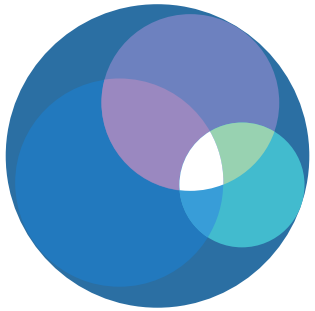

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5G SDN/NFV軟體研發技術與實務

SDN/NFV and Network Slicing

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Department of Computer Science
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September 23, 2021

Outline

- **Network Slicing and Its Enabling Technologies**
- SDN-enabled Network Slicing
- NFV-enabled Network Slicing
- Network Slice Template and Deployment
- Toward 5G End-to-End Network Slicing
- Open Sources for Network Slicing
- Outlook

Concept of Network Slicing (1)

The concept of “5G network slicing” was first proposed by the NGMN* Alliance in its 5G White Paper in 2015.

It said,

- A network slice, namely ‘5G slice’, supports the communication service of a particular connection type with a specific way of handling the C- and U-plane** for this service.
- To this end, a 5G slice is composed of a collection of 5G network functions and specific RAT*** settings that are combined together for the specific use case or business model.
- The flexibility behind the slice concept is a key enabler to both expand existing businesses and create new businesses.
- Third-party entities can be given permission to control certain aspects of slicing via a suitable API, in order to provide tailored services.

Source: NGMN 5G White Paper [1]

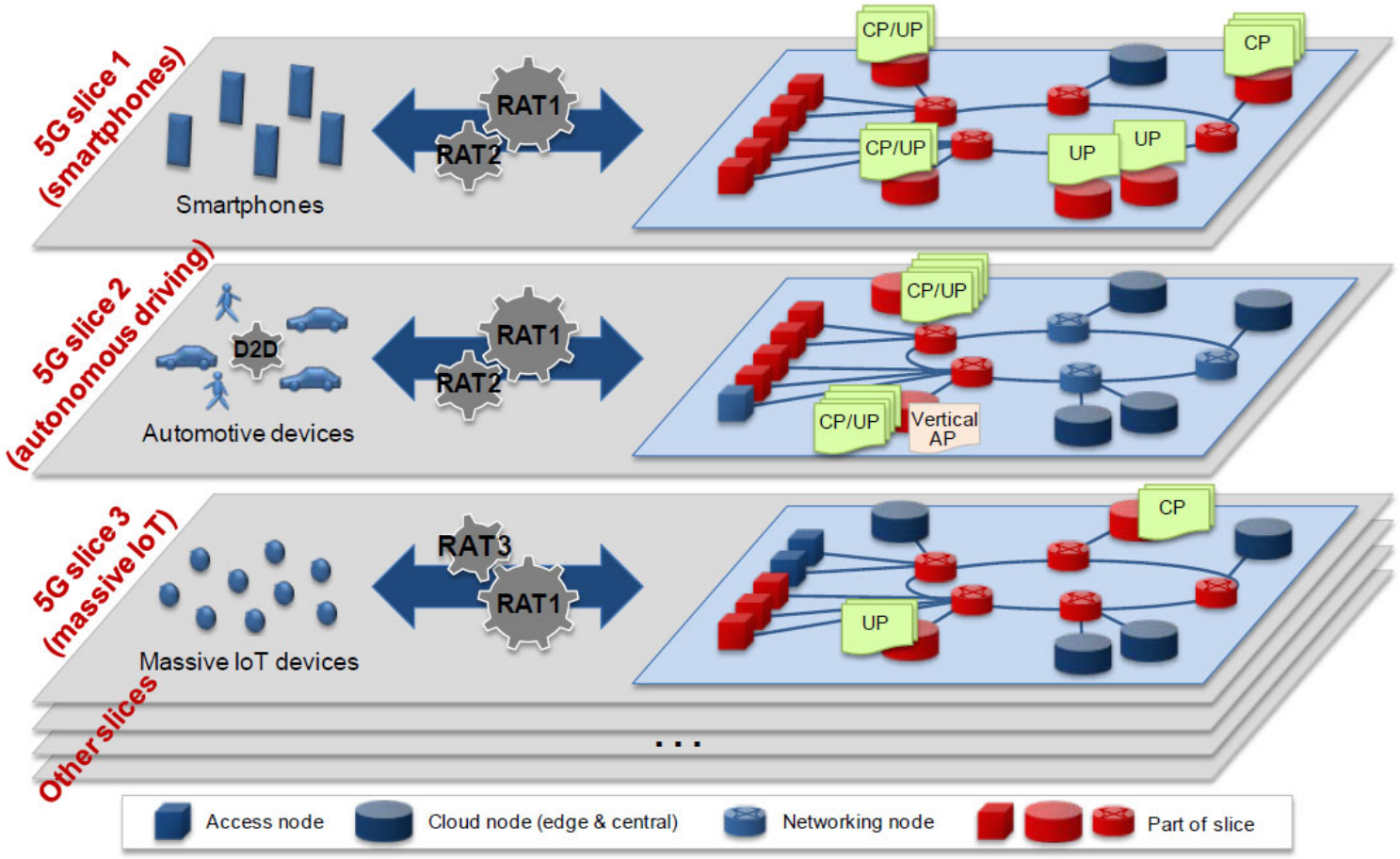
*NGMN - Next Generation Mobile Networks
**C- and U-Plane - Control and User Plane
***RAT - Radio Access Technology

Concept of Network Slicing (2)

- **5G network slicing** is a network architecture that enables the multiplexing of virtualized and independent logical networks on the same physical network infrastructure.
- Each network slice is an isolated end-to-end network tailored to fulfil diverse requirements requested by a particular application.
- For this reason, this technology assumes a central role to support **5G mobile networks** that are designed to efficiently embrace a plethora of services with very different service level requirements (SLR).
- The realization of this **service-oriented view of the network** leverages on the concepts of **Software-Defined Networking (SDN)** and **Network Function Virtualization (NFV)** that allow the implementation of flexible and scalable network slices on top of a common network infrastructure.

Source: Wikipedia

Examples of 5G Network Slices



Source: ngmn 5G White Paper [1]

Enabling Technologies of Network Slicing

- **Software-Defined Networks (SDN)**
  - Advocated by Open Networking Foundation (ONF)
  - Mainly used for slicing of transport network
- **Network Function Virtualization (NFV)**
  - Defined by ETSI ISG* NFV
  - Adopted by 3rd Generation Partnership Project (3GPP) for 5G
  - Mainly used for slicing 5G MEC** and Core
- **RAN Slicing Technologies**
  - Enabled by OpenRAN, O-RAN

*ETSI – European Telecom Standards Institute
*ISG – Industry Specification Group
** MEC – Muti-access Edge Computing

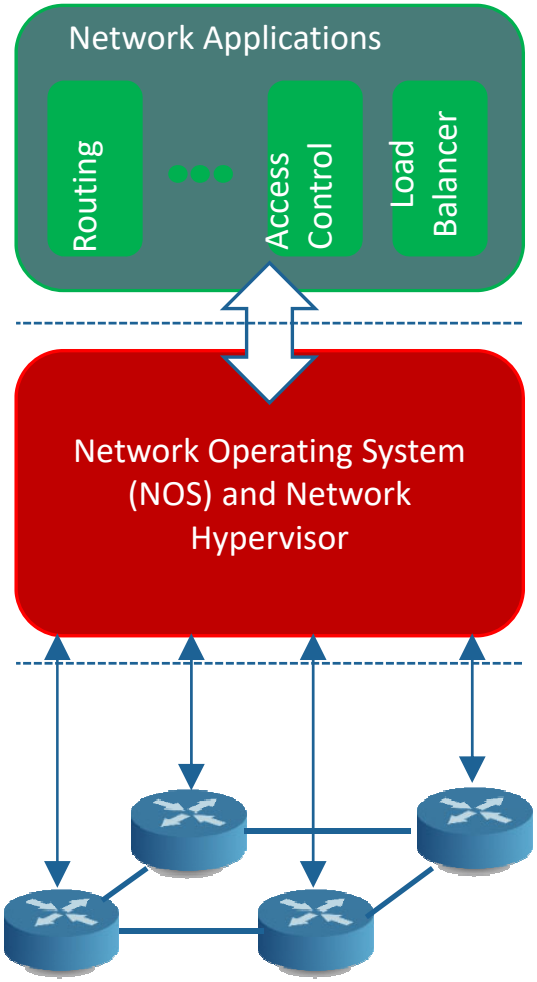
Role of SDN/NFV in 5G

SDN (Software-Defined Network) separates the control plane and the data plane of the network and thus enables network virtualization, softwarization and programmability

NFV (Network Function Virtualization) enables the virtualization of hardware-based network appliances to turn them into software-based network functions

SDN and NFV together are transforming the current networking paradigms to future 5G.

Software Defined Network (SDN)



Control Plane

Virtualization & Softwarization

Data Plane

North Bound Interface - Ad hoc APIs, RESTful APIs, NVP NBAPI, SDMN API

SDN Controller (NOS) - Ryu, ONOS, OpenDaylight, Floodlight, Onix

South Bound Interface - Openflow, OVSDB, SNMP, NetConf

Source: "Software-Defined Networking: A Comprehensive Survey" in Proceedings of IEEE, January, 2015. [2]

Software Defined Network (SDN)

Three major functions simultaneously

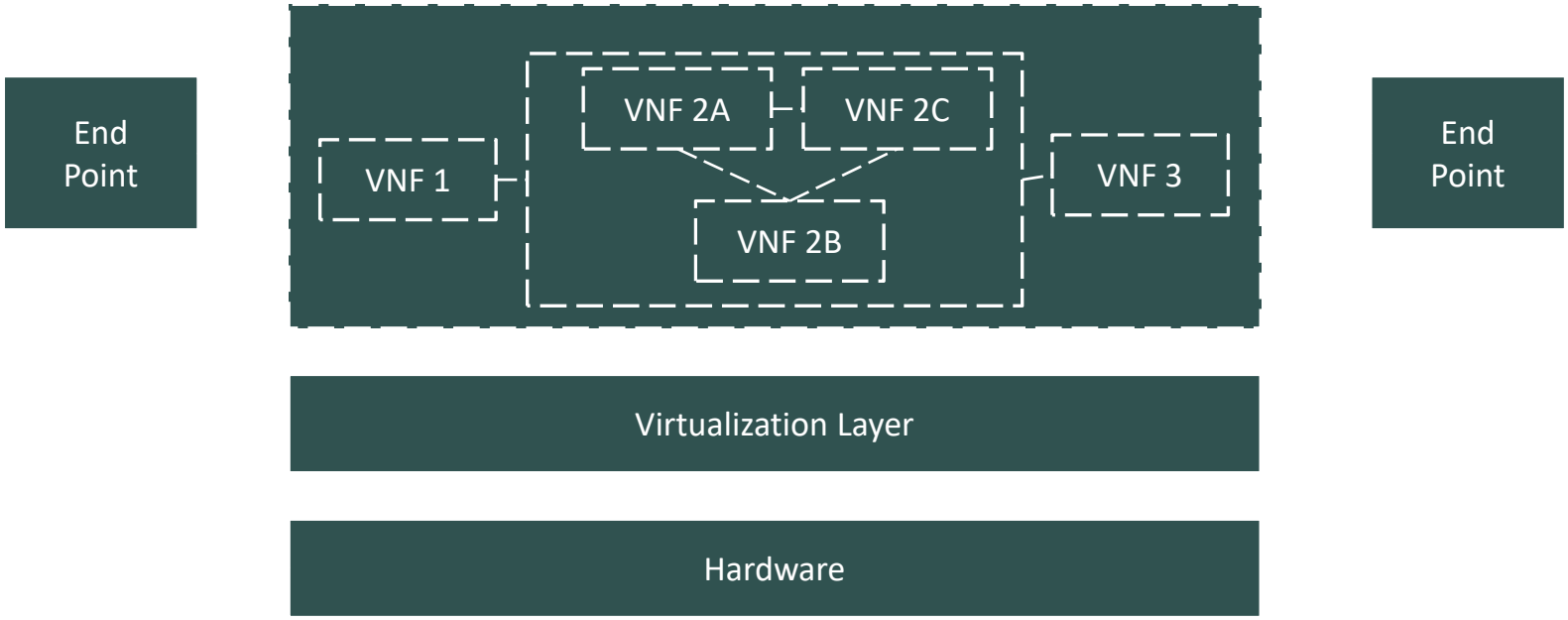
- Separation of control plane and forwarding plane
- Network virtualization
- Network softwarization/programmability

Via SDN Controllers to achieve

- Resource sharing - allows co-existence of multiple tenants
- Network slicing - enables different virtual networks for different tenants
- Network softwarization/programmability – Easy deployment of network applications to offer new services

Basic Concepts of Network Function Virtualization (NFV)

- Hardware network appliances become software-based virtual network functions (VNFs) running over virtualization layer
- These VNFs can be chained together (Service Function Chain) to provide end-to-end services

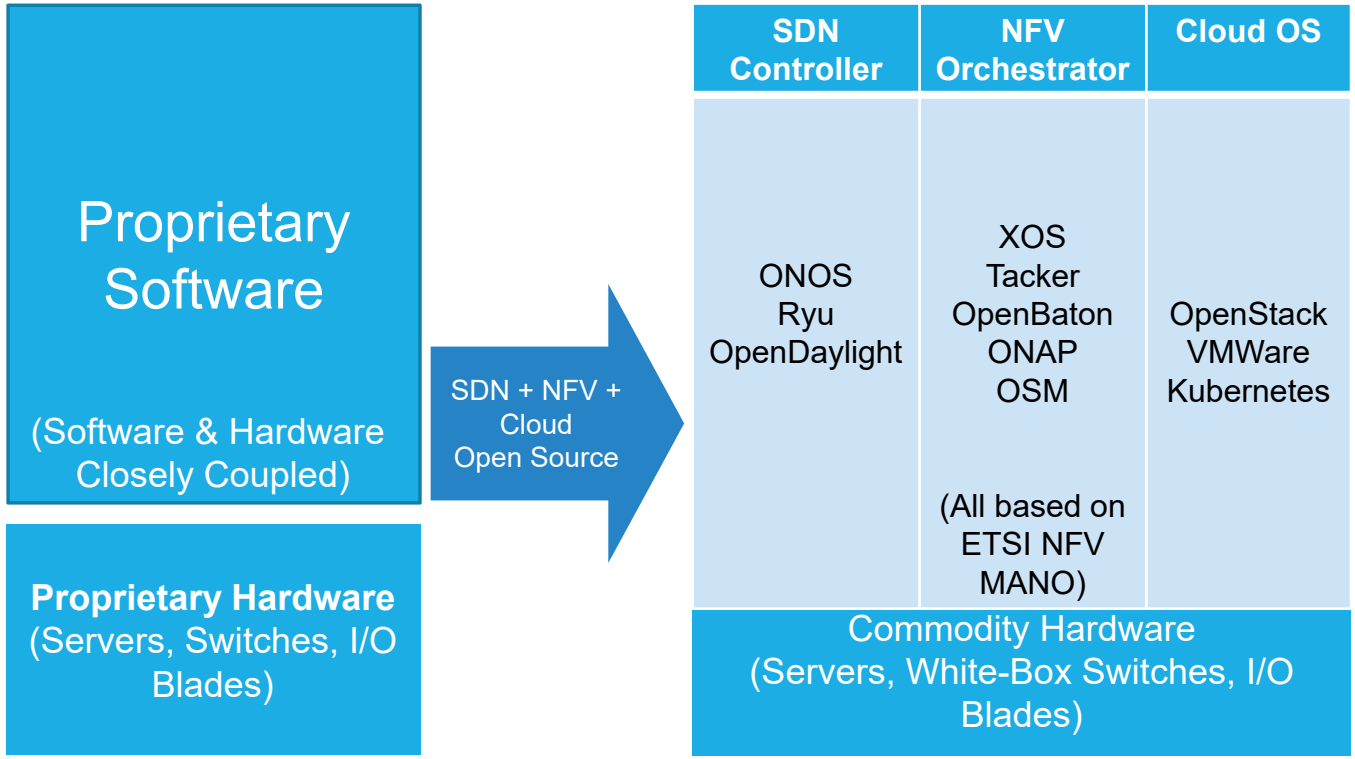


Source: ETSI GS NFV 002 V1.2.1, "Network Functions Virtualisation (NFV); Architectural Framework,", December 2014.[3]

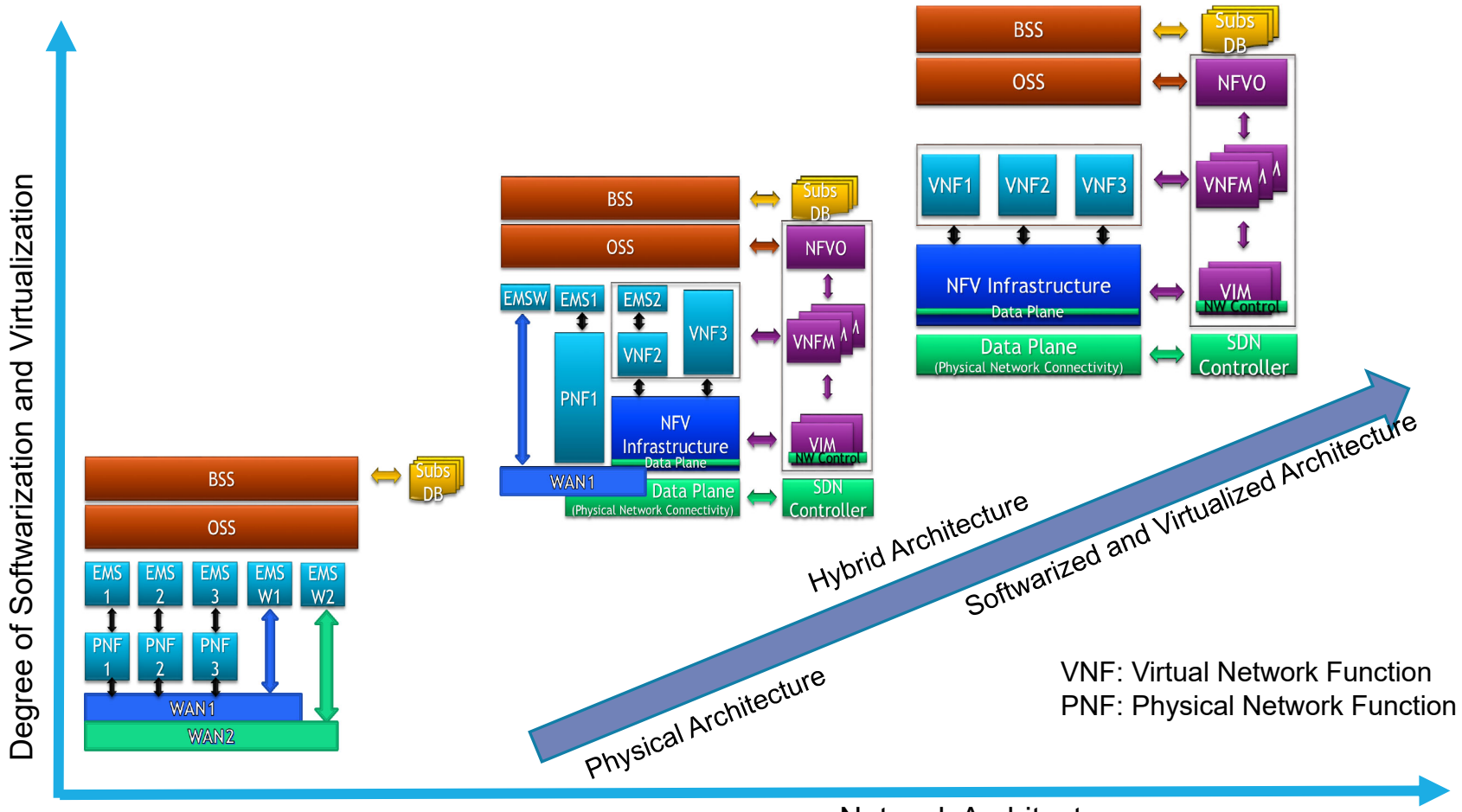
Network Function Virtualization (NFV)

- NFV aims to reduce OpEx with high automation and scalability by implementing network functions as virtual appliances.
- NFV also enabled virtualization and softwarization with its capabilities in orchestration, management, scaling, automation, hardware independence and network slicing.
- NFV and SDN are independent and complementary. We can do either or both.

Transformation of Traditional Networking Paradigms to SDN/NFV/Cloud-enabled 5G



Network Evolution enabled by SDN/NFV



Source: ONF Solution Brief: Impact of SDN and NFV on OSS/BSS, March 2016. [4]

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SDN-enabled Network Slicing (1)

- Slicing requires the partitioning and assignment of a set of resources that can be used in an isolated, disjunctive or shared manner.
- A set of such dedicated resources can be called a slice instance.
- Examples of resources, physical or virtual, would be: bandwidth on a network link, forwarding tables in a network element (switch, router), processing capacity of servers, processing capacity of network elements.
- Slice instances will often contain a combination/group of the above resources.

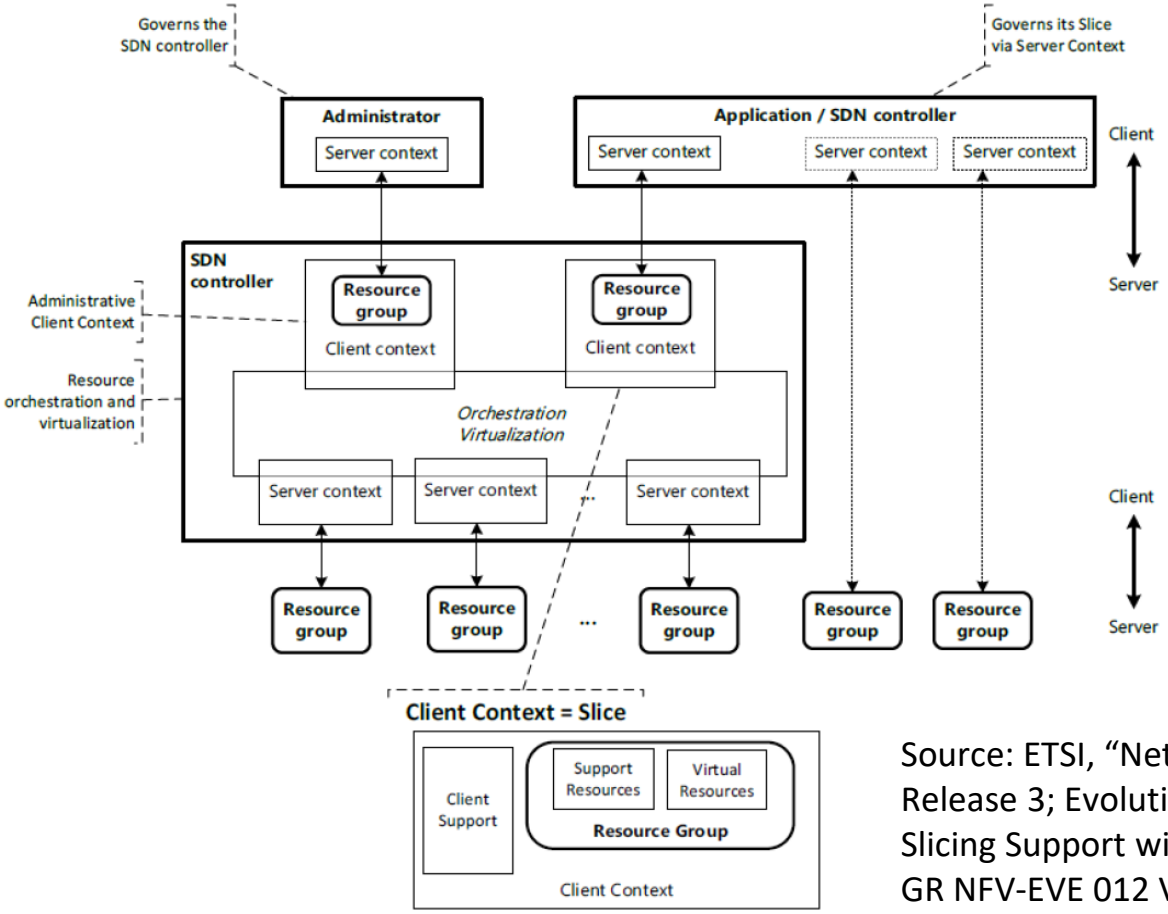
Source: ONF TR-526, “Applying SDN Architecture to 5G Slicing,” Issue 1, April 2016. [5]

SDN-enabled Network Slicing (2)

- Resources fall into the categories of network, storage and compute. Ranging from simple, e.g. switching between ports, to complex, e.g. firewall with DPI or a video transcoder.
- **The controller in the SDN architecture is the key element to manage slices**: it mediates client requirements with resource availability, supporting policy-driven real-/run-time optimization of changes in network state, service parameters, service and traffic flow.

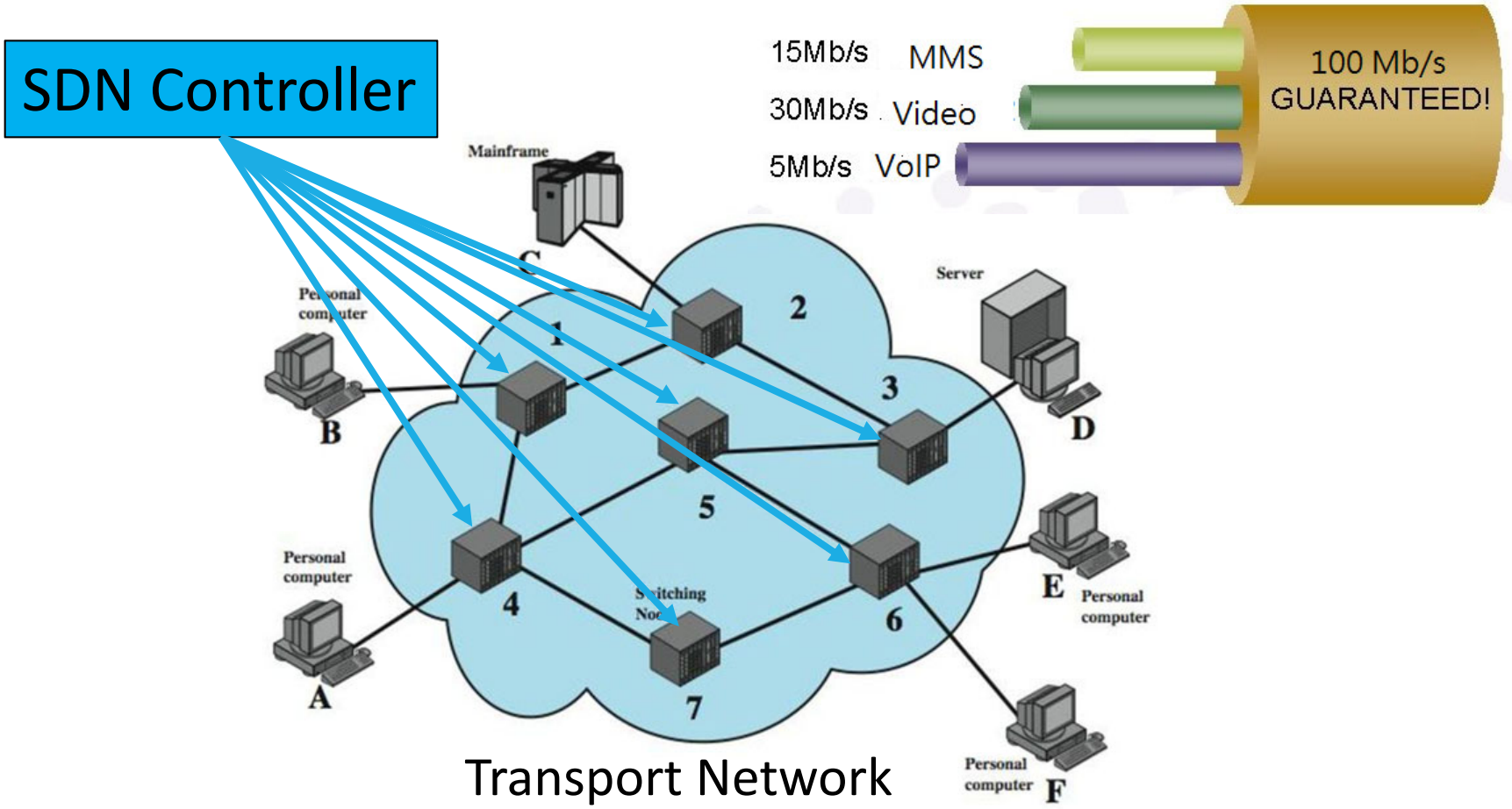
Source: ONF TR-526, “Applying SDN Architecture to 5G Slicing,” Issue 1, April 2016. [5]

SDN Architecture and Slice Abstraction



Source: ETSI, "Network Functions Virtualisation (NFV) Release 3; Evolution and Ecosystem; Report on Network Slicing Support with ETSI NFV Architecture Framework," GR NFV-EVE 012 V3.1.1, December 2017. [6]

Example of Bandwidth Slicing by SDN Controller



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NFV-enabled Network Slicing

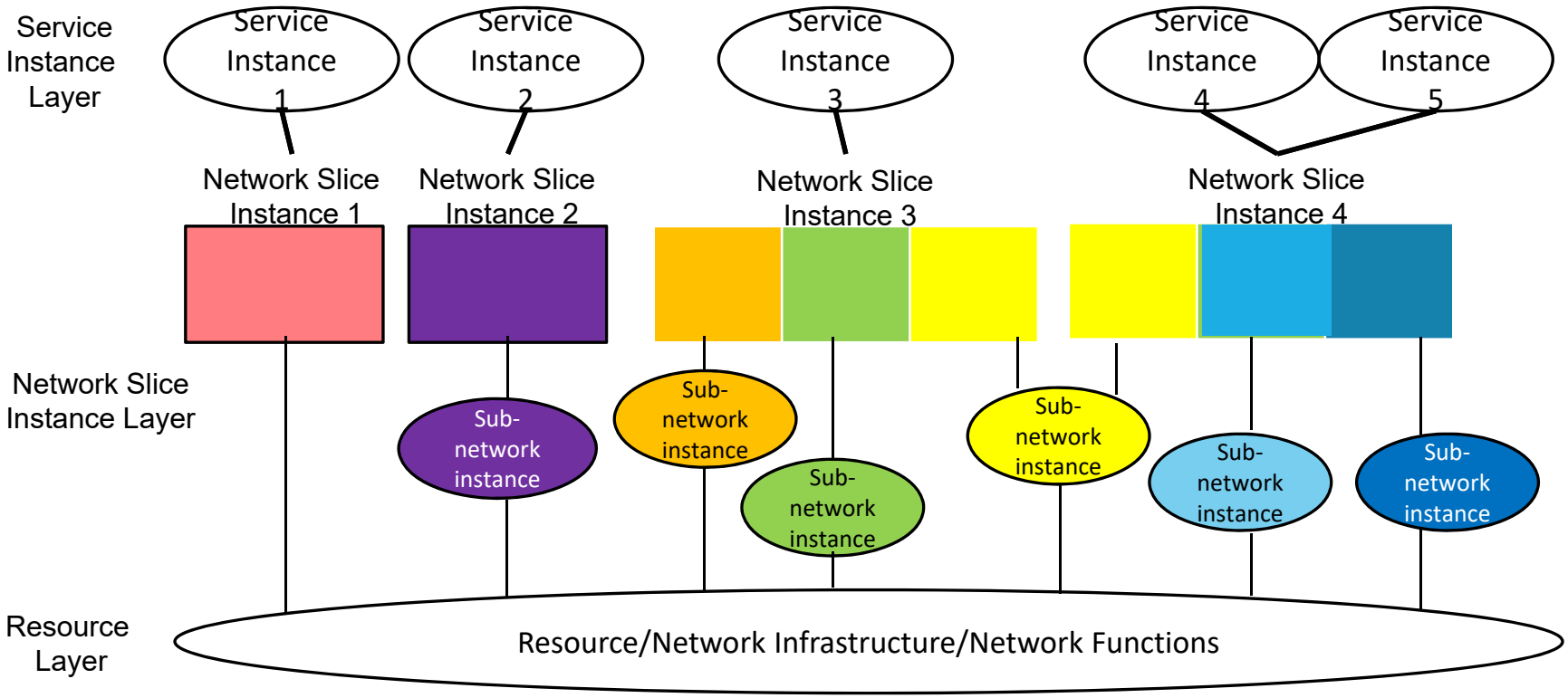
Network slicing as defined by NGMN

- A Network Slice Instance (NSI) may be composed by none, one or more Network Slice Subnet Instance (NSSI), which may be shared by another NSI.

- Similarly, the NSSI is formed of a set of Network Functions, which can be either VNFs or PNFs.

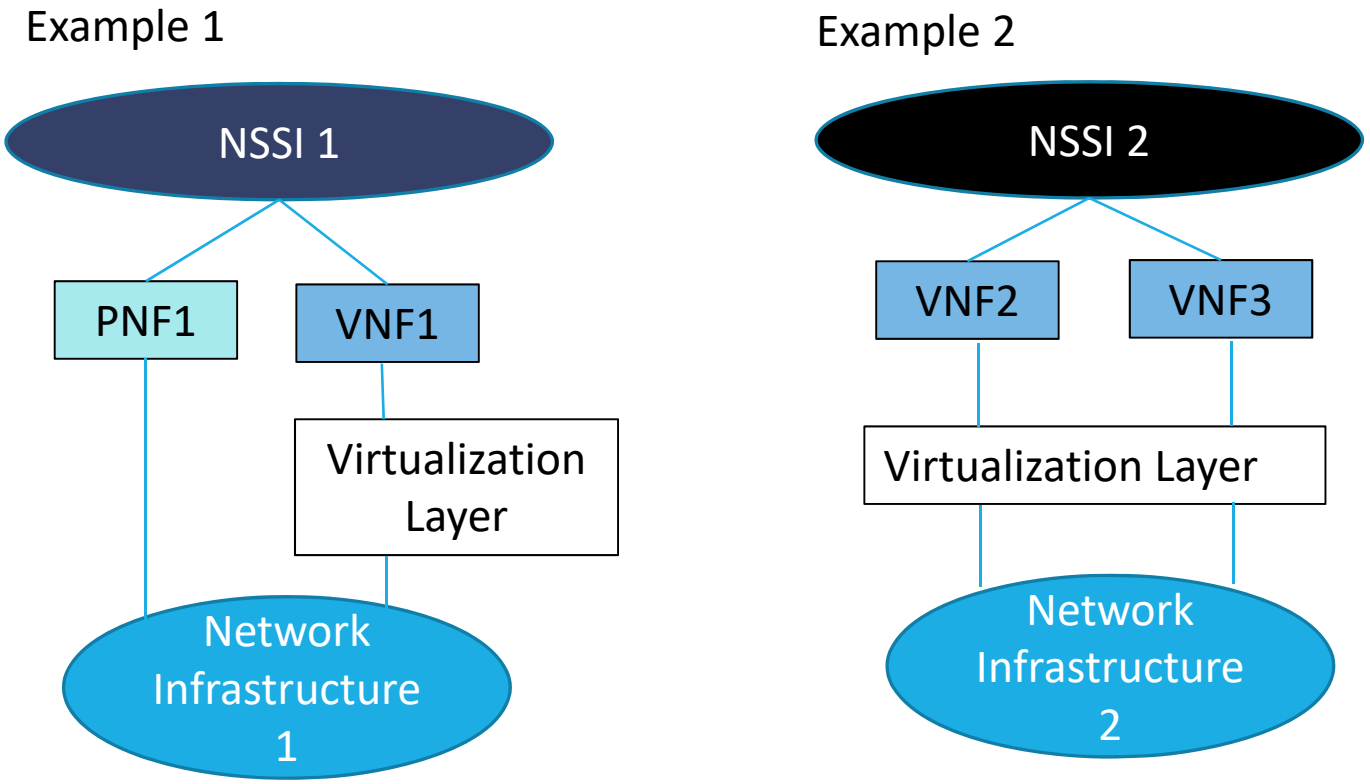
This definition is followed by 3GPP for 5G.

Network Slice vs. Network Slice Subnets



Source: Description of Network Slicing Concept by NGMN Alliance, January 2016. [7]

NSSI consisting of a set of Network Functions

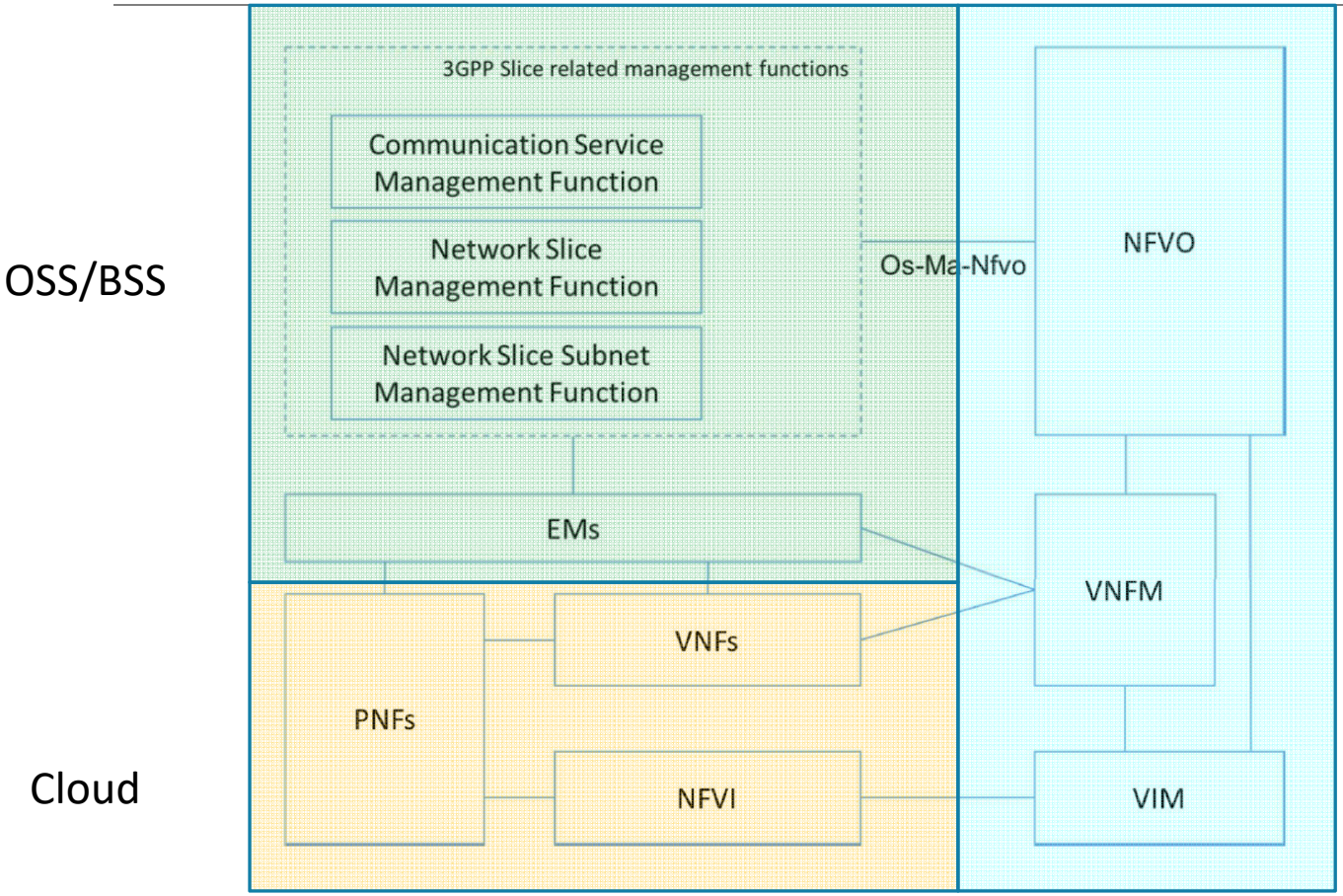


NFV MANO

- A MANagement and Orchestration (MANO) framework is thus required to handle the composition, creation and termination of NSIs and NSSIs.
- MANO has been defined by ETSI ISG NFV to standardize the reference points and interfaces. It can mix and match PNFs/VNFs from different sources.
- Moreover, NFV MANO can interact with OSS/BSS (Operation Support/Business Support Systems) for life cycle management of network slicing.

Source: ETSI GS NFV 002 V1.2.1, “Network Functions Virtualisation (NFV); Architectural Framework,”, December 2014.[4]

Network Slice in 3GPP/NFV Framework



NFVO: NFV Orchestrator
VNFM: VNF Manager
VIM: Virtual Infrastructure Manage
PNF: Physical Network Function
VNF: Virtual Network Function
NFVI: NFV Infrastructure

Network Slice as defined by 3GPP 5G

The network slice concept as defined by 3GPP includes the following aspects:

1. Completeness of an NSI/NSSI:
   - It includes all functionalities and resources necessary to support certain business purpose.
2. Components of an NSI/NSSI:
   - The NSI/NSSI contains NFs (e.g. belonging to Access Network and Core Network).
   - If the NFs are interconnected, the 3GPP management system contains the information relevant to the connections between these NFs including topology, and QoS attributes.

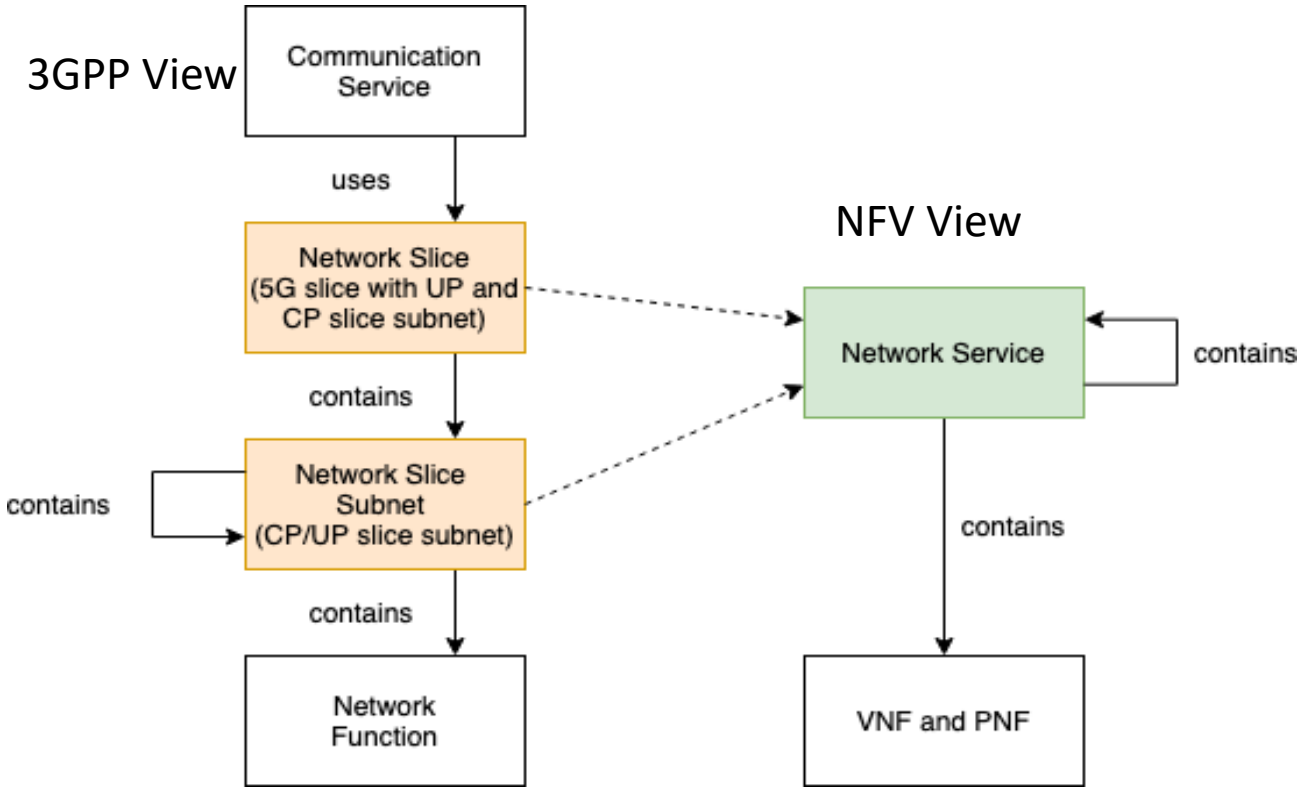
Network slicing as defined by 3GPP 5G (Cont.)

3. Resources used by the NSI/NSSI:
   - The NSI/NSSI is realized via the required physical and logical resources.
4. Network Slice Template:
   - The network slice is described by a Network Slice Template (NST). The NSI/NSSI is created using the NST and instance-specific information.
5. NSI/NSSI policies and configurations:
   - Instance-specific policies and configurations are required when creating an NSI/NSSI. For example: ultra-low-latency, ultra-reliability, etc.
   - NSI/NSSI contains a Core Network part and an Access Network part
6. Isolation of NSI/NSSIs:
   - An NSI/NSSI may be fully or partly, logically and/or physically, isolated from another NSI/NSSI.

Mapping NFV and 3GPP network slicing concepts (1)

- In 3GPP a network slice contains one or more network slice subnets, each of which contains one or more network functions and can also contain other network slice subnets. These network functions can be managed as VNFs and/or PNFs.
- 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 virtualized network function.
- The virtualized resources for the slice subnet and their connectivity to physical resources can be represented by nested NSs, or one or more VNFs and PNFs directly attached to the NS used by the network slice.

Mapping NFV and 3GPP network slicing concepts (2)



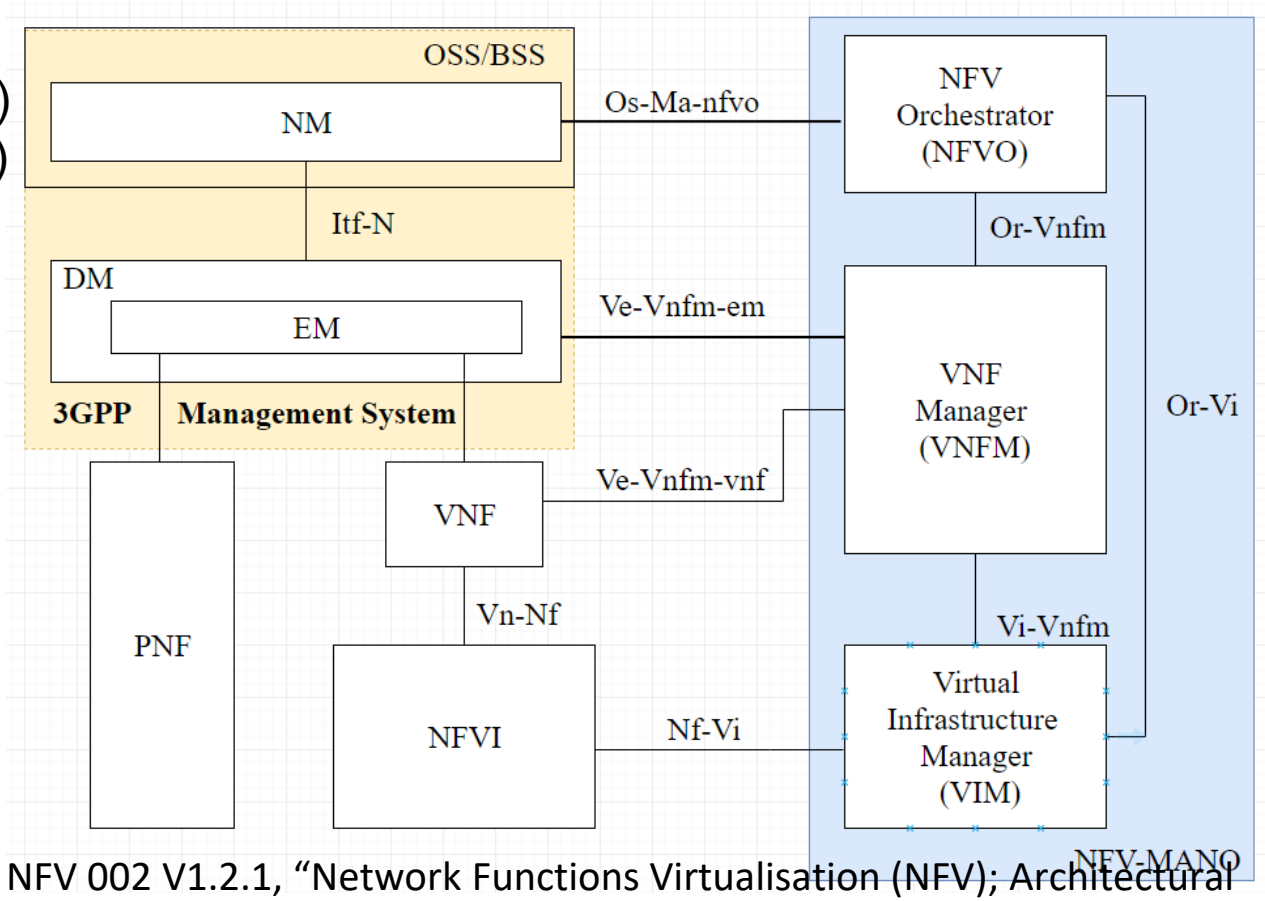
Source: ETSI, "Network Functions Virtualisation (NFV) Release 3; Evolution and Ecosystem; Report on Network Slicing Support with ETSI NFV Architecture Framework," GR NFV-EVE 012 V3.1.1, December 2017. [6]

NFV MANO Interfaces

OSS/BSS consists of
1. NM (Network Management)
2. EM (Element Management)

EM is to support Device Management (DM).

Interfaces defined in MANO include:
1. Os-Ma-nfvo
2. Ve-Vnfm-em
3. Ve-Vnfm-vnf
4. Nf-Vi
5. Or-Vnfm
6. Vi-Vnfm
7. Or-Vi
8. Vn-Nf



Source: ETSI GS NFV 002 V1.2.1, "Network Functions Virtualisation (NFV); Architectural Framework,", December 2014.[4]

NSSAI (Network Slice Selection Assistance Information)

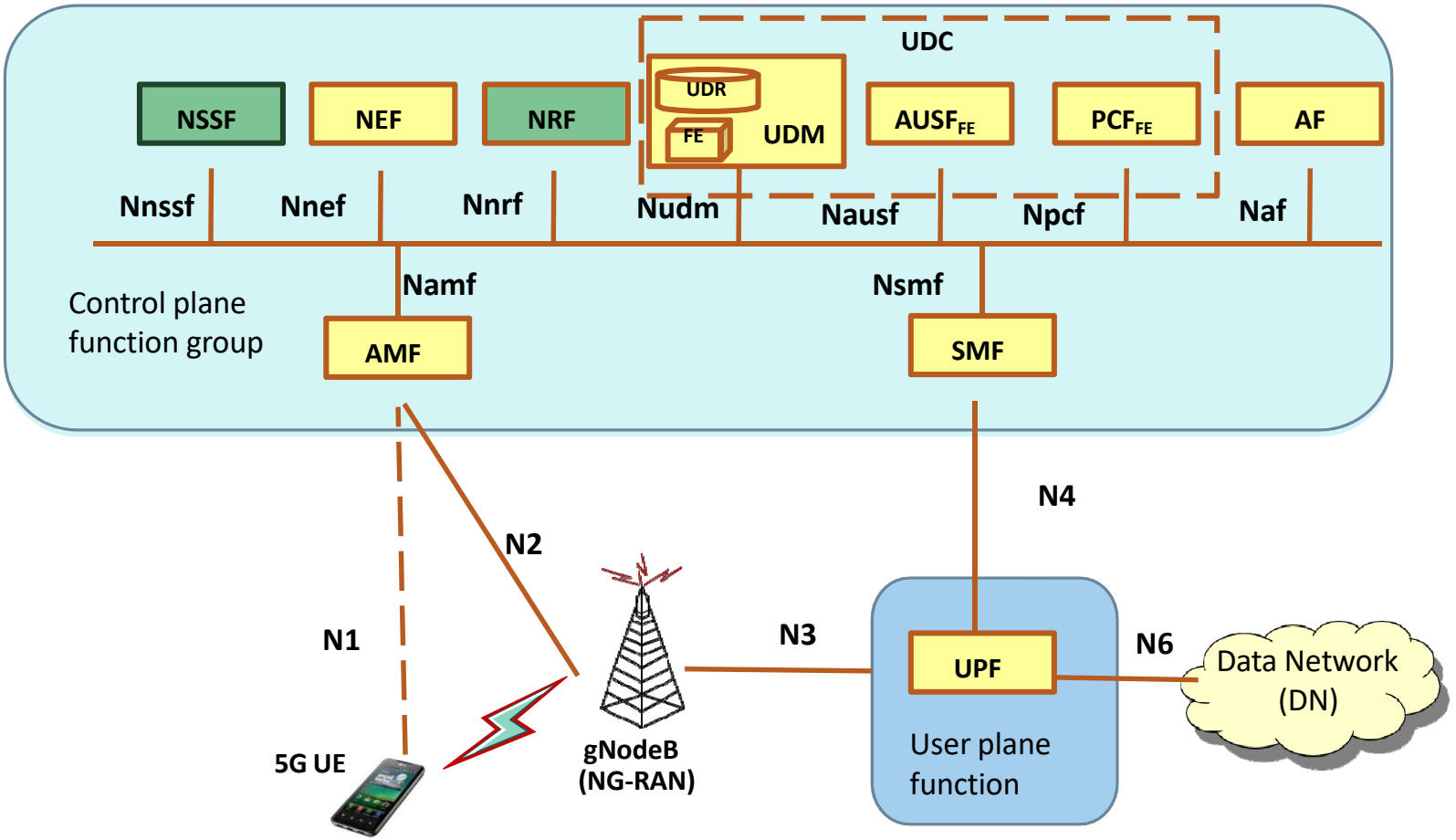
- The NSSAI is a collection of up to 8 S-NSSAIs (Single Network Slice Selection Assistance Information's). Each of the latter identifies a Network Slice.
- S-NSSAI consists of Slice/Service type (SST) and Slice Differentiator (SD).
- The S-NSSAI may be associated with a PLMN (e.g., PLMN ID) and have network-specific values or have standard values.

S-NSSAI = (SST, SD)

SST and SD

- SST (mandatory) refers to the expected Network Slice behavior in terms of features and services such as eMBB, mMTC, URLCC.
  - Standardized SST values provide a way for establishing global interoperability for slicing so that PLMNs can support the roaming use case more efficiently for the most commonly used Slice/Service Types.
- SD (optional) is a representation of the management aspects of a set of Managed Functions and the required resources (e.g. compute, storage and networking resources).

5G Service-based Architecture



3GPP TS 23.501 V15.2.0, "System Architecture for the 5G System; Stage 2 (Release 15)," June 2018. [8]

An Overview of 5G Network Functions (1)

AMF – Access and Mobility Management Function

- AMF is the node that manages all UE related functions
- The EPC functionality of MME, S-GW-C & P-GW-C has been reallocated so that all access and mobility functionality is done by AMF

SMF – Session Management Function

- SMF provides the functionalities of MME, S-GW-C & P-GW-C in EPC that are not covered by AMF
- It takes care of session management such as session establishment, modify and release, including tunnel maintain between UPF and AN node, UE IP address allocation & management

An Overview of 5G Network Functions (2)

UPF – User Plane Function

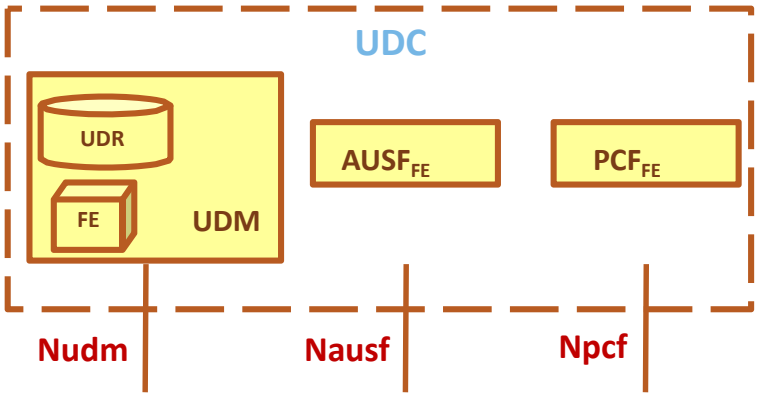
- UPF provides functions specific to U-plane processing the same as S-GW-U and P-GW-U in CUPS

S-GW-U, P-GW-U are user planes of 4G S-GW and P-GW after Control and User Plane Separation (CUPS) .

An Overview of 5G Network Functions (3)

UDR – Unified Data Repository

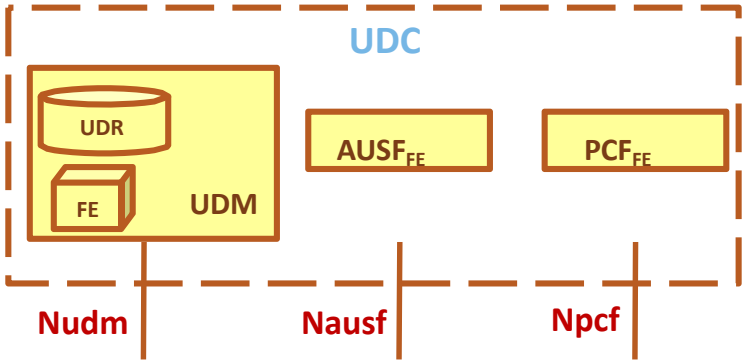
- UDR is a facility where user data can be accessed, stored and managed in a common way



An Overview of 5G Network Functions (4)

UDM - Unified Data Management

- UDM is analogous to the Home Subscriber Server (HSS) in EPC architecture.
- It introduces the concept of User Data Convergence (UDC) that separates the User Data Repository (UDR) storing and managing subscriber information from the front end processing subscriber information



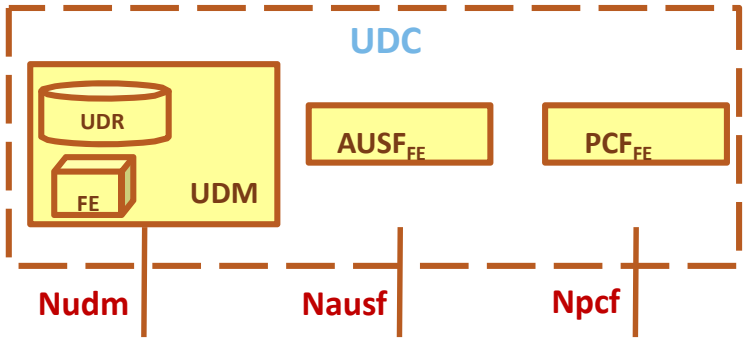
An Overview of 5G Network Functions (5)

AUSF –Authentication Server Function

- With a frontend interface, AUSF is dedicated to authentication processing

PCF – Policy Charging Function

- With a frontend interface, PCF supports unified policy framework to govern network behavior



An Overview of 5G Network Functions (6)

NEF – Network Exposure Function

- NEF support functions similar to the Service Capability Exposure Function (SCEF) in EPC
- SCEF allows IoT devices send small amount of data via 4G/5G networks without establishing a session

NRF – Network (Function) Repository Function

- A Network Functions (NF) in 5G consists of smaller unit functions called NF services, and an NF service in a certain NF can directly access an NF service in another NF without having to pass through another node.
- NRF provides a discovery function for NF services

An Overview of 5G Network Functions (7)

NSSF - Network Slice Selection Function

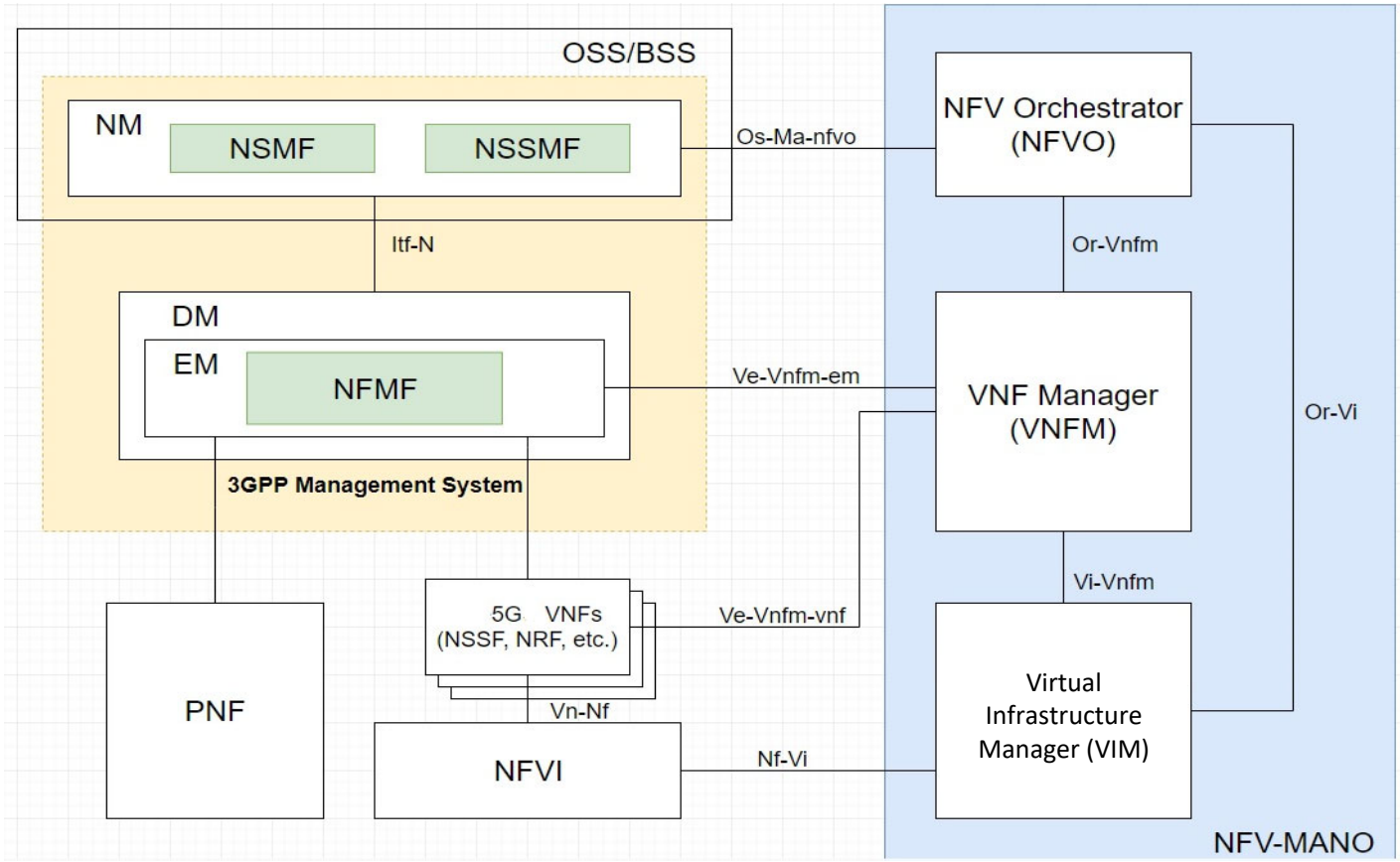
- Selects the set of Network Slice instances serving the UE
- Determines the Network Functions set to be used to serve the UE, possibly by querying the NRF

5G Network Slicing Components (1)

5G Core	NSSF	Network Slice Selection Function
	NRF	Network (Function) Repository Function
OSS/BSS	NSMF	Network Slice Management Function
	NSSMF	Network Slice Subnet Management Function
	NFMF	Network Function Management Function
MANO	NFVO	NFV Orchestrator
	VNFM	NVF Manager
	VIM	Virtual Infrastructure Manager

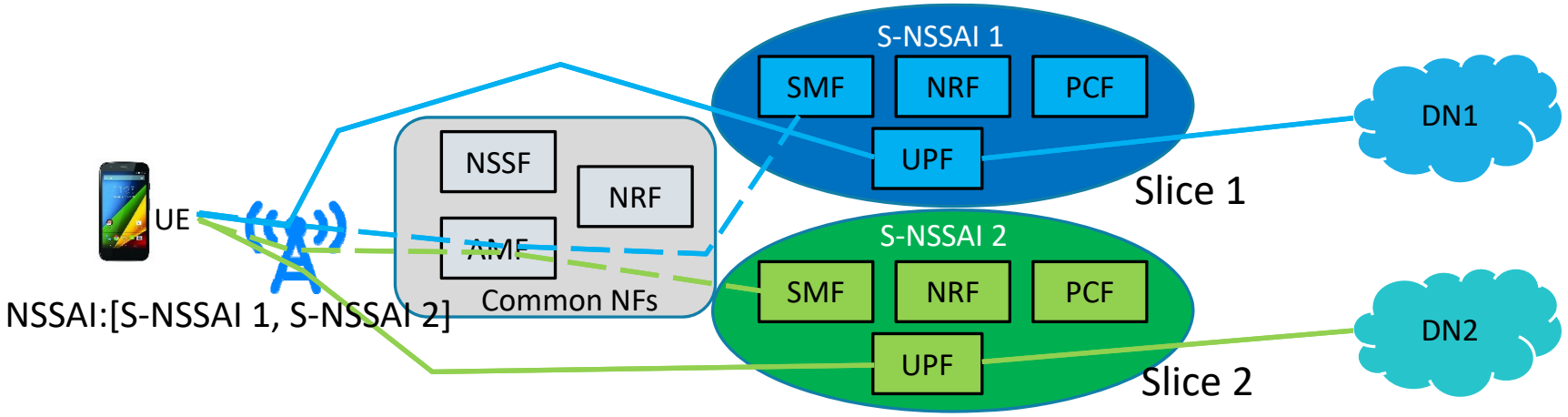
1. OSS/BSS collaborates with MANO for the creation of a network slice.
2. A network slice may consist of multiple VNFs.
3. MANO manages and orchestrates the life cycle of these VNFs.
4. Once a VNF is created, its information will be recorded in NRF.
5. Once a network slice is created, NSSF will be informed about its availability.
6. AMF then can query NSSF for slice selection.

5G Network Slicing Components (2)



Source: 3GPP TS 28.530 V15.1.0, “Management and orchestration; Concepts, use cases and requirements (Release 15),” December 2018. [9]

Basic Operations of 5G Network Slicing



1. A UE requests AMF for 5G services.
2. When AMF receives the request, it will asks NSSF for selecting a network slice.
3. NSSF will query NRF to get a set of Network Functions required for the slice.
4. The request will then forwarded to either the blue or the green slice and may reach different Data Networks (e.g. DN1, DN2).
5. Each slice consists of its own SMF, NRF, PCF and UPF.

Source: Tony Saboorian and Amanda, "Network Slicing and 3GPP Service and Systems Aspects (SA) Standard" , IEEE Softwarization, December 2017. [10]

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Network Slice Template

Network Slice Template consists of

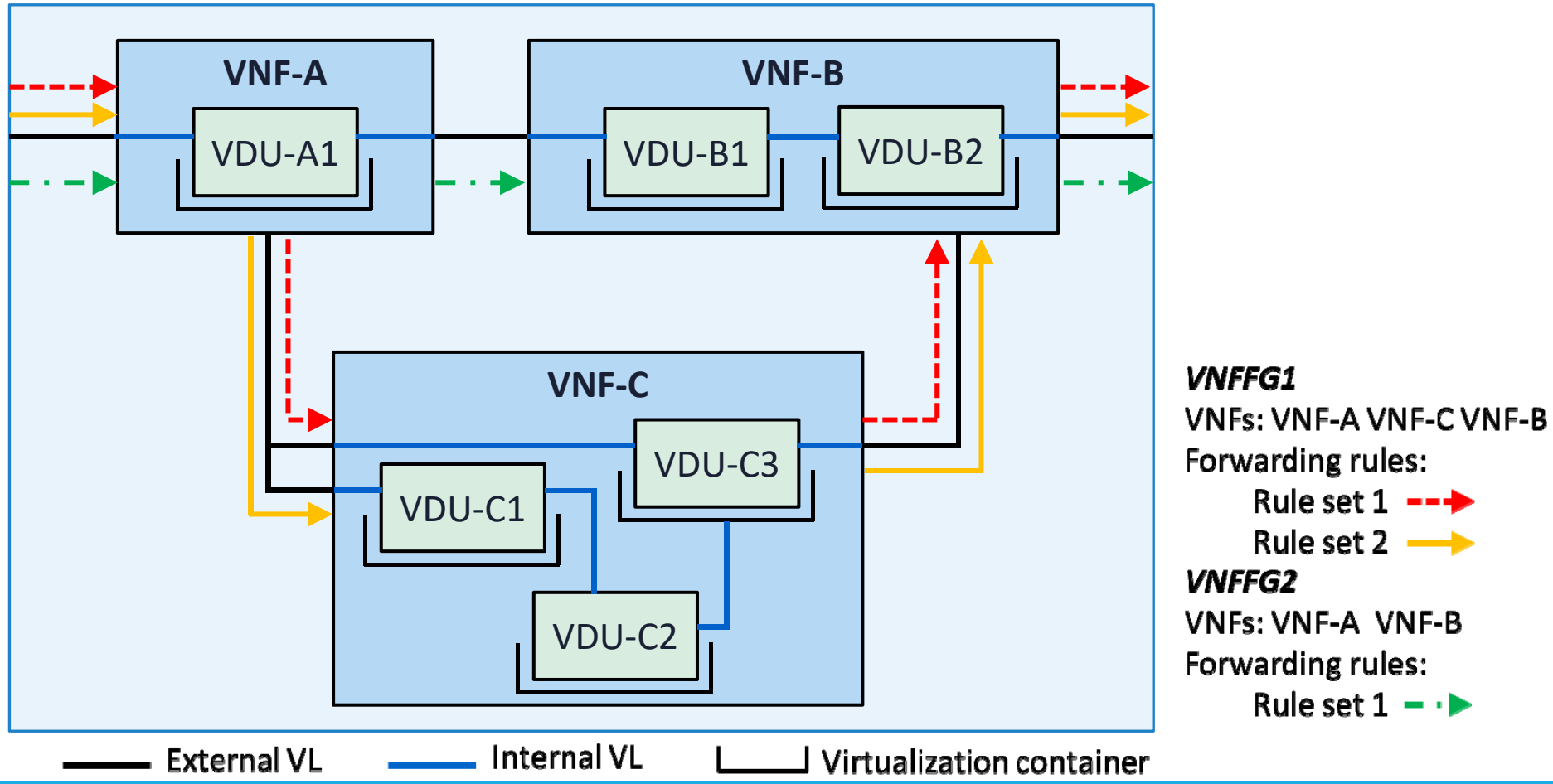
- Network Service Descriptor (NSD)
- Virtual Network Function Descriptor (VNFD)
- Virtual Link Descriptor (VLD)
- VNF Forwarding Graph Descriptor (VNFFGD)

  For specifying the topology of VNFs, used to orchestrate and manage traffic through VNFs.
- Virtual Deployment Unit (VDU)

  For describing a VNF component.

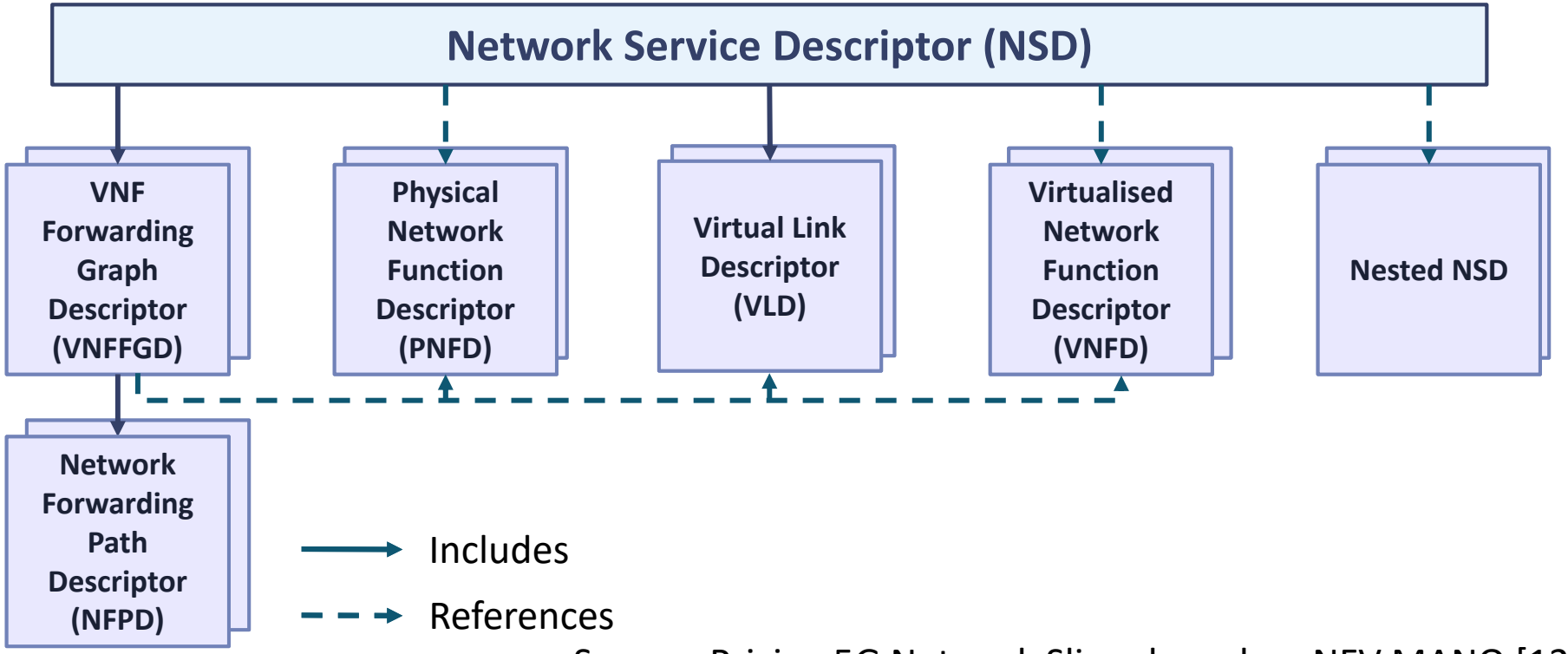
Network Service in NFV = Network Slice Subnet in 3GPP

An NS is a composition of network functions



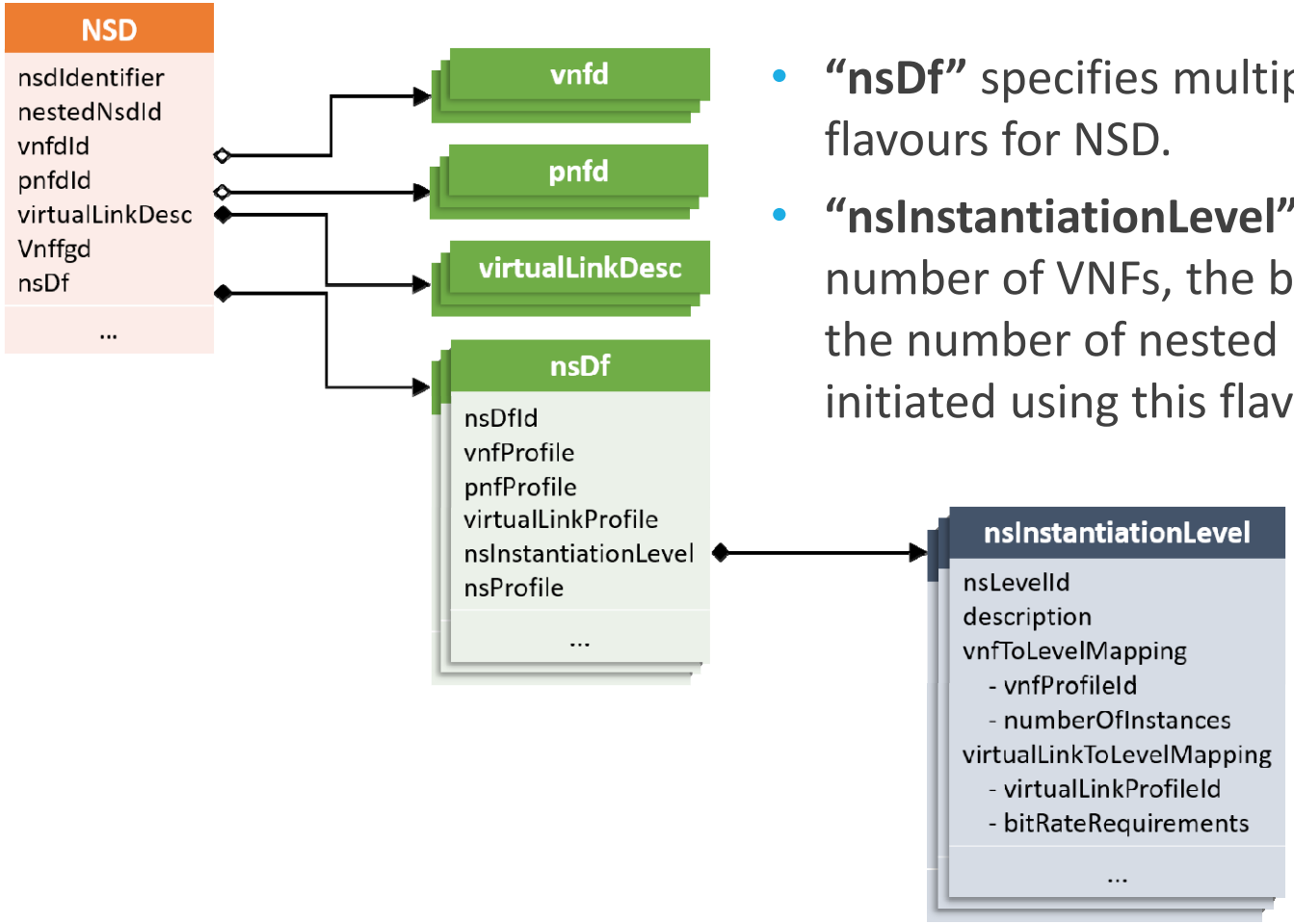
Network Service Descriptor (NSD)

- An NSD is the **description of a network service** as used by the NFV MANO functions to deploy a 5G network slice.



Source: Pricing 5G Network Slices based on NFV MANO [12]

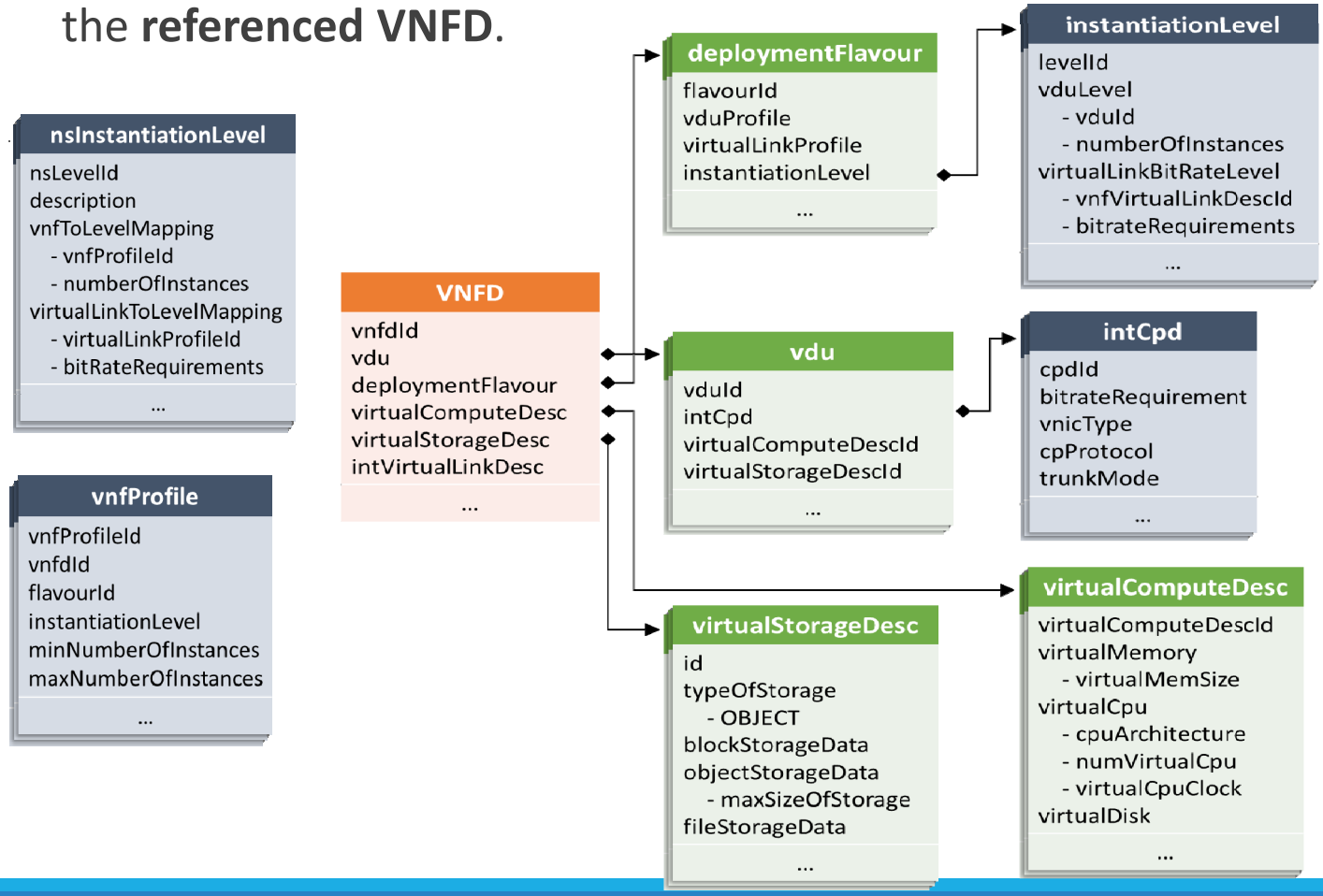
Information Elements in NSD



- **"nsDf"** specifies multiple deployment flavours for NSD.
- **"nsInstantiationLevel"** specifies the number of VNFs, the bitrate of VLs, and the number of nested NSs that will be initiated using this flavor.

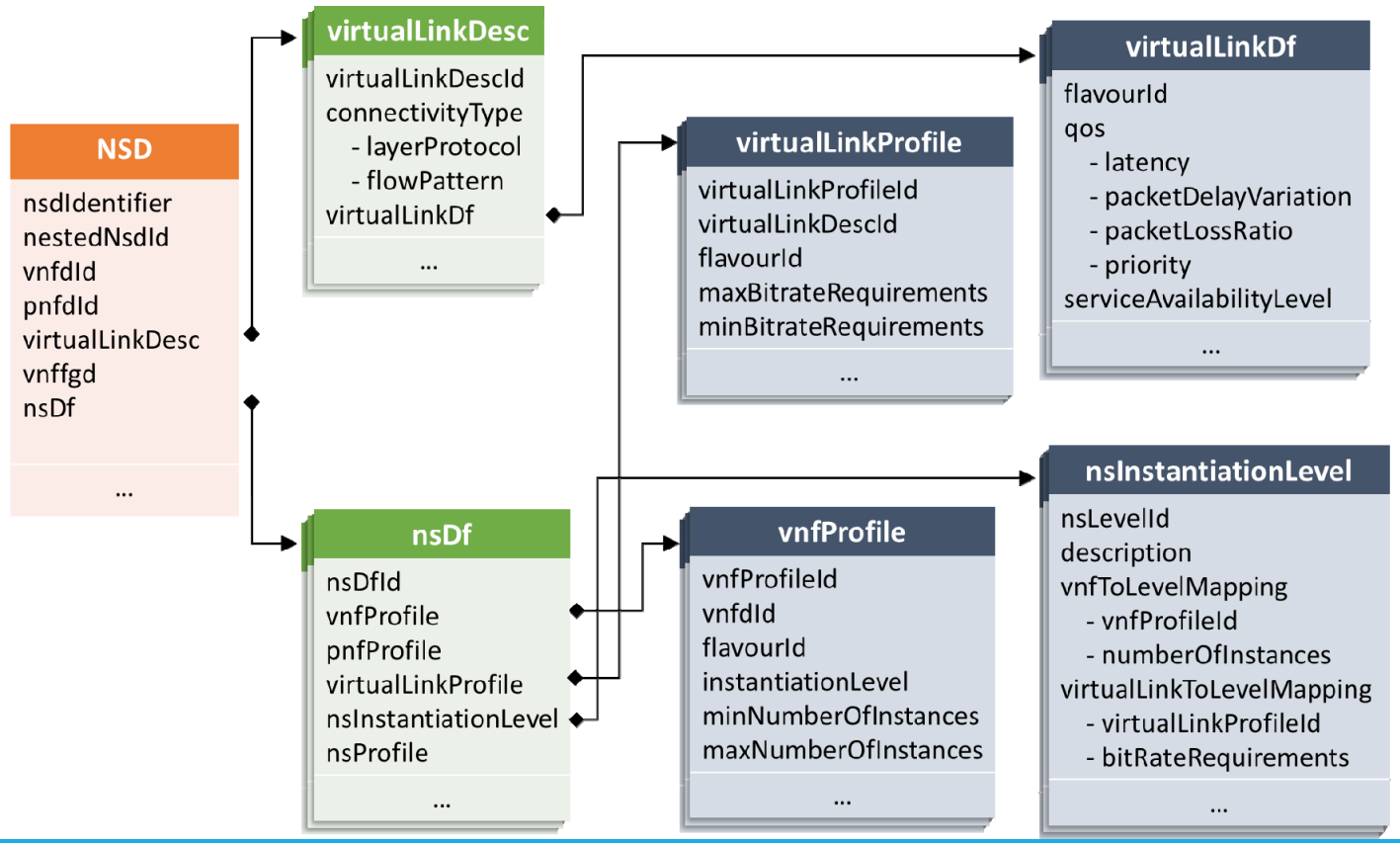
Information Elements in VNFD

- VNFs are described in terms of "**vnfToLevelMapping**", "**vnfProfile**" and the **referenced VNFD**.

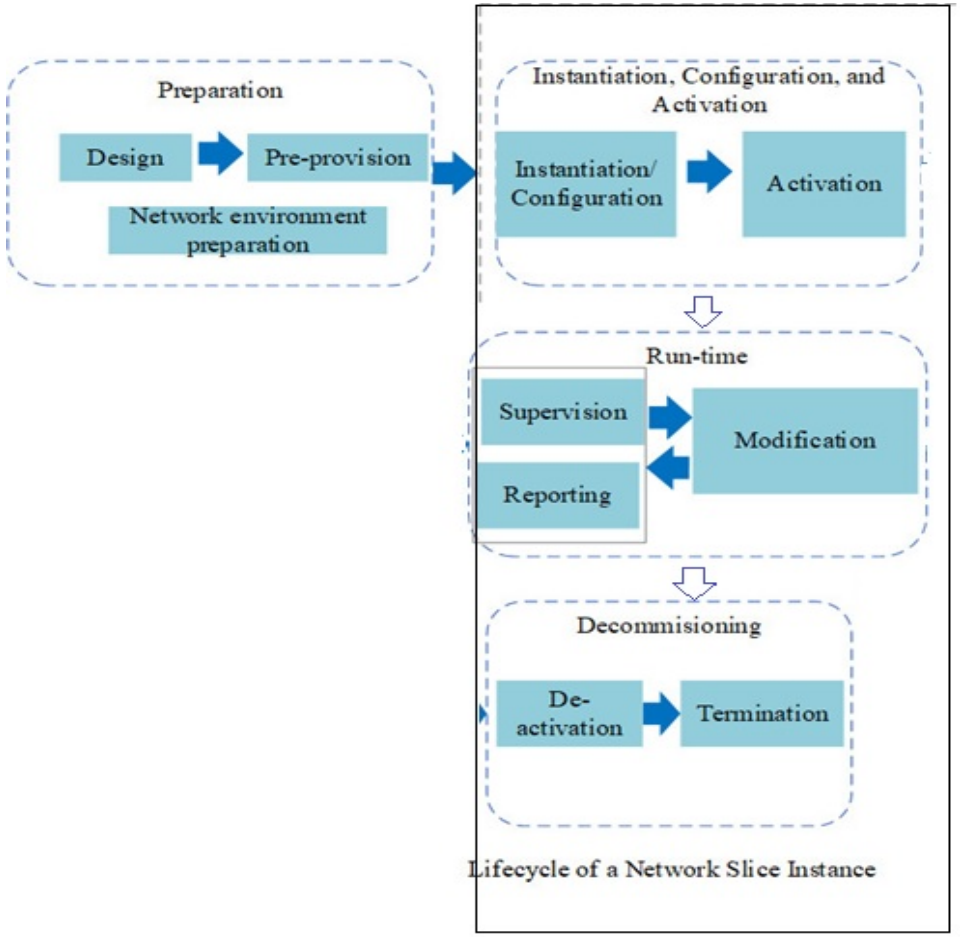


Information Elements in VLD

- VLs are described in an NSD in terms of "**virtualLinkToLevelMapping**", "**virtualLinkProfile**" and "**virtualLinkDesc**".



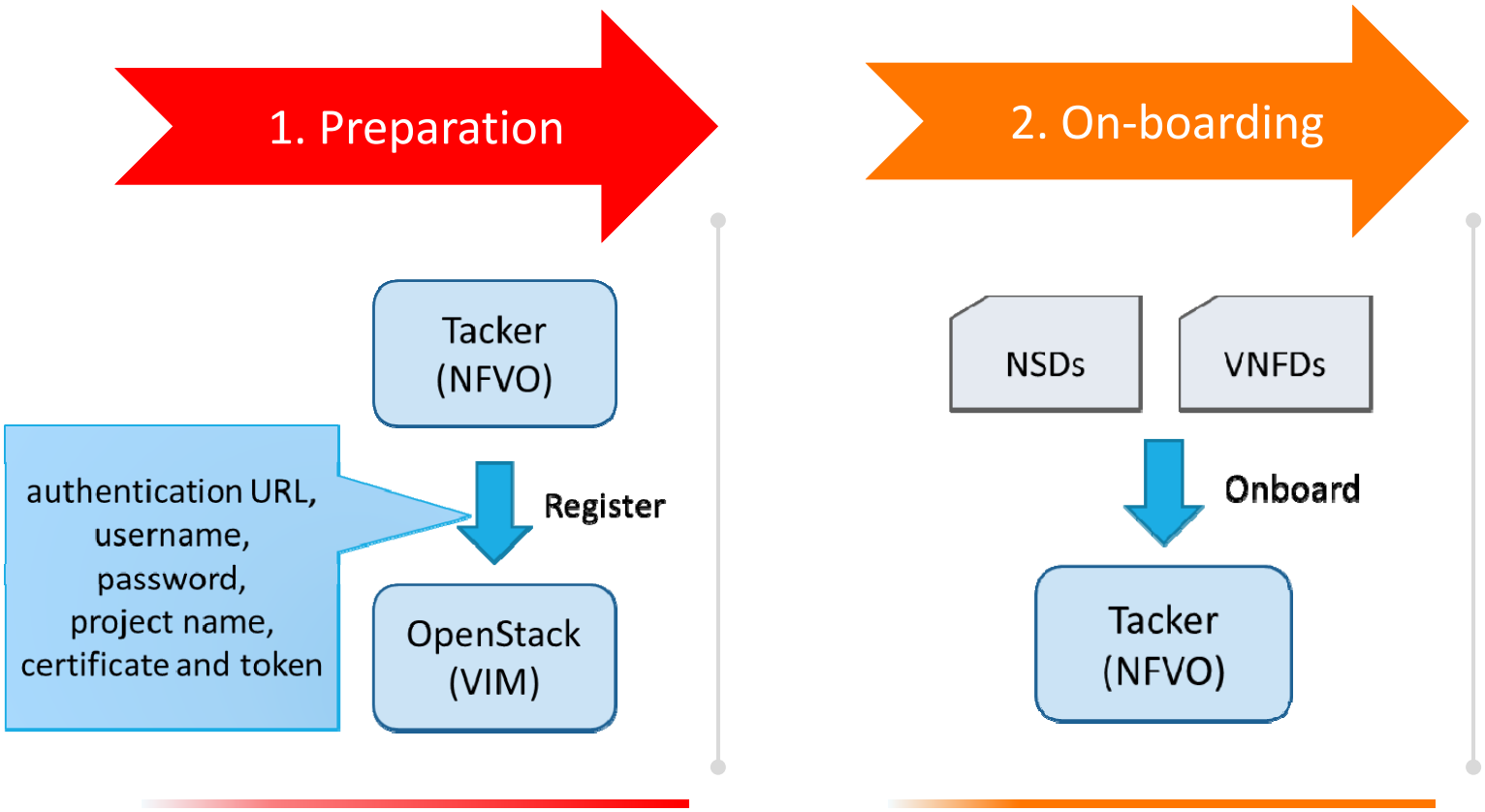
Life Cycle Management of a Network Slice Instance



Source: Tony Saboorian and Amanda, "Network Slicing and 3GPP Service and Systems Aspects (SA) Standard" , IEEE Softwarization, December 2017.[10]

Network Slice Deployment (1)

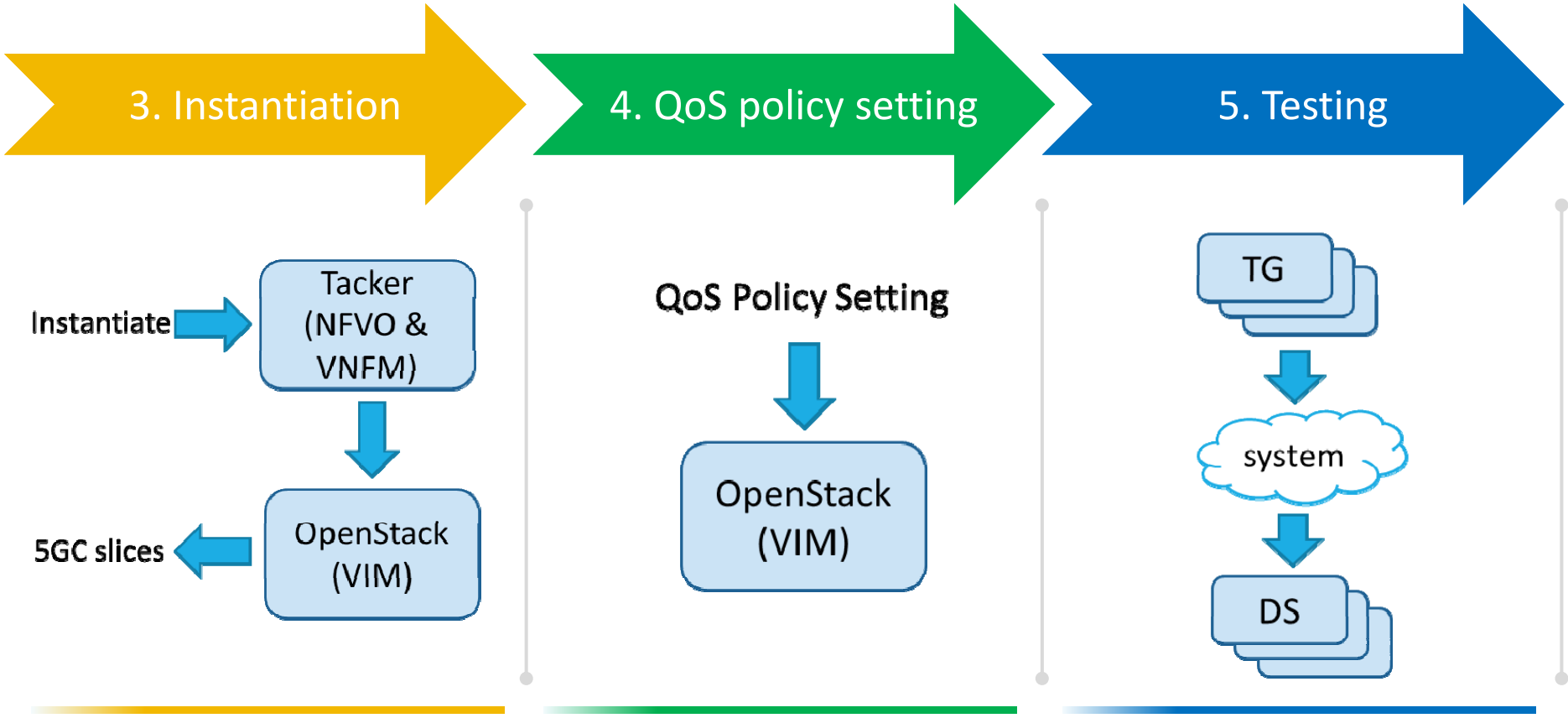
For NFV-MANO Architecture in OpenStack



Evaluating NFV-enabled Network Slicing for 5G Core [13]

Network Slice Deployment (2)

For NFV-MANO Architecture in OpenStack



Evaluating NFV-enabled Network Slicing for 5G Core [13]

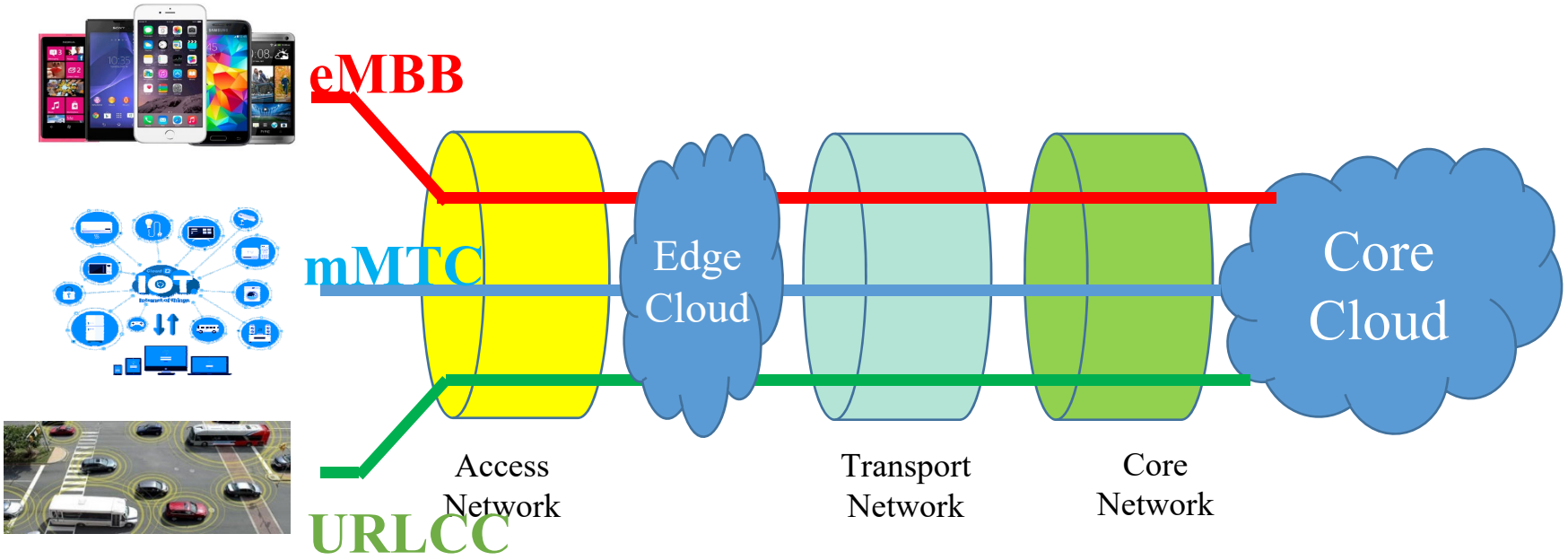
Outline

- Network Slicing and Its Enabling Technologies
- SDN-enabled Network Slicing
- NFV-enabled Network Slicing
- Network Slice Template and Deployment
- **Toward 5G End-to-End Network Slicing**
- Open Sources for Network Slicing
- Outlook

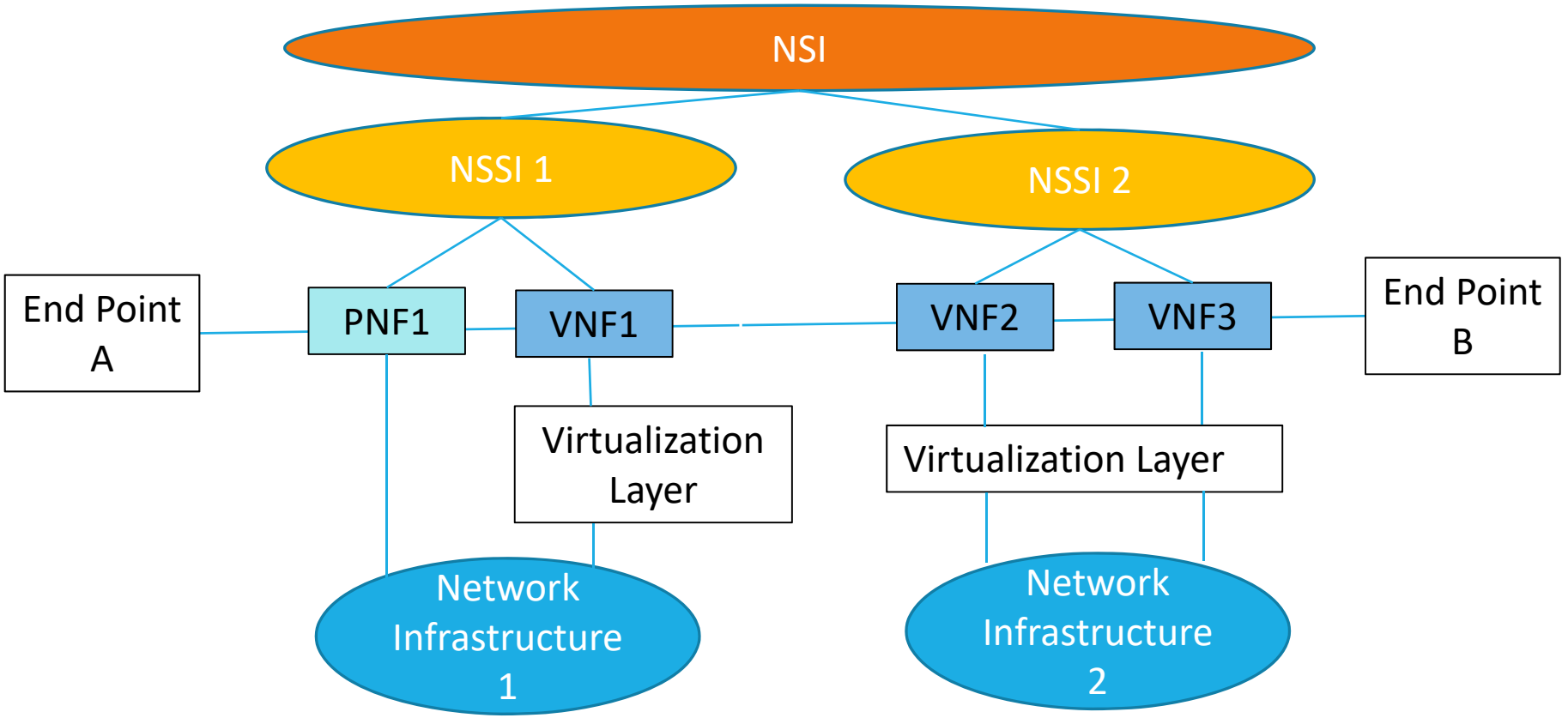
Toward 5G End-to-End Network Slicing

- Network slicing is an important concept in 5G networks.
- A network slice may consist of multiple network slice subnets.
- Each network slice subset is supported by a set of 5G VNFs.
- 5G VNFs are orchestrated and managed by NFV MANO.
- OSS/BSS instructs NFV MANO when to create and terminate 5G VNFs.

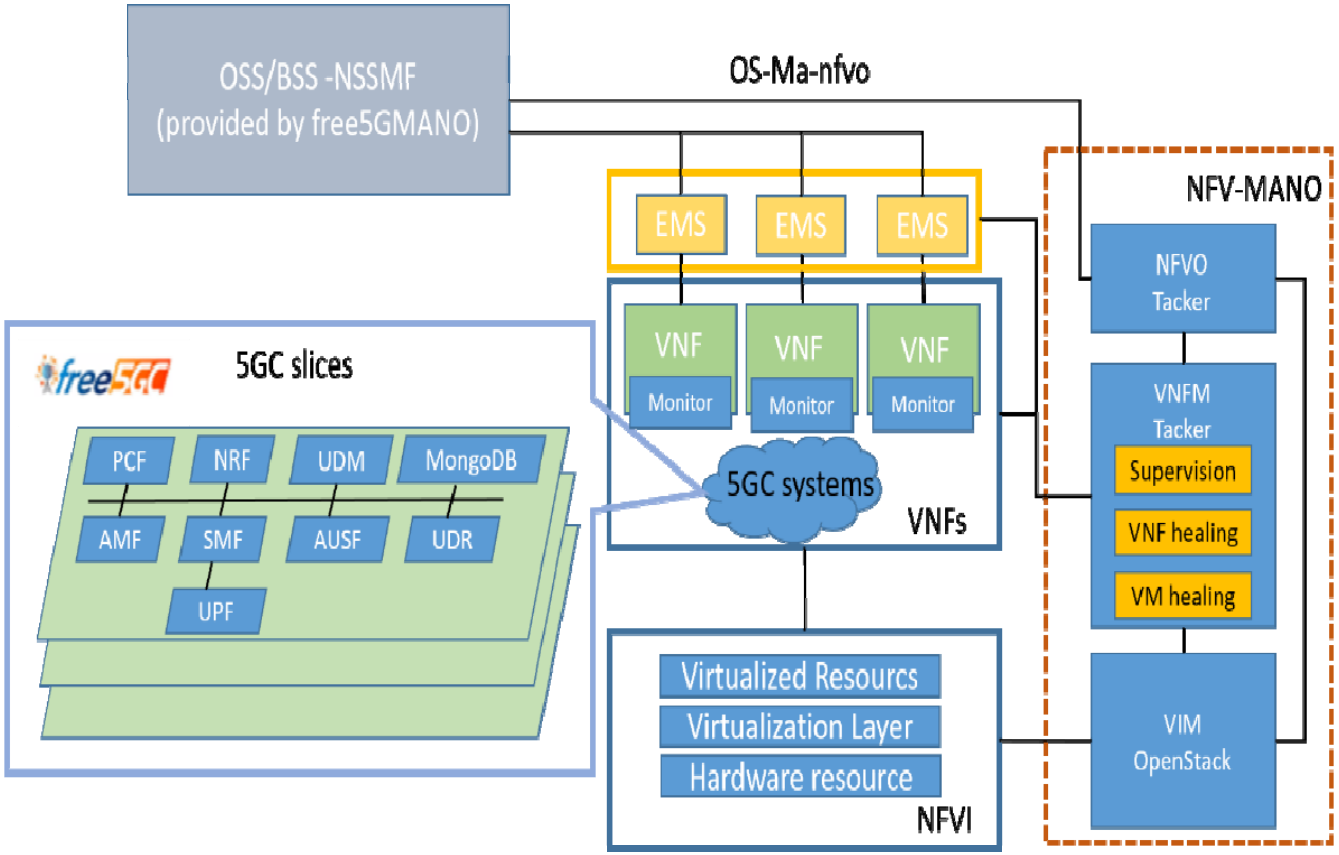
5G End-to-End Network Slicing



Anatomy of End-to-End Network Slicing

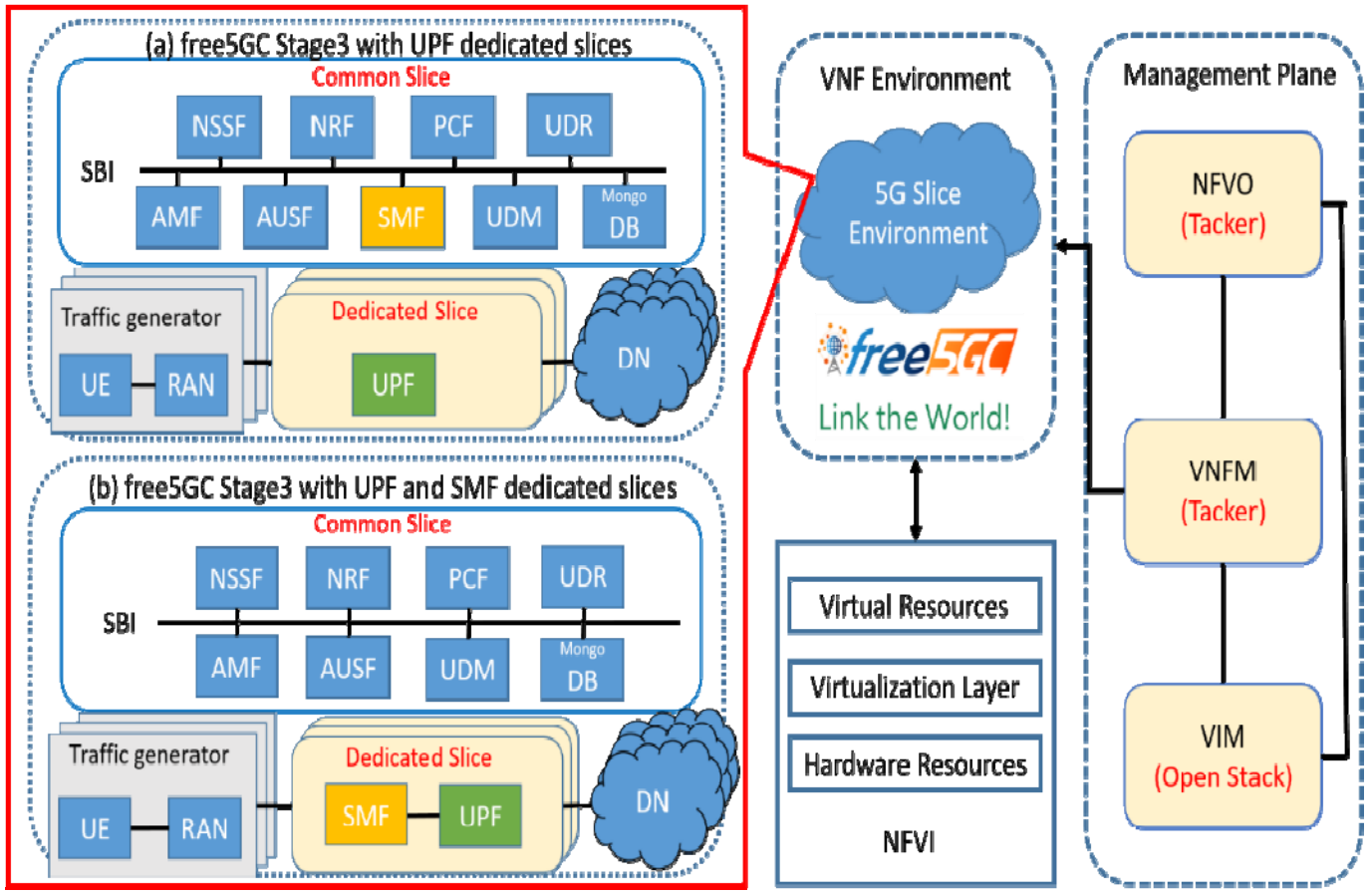


NFV-Enabled 5G Core Network Slicing Testbed at NYCU (1)



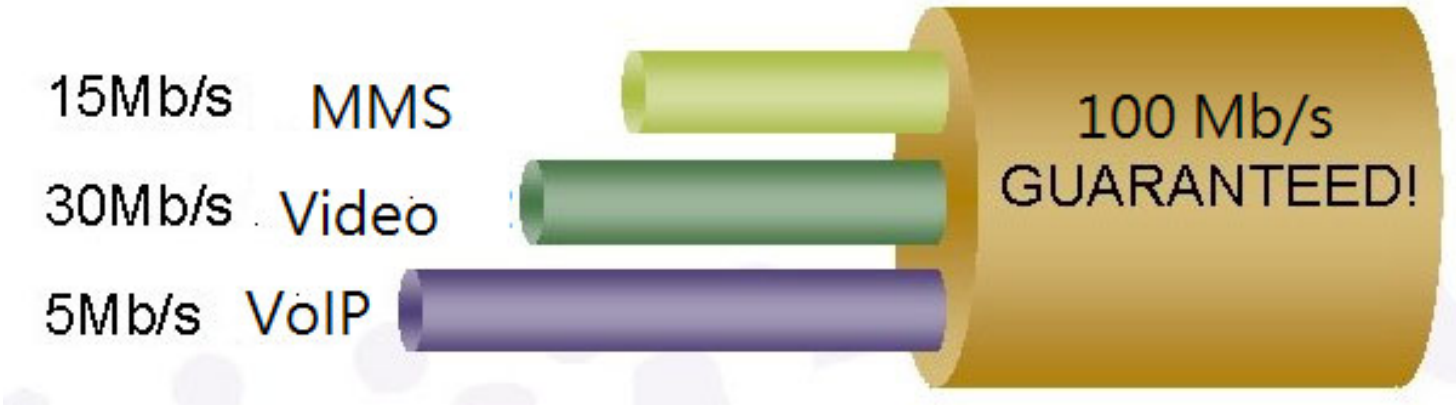
Coordinated Management of 5G Core Slices by MANO and OSS/BSS [14]

NFV-enabled 5G Core Network Slicing Testbed at NYCU (2)



Evaluating Dedicated Slices of Different Configurations in 5G Core [15]

SDN-enabled Transport Network Slicing

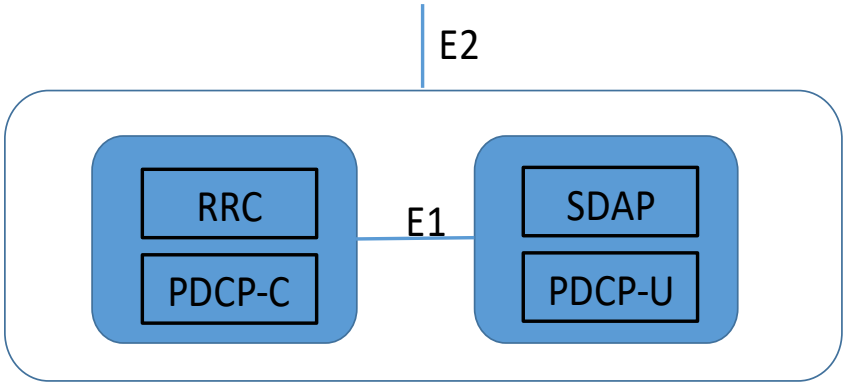


Example of bandwidth slicing
In Transport Network

RAN Slicing

Disaggregation of RAN in OpenRAN/O-RAN

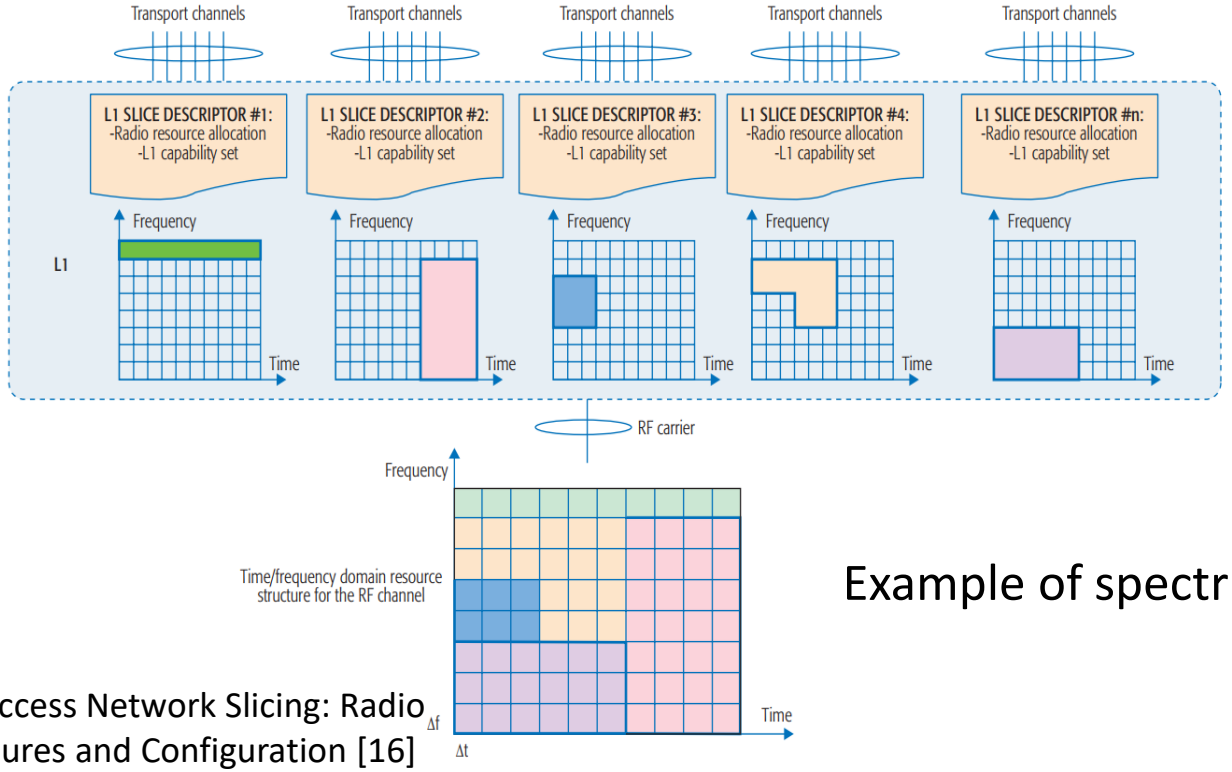
Protocol Layers	4G LTE	OpenRAN or O-RAN
PDCP	BBU	CU-CP and CU-UP
RLC		DU
MAC		
PHY-H		
PYH-L		RU
RF	RRH	



Control Plane and User Plane Separation at CU

Spectrum Slicing at RAN

- In the RAN, slicing can be built on physical radio resources (e.g. transmission point, spectrum, time) or on logical resources abstracted from physical radio resources.



Example of spectrum slicing

Source: On 5G Radio Access Network Slicing: Radio Interface Protocol Features and Configuration [16]

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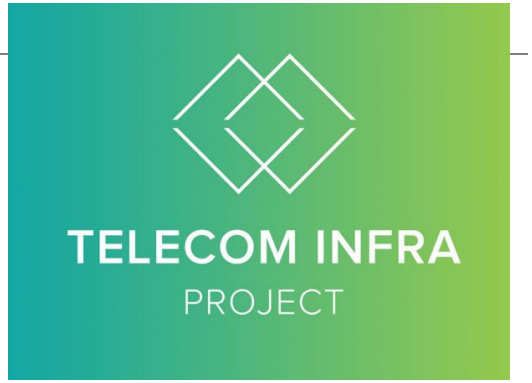
Open Sources for Network Slicing

Technologies	OpenRAN/O-RAN	NFV	SDN	5GC
Examples of Open Source Projects	OAI 5G RAN, O-RAN OSC, ONF SD-RAN, TIP OpenRAN	ONAP, OSM, Tacker, ONF XOS, FOKUS OpenBaton	OpenDaylight, ONF ONOS, RYU, Floodlight	NCTU free5GC, Open5GS, FOKUS Open5GCore (license required), Facebook Magma, OAI 5G Core

OpenRAN/O-RAN

- OAI 5G RAN
- O-RAN OSC
- ONF SD-RAN
- TIP OpenRAN



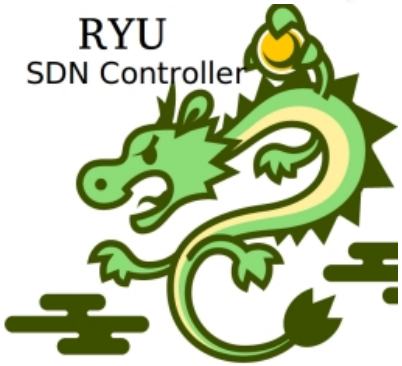
NFV

OPEN BATON

- ONAP (Open Network Automation Platform)
- OSM (Open Source MANO)
- Tacker (OpenStack Tacker)
- ONF XOS
- FOKUS OpenBaton

SDN

- OpenDaylight
- ONF ONOS
- RYU
- Floodlight



5GC (5G Core)

- NYCU free5GC
- Open5GS
- FOKUS Open5GCore (license required)
- Facebook Magma
- OAI 5G Core

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- **Outlook**

Outlook

- **Network Slicing Phase 2** (R16) and **Network Slicing Phase 3** (R17) (see 3GPP TR 23.700)
- **Network Slicing Phase 2** allows operators to outsource the management of network slicing subscriptions to third parties, allowing these third parties to use the operator's network to provide services to their customers, without having to go through the original operator to manage their own users' network slicing subscription.
- **Network Slicing Phase 3** will further improve the overall operability and automation of network slicing deployment.

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Thank you.