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NETWORK SLICING OVERVIEW

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Contents

Acronyms

AF Application Function.

AN Access Network.

API Application Program Interface.

BH Backthaul.

CN Core Network.

CP Control Plane.

CSMF Communication Service Management Function.

E2E End to End.

EM Element Management.

eMBB enhanced mobile broadband.

EPC Evolved Packet Core.

FH Fronthaul.

IaaS Infrastructure-as-a-Service.

IC Infrastructure SDN controller.

InP Infrastructure provider.

KPI Key Performance Indicators.

MANO Management and Orchestration.

mMTC massive machine-type communications.

MNO Mobile Network Operators.

MTA Multi-Tenancy Application.

N3IWF Non-3GPP InterWorking Function.

NBI Northbound Interface.

NEF Network Exposure Function.

NF Network Functions.

NFV Network Functions Virtualization.

NFVI Network Functions Virtualization Infrastructure.

NGMN Next Generation Mobile Networks.

NMS Network Management System.

NRF NF Repository Function.

NS Network Services.

NSIL Network Service Instance Layer.

NSMF Network Slice Management Function.

NSO Network Service Orchestrator.

NSSF Network slice selection Function.

ONF Open Networking Foundation.

OSS/BSS Operation/Business Support System.

PCF Policy Control Function.

QoE Quality of Experience.

QoS Quality of Service.

RAN Radio Access Network.

RO Resource Orchestrator.

SBI Southbound Interface.

SDN Software Defined Network.

SIL Service Instance Layer.

SLA Service Level Agreements.

TC Tenant SDN controller.

UDR Unified Data Repository.

UP User Plane.

URLLC ultra-reliable low-latency communications.

VI Virtual Infrastructures.

VIM Virtual Infrastructure Manager.

VM Virtual Machines.

VNF Virtual Network Functions.

VNFM Virtual Network Function Manager.

1 Introduction

Mobile networks are a fundamental topic for modern society because they guarantee communications and access to information on a tap of our fingers. Furthermore we expect that the data flowing per month will be around 50 exabytes and this is caused mainly by video services. Indeed in the last years, mobile operators are moving from a voice-oriented infrastructures to data-oriented ones and they cannot keep pace with the calculated traffic volume. Facing such new problems, operators have invested a lot in research efforts toward the designing of the Fifth Generation mobile architecture, in order to provide innovative solutions for new capabilities and incoming cash flow sources. Network slicing is one of proposed innovation to push forward the frontier of mobile communications and it will discussed in this overview.
5G Network slicing permits Mobile Network Operators (MNO) to share physical infrastructures they have to the simultaneous deployment of multiple independent logical networks, managed with respect to their specific service requirements. For example, different services like automotive, tactile internet or massive IoT can be put in practice by exploiting different network slice instances, that is a set of virtual network functions that run on the same infrastructure with customized policies. Thanks to that, heterogeneous requirements can run on the same infrastructure, since different instances can be orchestrated and set independently according to the specifics requested. Furthermore, this is executed in a costly efficient way because as the a network slice shares the same physical infrastructure with different slices.
A network slice is defined by Next Generation Mobile Networks (NGMN) as "*a set of network functions, and resources to run these network functions, forming a complete instantiated logical network to meet certain network characteristics required by the Service Instance(s)*".
According to NGMN, the concept of network slicing is ideally composed by: the Service Instance Layer (SIL) that involves the business/end user services provided by operators or by the party which leases the services by the operators; the Network Service Instance Layer (NSIL) is set of functions to run the instances and the resource layer, which consists of the resources such as compute, network, memory, storage.
The target of slicing is to realize End to End (E2E) network slices from the mobile edge, through the mobile transport (Fronthaul (FH)/Backthaul (BH)) and up until Core Network (CN).
The two main tools needed to allow different degrees of control and automation in NSIL and resource layers are: the Virtual Infrastructures (VI) under the control and operation of different tenants in agreement with an

Infrastructure-as-a-Service (IaaS) model[1] to split information from used hardware; Network Services (NS) owned by tenants, that is actually creation of a service instance. The VIs can be operated by Software Defined Network (SDN), NS are instantiated directly over a shared infrastructure and as a set of Virtual Network Functions (VNF) connected through one or more VNF forwarding graphs are necessary to define the life cycle of the slice; both of them will be discussed later.
Multi-tenancy is an characteristic that must be achieved to guarantee separation, isolation, and independence between different slices decoupled from the shared underlying resources.

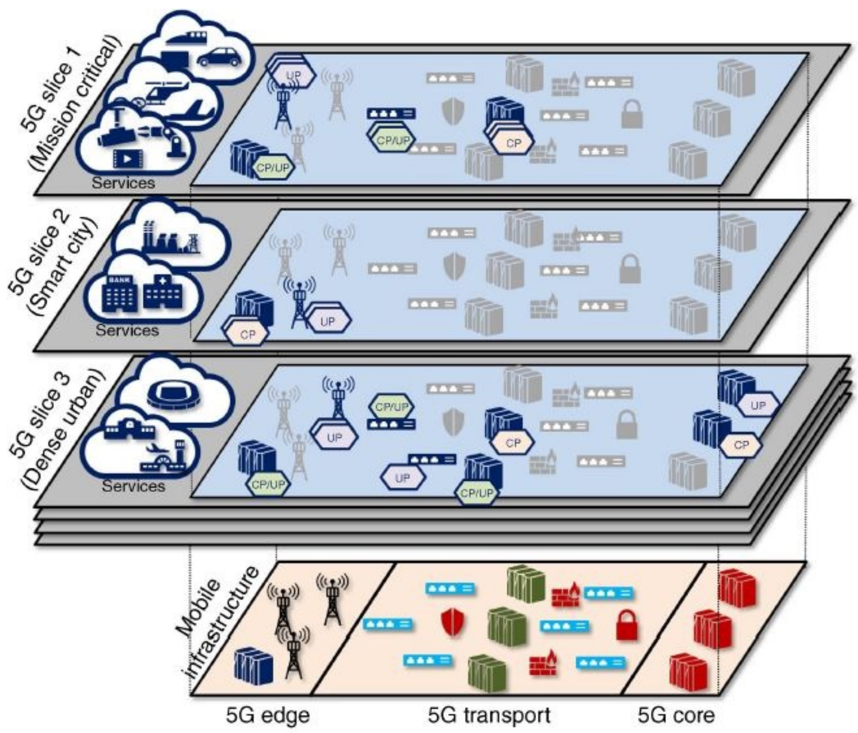

Figure 1: Example of network slicing in 5G. [1]

After this general overview this essay will treat accurately all the necessary fundamental components in order to fully understand how 5G network slicing is planned actually to be built. [1] [6]

[1]Form of cloud computing providing computed and virtualized resources over the internet

2 Structural components

Starting from how an architecture for network slicing is conceptually made, it will be explained what it should achieve and involve, that is, the aspects of modularization, resource virtualization, virtual infrastructure and NS management; they will be the main topics of this section. As anticipated about

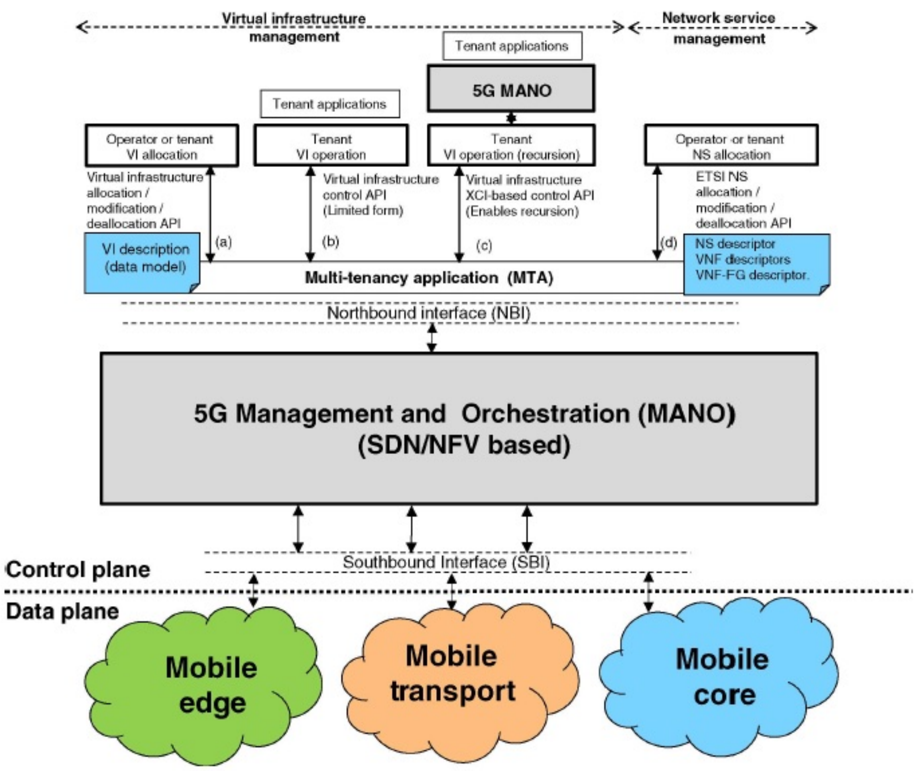

Figure 2: Architecture for network slicing. [1]

virtualization of the infrastructure, the SDN design is proposed in Fig. 2 and follows the principles of:

- data and control plane fully decoupled;
- control logically centralized;
- applications having an abstracted view of resources and states.

The data plane is actually the resource layer where mobile edge, mobile transport, and core are present. The infrastructure is made of links, forwarding

nodes like a router or a switch, cloud nodes and a set of network, computing and storage resources.
The control plane is divided into two layers: an application layer at the top and at the bottom the Management and Orchestration (MANO).
The design of the MANO is based on the ETSI management and orchestration of the network by means of a framework exploiting SDN-based control. The MANO provides a panoramic of the resources available by means of Northbound Interface (NBI), instead it is linked to data plane entities by means of Southbound Interface (SBI) to execute control and management functions on the actual hardware components (possible application to do the job are OpenFlow, SNMP, OVSDB). For what concerns the Multi-Tenancy Application (MTA), it realizes the multi-tenancy support because it applies a coordination of the tenants accessing the infrastructure shared by the clients: so in order to do that it performs isolation of resource assigned to various instances of different tenants, and implements services related to allocation and operation of VIs using some dedicated Application Program Interface (API)[2].
As shown in Fig. 2 the choice of APIs depends on the kind of service. [1] [7]

2.1 Enablers and Design Principles

Future 5G networks will be built on concepts absolutely not related with the previous generation network architectures. In the Fifth generation a revolution is actually provided by the introduction of SDN and Network Functions Virtualization (NFV)[3] opening the doors to a new huge number of applications, recalling that the latter focuses primarily on optimization of the network services, instead the former to separate the control and forwarding plane for a centralized view of the network.
The fundamental parts involved in the network slicing realization for the future 5G networks are now discussed.

2.1.1 Modularization and Function Decomposition

The idea to modularize the architecture and to decompose the network functions has been enunciated at the beginning stages of research in order to fulfill the above requirements.
Network Functions (NF)s are the entities that furnish specific network capabilities in order to realize and support the requested services. Generally they

[2] it is the code that permits softwares to create a communication among each other.

[3] Although NFV and VNF are often used without distinction, for the sake of clarity NFV is a general concept, instead the VNF is a building block of the NFV framework.

are software instances acting on infrastructure resources, but can be physical, a combination of them or virtualized, that is decoupled from the hardware it runs on; the last peculiarity will be fundamental. The general ”monolithic” network functions (4g as well) are proposed to be split into basic modules, both for the Control Plane (CP) and User Plane (UP), allowing the definition of different logical architectures by means of the interconnection of different subsets of NFs for CP and UP.
To realize the highest level of decomposition possible, it is necessary to affirm a strong distinction between NFs of the Access Network (AN) and CN, in order to achieve what is called a convergent network[4]; AN/CN split is mandatory to reach the essentials to support network slicing. [1] [6]

2.1.2 Virtualization

Virtualization is a main process in the network slicing architecture, because it allows to share effectively the resource among the various slices and it operates the abstraction of resources. Abstraction means the representation of the characteristics of the underlying resources in order to recreate a virtual scenario with same peculiarities.
The resources to be virtualized can be physical or already virtualized, generating a recursive structure in the system counting different abstraction levels. Exactly like server virtualization makes Virtual Machines (VM)s make them free from the physical hardware, network virtualization allows to generate multiple isolated virtual networks, completely independent from the physical network and it can run over it. The framework consists of three actors:

- Infrastructure provider (InP): owner or a manager of the physical network. It offers resources to be virtualized and delivered to a single or multiple tenants.

- Tenant: leaser of the virtual resources from the InPs, which exploits to provide the necessary network services to the users.

- End user: who uses the services supplied by the tenant.

[3] [8] [6]

[4]It is the coexistence of different kind of information to transmit, actually voice, video and data, within a single network.

2.1.3 Orchestration

Orchestration is another key point to realize slicing and accounts the problem of allowing the coexistence and organizing all the constitutive elements of the architecture. In a such scenario, where the entities involved are so various, the so called orchestrator, is needed to coordinate the different services related to all the assigned requirements.
The Open Networking Foundation (ONF) defines orchestration as "*the continuing process of selecting resources to fulfill client service demands in an optimal manner*". This means that a policy to handle the orchestrator behavior is required and which is expected to satisfy the service level agreements Service Level Agreements (SLA)s associated with clients requirements. This also has to remember that the available resources, the demands and optimization criteria may change in time.
Noteworthy is that orchestration is also referred to as the defining characteristic of an SDN controller. Orchestration process is not performed by a unique and central unity due to its complexity, but also because we want to maintain management independence and support recursion. Then a framework in which an entity performing orchestration functions is more suitable for the general architecture. [8] [6] [10]

2.1.3.1 Isolation

A effective isolation is, of course, an important requirement that must be fulfilled to let parallel slices run on a common underlying substrate. The isolation must be understood in terms of:

- Performance: each slice is defined to realize specific service requirements, expressed generally as Key Performance Indicators (KPI)s and it must ensure them always regardless of the congestion and performance levels on the others.
- Security and privacy: attacks or issues in a slice must not affect other slices. We say that we want each slice having independent security functions to block unauthorized entities to have access and so reading or writing capabilities on the configuration, management, accounting information.
- Management: each slice must be considered managed as a standalone network, that is as no other slices are present in parallel.

To get the wanted isolation then a set of policies and processes must be defined at each virtualization level, they are lists of rules and settings describing how the various entities have to be isolated; a team play of both virtualization and orchestration is actually needed.[8] [10]

2.1.4 SDN: Software-Defined Network

In a Software-Defined Network the admin or an engineer is able to handle the data traffic remotely exploiting a centralized control without putting hands on particular switches of the network. In this context, the SDN controller tunes the switches in order to deliver the NS wherever they are needed; this is a step away from the classical architecture, where devices take their traffic decisions based on the routing tables.
The SDN architecture is comprehensive of, as previously explained and shown in Fig. 1, an intermediate CP to set and abstract the underlying forwarding plane resources so that ocustom services are furnished to clients. After having said this, it is clear that SDN is a suitable tool for implementing slicing in the 5G architecture.
The main components in a SDN are resources and controllers. Resource is everything useful to provide services as answer to client requests that in this case are the infrastructure resources and NFs; also NS in application of the recursion principle are included. A controller, instead, is the centralized entity implemented at the control plane and it looks for trade-offs among clients and resources because it acts as server and client at the same time via client/server contexts respectively:

- Client context: all the information needed by a controller to manage the transmission to clients. It includes in turn: Resource Group, an abstraction of all the resources offered by the controller to the client via NBIs; the Client support function which contains the necessary to ease client operations, like policies.

- Server context: all the information needed by the controller to operate with a set of underlying resources grouped in a Resource Group via SBIs.

The idea is to transform a Resource Groups set instantiated in server contexts into those defined in client contexts, this indeed requires a SDN controller to virtualize and orchestrate the process.
During the virtualization function, the SDN controller first of all makes the abstraction and the merge or the partition of underneath resources. Then thanks to that, specific Resource Group provided by each client contexts are exploited by the client of that context to accomplish the wanted services. Afterwards, thanks to the orchestration, the SDN controller optimally gives the chosen resources to such separate Resource Groups. So the the services demanded by the clients are guaranteed and at the same time the isolation is maintained among them.

In the proposed architecture for a SDN an admin is present to accomplish the tasks of initialization and setting of controller, of the definition of server and client contexts and of selecting the related policies.
This provides a suitable solution for enabling slicing because the client context completely abstracts the set of resources into a Resource Group and furnishes the control logic that constitute a slice which includes the related client service attributes.
A noteworthy peculiarity that makes SDN ideal for slicing is recursion: thanks to the different abstraction layers that the recursion principle makes possible, the SDN CP may involve multiple controllers in a ranked ordered that enlarge the client-server relationships at more levels. Now it is clear that a SDN architecture does support a recursive composition of the slices and as consequence the resources that a controller brings to a client as a dedicated slice (client context), can in turn be virtualized and orchestrated by the client in the case of being an SDN controller. Hence, the new controller can exploit these resources it has accessed by means of its server contexts to define and bring new resources therefore guaranteeing effectively new slices to the clients. [8]

2.1.5 NFV: Network Functions Virtualization

An SDN architecture is not enough to enable slicing, because it lacks of right capabilities to manage the network slices life cycles an the related resources. VNFs, generally speaking, move NFs out of specific hardware devices into software running on generic hardware; some classic examples of i include firewalls, domain name system and caching. Then, the NFV architecture is suitable to administrate infrastructure resources and to orchestrate the allocation of the necessary resources to get VNFs and NSs.
The main problem is to embrace the right team play cooperation between SDN and NFV, this is not a easy task. ETSI presented a way to join a SDN within the NFV architecture. This framework includes the following entities:

- Network Functions Virtualization Infrastructure (NFVI): all the infrastructure resources necessary to host and make the VNFs operate.
- VNFs: software implementations of NFs running on top of NFVI.
- MANO: entity that operates virtualization management, automation and coordination processes in the NFV architecture. In turn MANO is made of three functional blocks:

- Virtual Infrastructure Manager (VIM): for controlling and managing the NFVI resources.

- Virtual Network Function Manager (VNFM): to configure and run life cycle management of the VNF.

- Orchestrator: we already know who it is but ETSI stated that can actuate two kind of functions performed by Resource Orchestrator (RO) and Network Service Orchestrator (NSO). The former orchestrates the NFVI resources across VIMs and the latter manages the life cycle of NSs using the capabilities provided by the RO and the VNFMs.

- Network Management System (NMS): it performs general processes for management, as MANO, but their tasks are "orthogonal"; NMS comprises:

  - Element Management (EM): anchor point who takes the burden for the so called FCAPS (fault, configuration accounting, performance and security) of a VNF.

  - Operation/Business Support System (OSS/BSS): a set of systems and management applications that providers exploit to provision and operate their NSs; tenants will run them.

The ETSI framework counts two SDN controllers placed at tenant level and at InP level; each of them centralizes the CP functionalities and abstracts the components related to the connectivity that it handles. They can be:

- Infrastructure SDN controller (IC): it configures and coordinates the underneath network resources to provide interaction among the VNFs. It is under control of the VIM and can choose to change infrastructure behavior for satisfying VIM specifications brought by requests of the tenants.

- Tenant SDN controller (TC): set up as a VNFs or as part of NMS, obviously at tenant domain, this controller readily organizes the VNFs to realize the tenant's NS; they are generally triggered by the applications of the OSS.

These controllers on the resource resources via SBI which implements protocols like OpenFlow or NETCONF. Must be underlined that IC furnishes

an "underlay" in supporting deployment and operability of VNFs, the TC instead carries an "overlay" related to VNFs to explicit NSs a tenant can manage on its slices. IC is not conscious of how many slices use VNFs or which tenants. Viceversa, for TC the network is abstracted as VNFs, without which VNFs are physically deployed. This is the right kind of isolation we want
Finally an overall description of the system is given by Fig. 3. [8] [3]

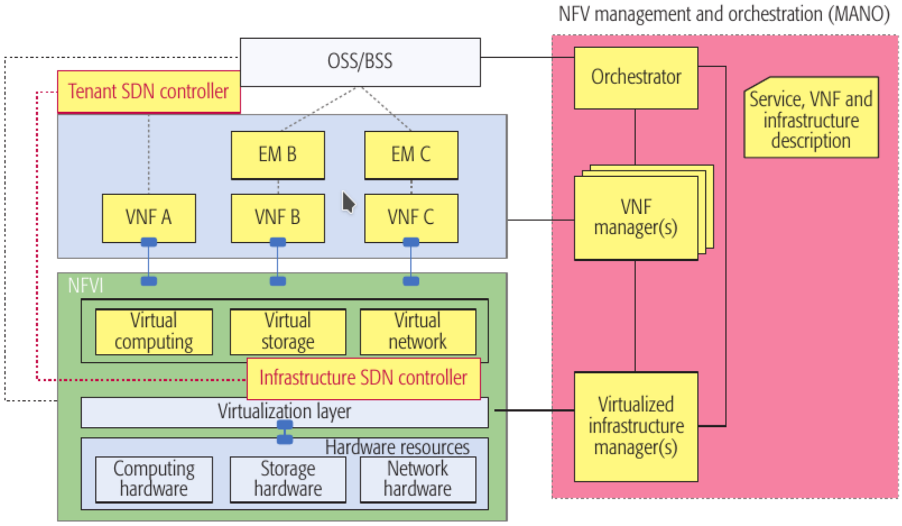

Figure 3: Integrating SDN controllers into the reference NFV architectural framework. [8]

3 Network Slicing

Now we have all the players to look inside what NGMN has proposed as the concept of network slicing. The previous telecommunication generation hosted different services as mobile broadband, voice and SMS over the same network architecture, 5G networks will allow shared and customized logical architectures to fulfill the requirements of vertical services as enhanced mobile broadband (eMBB), vehicular communications, ultra-reliable low-latency communications (URLLC), and massive machine-type communications (mMTC). These services request different KPIs hardly fulfilled by 3G-4G systems because they are characterized by network elements with strongly coupled at level of hardware, software, and functionalities.
As we previously said, 5G architectures must work on the decoupling of software-based NFs from the above infrastructure resources by means of various resource abstraction technologies. Then, exploiting modularization, some resource sharing technologies the actions of multiplexing and multitasking in general which actual example are wavelength division multiplexing or radio scheduling, can be supported by NFV and SDN in software manner techniques to share the not virtualized physical infrastructure.

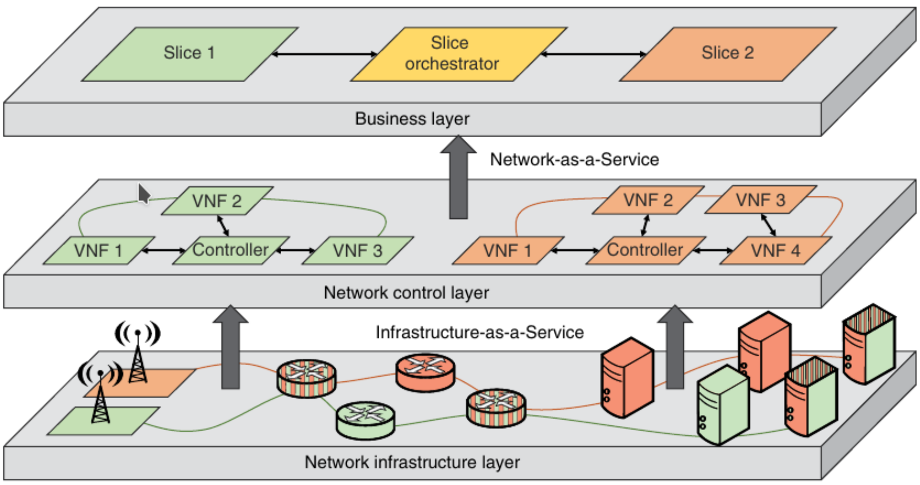

Figure 4: An example of a network-sliced architecture. [1]

Completely decoupled E2E networks can be built over a common and shared infrastructure and in turn multiplexing will not be at infrastructure level (and not anymore at network level), as depicted in Fig. 4, carrying out better Quality of Service (QoS) or Quality of Experience (QoE) because slices with different peculiarities will be customized for specific services.

The concept of network slice says that it is a logical network providing tailored network characteristics and including NFs, enhanced computing and networking resources to fulfill the KPIs the tenants ask. This involves Radio Access Network (RAN) and CN NFs that can include MANO components depending on the degree of freedom a tenant wants to achieve. Thanks to isolation, network slice can be offered to a single tenant or shared by multiple tenants having same requirements but different policies or security settings. The hardware/software decoupling allows an efficient slice scaling easing the economic feasibility of this architecture because it can be dynamically and smartly adapted to demanded resources.
The 5G atom proposed in Fig. 5 summarizes the discussion: in the middle the possible use cases; from the center outwards the layers list the requirements for the cases, the enabling concepts for operators to get the requirements and the technologies to implement them. [1] [4]

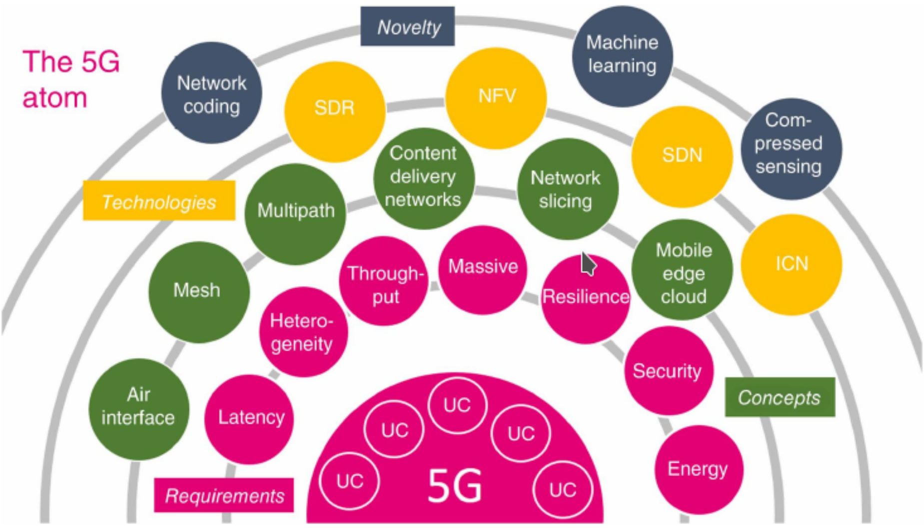

Figure 5: 5G atom representation. [6]

3.1 Main Services Types

The three 5G services considered for the beginning are:

- Enhanced mobile broadband (eMBB): it actually is an evolution of the today 4G network and it is related to operation done by humans with the target to enhance access to multimedia, to give services with improved performance with an increasing QoE. It also has to cope oppisite situations, that is a restricted high density user area with huge traffic and poor mobility of users, and also providing wide area coverage where user mobility is medium or high. Moreover 5G aims to furnish complete coverage everywhere with a guaranteed data rate of 50 Mbps;

- Ultra-reliable and low-latency communications (URLLC): it is necessary where the requirements for latency and reliability are very strict. It will play a fundamental role in the industry 4.0 and indeed involves situation as remote medical surgery, automation industries and smart grids.

- Massive machine-type communications (mMTC): it is the realization an efficient Internet of Things, a huge number of devices are connected transmitting a low volume of data traffic, usually non sensitive of the delay which can be about seconds or hours. In general, this devices must be low-cost with a long lifetime. Some examples are logistics applications, smart metering and agriculture where a lot of sensors are spread around to collect data.

Their 8 most important KPIs are the following:

- Peak data rate: ideal maximum e data rate achievabl per user in bits per second. The minimum requirement is 20 Gbps in downlink and 10 Gbps in uplink;

- User experienced data rate, achievable data rate available on whole coverage area perceived by a mobile user in bits per second. It can be seen as minimum user experience and is set to 100 Mbps in downlink and 50 Mbps in uplink;

- Average spectral efficiency, also called spectrum efficiency, it is the average data throughput per unit of spectrum resource and per cell in bps/Hz/cell. Here, the minimum requirement depends on the environment:

  - Indoor Hotspot: 9 bps/Hz/cell in downlink, 6.75 bps/Hz/cell in uplink;

  - Dense Urban: 7.8 bps/Hz/cell in downlink, 5.4 bps/Hz/cell in uplink;

  - Rural: 3.3 bps/Hz/cell in downlink, 1.6 bps/Hz/cell in uplink.

- Area traffic capacity, only for indoor,it is the total traffic throughput per area in Mbps/m^2, defined only, aiming of 10 Mbps/m^2 for downlink;
- User plane latency, time from when the source have sent a packet to the destination receives it, it is set to 4 ms for eMBB and 1 ms for URLLC;
- Connection density, it is the total number of connected UEs per unit area, it targets 1 billion devices per km^2 for mMTC;
- Energy efficiency, it is the ratio between users bits transmitted/received and energy consumption of the RAN/device to do the job in bits/Joule.
- Mobility, it is the maximum speed at which a defined QoS is guaranteed while UEs is moving between radio nodes. In rural environment, the normalized traffic channel link data rate is 500 km/h.

The following web-spider diagrams in Fig. 6-7, sum up optimally these capabilities and how they have to be split to realize each particular slice. [6] [2] [11] [1]

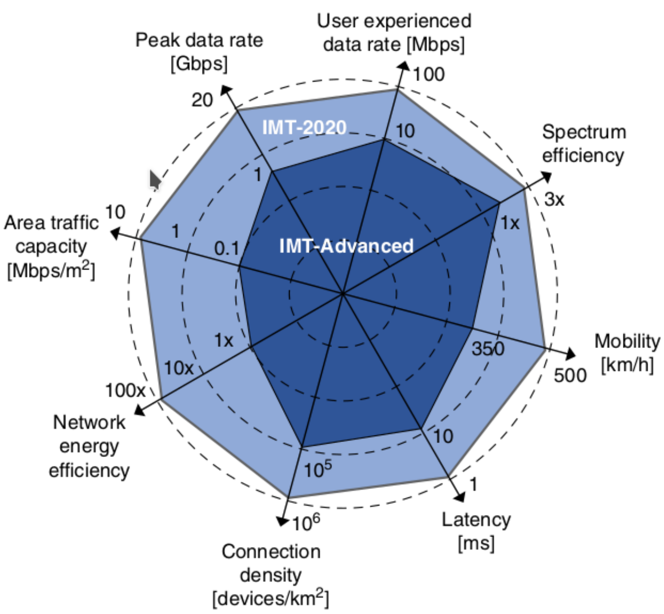

Figure 6: Capabilities to be achieved. [1]

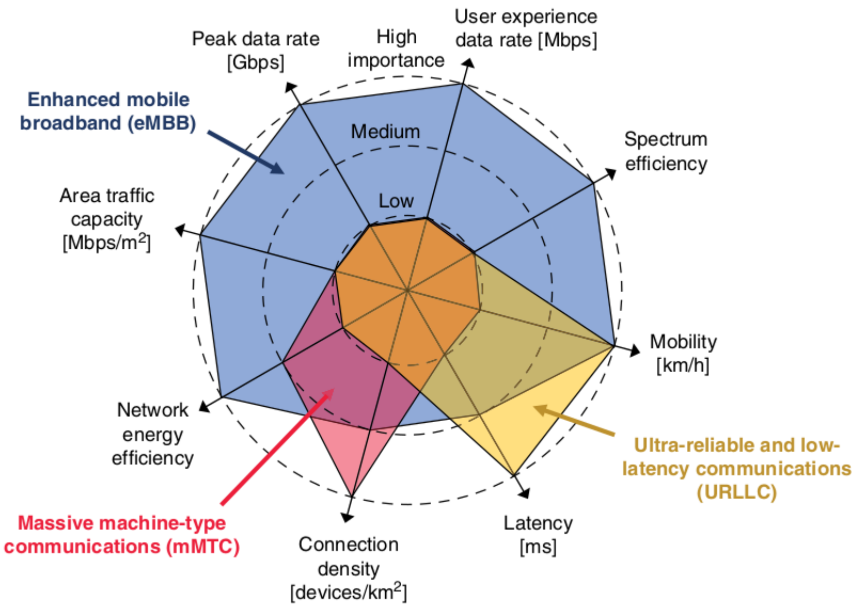

Figure 7: How capabilities are divided for each slice. [1]

4 5G Architecture

3GPP has decided to release 5G specifications into two phases, the Release-15 on August 2018 addressing related to commercial needs and Release-16 is planned for March 2020 to identify all use cases and related requirements. Now, a representation of 5G architecture is shown in order to understand how netowork slicing is implemented; Fig. 8 The CN is modularized and

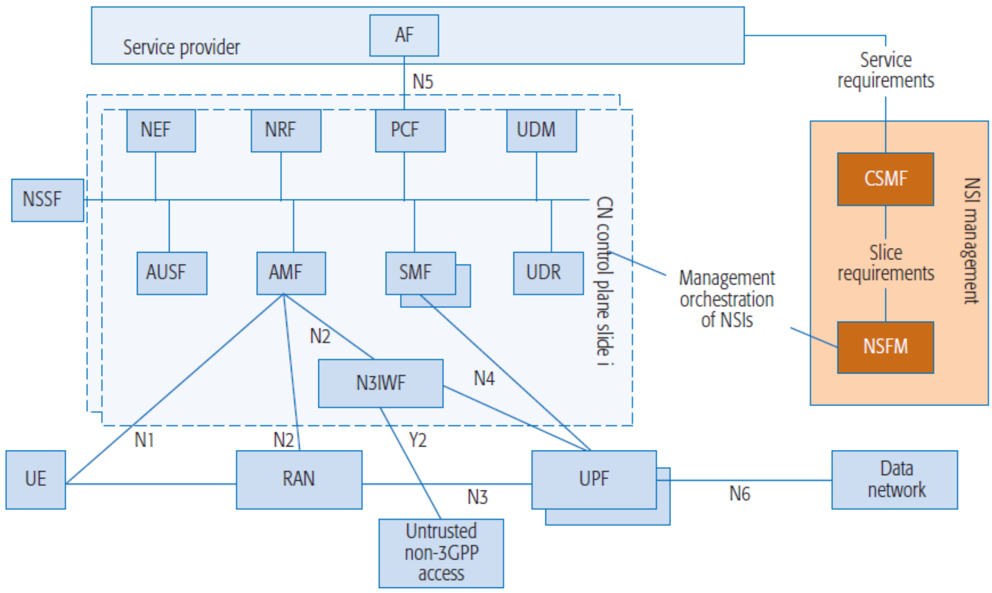

Figure 8: 5G System architecture. [2] [5]

slice NFs areallocated within it. The CP functions are:

- Core access and mobility management function (AMF) necessary to manage mobility, to authenticate and give authorization, for what concerns security functions and context selection;
- Session management function (SMF) handles session management, allocation of IP addresses, selection of UP functions and QoS;
- Policy Control Function (PCF) gives an unified policy framework to govern network behavior and plane functions;
- Network Exposure Function (NEF) makes secure the exposition of the services provided by NFs;

- NF Repository Function (NRF) is a service discovery function exploited by NFs;
- Unified data management (UDM) involves the repository where the authentication credentials are stored and the subscription management;
- Authentication server function (AUSF) supports the authentication server;
- Non-3GPP InterWorking Function (N3IWF) is necessary to support non-3GPP access networks;
- Unified Data Repository (UDR) stores subscription and policy data;

The architecture also contains the following functions:

- User plane function (UPF) is an anchor point for mobility, it is mandatory for packet routing and forwarding and define QoS for the UP;
- Network slice selection Function (NSSF) necessary to tie UE to a specific slice;
- Application Function (AF) influences traffic routing, accesses the NEF, interacts with PCF;

5G allows UEs to access multiple slices at the same time, but an only AMF will be involved for all slices; 8 slices in parallel is the limit. To recognize the slices, the network slice selection assistance information and the slice differentiator are exploited; the former is a slice/service type, necessary to recognize the NFs contained in a slice, and the latter is used to distinguish among multiple slices of the same type. 3GPP has standardized slice/service type values for eMBB, for URLLC and for mMTC. Therefore, CN is responsible to authorize the attachment of UE to a slice.
The management functions are called Communication Service Management Function (CSMF) and Network Slice Management Function (NSMF). The first translates the service requirements for communication to network slice requirements: we are talking about capacity, throughput, delay, number of users, etc.. The second takes care of the life cycle of a slice. In general it consists of the phases:

- Preparation phase;
- Instantiation, configuration, and activation phase;
- Runtime phase;

- Decommissioning phase;

The first phase is related to the creation of a slice template. During the second phase, all NFs and resources are allocated and set up. During the third a network slice is operating its functions. The last phase concerns the deactivation of a slice and the deallocation of the resources. [5] [2]

5 Conclusion

In this work has been given a general and as complete as possible overview of the novel technology of network slicing, starting from necessary concepts and the techniques to implement them arriving to the description of their functions and their requirements defined by ETSI. Then it has been investigated how the network slicing will be inserted in the future 5G architecture.

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