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OUTLOOK

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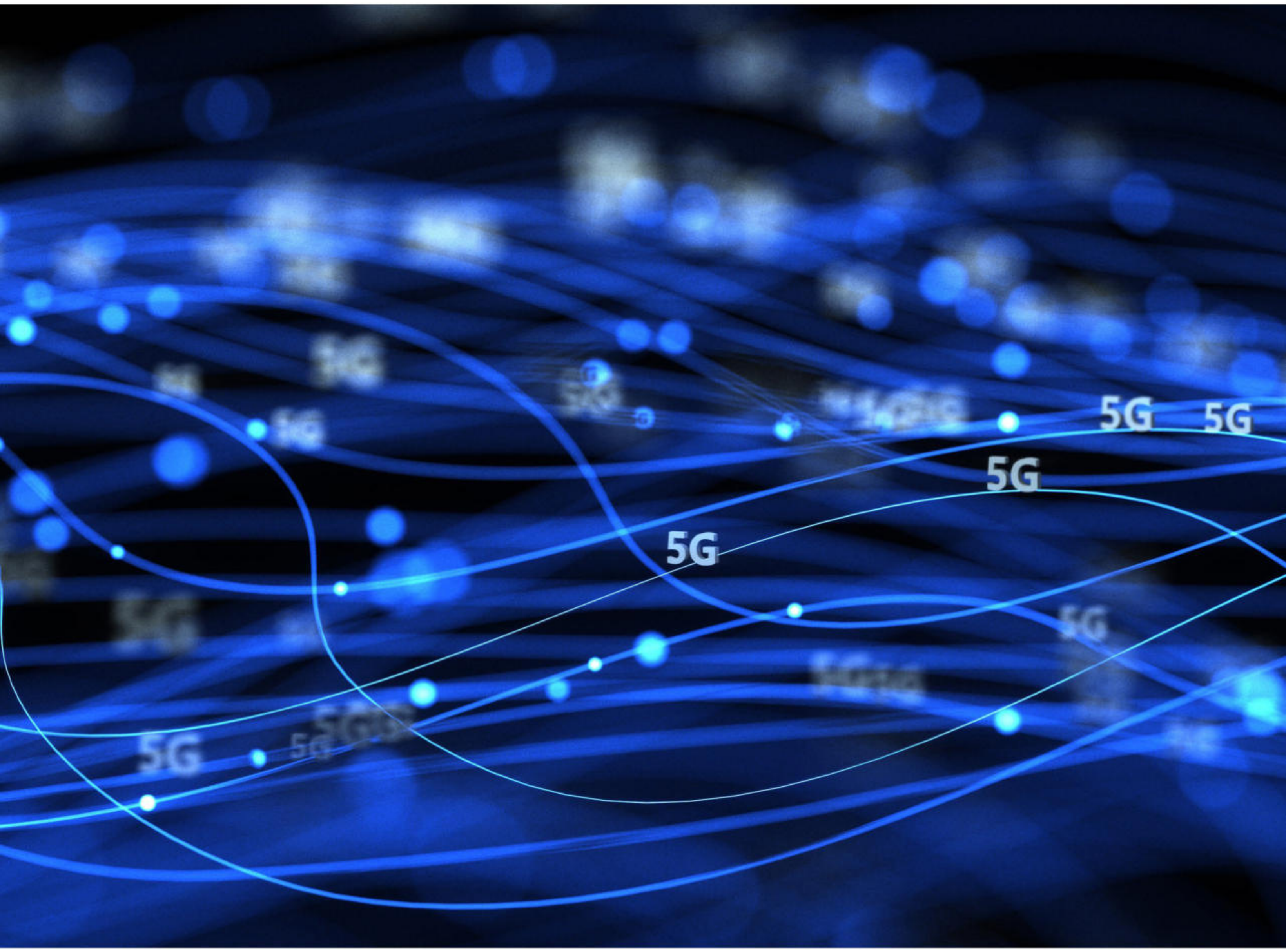
Network Slicing for 5G and Beyond Systems



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White Paper
Network Slicing for 5G and Beyond Systems

Editor

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Executive Summary

Network Slicing (NS) is a holy grail nowadays for future of networking, and is poised to transform the Internet and the services eco-system. Other closely associated technologies on which NS is built on are NFV, SDN, and OpenFlow. Since 5G would enable a range of new applications and services by delivering higher bandwidth, lower latency, and significant scalability, one size fits all approach of the past would not work. This has made network slicing in 5G an essential requirement of the overall 5G architecture. The concept of network slicing enables logically partitioning the network into slices based on different considerations of traffic types, application types, customers, industry verticals, etc, such that NS provides isolation between slices for the reasons of maintaining QoS/SLA, security and potential interference. Simply stated, the operators are pursuing the strategy of “divide and conquer.” A very important concept in NS is that of Orchestrator(s) that allows slices to be configured in the access network (RAN and fixed access), the core network, and very high capacity backbone transport which almost always is fibre-based.

Although there are several standards organizations and industry fora driving network slicing standardization, inter-operability and implementation details, 3GPP is at the core of driving the entire effort. This WWRF Outlook endeavours to capture the broad landscape of network slicing from basic concept to potential business and economic models. And, in-between, it describes how slices are configured in the RAN, the core network and the transport network. Since new advancements and new generations of wireless tend to overlook the requirements of the developing world (with close to over 3.5B people) who have yet to experience the value of the Internet, this Outlook dedicates a significant amount of space to the role of network slicing to bridge the digital divide as we usher a new era of 5G and B5G technologies for social impact.

As network management and operations is a significant aspect of any network, this topic is covered as well in this paper followed by a discussion on implementation and testing of network slicing in future networks.

On the business models aspect, network slicing is likely to unleash a plethora of new opportunities for the operators as they would be able to price the slices differently based on the QoS agreements, services offered, applications supported and who the customer is. Finally, since network slices would be tariffed differently, much different from the present day data-type agnostic best effort Internet, there potentially might be issues of network neutrality. Furthermore, since these slices would run across national boundaries, subject to different regulations and policies, it would seem that some level of harmonization and international cooperation would be required for network slicing to realize its full potential. Therefore, it would be necessary to be able to explain NS to all stakeholders, national SDOs, and government policy makers and regulators.

While network slicing is predicted to lead to the promised land, but this road is not without significant pot holes along the way. Some significant challenges that must be addressed to realize the vision of E2E slicing concern re-designing RAN and CN for slicing, spectrum slicing, E2E service assurance to meet QoS/SLA, inter-operability across multiple operator network domains, maintaining service concurrency enabled by network slicing, scheduling issues when a user device wishes to access multiple slices simultaneously, addressing security issues, including distributed denial of service (DDoS) attacks, and slice management to ensure they are adhering to the agreed or configured KPIs for individual slices.

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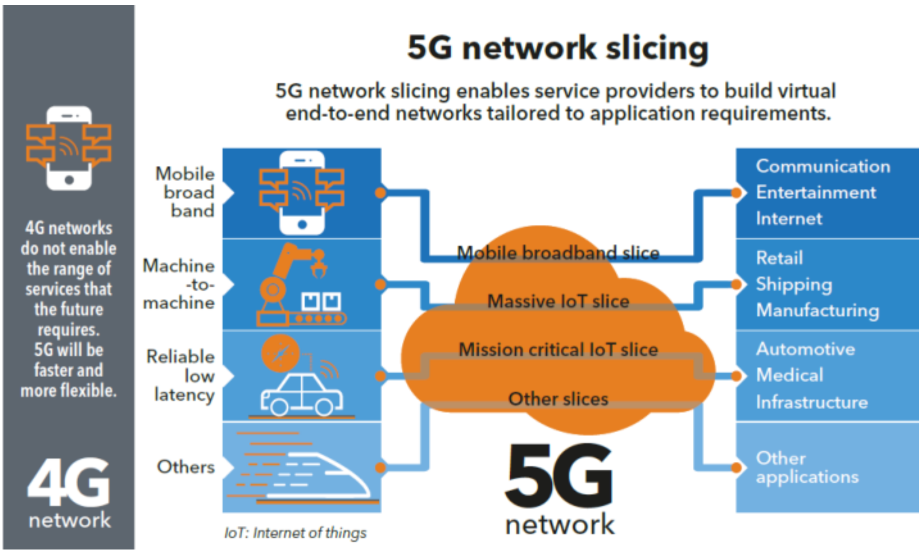
1. Introduction

There are currently several definitions of network slice which may be conflicting and to avoid confusion we adopt the 3GPP and GSMA definitions specified in [23, 24] as follows:

> *A Network Slice is a logical network that provides specific network capabilities and network characteristics.*

Simply stated, **network slicing** is the separation of multiple virtual **networks** that operate on the same physical hardware for different applications, services, purposes, and customers. The old paradigm of "one-size-fits-all" is no longer suitable for the new breed of applications and services, and it would be more so in the future with focus on industry verticals and a variety of new applications, falling under the categories of *enhanced mobile broadband*, massive *machine-type communication*, *ultra-reliable low latency communication*. The present-day Internet is "best effort" with some QoS control at the ingress from the access network, and due to more than 80% of video traffic, mostly entertainment, there is significant impact on other non-video applications. The slicing concept allows the network to be logically sliced for different types of traffic, different industry verticals, and even private slices for businesses and the government. This logical separation ensures that each slice operates independently and securely with guaranteed QoS. Network slicing is an important concept which differentiates 5G and B5G from its predecessors. Slicing is presently undergoing standardization and pilot implementations [1-4].



[Source: SDX Central]

Figure 1. An illustration of the network slicing architecture.

Network slicing will unlock an array of innovative 5G revenue opportunities as it opens up possibilities to charge differentially for each slice to meet user requirements for different industry verticals, organizations and consumers. It even allows the customer to define and configure or reconfigure his or her own slice as needed on-demand. Standards organizations, such as 3GPP are actively developing slicing concepts and capabilities both at the architecture and technical level, including its management and orchestration. 3GPP Release 16 has defined detailed specifications for slicing in next generation networks. SDN (Software Defined Network) is a related concept that enables development of a network slice, SDN being at the control plane level and slicing being at the data-plane level, but these are independent of each other. The ability to offer a network slice as a service minimizes CAPEX and OPEX. In some regions of the world, where net-neutrality is required, this regulation can still be complied with for all users in a particular slice. However, it is not yet a settled issue if and when slicing does get implemented and commercialized. For an excellent tutorial on the different aspects of network slicing, the reader is referred to [2]

At a conceptual framework level, network slicing can be abstracted as illustrated in Figure 2 (adapted from [3]). The critical module here is the network slice controller (or orchestrator) that manages each of the three layers: infrastructure, network function and service layer to define and configure a slice that is needed.

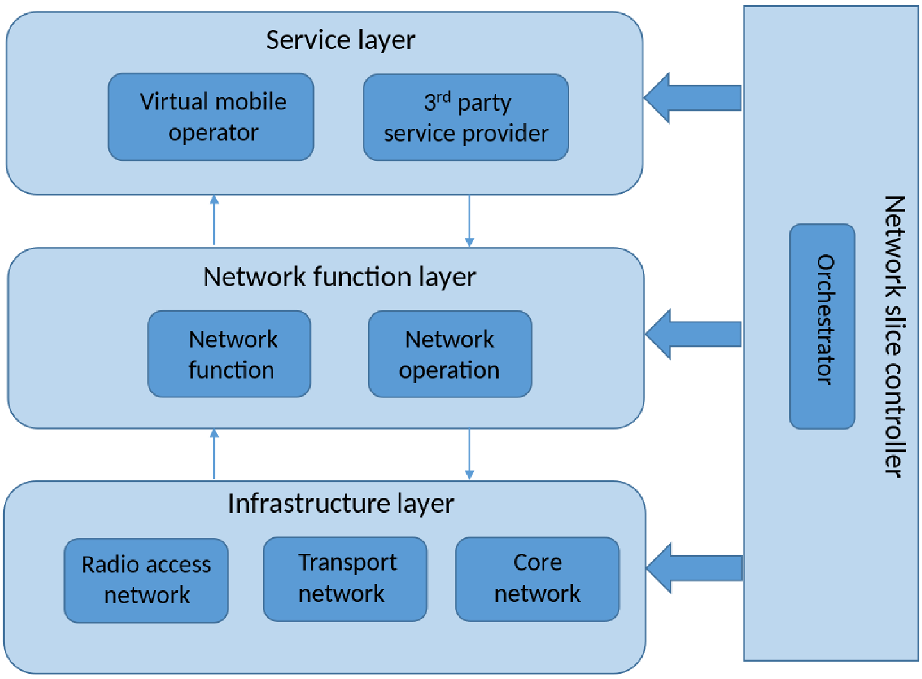


Figure 2. An abstract view of the network slicing architecture[1].

Figure 3 shows a systems architecture for network slicing and how an access network slice may be paired with a core network slice to build an end-to-end network slice. There could potentially be multiple slices on a RAN for different industry verticals and organizations.

[1] https://en.wikipedia.org/wiki/5G_network_slicing

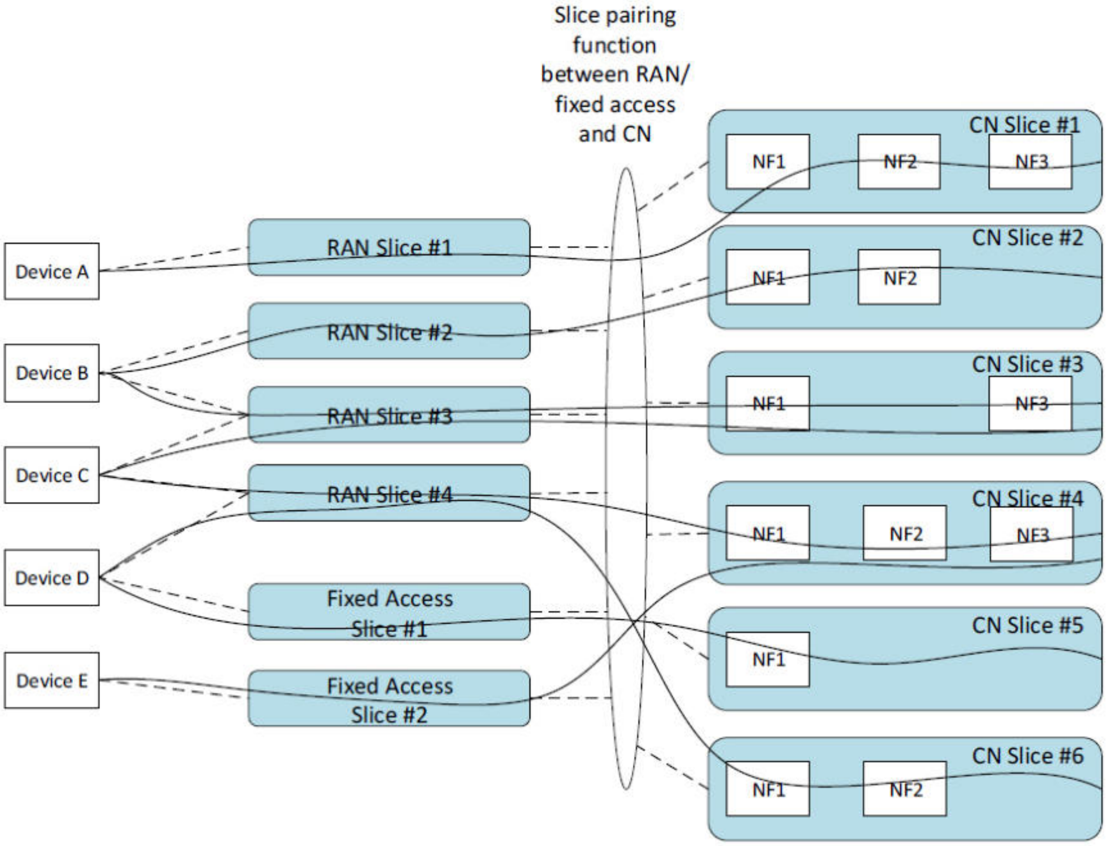


Figure 3. An illustration of a system architecture for network slicing and how an access slice can be paired with a CN slice [Source: 5G Americas].

2. State-of-the-art

Industry

AT&T, Verizon, Vodafone, Deutsche Telecom, SK Telecom, China Mobile, and Orange have already experimented or launched network slicing in their core network for 4G LTE networks, and are working to implement the concept when large-scale launch of 5G networks takes place in year 2020.

The major vendors, such as Ericsson, Nokia, Huawei, are already showing “5G Ready” network slicing demos, and would probably have them ready for launch in the commercial mobile networks in 2021. One concern, however, is that unless 5G is virtualized, network slicing would probably be expensive for the operators.

Research

There is a lot of research ongoing on network slicing in the universities and corporate R&D laboratories [1-4]. These can be found by doing online search.

Regulatory and Policy

Logically separating the infrastructure into slices based on applications, data types, customers and QoS, raises important issues of “network neutrality”, because then the service operator can charge for them differently. This is an unaddressed issue in almost all countries. This is a good example of how technology and public policy can collide

[5]. It is anticipated that future networks will support multi-tenancy with 5G Network Slice Brokers. The multi-tenancy players would be VNOs, OTTs, industry vertical players, and others, who would be able to request resources on-demand from infrastructure providers and pay on usage basis [2]. Regulations and policies would probably be needed to enable this transformation to sharing resources. Blockchain technology with distributed ledgers will likely play a role in ensuring that on-demand short-term contracts are reliable, legally binding and enforceable. GSMA has published a paper on use cases for 5G network slicing, and its implications on regulatory issues, [23]. There is some concern about the European data protection/GDPR when a slice runs through multiple countries to support industry verticals or large multi-national customers [2]. Thus, legal, regulatory and policy issues remain to be addressed and lag behind the technological advances in network slicing.

3. Standards activities

Three main techniques, network virtualization (NV), SDN and orchestration, are closely inter-twined and employed to create a network slice. Network orchestration is probably the most important component to identify, configure, inter-connect, and manage components at each layer to create an end-to-end slice. Therefore, several standards and industry fora become players in the slicing game. Nevertheless, 3GPP is the main standards organization integrating NV, SDN and orchestration to create and enable a slice. The 3GPP unites seven telecommunications standard development organization, ARIB, ATIS, CCSA, ETSI, TSDSI, TTA, TTC, and are known as "Organizational Partners". 3GPP provides their members a common platform to produce consensus on publications and specifications that define 3GPP technologies. The entire 3GPP eco-system working on 5G slicing is shown in Figure 4.

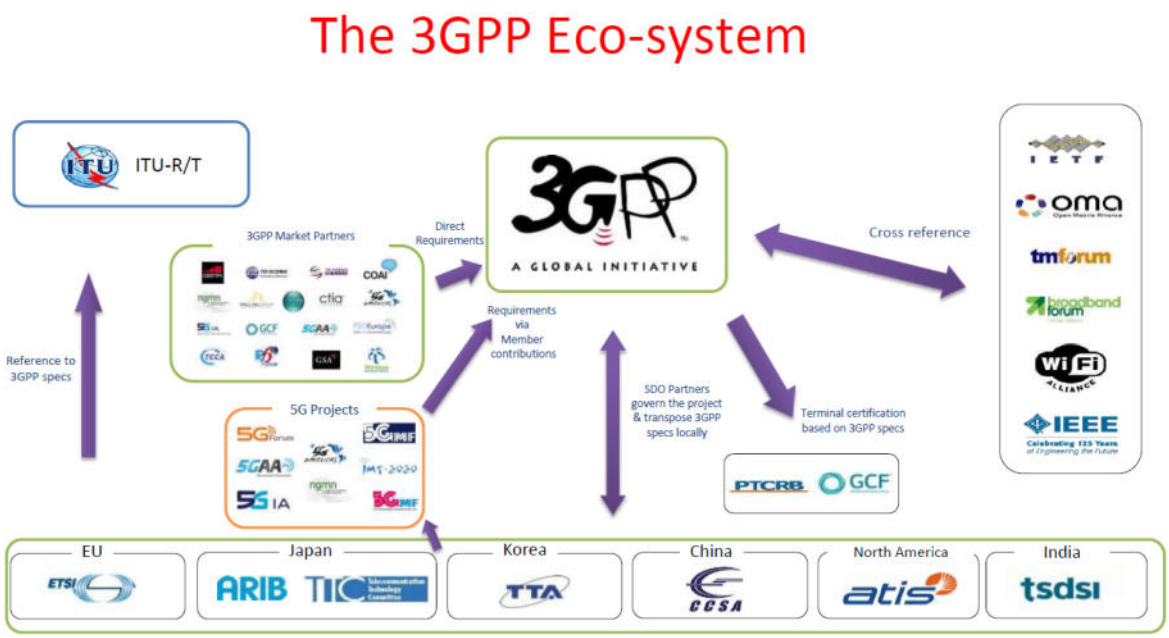


Figure 4. The 3GPP eco-system (adapted from [22]).

3GPP Release 15 defined networking slicing as a concept. Release 16 due to be completed this year (2020) defines additional slice specific features, like controlling what slices a user equipment may use simultaneously or slice specific authentication, allowing further differentiation on what slices may provide to slice customers with features like enabling private networks, such as factory automation, hospital, and so on. The objective of R16 is to meet ITU IMT 2020 requirements. Release 16 of the 3GPP will provide more specifics on network slicing, including low latency industrial IoT and autonomous driving. 3GPP technical specification (TS) 23.501 defines stage 2 with network slicing included [6, 21], while TS 22.261 specifies the provisioning of network slices, how devices are connected to slices, and performance isolation during normal and elastic slice operation [7].

3GPP has proposed a data model [8] that consists of a list of Network Slice Subnetworks instances (NSSI) and contains a set of network functions (NF) and resources for these network functions, which are being arranged and configured to form a logical network.

The Network Slice Instance (NSI) contains NSSI, which in turn contains NFs (e.g., belonging to Access Network and Core Network) as well as all information relevant to the interconnections between those NFs like topology of connections and individual link requirements (e.g., QoS attributes). The NSI is deployed based on the definitions that are described in its Network Slice Template (NST).

ETSI NFV ISG is actually highlighting the relationship between ETSI NFV network service definition and 3GPP Network Slice Subnets [10]. This is important since the NFV-O is familiar and supports the network service (and VNF) constructions. Figure 5 presents the relationship between 3GPP and ETSI NFV data models. It can be observed that the virtualised resources for the slice subnet and their connectivity to physical resources can be represented by the nested network service concept, or one or more VNFs and Physical Network Functions (PNF) are directly attached to the network service used by the network slice. ETSI states that "an NFV Network Service (NS) can thus be regarded as a resource-centric view of a network slice, for the cases where a Network Slice Instance (NSI) would contain at least one virtualised network function" [11].

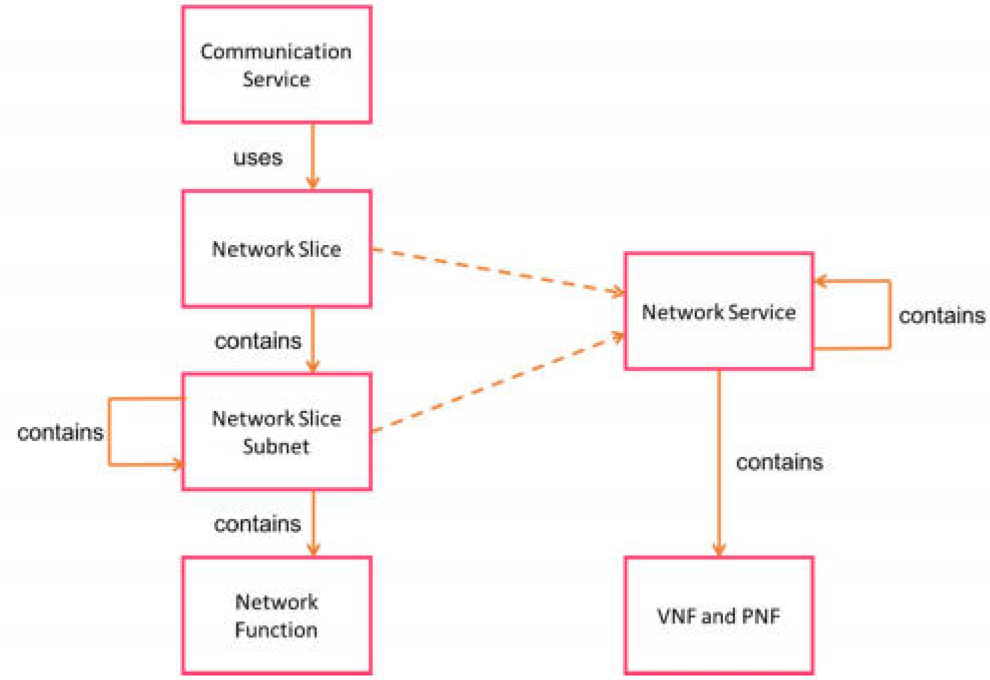


Figure 5. Relating the information mode [10].

The following table shows the work by the satellite community in various standards organizations in support of integrating with 5G (excluding work in support of assigned spectrums).

SDO	WG	WI reference	WI title	Document	Target completion date	Rapporteur
3GPP	SA1	FS_5GSAT	Study on using Satellite Access in 5G	TR 22.822	June 2018	Thales
3GPP	RAN	FS_NR_nonterr_nw on NR	Study on NR to support non-terrestrial networks	TR 38.811	June 2018	Thales
3GPP	SA1	5GSAT	New WID on Integration of Satellite Access in 5G (5GSAT)	CR to TS 22.261	December 2018	Thales
3GPP	SA2	FS_5GSAT_ARCH	Study on architecture aspects for using satellite access in 5G; (Release 16)	TR 23.737	June 2019	Thales
3GPP	RAN	FS_NR_NTN_solutions	Study on solutions for NR to support non-terrestrial networks (NTN) (Release 16)	TR 38.821	December 2019	Thales
ETSI	SCN	DTR/SES-00405	Integration of satellite and/or HAPS (High Altitude Platform Station) systems into 5G system and related architecture options	TR 103 611	December 2018	Thales

SDO	WG	WI reference	WI title	Document	Target completion date	Rapporteur
ETSI	SCN	DTR/SES-00447	Edge delivery in 5G through satellite multicast	TR ??	June 2019	Avanti
ETSI	SCN	DTR/SES-00446	Reference Virtualised Network Functions data model for satellite communication systems	TR ??	June 2019	Thales
CEPT ECC	FM44/ECC PT1	WI FM44_32	Satellite solutions for 5G	ECC Report 280	May 2018	SES
ITU-R	WP4B	NGSAT_SAT	Key elements for the integration of satellite systems into Next Generation Access Technologies	ITU-R.M Report	Q2/2020	SES

This work continues and in part allows satellite links to offer network slicing capabilities when providing either indirect or direct connections [9].

4. Network Slicing in Core Networks

The mobile core network has gone through a significant evolution during this last decade: GSM started with voice and circuit switched services up to LTE that introduced a full IP core network for all services. While deployments of LTE core network have been introduced with physical network elements, the evolution of the technology lead those elements, MME, GWs, HSS, IMS, etc., to be virtualized with network software functions running on commodity hardware. To serve multiple services LTE has standardized solutions, like eDecor, and built specifications (e.g. network slice discovery and selection, network function sharing, etc.) to enable an early network slicing solution through the creation of core network instances for different types of services. 3GPP also defined several solutions for sharing the network through specifications of MORAN, MOCN, MOGW.

Although those solutions are good for today's network, they show limitations when looking at the future use cases and business opportunities. 5G offers the opportunity to develop new use cases and business models for consumers, enterprises, specific industry verticals and third-party partners. Breaking the traditional model of "one-size-fits-all" the 5G network can be tailored to efficiently support a variety of very diverse and extreme requirements for latency, throughput, capacity, reliability, and availability.

Network slicing is the key technology underlying these new business model opportunities. Operators will be able to provide dedicated virtual networks to various customer groups much more economically than if these customers were to build, in the traditional model, their own dedicated private networks.

A network slice is an independent, virtualized e2e network, which, from a customer or business partner perspective, is behaving in the same way as a dedicated private physical network, including business logic and network management capabilities

5G network architecture provides more flexibility, elasticity and scalability compared to 4G by moving from current network of entities (like in LTE and previous cellular generations), to a network of capabilities architecture, driven by Network Function Virtualization (NFV) and Software-Defined Networking (SDN). This is achieved by decomposing the EPC into more fine-granular network functions thus allowing more agile software lifecycle management, also known as continuous integration and delivery. This enables a 'per network slice' tailored control plane. At the same time, building applications from smaller micro-services enables to deliver these as independent software building blocks which can be upgraded separately.

Figure 6 shows the 5G network functions in terms of slice dedicated and shared resources. A key requirement for the 5G network is the possibility for a given user equipment (UE) to connect to multiple slices at the same time. 3GPP decided that in such a case some network functions need to be shared among slices. This is obvious since subscriber, authentication and mobility functions are common to the UE that uses services at the same time.

Within the NG core architecture some Network Functions (NFs) have their equivalence in LTE:

- Access and Mobility Management Function (AMF)
- Session Management Function(s) (SMF)
- Policy Control Function(s) (PCF)
- User Plane Function(s) (UPF)
- Unified Data Management (UDM)
- Authentication Security Function (AUSF)

Other NFs are completely new:

- The **Network Slice Selection Function (NSSF)** centralizes some policy decisions that can be changed centrally without impacting all deployed AMFs, namely:
    - Allowed slices a UE can use based on policy per Tracking Area
    - AMF, NRF that can serve a certain (set of) slice(s)
    - Network Slice instance if more than one slice instance serves a certain slice.
    - The NSSF may be configured with operator policies specifying under what conditions the slices can be restricted per HPLMN and TA (so the NSSF can take decisions on allowed slices Per HPLMN of the UE).
- **Network Repository Function (NRF)** provides registration and discovery functionality allowing NFs to discover themselves via open APIs.

Support of a network slice in a PLMN is uniform in a Registration area; that is all cells of the same Tracking Area support same network slices.

At N2 connection establishment or update the AMF learns the slices supported per Tracking Area by the NG-RAN and the NG-RAN learns the slices the AMFs it connects to (see TS 38.413 [10] and TS 38.300 [11]). The AMF provides and updates as well the NSSF with the slices supported per TA.

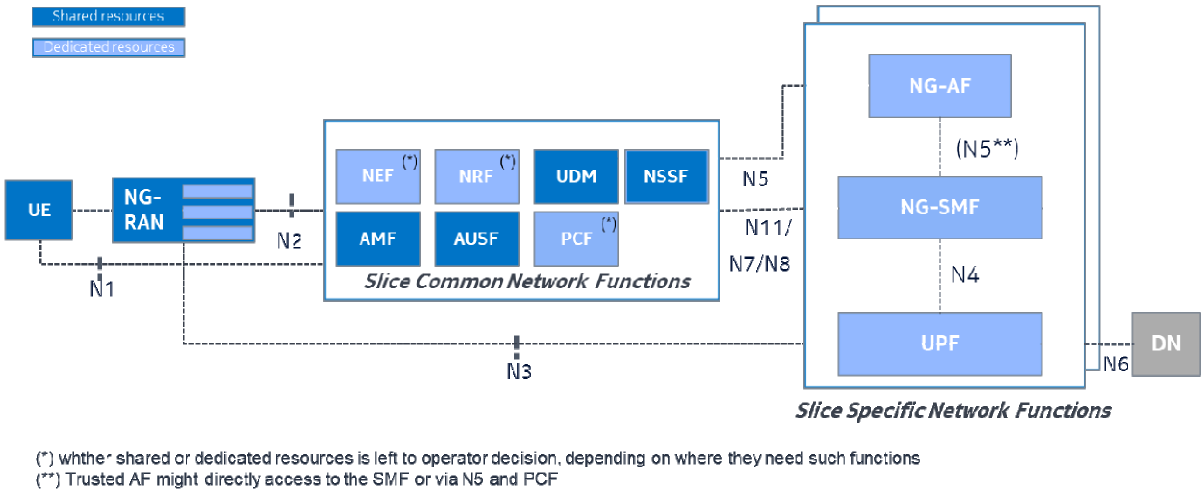


Figure 6. 5G Core Network and slice shared and dedicated resources

While in LTE a user can only connect to a single slice at a time, in 5G, depending on terminal capabilities, applications and subscribed services, a UE can simultaneously join multiple network slices. This is based on information provided by the UE using the network-slice-selection-assistance information (NSSAI), which assists the network to route different end-user or end-device services to the relevant network slice. NSSAI is an array of S-NSSAI (Single Network Slice Assistance Information). Each S-NSSAI includes two elements: the SST (Slice Service Type) is mandatory and indicates the type of service and the SD (Service Discriminator). SD is optional and indicates the enterprise / third party.

The SST field may have standardised (in Rel.15 only three types of SST are defined, eMBB, URLLC and MIoT) and non-standardized values. SD is operator defined only.

The ‘Registration Request’ message flow with exchange of S-NSSAIs through RAN and Core Network interfaces is shown in Figure 7. Example of UE connecting to one or multiple slices at the same time is given in Figure 8.

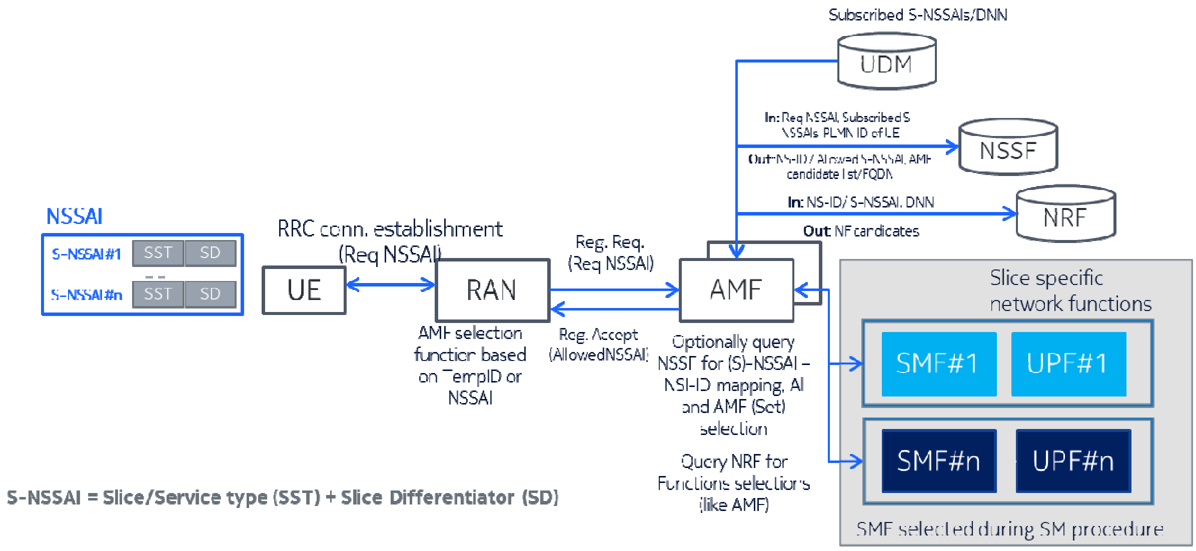


Figure 7. UE assisted Network Slice selection at registration time: the NSSAI.

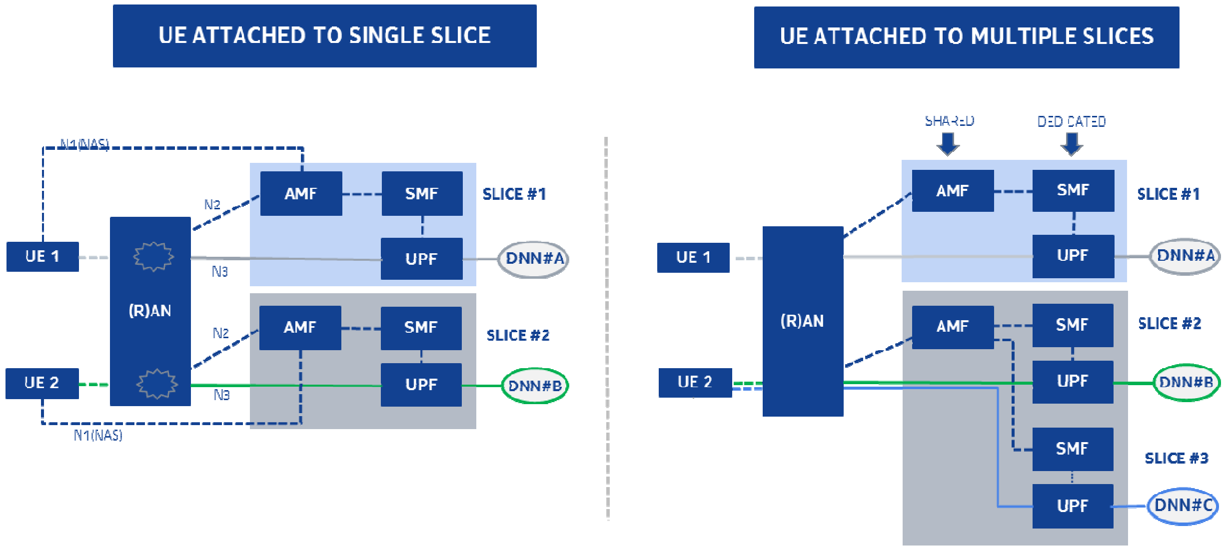


Figure 8. Slice examples in 5G CN.

5. Network Slicing in RAN

In 4G, only the Core Network can be sliced (APN, MOCN, (e)DECOR based), 5G allows, in addition to CN, RAN slicing. For example, FWA, IoT , eMBB and URLLC have very different traffic profiles and can benefit from a dedicated slice in RAN.

Depending on isolation requirements, spectrum can be dedicated to a network slice. However, the most common case is the one where the spectrum is shared amongst network slices and controlled by a single authority.

3GPP Release 15 introduced the exchange of S-NSSAI on RAN-CN as well as on RAN internal interfaces. The knowledge of S-NSSAI enables the RAN to enforce slice specific policies when the UE establishes PDU sessions as well as when the UE moves.

Having the slicing knowledge, the RAN can enforce slice specific policies. The way slice policies are enforced are not in the standards but they are implementation specific and can be used for:

- **ensuring suitable RAN configuration**. For example, IoT device may benefit from longer DRX and periodic routing area update intervals to extend longer battery life. Or slice carrying URLLC service requires low latencies and guaranteed bit rate thus impacting for example on scheduling and RACH configurations. In addition, there would be the possibility to chain proprietary and operator specific functions within a network slice
- **various degrees of slice isolation**: if the use case requires a high degree of isolation, resources can be dedicated to the slice. For example, many i4.0 use cases require fully isolated slices: this means spectrum reservation (i.e., dedicated PRBs or a subset of channels) along with high layer resources. However, to reserve the spectrum is rather an exception, and is required only for very special cases. In fact reserving radio resources per slice reduces resource elasticity and limits multiplexing gain (i.e., penalize spectrum efficiency). The most common case is the shared resource model that allows slices (user groups) to share MAC scheduler and spectrum. That is, the PRBs belonging to the shared spectrum are managed by a common scheduler that allocates resources to slices according to business criteria

Figure 9 shows an example of a UE connected to three slices at same time. As explained for the core network, the RAN also requires one RRC connection if connected to multiple slices. Higher layer protocol resources are dedicated per slice, while sharing physical and low layers.

In addition to slicing information (NSSAI), the Access Control Category (AGC) bits are enhanced with slice access specific information. The AGC bits are broadcast in system information and can be mapped to slices information. Those bits are used to allow /inhibit access of users subscribed to given network slices.

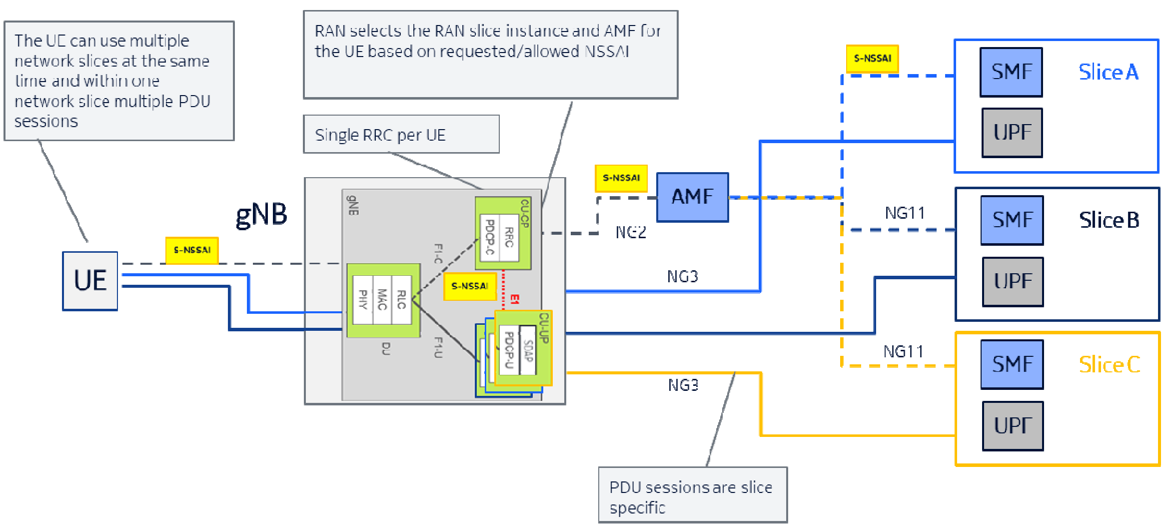


Figure 9. Illustration of a user equipment connected to three slices at the same time.

Automation of RAN slicing is a complex process where RAN slices can be offered to third parties [12].

6. Network Slicing and the 5G Transport Network

Slicing the transport network from edge to the core and cloud, consisting of the data centres, is required in 5G slicing. Antonio de la Oliva, et al, describe one such approach [13] called “5G Transformer” that allows slices across operator domains to be chained for industry verticals [2]. A 3-layer tiered approach is proposed: Vertical slicer, Service orchestrator, and Mobile transport and computing platform. The service orchestrator is obviously the brain behind slicing and chaining and leverages the SDN for configuring the network and data centre resources. Figure 10 shows the transformer approach.

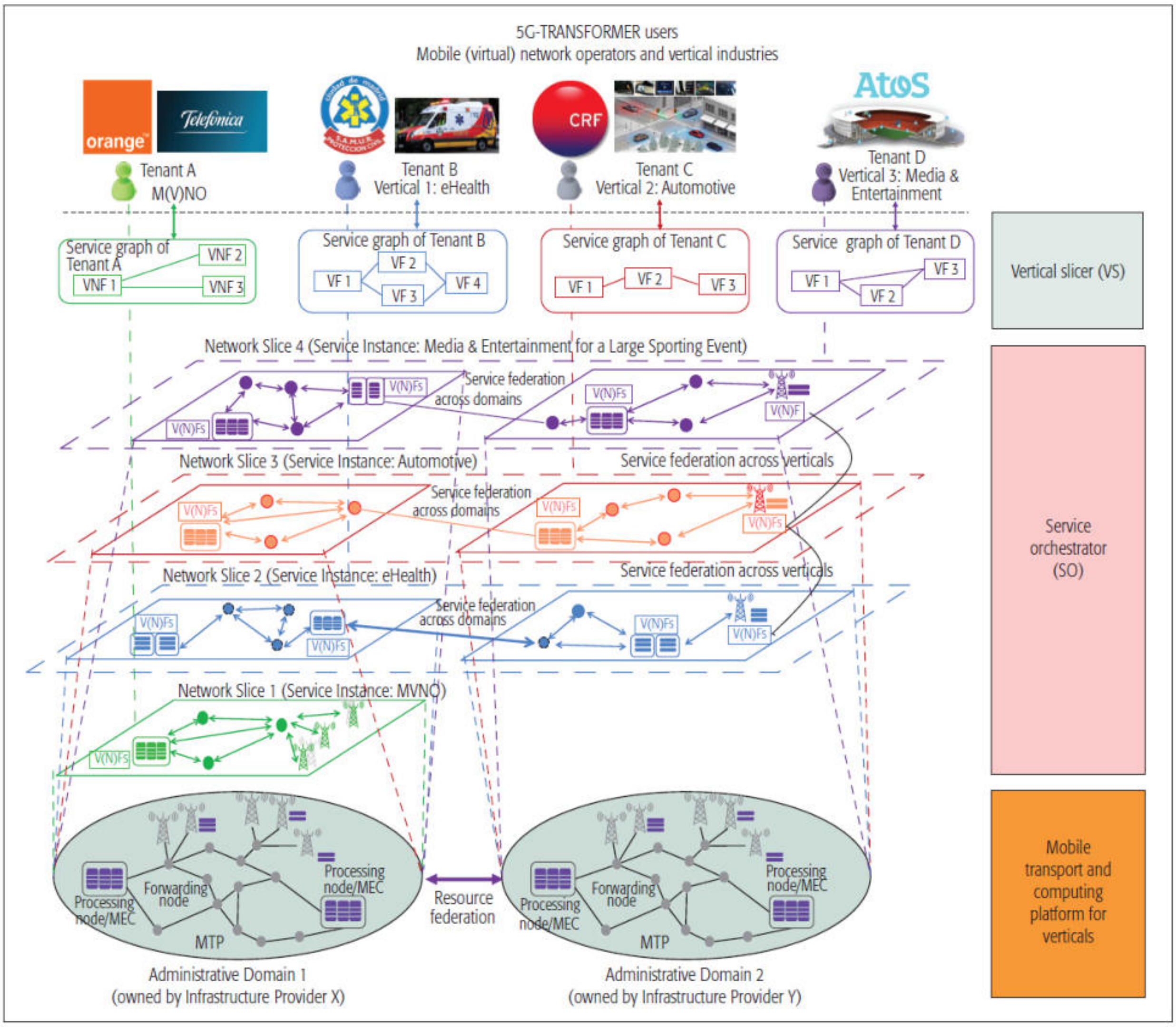


Figure 10. An example of a 5G transport network slicing concept [13].

IETF is another standards organisation deeply involved with network slicing, especially on the interface between the E2E Slice Controller and Transport Controller for Transport slices in conjunction with controllers in RAN and Core slices. Since it is E2E, it allows automation, assurance and optimisation of the network slices [14]. While 3GPP has defined interfaces between the E2E network slice controller and RAN and Core controllers, they have not yet defined the same interface for transport slices (i.e., between E2E Controller and transport slices across multiple domains). IETF is working on defining this interface. Figure 11 illustrates a high level architecture of 5G end-to-end network slicing.

```
    <-------------- End to End Network Slices ---------------->

    <----- RAN -----> <----- Transport ----> <----- Core ----->
           Slice                Slice                 Slice

    |----------------------------------------------------------|
    |              E2E Network Slice Controller                |
    |----------------------------------------------------------|

    |----------------| |-------------------| |-----------------|
    |      RAN       | |    Transport      | |      Core       |
    |   Controller   | |    Controller     | |   Controller    |
    |----------------| |-------------------| |-----------------|

      ................  ...................  ......... .......
      :              :  :                  :  :       : :     :
      :              :  :                  :  :       : :     :
     -----------------------------------------------------------
-- NS1

=============================================================
NS2

+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
NS3
      :              :  :                  :  :       : :     :
      :              :  :                  :  :       : :     :
     - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
- NS4
      :              :  :                  :  :       : :     :
      :              :  :                  :  :       : :     :
      :..............:  :..................:  :.......: :.....:

           RAN                Transport        Core      Mobile
           Network                  Network               Network
Application

Customers (aka Tenants): Public Safety and C1
MNO (Mobile Network Operator): Operator Y

Legend:
----- NS1: E2E network slice 1 for customer C1,
      service type Infotainment
===== NS2: E2E network slice 2 for customer C1,
      service type Autonomous Driving
+++++ NS3: E2E network slice 3 for customer C1,
      service type HD Map (NS3)
- - - NS4: E2E network slice 4 for customer Public Safety,
      service type Video Surveillance
```

Figure 11. High level architecture of 5G end-to-end network slicing [14].

7. Network Slicing to Bridge the Digital Divide

This section discusses network slicing technologies to offer affordable internet services to "*rural areas*' which are regarded by cellular network providers as low average revenue per user (Low-ARPU) regions. The slicing options consider network and operational cost-efficiency methods to make services affordable and accessible to users.

Although the fifth generation of cellular communications (5G) promises to revolutionize the telecom industry in unprecedented ways, developed markets are likely to more fully reap the benefits of 5G, compared to their developing counterparts. In the context of developing markets, adoption of 5G is likely to be driven by urban areas because of their high revenue potential. However, most developing markets are faced with the challenge of poor and inadequate broadband infrastructure in urban areas and even worse in rural areas. This is largely influenced by the monopolization of the telecommunications industry by established operators and the vertically integrated business models, which impedes competition and causes high entrance barriers to smaller and emerging telecommunications players. As far as rural areas (sparsely populated or geographically isolated areas) are concerned, operators are reluctant to extend coverage to these areas due to the potential low return on investments they present [15]. However, operators in most developing markets are often subjected to geographic coverage obligations that mandate them to extend coverage to areas with low or no network footprint and to still charge fair subscription fees. This calls for a mechanism to reduce costs associated with rolling out infrastructure optimized not only for broadband but for other 5G services such as massive IoT and mission-critical services — each with different QoS requirements. At this juncture, network slicing has appeared as an attractive solution to address the infrastructure hurdle in developing markets.

Network slicing is one of the key features for 5G networks to be able to accommodate the QoS requirements and constraints of various market segments (e.g., e-health, automotive, education, agriculture, utilities) and support dynamic and affordable service delivery models (such as infrastructure as a service (IaaS) for private mobile networks) [16, 17]. With network slicing, the network is partitioned into multiple logical networks on a unified physical infrastructure via virtualization technologies. This paradigm was initially proposed for application in mobile core network design, but has recently been extended to the radio access network to enable end-to-end multi-tenancy. Network slicing capitalizes on Software Defined Network (SDN) and Network Function Virtualization (NFV) technologies. NFV enables deployment of network functions (such as the baseband processing, serving and packet gateways) on commodity hardware, while SDN offers a mechanism to abstract the lower-level functionalities of the underlying physical infrastructure for protocol-agnostic network management and configuration. In the context of 5G network slicing, SDN and NFV collaboratively facilitate isolation and resource allocation among slices. For the management and orchestration (creation, modification, termination and chaining) of distributed virtualized network functions, software stacks aligned with the ETSI NFV MANO framework are used. To date, a prevalent choice for MANO has been OpenBaton and ONAP.

7.1 Network slicing options for rural developing areas (i.e., Low ARPU users)

The Basic Internet Foundation and Oslo Metropolitan University (OsloMet) have been working to support free access to information in an end-to-end network slice for all, both on wireless and mobile networks [18]. Free access to information, or the ***Internet Light*** solution, is seen as a minor extra cost (2-3% of network resources) for the network operator, being either an Internet Service Provider (ISP) or a mobile operator. Access to free Basic Internet will improve the quality of life of the citizens and empower them with information to generate new or additional income, will make them more productive by saving time, and enable access to healthcare, financial, educational, hospitality, and transportation related content and services, and eventually pass these benefits on to their families and future generations to bring overall prosperity for everyone. Basic Internet content and services are defined as non-dynamic without video embedded in them.

The *Internet Light* network architecture answering the need of a low-cost local infrastructure and rapid deployment is shown in Figure 12. Traffic management and network control centre are the key components of the architecture. The implementation of traffic management comprises two dimensions: (i) provide *Internet Light* to as many users as possible, and (ii) monitor and manage network infrastructure including a control centre and remote sites. Thus, the infrastructure is divided into two segments: a control centre at the head office (such as in Oslo, Norway, for the Basic Internet Foundation) and infrastructure in remote sites. The control centre is responsible for authentication and authorization of vouchers or prepaid credits in the account as presently done in the mobile systems. In addition, the control centre operators monitor and manage the network infrastructure in remote sites. The local network consists of a local control centre, a content server and the local distribution. The solution provides high capacity access to local content, paid access for Internet services, and free access to *Basic Information*.

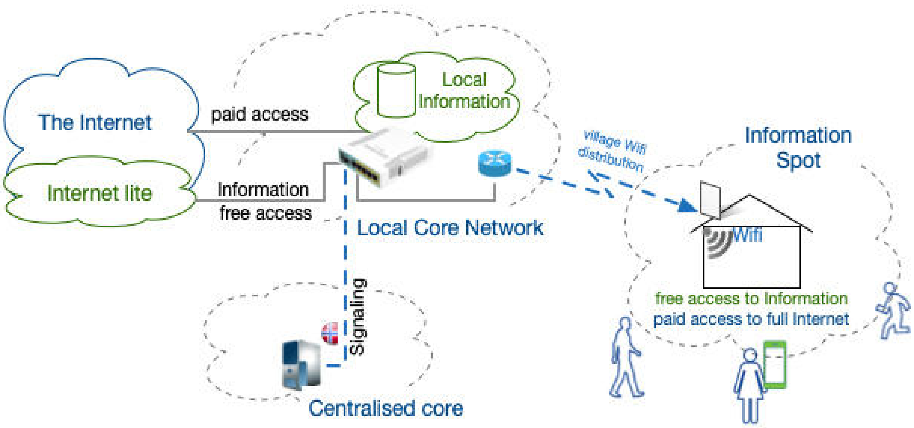


Figure 12. The cost effective Basic Internet architecture. The Basic Internet (free or the low capacity Internet) access is provided by network slicing technology [18].

The Basic Internet control centre monitors local content usage trends in order to forecast and plan required network capacity and local content demand in remote sites. Thus, operators can predict what kind of content should be localized in a remote site in order to manage expensive bandwidth efficiently. Monitoring the Basic Internet network infrastructure also improves the access network efficiency, while reducing operational and troubleshooting costs with network insight. However, monitoring network infrastructure in a location with limited bandwidth imposes implementation challenges regarding monitoring intervals and volume of data collected from the network infrastructure. The centralised control centre manages network infrastructure remotely so that it reduces the operational and maintenance cost of technical staff at remote locations. The remote management will simplify the network provisioning in remote sites so that new devices that are intended to expand the network can synchronize with the rest of the network smoothly.

To realize the vision of *Internet Light*, a 5G network slice dedicated to Internet Light called *Internet Light Network Slice (ILNS)* has been implemented [18]. This network slice or any slice to bridge the digital divide must fulfill the following requirements:

- The Internet Light Network Slice must provide a maximum downlink of 6 Mbps and a maximum uplink of 3 Mbps, which correspond to a typical data rate of 3G HSPA+
- There must be modification operation to redefine maximum capacity of the Internet Light Network Slice
- The Internet Light Network Slice must be capable of supporting a variety of applications such as web browser, social networks, news, education, etc.
- The Internet Light Network Slice must provide mechanism to switch to regular paid network slice upon request by the user for higher QoS (Quality of Service)
- The Internet Light Network Slice must be available and accessible freely by all the users carrying a feature phone or a smartphone
- The Internet Light Network Slice must be accessible by all the users without differentiation and including the ones without subscription at the providing mobile operators
- The Internet Light Network Slice should be, wherever possible, shared by several mobile operators for achieving high cost effectiveness
- The Internet Light Network Slice shall grant free access to every mobile phone carrying a valid SIM card issued by any legitimate mobile operator upon successful authentication
- The Internet Light Network Slice must perform a mutual authentication of the mobile phone to provide better, but simpler, security to the users
- The Internet Light Network Slice must provide a user-friendly and intuitive authentication scheme
- The Internet Light Network Slice shall provide sufficiently strong encryption to ensure privacy, confidentiality and integrity of the information exchange session
- The Internet Light Network Slice must be completely isolated from the other slices such that its operation shall have no impact on other slices and vice versa

- The users shall have the ability to change to another network slice by upgrading their mobile subscription
- The Internet Light shall offer to every citizen an Internet Light subscription with a corresponding Universal Integrated Circuit Card (UICC) free of charge or at an affordable fee.

As stated above, to ensure security and privacy of the users, the existence of a valid SIM card and mutual authentication is required. Indeed, without proper authentication it is not possible to provide necessary encryption to protect the Internet Light Network Slice.

7.1.1 Internet Light Network Slice Architecture

5G Reference Architecture

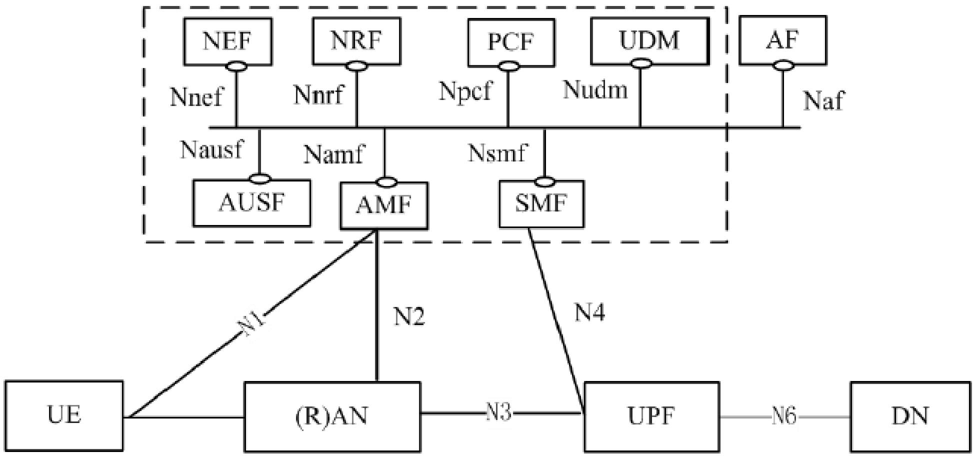


Figure 13. The 5G Reference Architecture (Courtesy of 3GPP)

As shown in Figure 13, the 5G Reference Architecture differs from the 4G architecture not only in their different Network Functions [21] but also in the separation of the User plane and Control plane.

Designing the Internet Light Network Slice (ILNS)

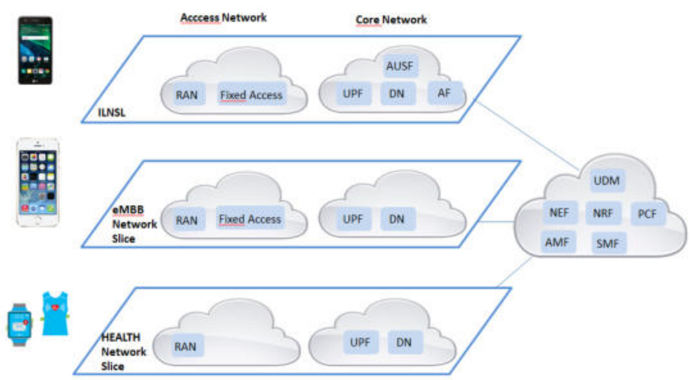


Figure 14. Internet Light Network Slice Architecture [18].

As shown in Figure 14, to ensure isolation, ILNS will be realized as an end to end network slice, i.e., it is comprised of Network Functions (NF) instances for the access network such as RAN, Fixed Access and for the Core Network such as UPF, DN. While most of the NF instances of the control plane are shared with the other network slices in order to allow the user to upgrade and switch to other network slices with higher QoS.

8. Operational Aspects of Network Slicing

The concept of network slicing derived from the network softwarization technologies, which allow slicing and sharing common resources (IT assets as well as radio resources) among different parties. Network slicing enables the virtualized and non-virtualized network elements and functions to be easily logically segmented, configured and reused (isolated from one another) in order to meet various demands. Each slice has its own specific network architecture, mechanism and network provisioning. The action of sharing common resources among different parties is called resource slicing. In this context, the owner of each resource slice is called a tenant. Each resource slice is provisioned, managed, and operated separately from the other resource slices. Each tenant can have multiple independent instances of added-value services.

Operational aspects of network slicing are illustrated in Figure 15, with four main phases: network slice configuration and provisioning, network slice operation, network slice management, and network slice performance management. All these elements are responsible for coordinating and allocating required slices and services in the network. It enables to configure and provision a slice with certain properties, deploy services and provision a network function, or modify the resources allocated to existing slice, and manage a slice during its life cycle.

Figure 15. Operational aspects of network slicing in four phases.

8.1 Network Slice Configuration and Provisioning

3GPP SA5 has been defining provisioning and configuration phases for network slicing for 5G networks and services. It prepares template design, capability planning for a network slice, evaluation of the requirements and onboarding the network slice. It also creates customisable and user-specific slices with flexible and dynamically deployable resources, based on explicit user request and existing slice templates, as well as terminating the slices.

The provisioning phase allows network operators to create single/multiple network slices on a shared physical infrastructure to be fitted with the characteristics required by different use cases; for example, Ultra High Definition (UHD), Augmented Reality (AR) and Virtual Reality (VR) require large bandwidth and less latency to manage massive amount of data produced and consumed.

SA5 provides specified management interfaces in support of 5G networks and network slicing. An operator can configure and manage the mobile network to support various types of services enabled by 5G, for example eMBB (enhanced Mobile Broadband) and URLLC (Ultra-Reliable and Low Latency Communications), depending on different customers' needs. The slice configuration can be managed as any other virtualized networking entity such as NFV, by allowing network operators to easily create slices by combining virtualized network components.

8.2 Network Slice Operation

Once the network slice is created, it becomes ready for activation, supervision, resource planning and de-activation. Resource planning in the operations phase involves assigning network services and network functions to the network slice. In other words, network slice operation is responsible for provisioning network functions to be used in the network slices, define network services and capabilities supported by a network slice. Network slice operation enables the operators (Mobile Network Operator – MNO) to monitor and interact with the network slices at the run-time, and grant access to the corresponding slice to the vendors and the users.

9. Implementation and Testbeds

9.1 Requirements Specification

- **Compliance:** The testbed must comply with the ETSI NFV MANO reference architecture and 3GPP specifications
- **Inter-domain Networking:** The testbed should allow cross cloud-domain networking (between access, edge and core clouds)
- **Protection:** The testbed should ensure strong isolation between slices

- **On-demand QoS:** The testbed should allow QoS control to meet the requirements of different slices
- **Heterogeneous UE:** The testbed should allow attachment and detachment of various end user devices according to their requirement specifications
- **IP Registration:** The testbed should allow registration of IP addresses of all VNFs to the DNS server
- **Elasticity:** The testbed should allow dynamic slice creation and termination across multiple cloud deployments (edge and core clouds)
- **Recursion:** The testbed should allow creating a new network slice out of other slices

9.2 Virtualization Technologies

The 5G core network can be implemented on various virtualization technologies such as VMware, KVM and LXCs. Unlike VMs (VMware and KVM), LXCs share the kernel with the OS which enables deployment of more containers as all resources are dedicated to a single OS than in the case of VMs where there is more than one OS running on the same host. This opens unprecedented opportunities such as deploying a fully-fledged 5G core on a resource-constrained environment such as Raspberry Pi. However, VMs are ideal to ensure strong security and isolation at the hardware abstraction layer. Between KVM and VMware, KVM has been a prevalent choice of virtualization platform because it is open-source and is tightly integrated with the host OS.

9.3 Virtual Infrastructure Manager (VIM)

For control and management of NFVI resources, VIMs such as AWS and OpenStack are recommended. These VIMs are keys to enable network slicing through multi-tenancy. OpenStack has been widely adopted in industry because it is open source, has support for deployment of private clouds on commodity hardware, has open APIs for integration with SDN controllers and NFV orchestrators, and are well supported by the community. This VIM constitutes various services such as networking (code-named neutron), identity (code-named keystone), compute (code-named nova), image service (code-named glance), telemetry (code-named ceilometer) and orchestration (code-named heat). OpenStack can be used with both type 1 and 2 hypervisors such as VMware, qemu, KVM and LXC. Below is a contextualized overview of the most popular OpenStack's services with respect to network slicing.

- **Identity Service (Keystone)** is used for authentication and authorization of users and services. It is capable of integrating with third-party directory such as LDAP. This service provides a catalogue of all services and endpoints. It facilitates the creation of new tenants and roles. In the context of slicing, this is key to ensuring slice differentiation and isolation
- **Image Service (Glance)** is responsible for the registration, discovery and retrieval of virtual disk images. The images are virtual copies of hard disks and can be of different formats such as qcow, iso, raw, and vmdk. Leveraging this

service, VNFs of the 5G core can be instantiated "on-the-fly" using their respective images

- **Compute Service (Nova)** responsible for deploying and maintaining virtual machine instances as well as managing their life cycles
- **Telemetry Service (Ceilometer)** is responsible for monitoring OpenStack services to gather event and metering data for various telemetry use cases. It also monitors usage of compute resources by tenants for billing purposes
- **Orchestration Service (Heat)** responsible for life-cycle management of virtual machines, floating IP addresses security group, volumes, etc. It enables dynamic instantiation of instances and uses Heat Orchestration Templates (HOT) to describe the infrastructure for an application. However, this orchestrator is not yet ETSI NFV MANO compliant and is thus not ideal for VNFs
- **Networking Service (Neutron)** provides networking as a service for the OpenStack. It enables connectivity for the virtual instances. Leveraging this service, tenant can create complex virtual network topologies which may include services such as firewall (FaaS), Load balancing (LaaS) and virtual private networks (VPN).

9.4 Management and Orchestration

A plethora of NFV orchestrators designed to comply with the ETSI NFV MANO reference architecture have been proposed both in industry and academia. These include OpenBaton, OpenMANO, ONAP and OPNFV. These orchestrators are responsible for lifecycle management and orchestration of a diverse ecosystem of VNFs, using their EMS and VNF Manager. Using these orchestrators, operations such as VNF instantiation, function chaining, QoS policy configuration and VNF termination are automated. At this juncture, OpenBaton has emerged as a prevalent choice in the research community. This is primarily because it has a small open source codebase and includes a generic VNF manager. Moreover, OpenBaton has major support for the OpenStack VIM. For VNFM integration, OpenBaton exposes message queues, RESTful APIs and SDKs programmed in various programming languages. To enable dynamic network slicing, a network slicing engine should be integrated to the NFV Orchestrator (NFVO) via OpenBaton's SDK. OpenBaton relies on VNF Descriptors (VNFD) of network functions for on-demand orchestrated instantiation of VNFs. VNFDs provide metadata to describes the VNF properties such as its name, virtual deployment unit, virtual compute resources (CPU cores, RAM and disk storage), virtual links (internal network to connect the VNF to the VIM) and lifecycle events (the necessary step to execute when deploying VNF on VM such as boot, instantiate, configure and terminate).

9.5 OpenStack Deployment

Figure 16 below illustrates a simple deployment of a sliced 5G core on a minimal OpenStack setup. The environment setup for this implementation constitutes two compute nodes and a controller node (each having 16GB RAM, 8 cores and 1TB HDD) sitting behind a firewall. Each VM running a component of the 5G core (e.g., AMF) is instantiated with different compute resources depending on how resource intensive it is. For instance, the AMF component is resource intensive and requires a minimum of

2 virtual CPUs and 2GB RAM. To support strong isolation between 5G slices, OpenStack's identity service and OpenBaton's SDN controller integration is used. For lifecycle service orchestration, auto scaling and fault management, OpenBaton is integrated. A slicing engine is included as part of OpenBaton's SDK for dynamic slice instantiation and termination. For networking between the VNFs, OpenStacks networking service (Neutron) is "preconfigure". In order to ensure optimal performance, a type 1 hypervisor (bare metal) is recommended. RabbitMQ message queue is used to facilitate operations between services. A management network is setup for the exchange of control traffic between VNFs.

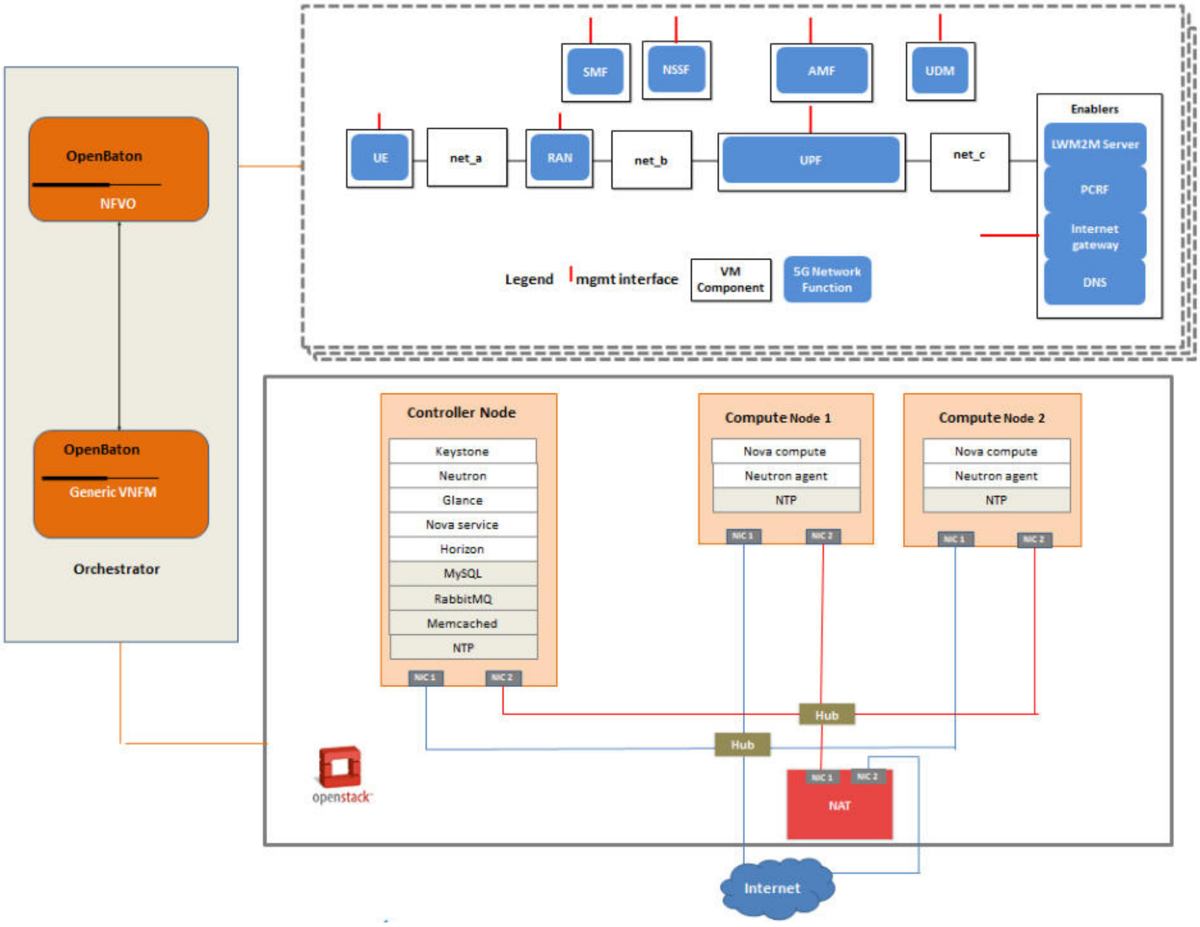


Figure 16. Minimal Deployment of 5G core on OpenStack.

10. Business and Economic Models (and Considerations) of Network Slicing

Understanding the technologies for network slicing and its operational framework is vital to network providers to evaluate economic position before investing money for those slicing frameworks. However, there could be a strong need to update technical and policy regulations so that the service provisioning through network slicing guarantees QoS/QoE and adheres to government regulations. This section describes network slicing value proposition and highlights slicing impacts over OPEX and CAPEX. Considerations will involve cost analysis framework with specific consideration to two market players, i.e., the infrastructure provider which is the technology infrastructure provider and the tenants, which lease the network slice from the provider for specific service deployment.

10.1 Network Slicing value Proposition

Network slicing offer benefits such as the flexibility to provide variety of services to a wide range of customer base and the deployment of network functions as required. Understanding the technologies for network slicing and its operational framework is vital for network providers to evaluate economic position before investing money on those slicing frameworks. Business and economic models for traditional networks are built based on Operational Expenditures (OPEX) and Capital Expenditures (CAPEX) which are estimated based on number of, for example, base stations, network capacity and transmission power. For 5G sliced networks, this method is not appropriate, because each network resource can be shared by several other network slices, sometimes, with each resource following a different slicing technique.

Business models for network slicing are considered from two different perspectives, namely, from Own slice implementation and resource leasing for outsourced slices. In Own slice implementation, network operator implements slices from their own network infrastructure/resources to offer services. In resource leasing for outsourced slices, network operator rents resources from another operator to create their slice or rent a slice from infrastructure owner to provide services. Before considering these models, an operator may need to decide the facet of their slicing to provide services; for example, slicing for sharing network infrastructure or slicing to provide Quality of Services (QoS). Slicing for infrastructure sharing is purely intended for enabling sharing of infrastructure for different service providers. The infrastructure owner is the slice owner and the service provider is the slice tenant. The tenant has full control of the slice and the infrastructure. In contrast to traditional business models, the infrastructure owner method follows the wholesale provider concept. Slicing for QoS is ideally for providing various services and to guarantee different QoS within each slice as required by end users/tenants.

In order to efficiently come up with relevant business and economic modeling framework which can derive relevant costing and pricing models and generate revenue for sliced networks, while at the same time making resource management structured, the impacts of network slicing on OPEX and CAPEX have to be understood.

10.2 Network slicing impact over CAPEX

CAPEX for a network is classified as the costs incurred by obtaining physical, non-consumable assets or upgrading physical assets [19]. These costs include, for example, the land and building costs, initial software costs, operational network upgrades costs, etc. Network slicing is based on virtualization, flexible network function placements, and effective resource utilization which have the potential of reducing CAPEX. Some of the factors that can have impact on CAPEX include:

- **Operational network upgrades costs**: Since sliced networks are managed and controlled by SDN based network controllers and orchestrators, which have global view of the network, resource utilization and management is greatly improved. Therefore, there won't be a need for network over provisioning which can reduce CAPEX.

- **Simpler and cheaper network devices:** Network devices employed in 5G sliced networks would be simpler and cheaper white boxes since complicated features which are usually implemented by proprietary vendors won't be needed.
- **Additional network components:** As additional components, the 5G sliced networks include the controller and orchestrator hardware, controller and orchestrator software together with software licenses if not using open source software.

10.3 Network Slicing impacts over OPEX

OPEX is classified as the costs for operating and running a network on a daily basis [20]. These expenses include, for example, the costs for running network, network setup costs, and energy costs of infrastructure, provisioning and service management and others. Some of the network slicing impacts over OPEX are:

- **Service provisioning costs**: In 5G sliced networks, this cost is anticipated to be lower because of the automated configuration and less human intervention and manual configurations
- **Energy costs**: Due to heavy reliance on SDN and NFV technologies, 5G sliced networks utilize virtualized switches which are controlled via a centralized control plane. Therefore, this leads to less energy usage by the switches as compared to switches with fixed control plane
- **Maintenance and management costs**: In most cases, the 5G sliced network would be based on software, and different vendor-dependent devices won't be needed. Therefore, maintenance would mainly be based on software fixes which can be remotely handled.

10.4 Considerations for Network slicing cost analysis

The initial cost to transforming networks into logical slices is rather steep as it typically requires software upgrades to the control plane, which should get even cheaper and easier with SDN and OpenFlow. The upside to deploying slicing is huge for the service providers. The service providers can offer slices for industry verticals and individual organizations and guarantee an agreed QoS in return for differential billings. Thus, rather than billing at flat rate for everybody for the best effort network, now they can charge more while controlling traffic at the ingress and optimizing their aggregate revenue. When organizations are enabled to define and configure their own slices, the upside is even bigger as a lot of operations and management is out-sourced to the customer or a third party. However, there is some scepticism whether there is sufficient business to transform networks to support slicing given the amount of investment that is required. For example, PPDR (Public Protection and Disaster Relief) is a perfect candidate for a network slice for use by the first responders, but major operators find that there is not yet a justifiable business case. Also, with lack of support in the 3GPP at the present time, it would probably be addressed in B5G evolution timeline of 5G.

11. Future Directions and Long-Term Aspects of Network Slicing in B5G Systems

Network slicing is a very powerful concept and is similar to VLANs invented in the 1980's, as individual slices of Internet allocated for different purposes and different organizations on an end-to-end basis. The major value is derived from leveraging the same common transport infrastructure, which in some ways is similar to virtualization and cloud computing. However, slicing orchestration and its integration with SDN and NFV is going to be the key to its success. It is not going to be easy to operationalize slicing on an end-to-end basis across different network domains and national boundaries. Therefore, issues of policies, regulations, standards, and legal jurisdictions will need to be addressed and harmonized to fully realize the potential of network slicing. Traffic management at the ingress and fair resource allocation across slices on-demand will need to be done, including complete isolation for the reasons of security and legal compliance. Longer-term it would be possible to move resources from one lightly loaded slice to the other heavily loaded slice automatically while being active. It is anticipated that the slice(s) will extend all the way to the UE (user equipment).

Despite significant opportunities and progress, there remain many challenges for operators and developers, summarized as follows: (i) RANs will need to be redsigned to accommodate slicing, (ii) Adaptation or shim layer above the core network is needed or standardized for the transport networks across operator domains and Internet backbone for seamless configuration between the two RANs connecting the end users, (iii) Slicing orchestrators across the E2E network would need to work harmoniously with the master orchestrator for an E2E network slice and in concert with the principles of SDN and NFV, (iv) Need for consensus in the industry on 5G network slicing deployment and interoperability with other architectural elements of the network, such as mobility management, operations, administration, management, and provisioning, and (v) Logistical challenges for the operators to deliver and maintain SLA, QoS, managing sliced spectrum resources, and security assurances in a dynamic environment when the same physical infrastructure is sliced into many end-to-end networks.

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