Dynamic Network Slicing: Challenges and Opportunities

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Abstract. Network Slicing (NS) is an evolving area of research, performing a logical arrangement of resources to operate as individual networks, hence allowing for massively customizable service and tenant requirements. NS, via the respective network architecture can enable an effective deployment of 5G networks and support a great variety of emerging use cases and/or related services. In this scope and with the aim of extending all potential network and service benefits, the concept of dynamic NS becomes a prominent feature of 5G allowing for connectivity and data processing tailored to specific customers' requirements. We discuss several essential features and fundamental designing principles that can affect the realization of a reliable dynamic NS, capable of serving an immense multiplicity of 5G-based innovations, towards structuring a fully mobile and inclusive society. Furthermore, due to its context, dynamic NS can support digital transformation and mobilization of industry vertical customers, implicating for significant commercial potential. To this aim, we also discuss related perspectives for market growth coming from proposed business models, together with regulatory concerns that could affect future growth of dynamic NS.

Keywords: 5G · Dynamic network slicing · Network functions virtualisation (NFV) · Network slicing (NS) · Orchestration · Programmability · Software-Defined Networking (SDN) · Virtual network function (VNF)

1 Introduction

Network Slicing (NS) refers to partitioning of one physical network into multiple virtual networks, each architected and optimized for a specific application/service [1, 2]. Specifically speaking, a network slice is a virtual network that is created on top of a

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physical network in such a way that it gives the illusion to the slice tenant of operating its own dedicated physical network. Consequently, a network slice can be assessed as a self-contained network with its own virtual resources, topology, traffic flow and provisioning rules [3]. Each slice may have its own network architecture and protocols. The related customizable network capabilities can include data speed, quality, latency, reliability, security and services. These capabilities are always provided based on a relevant Service Level Agreement (SLA) between the involved network operator and the business customer.

In its simplest description, NS is the capability to modify a set of functions to improve use of the network for each involved device. All of the functionality needed is accumulated so that to optimize a devices' ability to find the correct underlying network and access it in an efficient and secure manner and then to be attached to the respective core network with the appropriate set of functionality, as needed by that specific device. From a business perspective, a slice can include a combination of all the relevant network resources, functions and other assets required to fulfil a specific business case or a dedicated service, including OSS (Operations Support Systems), BSS (Business Support Systems) and DevOps processes. There may be various network slices to "meet" the detailed communication needs of diverse users in future network systems: for example, a massive industrial IoT slice may need a light 5G core network, no handover but a large number of connections; on the other hand, a mobile broadband slice may need a high capacity core, full feature of mobility and low latency. Slices are logically isolated, but involved resources can be shared among them [4]. NS allows core networks to be logically separated, with each slice providing customized connectivity and all slices running on the same, shared infrastructure or on separate infrastructures as the operator desires, following to related market needs. This is a much more flexible solution than a single physical network providing a maximum level of connectivity.

In any case, a network slice comprises of dedicated and/or shared resources (e.g. in terms of processing power, storage, and bandwidth) and has isolation from the other network slices. In this context, NS is an innovative technology permitting multiple logical networks to be created on the top of a common shared physical infrastructure. The "key" benefits [5] can include, *among others*: (i) Greater elasticity, robustness, secure and stable operations and functionalities through the compartmentalization of the network, applied end-to-end (E2E); (ii) uncompromising and customizable slices, each optimized for the needs of the services -or segment- cluster they are defined to serve, and; (iii) built-in flexibility and efficiency with Artificial Intelligence-powered automated service orchestration, from test to launch to the maintenance of new services.

In the scope of the efforts towards achieving the much promising 5G potential [6], NS explicitly responds to any request about how to perform both increased efficiencies and revenues, through differentiation and faster time-to-market [7]. 5G NS includes slicing 5G radio access network (RAN), 5G core network and even end-user devices. Based on recent technological trends coming from the 5G growth [8], it appears that networks will need to be deployed using different hardware technologies, with different feature sets placed at different physical locations in the network, depending on the use case [9]. To support a specific set of services efficiently, a network slice should have access to different types of resources, such as infrastructure -including virtual private networks (VPNs), cloud services and access- as well as resources for the core network in the form of virtual network functions (VNFs). The flexibility of 5G core networks will improve significantly by supporting a full separation of control plane and user plane, and through adopting selected SDN (Software-Defined Networking) principles and technologies.

NS will allow 5G networks to be sliced logically into multiple virtual networks [10]. Each slice can be optimized to serve a specific vertical application to efficiently support network services, thus providing high degree of flexibility in enabling several use cases to be active concurrently. This is already a well understood methodology in the wireless industry in some limited environments, such as software-defined core networks [11]. In this scope, NS is a fundamental feature of 5G networks and can offer significant advantages when compared to the traditional networks, such as: (i) It can provide logical networks with better and more enhanced performance; (ii) a network slice can scale up or down, depending on the service requirements and the number of involved users, as both they may vary in time; (iii) network slices can separate the network resources of one specific service from the others; in this scope the configurations between various slices do not affect each other, implicating that both reliability and security of each separate slice can be improved, and; (iv) a slice is tailored to dedicated service requirements, which can optimize the allocation and the respective use of involved physical network resources. The NGMN alliance proposed a three layer model [12]; 3GPP defined the required network functions for NS selection and management and so proposed three network slice types [13, 28].

The NS concept is currently a topic of numerous research projects, mostly linked with 5G. The projects have provided some progress, but there is no integrated NS approach that combines the research efforts into a single, coherent concept. Moreover, many details of the proposed approaches still have to be developed. So far, there is no standardized approach to NS that addresses the typical carrier-grade requirements as interoperability, scalability, controllable performance, security, accounting and more. The above implicate for the challenging character of introducing dynamic network slicing, within a fully competitive and fast growing environment.

2 Trends Towards Defining Dynamic Network Slicing

As noted by the NGMN 5G White Paper [14], the success of the forthcoming 5G technology will depend on the ability of the involved operators/market actors to provide multiple solutions for all implied requirements and the ability to provide all participating stakeholders with a unique (set of) solution(s) tailored to everyone's specific needs, under a dynamic consideration. Nevertheless, existing network architectures are not entirely up to this challenge. The current approach, usually assessed as the "one-size-fits-all", cannot be effective to wireless networks for all potential use cases and/or services related to any sort of device/equipment everywhere. Especially, this does not offer the level of adaptability needed to "meet" the performance expectations for new and legacy use cases, services, business models, infrastructure usage approaches and radio access needs that will emerge with 5G growth and penetration. Driven by the new business paradigms such as 5G verticals, the future 5G network should support very heterogeneous services on the same infrastructure.

Furthermore, among the core challenges for 5G network operators is about allocating existing network resources in a way to maximize their advantages. NS provides a network as-a-Service (NaaS) model, which can be very flexible to allocate and reallocate resources according to the dynamic demands such that it can customize network slices for diverse and complex 5G communication scenarios. Within this framework, the life-cycle management of the network slices becomes a critical problem to be taken into account and solved, accordingly. Aiming to support the maximum possible number of diversified service requests, 5G network operators have to deploy VNFs [15] and allocate network resources quickly so that to be able to "structure" related network slices [16]. Moreover, they need to scale slices dynamically [17], according to the varying service load of the underlying infrastructure(s). In contrast, although a network operator has the maximum control over his own network slices, it is essential that one slice may still need to perform some sort of control over itself, so that to improve the corresponding service quality. Therefore, the intended dynamic NS technique has to consider how to "open" partial permissions to each slice to configure and manage it, without rising unnecessary -or complex- security issues [18]. In addition, management of network slice has to take place automatically, to avoid manual efforts and respective errors. To this aim, it can be expected that dynamic NS deployment will benefit from network automation. The automation in rolling network slices will be subject to normal learning curve that new technologies are commonly experiencing, thus it can be expected that the degree of automation of deployment of a network slice will further evolve.

On the other hand, the perspective of 5G dynamic network slicing can be assessed as a suitable "means" to guarantee that intended E2E performance fulfils specific customer prospects together with requirements implied by the services that are to be offered (within several platforms and/or infrastructures and also involving a diversity of related equipment/devices and tools, in a fully converged context). With the aim of properly maximising the efficiency of NS, all individual network segments (such as core, transport, metro, radio access, edge cloud and central cloud) have to be examined "overall", although these are usually treated separately. Simultaneously, performance optimization has to be coordinated and assessed through the entire network; thus, the intended slicing actions can be relevant to a multiplicity of industrial use cases with several instances on one physical network and this offers both reliability and viability in market terms.

Any consistent effort for the realization of an efficient 5G dynamic network slicing process has either to incorporate or to consider several essential features, such as those listed as follows [19]. These could implicate, *inter-alia*, for: (i) Coverage of requests as these are implied by actual business models, tailored to satisfy industrial needs and, preferably, within a broader context for multi-tenancy support [20]; network multi-tenancy aims to reduce capital and operational costs by allowing infrastructure providers to make the best use of available resources, including spectrum and infrastructure; hence, multiple tenants may share resources within the mobile network while offering diverse services; (ii) substantial reduction of new service creation and activation times, so that to enhance network efficiency; (iii) inclusion of an adequate level of network agility, so that to fulfil various service-specific needs; (iv) provision of a (substantial) elasticity to the underlying network infrastructure, thus making it capable to respond to traffic demands that may vary dynamically; (v) consideration of a framework to adapt services and networks in a predictive way and in real time; (vi) structuring of a reliable operating environment for the promotion of open and innovative services with the participation of several market actors from various sectors, to satisfy specific user or industry demands; (vii) care for extension of the intended network and service activities to enterprises and industry verticals as well as to application and content providers; (viii) inclusion of programmability features [21], so that to support easy and fast integration of new network capabilities, extension of existing ones and creation of new services and/or business models; (ix) incorporation of management and orchestration techniques and of related capabilities allowing for dynamic network (re-)configuration to support E2E performance purposes, and; (x) support a high level of automation, powered by advances in analytics and machine learning [22].

The fundamental aim proposed by the innovative context of the dynamic network slicing is to "extend", *further*, the capabilities of 5G networks so that for the latter to become able to effectively "address" a variety of related use cases and possible applications [23] covering actual 5G trends. This permits market telecom operators to design, deploy, customize and optimize the various network slices that are running on the commonly assessed network infrastructure. In addition, beyond its conceptual dependence upon the well-known SDN and NFV features [24–26], the dynamic network slicing also depends on E2E orchestration and analytics. However, although the 5G NS process brings flexibility, it also "increases" the complexity of network management [27]. Thus, there is a need to design automated management schemes, implicating that a proper lifecycle network management is responsible for slice creation, reconfiguration, deletion, etc., but it also involves orchestrating and allocating of infrastructure resources. Vendors usually take into account the term of dynamic network slicing because operators will be able to deliver these network slices quickly and on demand, to any applicant; as a consequence, operators can rapidly start deployments, architecture types and performance thresholds for distinct use cases or service groups, responding to market needs. The dynamic network slicing concept practically extends the slicing vision (as proposed in [28]) and satisfactorily covers diverse requirements, as identified above. The "outcome" is that dynamic network slicing partitions a common network infrastructure into multiple, logical, E2E, virtual network instances -or slices- with several key characteristics summarized as follows:

- *The related slices support a group of services, use-cases and business models with associated requirements:* For example, an operator can "run" enhanced broadband slices to offer a variety of broadband services to its customers, which may include web browsing, audio and video streaming and chat.
- *The slices are built with only relevant network capabilities that do "match" the needs of the corresponding supported service, use case or business case*: For example, an ultra-low latency capability can be created for a slice supporting ultra-low latency use cases. The capabilities in the slice are not restricted to the user plane. The slices can also control and manage plane-relevant capabilities, such as a dynamic video stream controller or a specific type of billing application relevant to the business case.

- *The slices are dynamic in runtime*: They comprise an automation framework that uses real-time analytics and monitoring for efficient use of network, cloud resources and optimization for the dynamic needs of services or traffic demands.

3 Dynamic E2E Network Slicing as Enabler for 5G Promotion

5G is an E2E ecosystem allowing the structuring of a fully mobile and connected society. It empowers value creation towards customers and partners, via current and emergent use cases, delivered with reliable experience and enabled by sustainable business models. The 5G networks need to incorporate various services with dissimilar performance requirements (such as high throughput, low latency, high reliability, high mobility and high security) into a single physical network infrastructure and also to provide each service with a customized logical network (via NS). One among the fundamental concerns for future 5G network operators is about how to allocate network resource in a way to maximize their benefits and, *in this perspective*, the life-cycle management of the network slices becomes a critical issue to deal with. In order to accommodate the maximum number of diversified service requests, 5G network operators need to deploy suitable VNFs and allocate network resources rapidly so that to build *ad-hoc* network slices [26]. Moreover, they need to scale slices dynamically, according to the varying service load, *per case*. On the other hand, although a network operator has the maximum control over his network slices, one slice may still need to exercise some “control” over itself for improving the service quality; therefore, the NS technique should consider how to “open” partial permissions to each slice to configure and manage it, without raising any security issues. In all such actions, the intended management of network slice need to be implemented in an automated fashion for the avoidance of manual efforts and errors.

The response to this challenge can be a dynamic E2E network slicing, thus providing an optimal approach to NS in 5G networks [29]. This allows operators to support the miscellaneous and occasionally demanding requirements for latency, throughput and availability that are essential for the delivery of 5G services to a wide variety of “recipients” such as users, machines, industries and other entities [30, 31]. The dynamic network slicing concept will be beneficial in the 5G framework, especially by allowing dynamic E2E network partitioning at all network levels (i.e.: from the Radio Access Network (RAN) to the transport network and to the core network). This offers to the 5G operators the possibility to promote appropriate deployments and architectures for each separate business model, thus enabling the appearance of new use cases, and occasionally for dedicated service group(s). Furthermore, the operators can “run” and deploy existing network implementations in parallel and simultaneously upon a common network infrastructure, which promotes new communications possibilities. Monetizing the quality of experience (QoE) is another area where operators can benefit from dynamic network slicing [32]. In 5G it is possible to define a QoS based on each application’s unique requirements, as an involved network operator may create different slices for different participating Mobile (Virtual) Network Operators (MNOs/MVNOs) and each respective slice may have different QoE values [33].

Following to the above and in order to "address" a variety of miscellaneous requirements, modern 5G network architectures have to "shift" from the current network of entities to a sort of network of capabilities, implicating a way of "transition" from a network for connectivity to a network for services model [34]. Dynamic network slicing offers an effective way to enable this "shifting" and the partition of a single common 5G infrastructure into multiple logical E2E networks. This provides the service agility needed to deal with a diversity of factors including, *inter-alia*: (i) "Users" (i.e.: both people and machines or other type(s) of equipment); (ii) corresponding use cases that support new services and devices, connect new industries and empower new user experiences [35], and; (iii) related requirements for latency throughput and availability. The dynamic network slicing allows network operators to: perform various deployments; implement specific architectural features and; achieve a considerable variety of performance for different use cases of practical interest [36]. This approach permits for simultaneous network implementations that can take place in parallel and it is strongly affected by several "key principles" [5], implicating for the consideration of:

A distributed cloud infrastructure including virtualization features: Virtualization allows for (mobile) networks to be less "tied" to physical resources and, *therefore*, to be more customizable in their design and users. Thus, *whenever possible*, there is a trends for the 5G network functions and/or capabilities to be developed upon distributed cloud and virtualization infrastructures. Furthermore, dedicated and purpose-built network entities are only used when necessary [37].

A network of capabilities instead of network of entities: In this scope, the 5G network slices are made of modular network capabilities. Related Network Capability Units (NCUs) are the "abstractions" of these network capabilities and can have varying degrees of granularity, although usually expected to be modular for easy "plug-and-play" deployment and operation.

A network for services in place of a network for connectivity: The 5G network slices are designed with the aim of offering and supporting diverse classes of services. Consequently, the 5G network slices can have unique capabilities required for supporting dedicated group(s) of services but also for individual services.

Easy and effective design and dynamic creation of E2E slices: Dynamic 5G network slices need to be easily designed by packaging the related and necessary NCUs. Network slices need to be created dynamically by using proven orchestration and management technologies [28]. Moreover, customization through a virtual network allows for the exact definition of the network slice to no longer be pre-defined. This means that anything could actually be provided "as-a-service", since the combination of resources is not restricted. This further "opens up" the market to a broader range of usage cases [38].

Inclusion of dynamic programmability and control: The 5G network slices have to support dynamic programmability and control by leveraging SDN principles [39], thus allowing for the inclusion of a multiplicity of benefits for their operation.

Automation of the network operation and optimization: Although beneficial, the creation of network slices practically increases both the complexity of network operations and also of the ongoing optimization efforts. To overpass this "obstacle", dynamic network slices have to enable automation of operations and optimizations via several means such as analytics, machine learning, big-data, etc. [22].

End-to-end perspective and approach: The 5G network slices are composed of capabilities from multiple network segments that span the network from access to core, as well as network applications. This E2E perspective is needed to satisfactorily meet the needs of diverse services, use cases, and business models.

4 Market and Regulatory Challenges

In the 5G era, different industry verticals are looking for leveraging the influence of modern technologies to boost productivity across paths of the economy [7]. NS builds upon this expectation and, *together with the promise of Massive IoT and ultra-reliable/low latency services*, it can support digital transformation and mobilization of industry vertical customers. Providing "tailored" services to business customers has significant commercial potential; thus, NS does "drive" the business models behind 5G ecosystem [18] by providing an effective way to delivery heterogeneous services of interest for different verticals [40]. In the literature there are three different of business models for NS, that is: B2B, B2C and B2B2C [41, 42]. In the B2B model, operators sell customized network resources to enterprises and release full control of end-consumers to enterprises. In the B2C model, customers purchase customized network resource based on their requirements without considering which operator provides the requested resources. In the B2B2C model, operators just provide customized network resources to a broker, and the broker gets more control of the network and engages with the end-consumer directly. All previously mentioned business models deal with the allocation of network resources and, *consequently*, the effective revenue as well as the network performance directly depend on the way the operator manages such resources [43]. Following to the above, it is expected that dynamic network slicing will further support market growth and related investments [44]. A probable "go-to-market" strategy may implicate for three distinct stages, able to deliver value across the value chain [45]. These stages may happen in parallel, depending on local market conditions. These are briefly summarised as follows:

- *Deployment of NS for internal use*: This will prove the NS validity by using the solution to serve internal customers within an operator. This option offers a low risk opportunity to experiment and to validate the proposition, in order to refine it ahead of rollout to commercial customers.
- *Upsell NS capabilities to existing enterprise customers*: This will prove value to existing enterprise customers and based on the typical buying behaviour of such

customers, upselling network slicing capabilities needs to be an easier opportunity than targeting new customers. These customers can then become proof points and advocates for the new capabilities.

- *Sell to new enterprise customers*: When commercially ready, slicing will be made more broadly available to enterprise customers who often require a proven solution and seek market validation, before they buy.

NS will be an essential attribute of 5G, based upon SDN and NFV [41]. Assessing the importance of NS for future 5G networks implicates that regulation shall be around several fundamental domains/areas as briefly discussed in the following sections. It is important to mention that regulators need to assess practically whether -or not- NS is able to affect customers regarding their common actions and/or their market-related behaviour(s). In the scope of the present work, we only identify several regulatory issues that could be affected to a certain extent by dynamic NS growth and, by turn, they could able to influence further development. These are described as follows.

Security and privacy policy requirements: The notion of sharing resources among slices may create security problems in 5G NS [18]. This is so because network slices that serve different types of services -for different verticals- may have different levels of security and privacy policy requirements [46]. This calls for the new development of 5G (dynamic) NS security and privacy protocols that consider the impact on other slices and the entire network systems, while allocating resources to a particular slice(s). Also, security issues become even more complicated when 5G NS is implemented in multi-domain infrastructures. To address this issue, security policy and efficient coordination mechanisms among different administrative domains infrastructure in 5G systems need to be designed and developed [47].

Net neutrality: While there is no single definition of “net neutrality”, the term is frequently used to denote issues related to the optimization of traffic over underlying networks. In particular, due to current market needs, involved network operators have to act so that to offer fast and reliable Internet access to their customers, by taking into account any actual shared use of network resources as well as the limited availability of spectrum. Dynamic NS can be a “tool” to deliver suitable choices and to satisfy customers’ needs via managing corresponding traffic patterns and by offering flexibility for differentiation between them. The core objective is to guarantee that consumers shall have the possibility to choose the best offered solution to meet their own needs. Here, the large concern is the way that prioritization and differentiation of network slices might account to discrimination under the net neutrality laws, causing a fear that the development of the technology might be hindered by the lack of regulatory clarity [48]. The intent of the laws are both clear and desirable.

Quality of Service (QoS): The quality of a mobile data services is delineated by several parameters, including but not limited to speed, packet loss, delay and jitter [49]. QoS is also affected by signal strength, network load and user device and application design; however OoS is also influenced by several extra factors that can be beyond the control of operators (such as the type of the devices, the application and propagation environment). In the 5G scope, continually changing traffic patterns and congestions may have a critical result upon the whole performance. The QoS differentiation that is at the heart of the dynamic NS value proposition, what the EU regulation [50] calls as "traffic management". This respective regulation allows for differentiation to take place on the Internet, in a limited capacity. Applied to NS, we can mention that different use cases like virtual reality (VR) video content, smart grid solutions and automated cars fit into having "objectively different" QoS demands, and thus discrimination between them would be within the framework of the regulation.

Cross-border data transfers: The worldwide digital economy is also influenced by the cross-border data transfers aiming to provide important (form both social and economic point of view) benefits to all potential categories of end-users (individuals, businesses and governments). When data is allowed to flow freely across national borders, this permits the involved legal entities operate, innovate, access solutions and offer global support. Policies constraining free flow of data through unjustified restrictions or local data storage requirements can have an adverse impact on all involved market players and the economy. Cross-border transfers of personal data are now regulated by a number of international, regional and national instruments and laws intended to protect individuals' privacy, the local economy or national security. It is foreseen that network slices may be utilised to offer services outside of the home jurisdiction, potentially in a similar manner to international roaming. If so, any transfer of data across borders may need to consider regulatory requirements.

Illegal content: In our current market framework, mobile networks not only offer traditional services but can also deliver virtual access to all forms of digital content via the Internet. Thus, mobile network operators can be assessed as the "equivalent" of other Internet Service Providers (ISPs). However, this also implicates that the involved mobile networks can also be occasionally used to access various forms of illegal content. The respective legal framework affecting this domain demonstrates a significant degree of variation at the global level. Mobile network operators are warned for transfer of or access to illegal content by the national hotline organisations or law-enforcement agencies. When content is reported, the operators follow procedures according to the relevant data protection, privacy and disclosure legislation. The related issues and/or and commitments have to be addressed with the introduction of NS and can vary depending on the implementation of slices.

5 Conclusion

Network slicing is an emerging area of research, featuring a logical arrangement of resources to operate as individual networks, thus allowing for massively customizable services and tenant requirements. NS offers an effective way to support different use cases with diverse requirements and exploits the benefits of a common network infrastructure. It enables operators to establish different deployments, architectural flavors and performance levels for each use case -or service group- and it can "run" all network implementations, occasionally in parallel. Due to its innovative features and to the multiplicity of the beneficial impacts, the NS has been identified as among the fundamental "building blocks" of 5G towards the successful adoption of respective modern infrastructures and for the offering of related services/facilities.

However, as the success of the upcoming 5G technology and its market inclusion is strongly dependent on the capability of the involved market actors/players to provide "suitable" sets of solutions tailored to specific end-users' (i.e.: residential, corporate, governmental and all potential ones) needs/requests, under a continuously evolved context (so that to ensure "alignment" and conformance to any sort of performed technological, business, financial, regulatory or other evolution), a dynamic NS concept has to be taken into account. This allows for a more flexible and more reliable design, establishment, assessment and exploitation of the intended 5G realization and becomes a practical 5G enabler. Towards an effective market-oriented approach, the dynamic NS leverages "key technology" advancements in a variety of sectors, including but not limited to: (i) Distributed cloud infrastructure and cloud native applications; (ii) NFV; (iii) E2E orchestration; (iv) SDN and programmable networking; (v) network big data, analytics and machine learning; (vi) services oriented architectures, and; (vii) intent based network programming. These implicate for innovative attributes to become indispensable parts of the networks of the future and support a variety of services.

In the development of the 5G world, there are also challenges for the market sector and especially for the participating industry verticals, who desire increasing their productivity. To this aim (dynamic) NS enables operators to create pre-defined, differing levels of services to different enterprise verticals, allowing them to customize their own operations. There are several market models for adopting NS and for the support of related "go to market" strategies. However, in order to realize an effective market penetration, dynamic NS also depends on several regulatory perspectives that have to be examined in every attempt for future growth, to avoid potential uncertainties that could harm market growth. In our approach we have also identified several such factors and have realised a first assessment. Due to its nature, the dynamic NS can offer a substantial support for the 5G success.

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