI), over which virtual network functions (VNF) runs and provides specific network functions. Overall, the NFV Management and Orchestration entity (consisting of an orchestrator, VNF managers and virtualized infrastructure managers) coordinates the deployment, operation and management of both the VNFs and NFVI. These also interact with the Operations Support System (OSS) and Billing Support System (BSS) of the mobile operators.

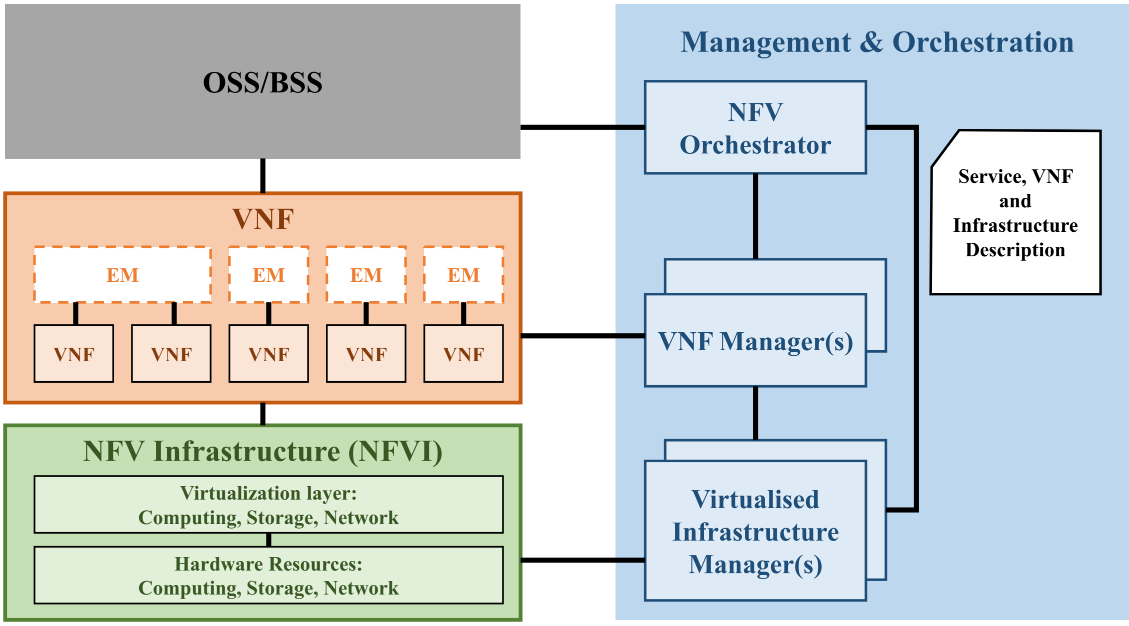
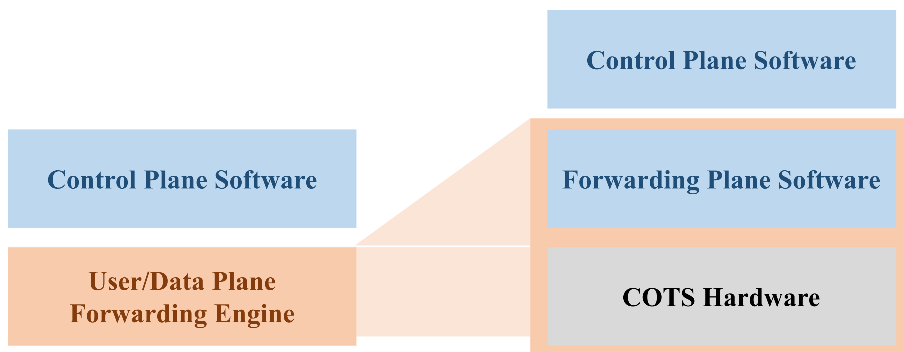


Fig. 3 High-level overview of NFV architecture (reconstructed from [12, 14, 15])

Fig. 4 Combination of SDN and NFV to provide programmable networks (reconstructed from [12])



2.3 SDN, NFV and network slicing

In essence, SDN provides "flexible forwarding and steering of traffic in a physical or virtual network environment" whereas NFV provides "flexible placement of virtualized network functions across the network and cloud" [12]. These two complement each other to create a truly programmable network. Figure 4 shows how SDN and NFV complement each other. By decoupling the software and the hardware, and then the control plane from the data plane, the network is able to leverage commercial off-the-shelf (COTS) hardware while benefiting from centralized control and simplified network nodes.

Applying SDN and NFV to the context of mobile networks enables network slicing. Indeed, the 5G core networks are designed with network slicing in mind and enable the separation of the control plane from the user plane (data forwarding) on top of the virtualized infrastructure. As the majority of user-plane traffic requires only very simple processing, it can run on low-cost hardware. However, separated control-plane entities require advanced processing. This enables cost-efficient scaling depending on the user plane demand, as the control-plane is independent from the user-plane [8]. 5G PPP provides an overall architecture for 5G mobile networks that utilizes network slicing [16]. In this architecture, networks slices are created at the network level to support each respective service, and the network slices are programmable with programmable control. A virtualized infrastructure underlies in the resources and functional level. The slices are end-to-end, where they span from the access networks to the core networks, and are managed and orchestrated by the "secure network and service management" and "end-to-end secure service orchestrator."

There are, of course, fundamental challenges that are introduced with SDN and NFV. First, whereas traditional mobile networks consist of physical equipment coupled with specific functionality, which makes deployment and operations modular, network slicing introduces layers of complexity. For example, mobile operators could deploy specific equipment in necessary locations (e.g., controllers of base stations in densely populated areas) according to demand, but it is more difficult conceptually to deploy and operate commodity hardware in different places let alone the instantiation/termination of the necessary software functions. Second, the softwarization of networks is from the Information Technology (IT) industry where there is a large concentrated server farm trying to process data efficiently. The Communications Technology (CT) industry, however, has a fundamentally different objective as its focus is more on the transport of the data than the processing of the data. Trying to fit the IT industry's software paradigm into the CT industry's mission-critical data transport paradigm (also known as five 9's: 99.999% reliability) is a difficult challenge in itself. It is no coincidence that numerous organizations endeavor to develop relevant technologies to realize network slicing as described in Sect. 3.

3 State-of-the-art of network slicing standardization

In telecommunications, network effects dominate and therefore systems have to be interoperable to fully leverage the potential of communications networks. In this context, the standardization of technology is crucial and it is necessary to analyze the state-of-the-art of network slicing standardization such that both mobile operators and vendors know where to provide input covering their interested domains. As network slicing involves innovations in networking technology, more organizations are involved in the standardization than the case of traditional cellular networks.

3.1 Organizations approaching network slicing from the business perspective

There are business industry alliances that unite the mobile industry. GSM Association (GSMA) is a trade association that represents the interests of mobile network operators, with approximately 800 mobile operators and a further 300 companies in the broader mobile ecosystem as members [17]. GSMA specifically facilitates interoperability and roaming among mobile operators by profiling standardized technologies and guiding business principles/relationships (e.g., charging principles and roaming agreements). In particular, the Network Slicing Templates Taskforce (NEST) under the GSMA Future Networks programme has been working on the business and high-level requirements of different 5G use cases (e.g., healthcare, Augmented Reality, Virtual Reality and smart energy) to facilitate the use of network slicing in the context of business relationships. GSMA, as an organization advocating interoperability, also calls for an interoperable approach in adopting network slicing. Next Generation Mobile Networks (NGMN) alliance is a mobile telecommunications association of mobile operators, vendors, manufacturers and research institutes, which ensures the successful commercial launch of future mobile broadband networks through a roadmap for technology and friendly user trials [18]. NGMN analyzes use cases of the next generation mobile networks and evaluates technologies for mobile networks from the use case perspective. NGMN is working on technology architectures (e.g., network slicing architecture) that can enable the use cases it identified for 5G.

3.2 Organizations focusing on implementation of network slicing constituents

There are also technological industry alliances that aim to provide technical solutions, beyond the scope of standard bodies, for the mobile industry. Telecom Infra Project (TIP) is an engineering-focused initiative driven by operators, suppliers, developers, integrators and startups to disaggregate the traditional network deployment approach. They have projects covering mobile access networks (open cellular rugged wireless access platforms for cost-effective deployment), backhaul networks and core networks (end-to-end network slicing and machine learning applied to networks) [19]. TIP focuses on making network infrastructure more affordable, and hence focuses on the implementation rather than on holistic architecture. TM Forum (TMF) is a global industry association that drives collaboration and collective problem-solving to maximize the business success of telecom operators and suppliers. TMF currently has Zero-touch Orchestration, Operations and Management (ZOOM) program that enables the implementation of hybrid management solutions and common architecture for describing end-to-end orchestration [20]. TMF also examines business models and scenarios of network slicing and hence is likely to lead to implementations that address near-term customer needs. Broadband Forum (BBF) is a forum focused on engineering smarter and faster broadband networks. BBF provides virtualization framework along with virtual gateways for business/residential purposes [21]. Finally, extensible Radio Access Network (xRAN) is an alliance to promote software-based radio access network and to standardize critical elements of the xRAN architecture. xRAN covers the overall architecture and fronthaul networks that are becoming even more relevant with the proliferation of small cells [22]. xRAN, similar to TIP, also attempts to make network infrastructure more accessible and cost-effective.

3.3 Traditional standard development organizations

Standard development organizations are essential to mobile communications technology. 3GPP unites seven telecommunications standard development organizations[1] and covers cellular network technologies including radio access, the core transport network and service capabilities [23]. 3GPP is the major player in mobile communications as they define the cellular network architecture and technologies. Within 3GPP, the sub-working groups of Service and System Aspects (SA), Radio Access Network (RAN) and Core Networks and Terminals (CT) are standardizing network slicing for mobile networks [24]. 3GPP, as the de-facto owner of the mobile communications network standard, will dictate how network slicing would be applied in mobile networks and how technologies of different organizations interact within the whole architecture. The Internet Engineering Task Force (IETF) is a large open international community of network designers, operators, vendors and researchers concerned with the evolution of the Internet architecture and the smooth operation of the Internet [25]. In network slicing, IETF focuses on the re-architecting of network functions, management frameworks for network slicing, as well as measurement and benchmarking of slices [26]. In network slicing, ETSI NFV plays a key role. ETSI NFV provides the basis of NFV architecture and provides relevant and related specifications. Since its inception in November 2012, the publications have moved from pre-standardization studies to detailed specifications with early Proof of Concept (PoC) efforts and interoperability events (Plugtests) [27]. ETSI's NFV architecture has provided a baseline for architectures conceived by other organizations (e.g., 5GPPP and NGMN).

3.4 Open source community

As network slicing utilizes open and vendor-neutral standards, open source organizations come into play, which is a key difference when compared to the traditional standardization landscape of mobile networks. Open Networking foundation (ONF) is an open source organization leveraging SDN principles and disaggregation, using open source platforms and defined standards to build operator networks. ONF focuses on applying SDN and NFV on transport networks (backhaul or backbone) by providing Central Office Rearchitected as a Datacenter (CORD) platforms [28]. Open Source MANO (OSM) delivers open source Management and Orchestration (MANO) stack aligned with ETSI NFV Information Models. It offers a production-quality open source MANO stack that meets the requirements of commercial NFV networks [29]. Open Platform for NFV (OPNFV) builds NFVI and VIM by integrating components from upstream projects such as OpenStack. OPNFV includes a portfolio of forwarding solutions as well as various functions and MANO [30]. OPNFV therefore covers MANO and core network functions. Open Network Automation Platform (ONAP) is a Linux Foundation project in collaboration with AT&T. It provides a comprehensive platform for real-time, policy-driven orchestration and automation of physical and virtual network functions [31]. ONAP is consequently focused on the core network functions and MANO. Finally, OpenStack is an open source organization that develops software and API for controlling and managing large pools of compute, storage and network resources throughout a datacenter. OpenStack is therefore focused on the datacenter-like environments of mobile networks.

3.5 Summary and holistic view

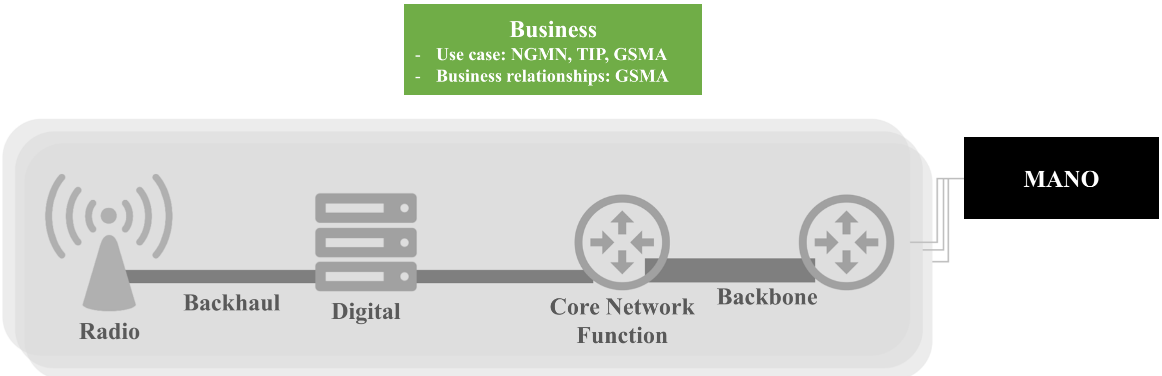
The description of the relevant organizations engaged in network slicing above is insufficient to identify the scope and the state-of-the-art of network slicing. Figure 5 shows the mapping of organizations on the architecture of mobile networks. In Fig. 5, we provide three different layers of scope for standardization: function (SW), function (HW) and implementation. The functions indicate the specifications, which describe the rules and the policies of SW/HW, whereas the implementation indicates the solutions developed by different communities (mostly open source organizations). We also divide the mobile networks into three large sections: radio access network (RAN), core and MANO. RAN is further decomposed into radio (the part that communicates with the device via a radio interface), digital (the part that processes communications) and backhaul (transport network). The core network is divided into core functions and backbone (transport network within the core network). In the business perspective, we observe that the business-side is covered by NGMN, GSMA and TIP where use cases are covered by NGMN, GSMA and TIP while business relationships (e.g., charging principles and roaming agreements) are covered by GSMA.

The number of organizations in the network slicing standardization landscape demonstrates the gravity of the challenge in realizing network slicing for mobile operators. Section 4 highlights four major challenges from the perspective of mobile operators that must be addressed before mobile operators can confidently adopt network slicing.

4 Future challenges for network slicing in the 5G era

The following subsections highlight the challenges in achieving end-to-end network slicing, roaming of network slices,

[1] Association of Radio Industries and Businesses (ARIB), Alliance of Telecommunications Industry Solutions (ATIS), China Communications Standards Association (CCSA), ETSI, Telecommunications Standards Development Society (TSDSI), Telecommunications Technology Association (TTA) and Telecommunication Technology Committee (TTC).



	Radio	Backhaul	Digital	CN Function	Backbone	MANO
Function (SW)	3GPP, xRAN	xRAN, BBF	3GPP, xRAN	3GPP, IETF, BBF	BBF	ETSI NFV, TMF
Function (HW)	TIP	TIP	TIP	ETSI NFV, OPNFV		ETSI NFV, OPNFV
Implementation	TIP	TIP, ONF	TIP	OpenStack, ONAP, OPNFV, TIP	OpenStack, ONF	OpenStack, ONAP, OPNFV, OSM, TMF

Fig. 5 Standardization organizations and their roles in mobile network slicing

interoperability of different network slices and migration from legacy physical networks to virtual networks.

4.1 Achieving the scope of end-to-end

Whereas network slicing utilizes advanced computing technologies to make networks programmable and agile, mobile networks are different from datacenters in two ways [12]. First, the data plane workloads are significant and thus put high pressure on performance. Second, mobile networks, unlike datacenters, require end-to-end interconnection which means that a global network view, not simply a view of the core network is required for management. The second point complicates the challenges, as end-to-end network slices includes RANs and core networks [5], where the radio interfaces in RANs are vulnerable to interference [6].

4.1.1 Slicing radio access network in interoperable and scalable manner

The end-to-end architecture, not only the RAN, must be prepared to handle uncertainties in the radio interface while guaranteeing service levels to customers as agreed through business contracts. Indeed, there are already solutions researched and developed by academia such as that of Eurecom, where radio resources are allocated to maximize the size of unallocated radio resources in a given time and frequency domain while satisfying as many slice requests as possible [32]. It also identifies an algorithm for the prioritization of network slices where slices are prioritized based on their granularities in radio resources and then sequentially based on the ability to generate the largest unallocated radio resources in a given time and frequency domain. Another example is Orion [4], the end-to-end slicing solution for the mobile network with a novel radio access network slicing system design. It introduces a base station hypervisor to an intermediate data plane of the physical base station and virtual control plane of the slices, where the virtual control plane is a logically separate process allocated per slice to tailor and manage the particular slice. The hypervisor enables the virtual control planes to manage physical radio resources by abstracting radio resources and managing each slice according to the service level agreed with the customer.

Whereas these solutions are effective and innovative, mobile networks require scalable and cost-effective solutions, especially in the context of densified 5G RANs. The existing solutions therefore need to be tested and developed further. For example, the algorithms and solutions must be extended to case of numerous mobile User Equipment (UEs) (given the massive connectivity requirement of 5G) and slices. Therefore, achieving end-to-end slicing for mobile networks is a very challenging task, the realization of which would require more consideration and studies.

4.2 Roaming of network slicing

Another major challenge for mobile operators is to support the roaming of network slices. Roaming is more relevant in the era of Internet of Things (IoT) as it harnesses the full potential of network slicing in enabling services involving mobile things (e.g., vehicles, asset management, tracking and enterprise communications for Multi-National Corporations). Indeed leading operators have conducted trials to test roaming in the environment of network slicing. SK Telecom (SKT) from Korea and Deutsche Telekom (DT) from Germany partnered to test roaming of network slicing in February 2017 [33]. SKT suggests that the currently adopted roaming scheme of home-routed traffic, where the traffic of roamers is routed back to the Packet Data Network (PDN) Gateway of the home mobile operator, may not be sufficient for mobile applications such as vehicles. In turn, they propose the concept of "federated network slicing" under which the traffic of roamers locally breaks out to the generated slice of the home operator created on the visited operator network to enhance performance [34]. DT outlines both the options of home routed traffic and locally broken out traffic, but still proposes to generate the home mobile operator's network slice on the physical network of the visited operator [7].

Although the proposals by both SKT and DT are valid and meaningful steps to achieving fully interconnected and "roamable" mobile networks, there is a scalability issue to be addressed. Whereas creating a slice of the home mobile operator on the physical network of the visited mobile operator is feasible in bilateral roaming agreements, it is simply not scalable if extended to the more than 800 worldwide mobile operators. The proposed solution would work in the initial stages of network slicing, but mobile operators should also have a long-term view and consider future solutions that would be scalable even when extended to the global mobile community.

One solution to this could be to have a standardized slice for set verticals. For example, there could be a standardized slice for telematics and another for vehicle infotainment. With standardized slices, there is no need to create a separate slice for each different home operator in the networks of the visited operator, but simply to connect to the standardized slice in the visited operator and let the slice in the visited operator interact with the home operator for subscription and charging operations. Indeed, this solution is feasible as 3GPP has a standardized slice type parameter (SST) to identify slices [24]. However, it is currently limited to enhanced Mobile Broadband, ultra reliable low latency communications and massive IoT. It is therefore necessary to identify the set verticals for which slices should be standardized, as well as the requirements for the identified verticals. The selection of verticals and the requirement identification are best addressed by business industry alliances such as GSMA and NGMN. Whereas NGMN has already studied the requirements of various potential verticals, GSMA seems to be more appropriate to address the selection and formulation of the verticals as NEST under the GSMA Future Networks programme has been tackling the task. In fact, GSMA NEST has recently identified the requirements of key 5G use cases and is working on the Generic Slicing Template (GST) that will serve as the baseline for the roaming of network slices. That is, these GSTs will be the minimum mandatory required slice types that most (if not all) mobile operators will need to support. Indeed, GSMA, as a roaming agreements exchange and a publisher of commercial profiles of standardized technologies to ensure interoperability, will be the appropriate venue for this discussion to take place. It should be emphasized that mobile operators will be able to create slices that are outside the scope of the standardized slices, but these proprietary slices will not ensure interoperability or roaming with other mobile operators.

4.3 Interoperability of network software functions and hardware

The advantages of a vendor neutral standards-based approach of network slicing are fully harnessed when the interoperability of network software functions and hardware are ensured. In fact, the clear definition of open interfaces between the network nodes specified by 3GPP enabled a multi-vendor environment that fostered innovation and competition in traditional mobile networks [15]. Mobile networks in the era of network slicing are no exception to this and interfaces among network software functions, hardware and different layers of network virtualization must be open and interoperable. 5G PPP also implies the importance of interoperability as various types of network slices will coexist in a mobile network that will reach from one layer to another [16].

GSMA identifies four motivations to ensure interoperability of virtual network functions and hardware: vertical integration, network service deployment, service assurance and software upgrade [15]. Vertical integration refers to issues in the integration of different technologies, interfaces and vendors into one single cloud platform. As the setting up of a large-scale commercial cloud platform for commercial mobile networks is a huge and complex integration project, interoperability is key to accelerate the time-to-market and to reduce cost. Network service deployment refers to the issues in employing multiple components from different vendors. The interoperability enabled by the standardized format of different components is essential to maintaining a multi-vendor environment. Service assurance refers to assuring service quality (e.g., self-healing mechanism or alarm trigger) in case of failures. If interoperability is not ensured, the failure information necessary to trigger the alarm or self-healing mechanism may not be propagated quickly. Finally, software upgrade refers to the issues that may arise from changes in software component affecting other layers. Interoperability is essential in resolving challenges in vertically testing the impact of software upgrade.

4.4 Migration from physical network to virtual network

Most of the arguments or descriptions of network slicing assume that mobile networks will be fully virtualized. However, mobile networks are currently mostly physical and considerations of migrating from physical networks to fully virtualized network are necessary for mobile operators. Furthermore, a stable migration that maintains the reliability and performance of the mobile network is indispensable for commercial mobile networks.

In migrating a commercial traditional mobile network to a fully virtualized network, the technical community must take into account more diverse and numerous stakeholders in the network slicing technology/standardization landscape. This means that it is more difficult to coordinate different solutions from different stakeholders. Interoperability among different layers of network slicing could address this challenge, but it will also be difficult to achieve given the diversity of potential available solutions. Furthermore, mobile operators will have to integrate solutions from different layers (network function, infrastructure and operations and management) when moving to virtualized network. Before, the network entities were mostly physically separate and thus there would be less complexity with respect to specializing in specific functions and integrating the equipment. With virtualized networks, the mobile operators will need to take into consideration a multitude of combinations and careful decomposition of network knowledge/task. Finally, the mobile operators will have choice of migrating different layers (network function, infrastructure and operations & management) in parallel or in different sequential order. Whereas the order may not appear to matter on the surface, real experiences recommend migrating the infrastructure layer first and then the other two. This is because the migration of the infrastructure layer allows shared resources/knowledge of the network whereas migration of the network functions (e.g., virtualized evolved packet core) leads to isolation of resource/knowledge before the infrastructure migration is complete.

4.5 Developing innovative features not addressed in traditional networks

In addition to the technical challenges, the adoption of network slicing will also depend on the techno-business aspects of network slicing. The lessons of Internet Protocol (IP) communications over IP Multimedia Subsystem (IMS) provide important implications for the technical community. As of May 2018, 661 operators had launched LTE networks whereas only 138 operators had adopted Voice over LTE (VoLTE) service [35]. Although VoLTE allows operators to provide voice communications services at higher quality and establish a basis for converging other on-top services with voice communications, the operators were slow in adopting VoLTE (along with IMS) because they already had a working solution for voice communications on CS (circuit-switched) networks. Furthermore, VoLTE would not guarantee increase in revenue. This indicates that having a better performing technology is not enough to guarantee adoption by the mobile networks.

Therefore, for network slicing to be quickly adopted by the mobile operators, features beyond those of today's mobile networks need to be addressed and supported by network slicing. The features should also ensure that it generates additional revenue and/or requires incremental cost to implement. In this context, it is essential to monitor the activities of GSMA. GSMA is evaluating different business models and opportunities that network slicing (along with new technologies of 5G) could enable for mobile operators. This activity may provide a hint in identifying the innovative features that network slicing should address. Furthermore, network slicing enables agile adoption of new functions/features that could suit the needs of different verticals. GSMA NEST's analysis of vertical requirements and prioritization of the verticals would provide valuable insight to the technical community in identifying verticals on which to target relevant research and development efforts.

5 Conclusion

Network slicing is indispensable in enabling a diverse set of 5G use cases and requirements over a single physical mobile network. However, as network slicing utilizes innovative networking technologies such as NFV and SDN, the complexity of the mobile network increases and mobile operators are faced with greater challenges. This is prevalent in the complex standardization landscapes of network slicing. This paper identified the major challenges in network slicing from the perspective of mobile operators, including the difficulties in achieving end-to-end network slices, roaming of network slices, interoperability, and stable migration.

The challenges imply the following future research topics for academia and focus of investigation for the industry. Regarding achieving end-to-end network slices, the virtualization of RANs seems to be the bottleneck. Therefore, future efforts should focus on designing new virtualization mechanisms to achieve the sharing of wireless spectrum resources and virtualization of base stations [6], as well as the cooperation of multiple radio access technologies for seamless mobility and high transmission throughput [5]. Additionally, work should be done to investigate whether multiple access technologies could be multiplexed over the same hardware [36], and to ensure radio resource isolation for different slices by adapting software defined controllers in RANs [37]. We believe that academia is headed in the right direction with development of relevant solutions, such as those of Eurecom [32] and Orion [4]. However, the solutions would need to be developed further to handle massive connection of UEs to numerous slices while ensuring the interoperability of the different implemented network slicing solutions. If interoperability is not addressed, a UE would be able to benefit from network slicing only in the networks that support the particular solution. If scalability is not addressed, the solution would be adopted for mobile networks only in trial or pre-commercial phases.

In terms of roaming of network slicing, we identified that there is a need for standardized slices for different set verticals to ensure the scalability of roaming. Note that the operators and the providers are not restricted to these slices for their services but only standardized slices will ensure interoperability and smooth roaming. Whereas most of the effort would come from the industry in alliances such as GSMA, academia should also study the requirements of different set verticals to optimize the standardized slice to the vertical concerned. Furthermore, academia is encouraged to monitor the progress of GSMA NEST on GSTs to ensure that its studies are aligned with the global mobile industry.

To ensure interoperability of different layers of network slicing including network software functions and hardware, both the industry and academia must consider the gaps or inconsistencies among different open source technologies and/or standardized protocols and interfaces. The gaps/inconsistencies must then be addressed with objective analysis and experimental results to create a globally interoperable network slicing standard.[2]

For migration, future studies should focus on ensuring interoperability among the diverse stakeholders present in the virtual network technology/standardization landscape. Furthermore, academia should also study the optimized organizational structure within a mobile operator to absorb knowledge of the virtualized network and to operate it with carrier-grade performance.

Finally, network slicing must come with features that are not addressed by traditional mobile networks to drive adoption. Learning from the relatively slow adoption of IP communications compared with that of 4G LTE networks, network slicing should not only address existing service features in a more efficient manner, but also address new value propositions and business models for mobile operators to adopt it. While it is still early to identify the new features, academia and the industry should pay attention to GSMA activity that attempts to identify the opportunities enabled by network slicing, which will provide insight for developers in determining the innovative features to be developed. Furthermore, the innovative features may also be targeted at specific verticals, and the identification of the prospective verticals may be assisted by GSMA NEST's analysis and prioritization of different verticals.

We believe that if the challenges mentioned above are resolved, network slicing would be more easily applicable to the context of mobile networks and would therefore enable mobile operators to fully harness the 5G use cases and requirements. This would not only impact the mobile industry, but also impact the global society in general by ushering in innovations and enhancing the efficiencies of traditional vertical industries.

Introduction and definition of organizations in this paper have been directly quoted from respective organizations without quotation marks.

Compliance with ethical standards

Conflict of interest On behalf of all authors, the corresponding author declares that there is no conflict of interest.

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[2] This paragraph is based on the works of GSMA [15].

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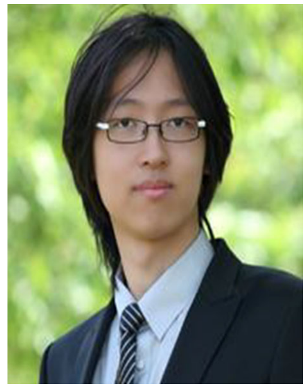

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