



End-to-end, multi-domain and multi-tenant aspects in 5G network slicing

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■ Acknowledgement

- This overview and analysis is compiled and structured, based on several public documents, conferences material, studies, research papers, standards, projects, overviews, tutorials, etc. (see specific references in the text and Reference list).
- The selection and structuring of the material belongs to the author.
- Given the extension of the topics, this presentation is limited to a high level overview only, mainly on architectural aspects.



End-to-end, multi-domain and multi-tenant aspects in 5G network slicing



- **Motivation of this talk**
- **The 5G (fifth generation) networks, in E2E architectures**
 - 5G- Important technology ← increasing demand of the current and future networks and services, (flexibility, capacity, response time, number of terminals, energy saving, etc.)
 - Driving forces for 5G: IoT, smart cities, industry, governance, IoV/automotive, safety/emergency, entertainment, environment, etc.,
 - Many R&D projects related to different areas of 5G
 - Standardization/fora organizations – strongly involved
 - 3GPP, 5GPP, ETSI, ITU-T, GSMA, ONF, NGNM, IETF, IEEE, etc.
 - **Network slicing** - resource sharing (w. logical isolation) among multiple tenants or network operators and/or services in multi-domain context
 - **5G slicing in E2E, multi-domain and multi-tenant context → many open issues and challenges**



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- 6. Conclusions**



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3. **5G slicing general architectures**
4. **Multi-tenant 5G slicing**
5. **Multi-domain and end to end 5G slicing**
6. **Conclusions**



1. 5G Vision and Architectures



1.1 Key Drivers, Requirements, Technologies

- **Driving factors for cellular network evolution 3G → 4G → 5G**
 - Device, Data, and Data transfer rates
 - continuous growth in wireless user devices, data usage
 - desired: better quality of experience (QoE)
 - ~ 50 billion connected devices (IoT) will utilize the cellular network services until 2025 → high increase in data traffic

- **Three views/sets-of-requirements for 5G**
 - ***user-centric*** (uninterrupted connectivity and communication services, smooth consumer experience)
 - ***service-provider-centric*** (connected intelligent systems, multi-tenant, multi-domain capabilities, large area of IoT services, critical monitoring/tracking services)
 - ***network-operator-centric*** (scalable, energy-efficient, low-cost, efficiently managed, programmable, and secure - communication infrastructure)

1.1 Key Drivers, Requirements, Technologies (cont'd)

- **Consequence: three main 5G features**
 - ***Ubiquitous connectivity for large sets of users*** : devices connected ubiquitously; uninterrupted user experience
 - ***Very low latency*** (~ few ms): for life-critical systems, real-time applications, services with zero delay tolerance
 - ***High-speed Gigabit connection***

- **5G: evolution of mobile *broadband networks* + *new unique network and service capabilities*:**
 - It will ensure *user experience continuity* in various situations
 - high mobility (e.g. in trains)
 - very dense or sparsely populated areas
 - regions covered by heterogeneous technologies

- **5G - key enabler for the Internet of Things, M2M**



1. 5G Vision and Architectures



1.1 Key Drivers, Requirements, Technologies (cont'd)

- **Mission critical services**
 - high reliability, global coverage and/or very low latency (currently these features are offered by specialised networks), public safety
- **5G will integrate: *networking + computing + storage* resources into one programmable and unified infrastructure**
 - **optimized** and **dynamic usage** of all distributed resources
 - **convergence of fixed, mobile** and unicast/mcast/broadcast services
 - support **multi tenancy models**, enabling players collaboration
 - Cooperation with **cloud/fog/edge computing**

1.1 Key Drivers, Requirements, Technologies (cont'd)

- **5G Key technological characteristics**
 - Heterogeneous set of integrated air interfaces
 - Cellular and satellite solutions
 - Simultaneous use of different **Radio Access Technologies (RAT)**
 - **Seamless handover** between heterogeneous RATs
 - Ultra-dense networks with numerous small cells
 - Need new interference mitigation, backhauling and installation techniques
- **Driven by SW**
 - unified OS in a number of PoPs, especially at the network edge
- To achieve the required performance, scalability and agility it will rely on
 - **Software Defined Networking (SDN)**
 - **Network Functions Virtualization (NFV)**
 - **Cloud/Mobile Edge Computing (MEC) /Fog Computing (FC)**
- **Ease and optimize network management** operations, through
 - **cognitive features**
 - advanced **automation** of operation through proper algorithms
 - Data Analytics and Big Data techniques -> monitor the users' QoE

1.1 Key Drivers, Requirements, Technologies (cont'd)

- **5G disruptive capabilities (general requirements)**
 - **x 10 improvement in performance** : capacity, latency, mobility, accuracy of terminal location, reliability and availability
 - **simultaneous connection of many devices** + improvement of the terminal battery capacity life
 - **lower energy consumption** w.r.t. today 4G networks; energy harvesting
 - **better spectral efficiency** than in 3G, 4G
 - **citizens may manage their personal data**, tune their exposure over the Internet and protect their privacy
 - **reduce service creation time** and facilitate integration of various players delivering parts of a service
 - built on **more efficient hardware**
 - **flexible and interworking in heterogeneous** environments

1.1 5G Key Specific Requirements

- **Summary of 5G figures - strong goals:**
 - **1,000 X in mobile data volume** per geographical area reaching a target ≥ 10 Tb/s/km²
 - **1,000 X in number of connected devices** reaching a density ≥ 1 M terminals/km²
 - **100 X in user data rate** reaching a peak terminal data rate ≥ 10 Gb/s
 - **1/10 X in energy** consumption compared to 2010
 - **1/5 X in E2E latency reaching 5 ms** for e.g. tactile Internet and radio link latency reaching a target ≤ 1 ms, e.g. for Vehicle to Vehicle (V2V) communication
 - **1/5 X in network management** OPEX
 - **1/1,000 X in service** deployment time, reaching a complete deployment in ≤ 90 minutes

1.1 5G Requirements (cont'd)

- **Additional requirements (and objectives) :**
 - sustainable and scalable technology
 - cost reduction through human task automation and hardware optimization
 - ecosystem for technical and business innovation

- **Application fields:**
 - network solutions and vertical markets
 - Automotive/loV, energy
 - IoT
 - food and agriculture
 - city management, government
 - education
 - healthcare, manufacturing
 - public transportation
 -



1. 5G Vision and Architectures



1.2 Trends in 5G networking

Network softwarization: represents sets of functions assuring **programmability** of

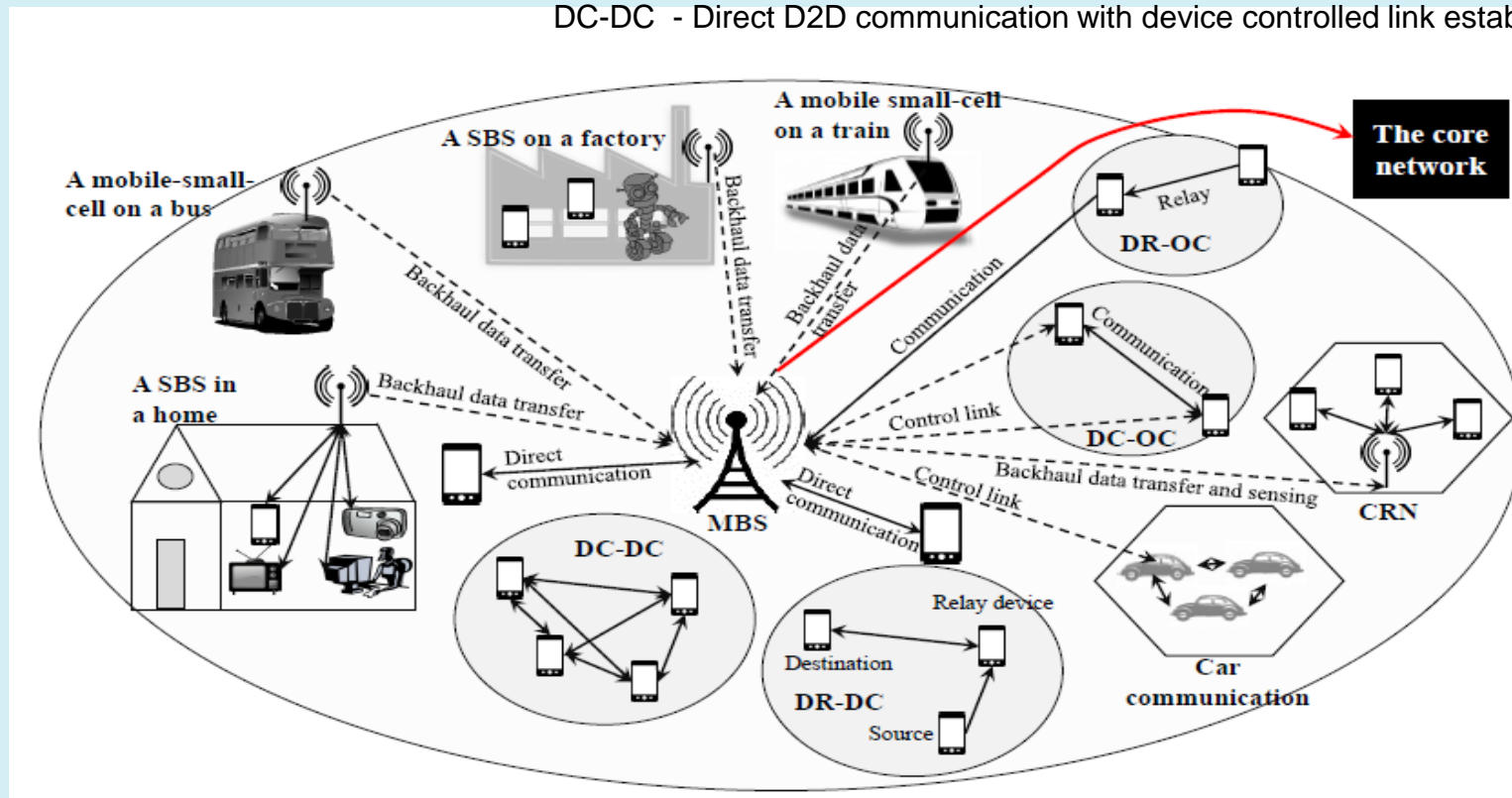
- network devices
- **network functions (NF)**- virtual or physical
- **network slices** – logical, on demand, customized networks
- network services and applications
- **Architectural planes:** Data/user, control, management
- **Shift** from network of entities, to **network of (virtual) functions** /capabilities.
 - NFs become units of networking
- **Separation** of concerns between
 - control/ management/ softwarization/ services
 - logical / physical resources functions (connectivity, computing and storage) and network capabilities
- **On demand composition** of NFs and network capabilities
- Develop network softwarization capabilities in all network segments and network components.

See: A.Galis, 5G Architecture Viewpoints H2020 5G PPP Infrastructure Association July 2016, August 2017, <https://5g-ppp.eu/white-papers/>

1.3 5G Generic Architecture

- multi-tier arch.: small-cells, mobile small-cells, and D2D- and Cognitive Radio Network (CRN)

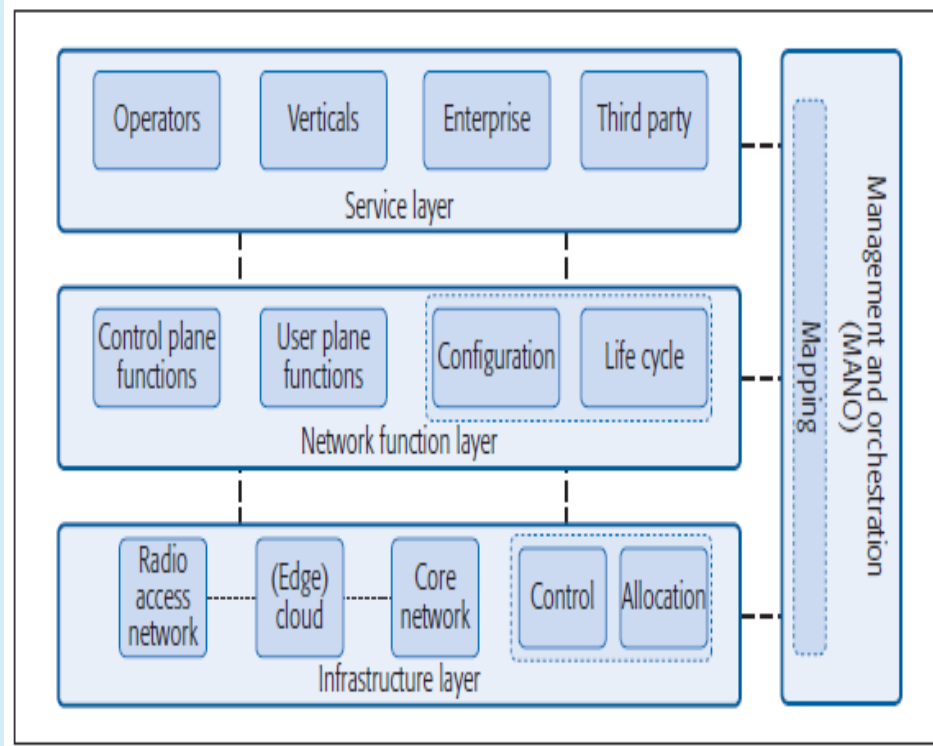
DR-OC - Device relaying with operator controlled link establishment
 DC-OC - Direct D2D communication with operator controlled link establishment
 DR-DC - Device relaying with device controlled link establishment
 DC-DC - Direct D2D communication with device controlled link establishment



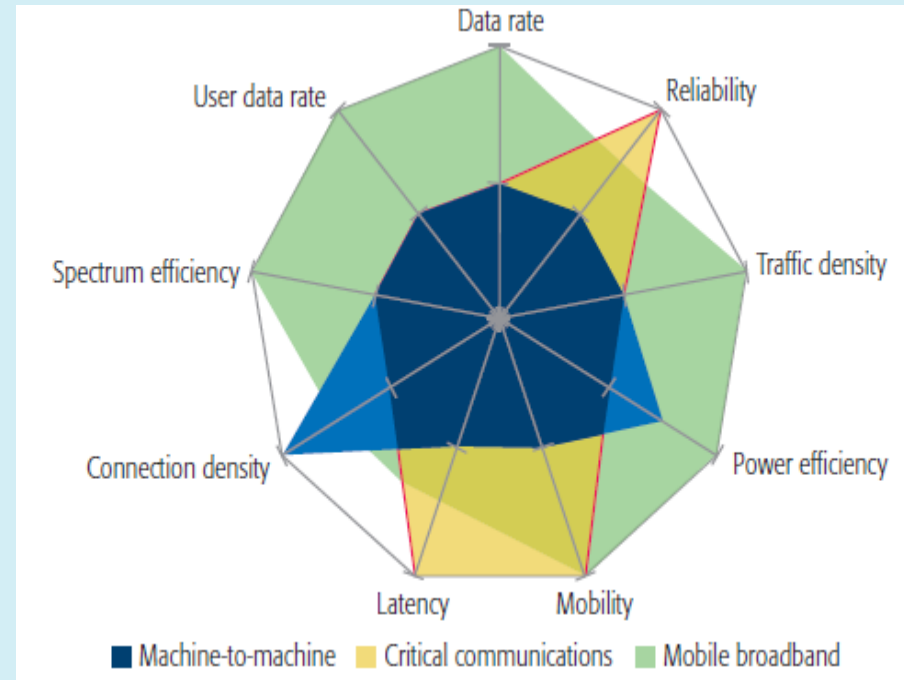
Source: Panwar N., Sharma S., Singh A. K. 'A Survey on 5G: The Next Generation of Mobile Communication'. Accepted in Elsevier Physical Communication, 4 Nov 2015, <http://arxiv.org/pdf/1511.01643v1.pdf>

1.4 5G Layered Architecture

- **Generic layered architecture**
 - High level representation

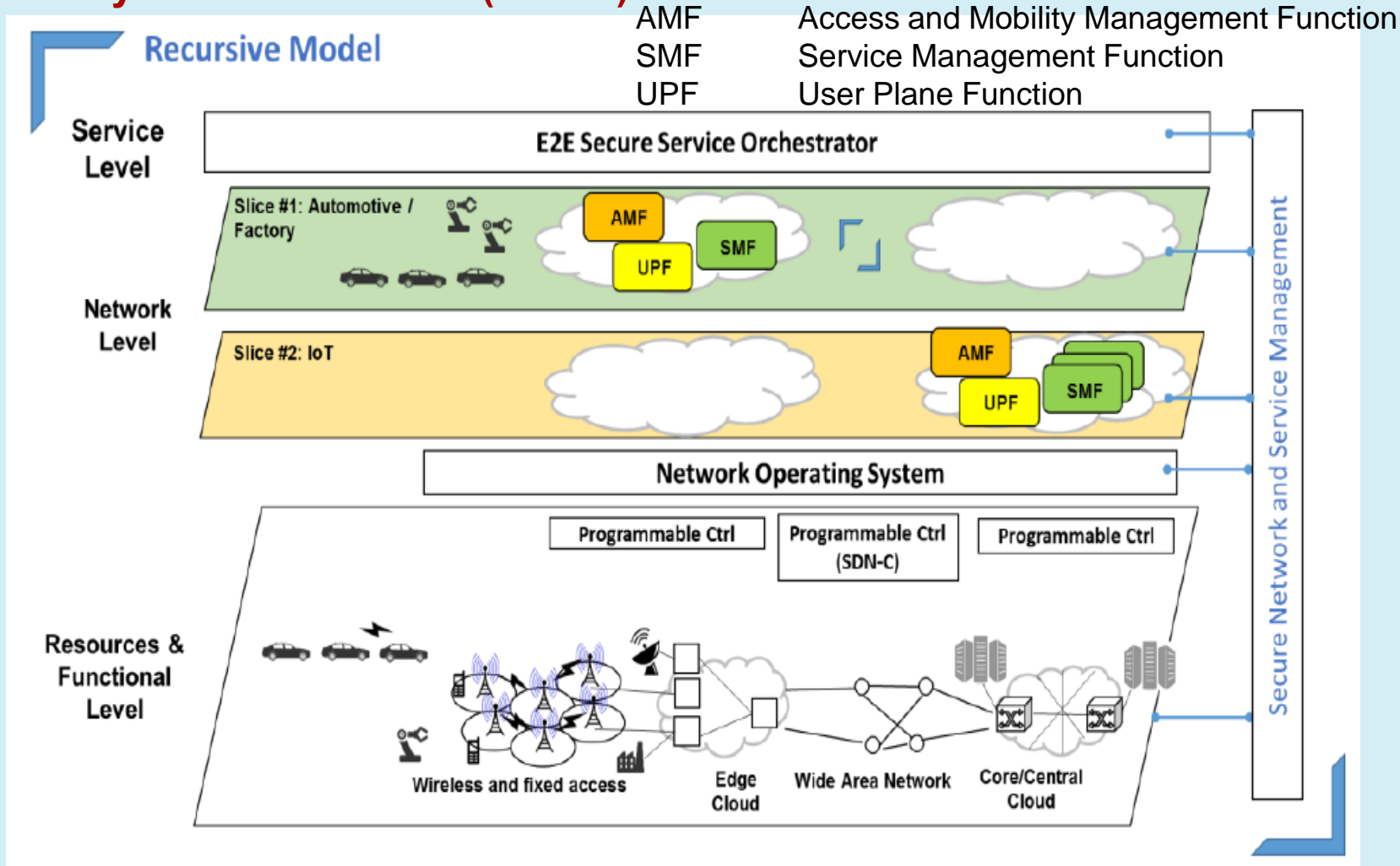


- Key 5G use cases and their requirements
- difficult for a traditional unique arch to meet all of them
 - **dedicated slicing can be the solution**



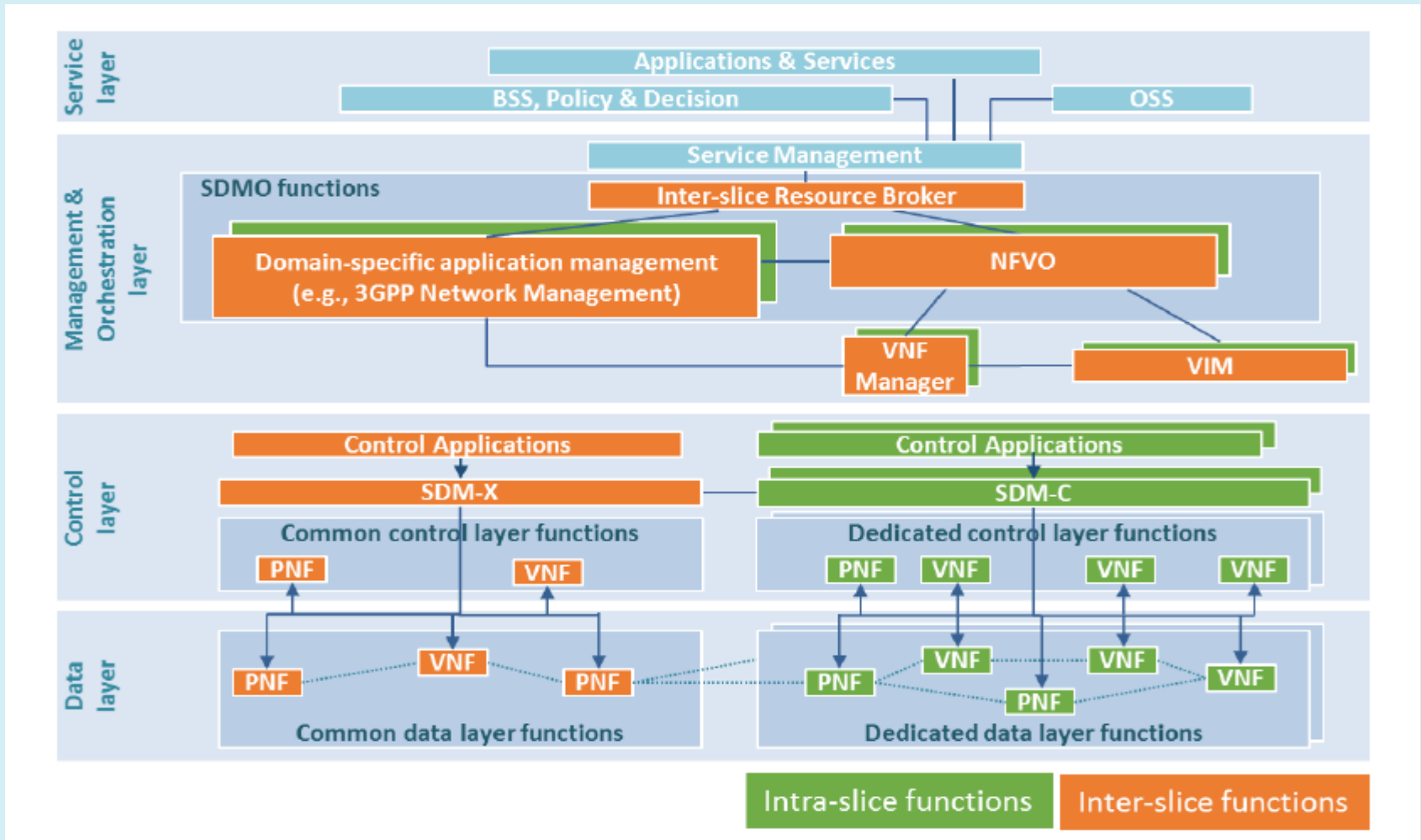
Source: X. Foukas, G. Patounas, A. Elmokashfi, and M.K. Marina, Network Slicing in 5G: Survey and Challenges, IEEE Communications Magazine, May 2017, pp.94-100

1.4 5G Layered Architecture (cont'd) - 5GPP vision



Source: 5GPP Architecture Working Group, View on 5G Architecture, Version 2.0, December 2017

1.4 5G Layered Architecture (cont'd)



Source: 5GPPP Architecture Working Group, View on 5G Architecture, Version 2.0, December 2017



1. 5G Vision and Architectures



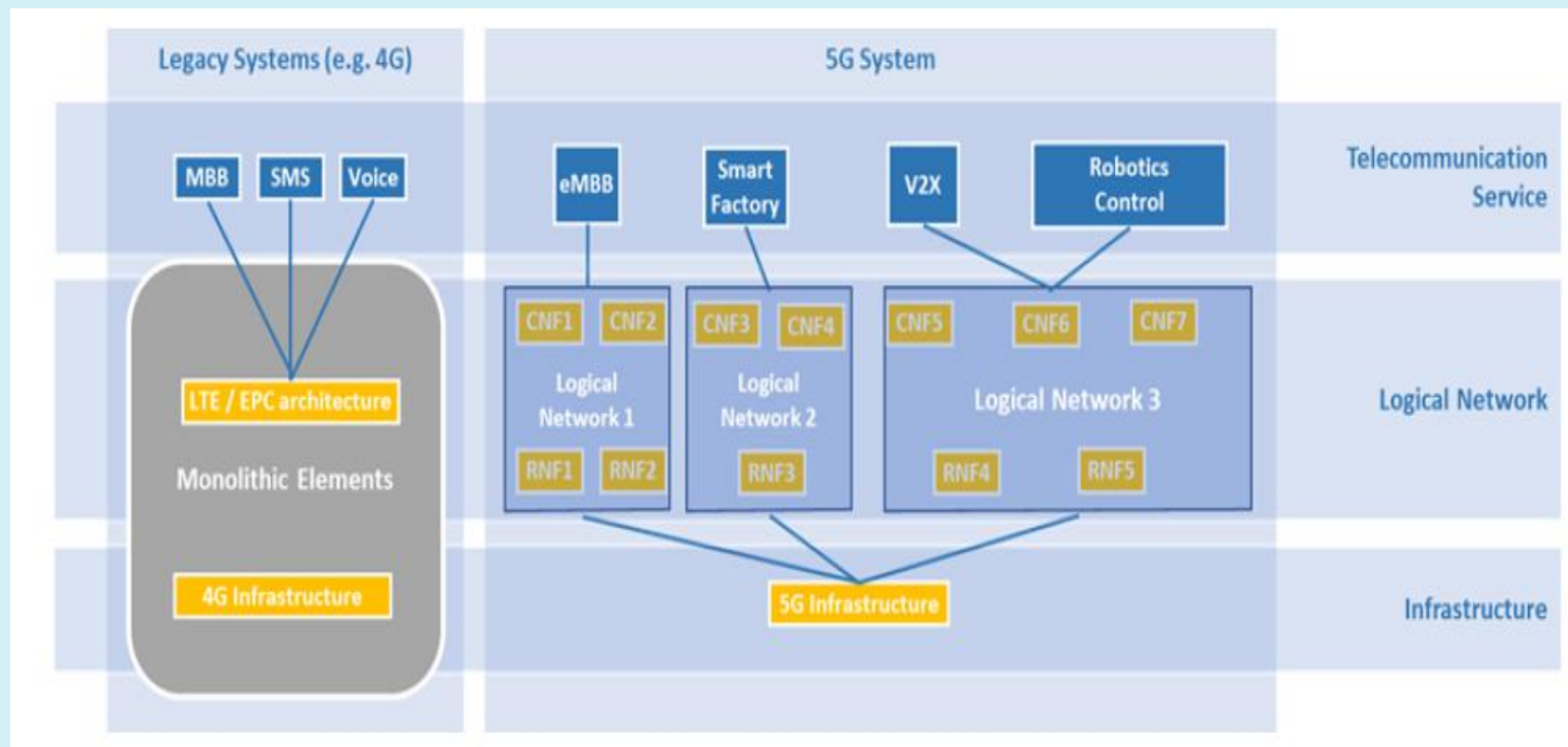
1.4 5G Layered Architecture (cont'd)

- **Previous slide:**
- **Service layer** includes
 - Business Support Systems (BSSs)
 - Business-level Policy and Decision functions
 - Apps. and services operated by the tenant (includes the E2E orchestration system)
- **Management and Orchestration layer**
 - Service Management function
 - Software-Defined Mobile Network Orchestrator (SDM-O)
 - Inter-slice resource Broker (handles cross-slice resource allocation)
 - ETSI NFV (Mgmt. and Orchestration) MANO higher level functions (NFVO)
 - Domain specific application manager (e.g., 3GPP Net Mng)
 - ETSI NFV MANO lower level functions (VIM, VNF Manager)
- **Control layer**
 - Software-Defined Mobile Network Coordinator (SDM-X) – **inter-slice**
 - Software-Defined Mobile Network Controller (SDM-C) – **intra-slice**
 - other control applications
- **Data layer** - VNFs and PNFs needed to carry and process the user data traffic
- **Auxiliary: Multi-Domain Network Operating System Facilities**
 - different adaptors and network abstractions above the networks and clouds heterogeneous fabrics

Note: The name “layer” here does not correspond to the classic one;. Here the semantic is rather “plane”

See: 5GPPP Architecture Working Group , View on 5G Architecture, Version 2.0, December 2017

1.5 4G versus 5G concepts



MBB - Mobile Broadband;

LTE - Long Term Evolution (4G) ;

V2X - vehicle to X ; **CNF**- Core Network Functions;

SMS - Short Messages service;

EPC- Evolved Packet Core

RNF- RAN network Functions



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6. **Conclusions**

2.1 Network slicing concepts

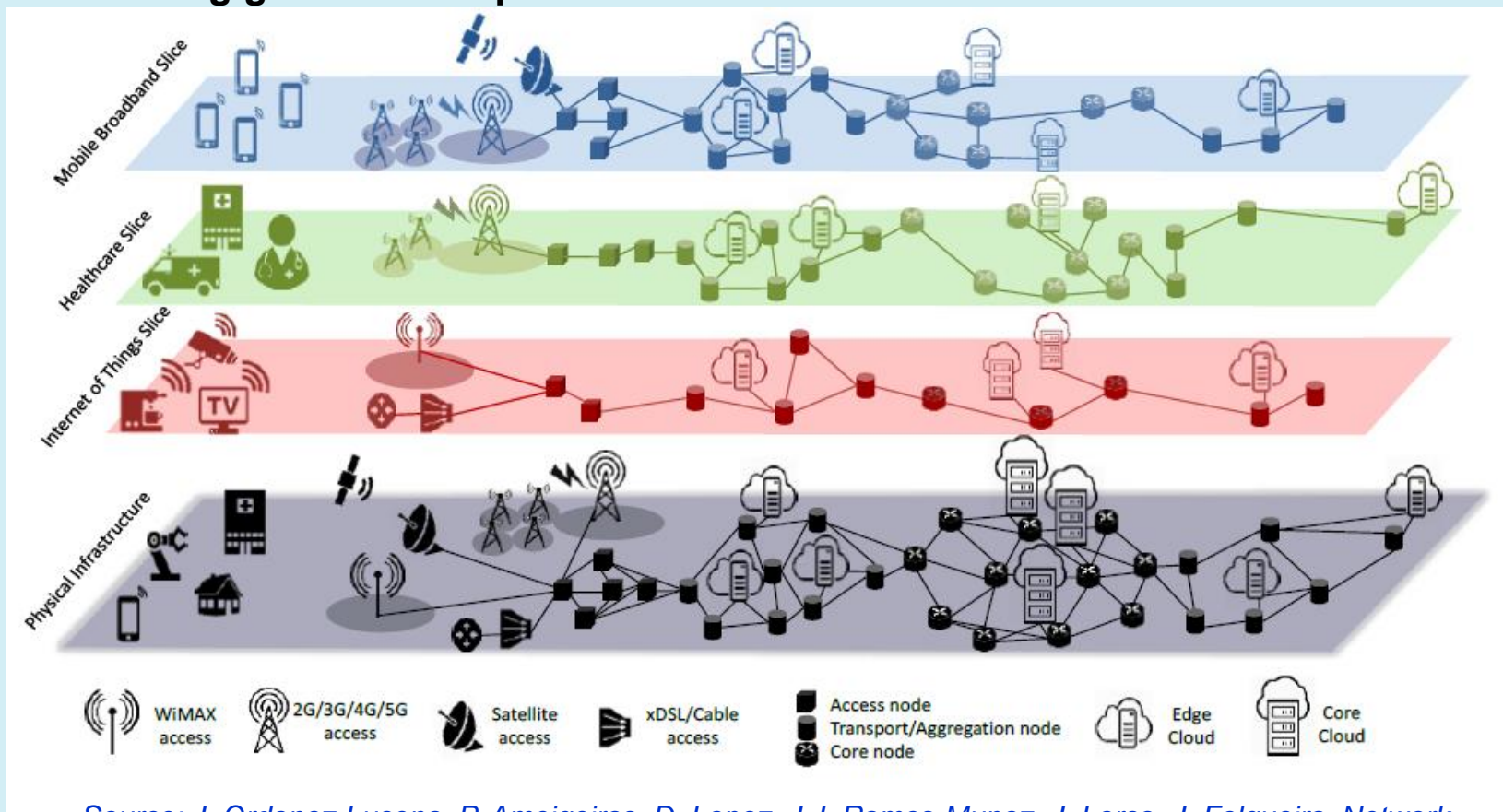
■ Network Slicing :

- **E2E concept** covers all network segments : radio, wire access, core, transport and edge networks.
- **concurrent deployment of multiple E2E logical, self-contained and independent shared or partitioned networks** on a common infrastructure platform
- **Slices**
 - created **on demand**, running on a common underlying (PHY/V) network, mutually isolated with independent M&C
 - **composition** of adequately configured **NFs**, network apps., and the underlying cloud infrastructure (PHY/virtual/ emulated resources, etc.)
 - **resources are bundled together** to meet specific UC reqs. (e.g., bandwidth, latency, processing, resiliency) coupled with a business purpose
- **SDN and NFV** – support technologies providing virtualisation, programmability, flexibility, and modularity to create **multiple network slices** each tailored for a given UC

2. 5G slicing concepts, characteristics and use cases

2.1 Network slicing concepts (cont'd)

- 5G slicing generic example



Source: J. Ordonez-Lucena, P. Ameigeiras, D. Lopez, J.J. Ramos-Munoz, J. Lorca, J. Folgueira, Network "Slicing for 5G with SDN/NFV: Concepts, Architectures and Challenges", IEEE Communications Magazine, 2017, Citation information: DOI 10.1109/MCOM.2017.1600935



2. 5G slicing concepts, characteristics and use cases

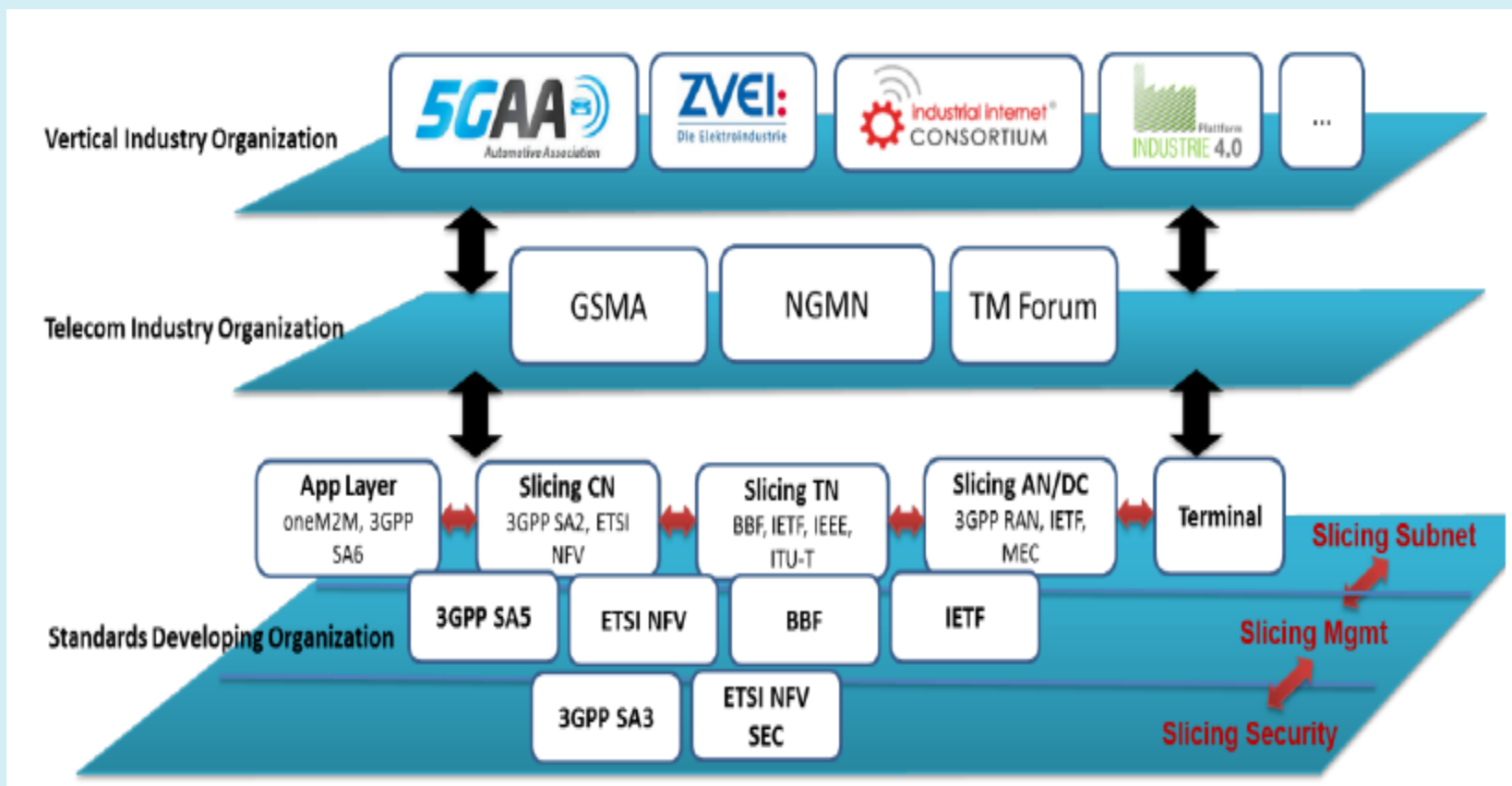


2.2 Standardisation effort oriented to slicing

- **European Telecom Std. Institute (ETSI) –Next Generation Protocols (NGP) –** Technology independent approach to slicing
 - **ETSI- Network Function Virtualisation (NFV)–** studies on SDN and NFV support for slices
- **3rd Generation Partnership Project (3GPP) –** contributions on RAN, Services and architectures, Core networks and terminals, Mgmt. and orchestration
- **5G-PPP –** details the roles and relationships between different parts of the 5G network.
- **Next Generation Mobile Networks (NGMN) –**Slicing concept for 5G with IMT2020
- **Int'l Telecom Union (ITU-T) –** Works on Slices in IMT-2020, SG13 and SG15: management & transport aspects; alignment with 5G
- **Open Networking Foundation (ONF) , Broadband Forum (BBF)**
- **Internet Engineering Task Force (IETF) –** focused more on fixed network and management of network slicing
- **GSM Association (GSMA)-** business aspects, use cases, etc.

2. 5G slicing concepts, characteristics and use cases

2.2 Standardisation effort oriented to slicing (cont'd)



Source: GSMA, Network Slicing, - Use Cases and Requirements , April 2018

2.3 Terminology summary

■ Networking Servicing terms

- **Service** - A SW piece performing one or more functions and providing one or more APIs to apps. or other services of the same or different layers
Services can be combined with other services
- **Service Instance** - An instance of an EU service or a business service that is realized within or by a network slice
 - Services and service instances would be provided by the network operator or by third parties
- **Administrative domain (AD)** - A collection of systems and networks operated by a single organization or administrative authority
- **Infrastructure domain** – an admin. domain
 - providing virtualised infrastructure resources (compute, network, storage)
 - or a composition of resources via a service abstraction to another AD responsible for the management and orchestration of those resources

See: L. Geng , et.al., IETF- “Network Slicing Architecture draft-geng-netslices-architecture-02”, 2017
ETSI GS NFV 003 V1.3.1 (2018-01) Network Functions Virtualisation (NFV); Terminology for Main Concepts in NFV



2. 5G slicing concepts, characteristics and use cases



2.2 Terminology summary (cont'd)

■ Networking Servicing terms

- **Tenant:** one or more service users sharing access to a set of physical, virtual resources or service resources (e.g. offered by NFV-MANO framework)
- **Multi-tenancy:** feature where physical, virtual or service resources are allocated so that multiple tenants and their computations and data are isolated from and inaccessible by each another
- **Tenant domain:** domain that provides VNFs, and combinations of VNFs into Network Services, and is responsible for their management and orchestration, including their functional configuration and maintenance at application level
- **Trust domain:** collection of entities that share a set of security policies

*See: L. Geng, et al., IETF- "Network Slicing Architecture draft-geng-netslices-architecture-02", 2017
ETSI GS NFV 003 V1.3.1 (2018-01) Network Functions Virtualisation (NFV); Terminology for Main Concepts in NFV*

2.3 Terminology summary (cont'd)

■ Network Resources

- **Resource** - P/V (network, compute, storage) component available within a system (can be very simple or comprised of multiple other resources)
- **Logical Resource** - An independently manageable partition of a Physical (P) resource, inheriting the same characteristics as the P resource
- **Virtual Resource** - An abstraction of a P/L resource, maybe with different characteristics and extended capabilities w.r.t the original

- **Network Function (NF)** - A processing function in a network, including but not limited to network nodes functionality
 - NFs implementation: as a network node on a dedicated HW, or as VNFs
- **Virtual Network Function (VNF)** - A NF whose functional SW is decoupled from HW
 - It is implemented by **one or more virtual machines (VM)**

- **Network Element (NE)** - a manageable logical entity uniting one or more network devices. This allows distributed devices to be managed in a unified way using one management system

2.3 Terminology summary (cont'd)

■ Network Slicing Terms

- **Resource Slice** - A grouping of P/V (network, compute, storage) resources; it can be a component of a NS, but on its own does not represent fully a NS
- **Network Slice (NS)**
 - a managed group of subsets of resources, NFs/VNFs at the DPI, CPI, M/OPI, and services at a given time
 - programmable and having the ability to expose its capabilities
 - the NS behaviour is realized via **network slice instance(s)**
- **End-to-end NS (E2E-NS)** - A cross-domain NS
 - it may consist of access (fixed or cellular), transport (mobile) core networks and etc. It can be customized according to the requirements of network slice tenants
- **Network Slice Instance (NSI)** - An activated NS, created based on network template
 - It corresponds to a **set of managed run-time NFs and resources** to run them, forming a complete instantiated logical network to meet the reqs. of the service instance(s).
 - **May be shared** across multiple service instances provided by the NO

2.3 Terminology summary (cont'd)

■ Network Slicing Terms

- **Network Slice Provider (NSP)** - typically is a telecom SrvP; **is the owner or tenant** of the network infrastructures (NI) from which network slices are created
 - The NSP manages and orchestrates the resources supporting NS
- **Network Slice Terminal (NST)** - A terminal NS-aware, typically subscribed to the service hosted by NSI.
 - It may subscribe to several NSIs simultaneously
- **Network Slice Tenant (NSTn)** - is the user of specific NSIs, who offer specific services to end customers
 - The operators' customers (e.g., customers from vertical industries) or the operators themselves. They utilize the NSIs to provide services to their end users
 - Tenants may have independent O&M reqs., uniquely applicable to the NSIs
 - NSTn-s can request the creation of new NSI
 - The NSP usually grants some management capability to NSTn



2. 5G slicing concepts, characteristics and use cases



2.3 Terminology summary (cont'd)

■ Network Slicing Terms

- **Network Slice Repository (NSRp)**- in each domain; it consists of a list of active NSes with their identifiers and description
 - This description defines also the access rules to a slice
 - NSRp is updated by slice orchestrator
 - If recursive slicing, then NSRp keeps info about all slices that compose a higher level slice but such a slice has its own identifier and descriptors

2.4 Business model (actors)- variant of definition

- **Infrastructure Provider (InP)**– owner of the PHY infrastructure (network/cloud/data center) and lease them to operators
 - It can become an ISLP if it leases the infrastructure in slicing fashion
- **Infrastructure Slice Provider (ISLP)** – typically a telecom SP, **owner or tenant** of the infrastructures from which network slices can be created



2. 5G slicing concepts, characteristics and use cases



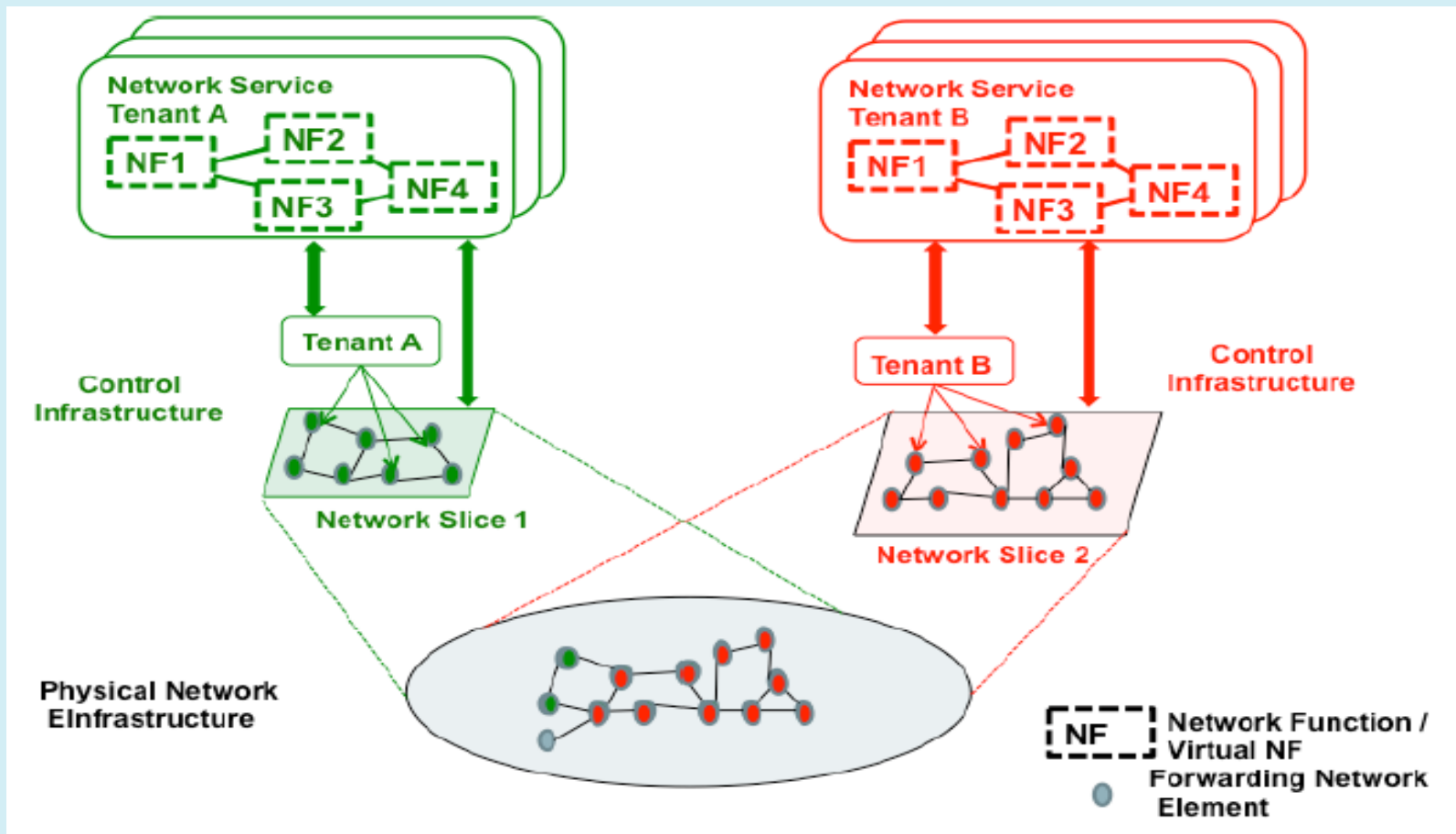
2.4 Business model (actors)- variant of definition (cont'd)

- **Infrastructure Slice Tenant (IST)** - the user of specific network/cloud/data centre slice, hosting customized services
 - ISTs can request creation of new infrastructure slice through a service model
 - **IST leases virtual resources from one or more ISLP** in the form of a virtual network, where the tenant can realize, manage and provide network services to its users
 - **A network service is a composition of NFs**, and it is defined
 - in terms of the **individual NFs**
 - and the **mechanism** used to **connect them**
- **End user:** consumes (part of) the services supplied by the tenant, ***without providing them to other business actors.***

See A.Galis and K.Makhijani, *Network Slicing Landscape: A holistic architectural approach, orchestration and management with applicability in mobile and fixed networks and clouds, v1.0, Network Slicing Tutorial – IEEE NetSoft 2018 – Montreal 29th June 2018.*

2. 5G slicing concepts, characteristics and use cases

2.4 Business model (actors)



Source: A. Galis, *Towards Slice Networking*, presentation at IETF98 -, March 2017;
<https://github.com/netslices/IETF-NetSlices>



2. 5G slicing concepts, characteristics and use cases



2.5 Summary of Network Slices key characteristics

- **User/tenant related characteristics**
 - **dedicated logical networks** built on **demand**, on an **common infrastructure** (connectivity, storage, computing- but not limited to these)
 - **independent and self-contained**, partitioned NFs and resources on a shared infrastructure
 - **supporting at least one service** at a given time, guaranteed service level
 - **fast** service/network **deployment**
 - **cost effective**
 - **customizable NSes** (due to SDN and NFV support) and **powerful M&C** of the network resources
 - provide an **abstraction capability** by the creation of logically or physically isolated groups of network resources and VNF configurations

See: L. Geng , et.a;., IETF- “Network Slicing Architecture draft-geng-netslices-architecture-02”, 2017
A.Galiş and K.Makhijani, Network Slicing Landscape: A holistic architectural approach, orchestration and management with applicability in mobile and fixed networks and clouds, v1.0, Network Slicing Tutorial – IEEE NetSoft 2018– Montreal 29th June2018.

Softnet 2018 Conference, October 14 - 18, Nice



2. 5G slicing concepts, characteristics and use cases



2.5 Summary of Network Slices key characteristics (cont'd)

■ User/tenant related characteristics

- **dynamic multi-service** support, **multi-domain, multi-tenant** (independent on infrastructure) **E2E – capable**, possible integration of various market verticals
- one NS may consist of **several cross-domain components**
 - from separate domains in the same or different admin.
 - or components applicable to the access/transport/core/ edge networks
- **NS creation**: on demand, dynamically and have non-disruptive re-provisioning capabilities
 - concurrently deployed with isolation guarantees
- **NSes are configurable and programmable**; possible negotiation of parameters

See: L. Geng , et.a;., IETF- “Network Slicing Architecture draft-geng-netslices-architecture-02”, 2017
A.Galis and K.Makhijani, Network Slicing Landscape: A holistic architectural approach, orchestration and management with applicability in mobile and fixed networks and clouds, v1.0, Network Slicing Tutorial – IEEE NetSoft 2018– Montreal 29th June2018.

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2.5 Summary of Network Slices key characteristics (cont'd)

- **NS Management and control characteristics**
 - **embedded mgmt. concept**, including coordination/ orchestration of NFs and resources
 - **managed group of subsets** of resources, PNF/VNF at the D/U, C, M/O Planes
 - **automation** of
 - **network operation, LCM of network slicing** (create, deploy, change, delete) and **auto-healing**
 - **optimization of resources** (auto-scaling/migration)
 - efficient **cooperation between Mgmt and Data Planes**
 - NS is seen by an operator as a complete network infrastructure and uses part of the network resources
- **Scalability**- high: many slices (hundreds), large communities of customers (millions)
- **Reliability**- high : redundancy, isolation, fault detection and repair

See: L. Geng , et.a.;, *IETF- “Network Slicing Architecture draft-geng-netslices-architecture-02”, 2017*
A.Galis and K.Makhijani, *Network Slicing Landscape: A holistic architectural approach, orchestration and management with applicability in mobile and fixed networks and clouds, v1.0, Network Slicing Tutorial – IEEE NetSoft 2018– Montreal 29th June2018.*

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2. 5G slicing concepts, characteristics and use cases



2.5 Summary of Network Slices key characteristics (cont'd)

- **Business and network operator/ISP –related characteristics**
- NS
 - open possibility of **new business models** (e.g. due to E2E NSes)
 - industrial companies can use NSes as a part of their own services
 - **reduced operations expenditures**

 - **programmability** allows to enrich the offered services
 - **OTT providers** and other **market players can use NSes without changing the PHY infrastructure**
 - simplifies the provisioning of services, manageability, integration and operation
 - creates a layer of abstraction by the creation of L/P isolated groups of network resources and VNFs
 - isolation, orchestration and separation of logical network behaviors from the underlying PHY network resources.

See: L. Geng , et.a;., IETF- “Network Slicing Architecture draft-geng-netslices-architecture-02”, 2017
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2. 5G slicing concepts, characteristics and use cases

2.6 Network slicing components

■ Resources

■ Two types of resources:

- **(1) Network Functions (NFs): functional blocks (FB)**, providing specific network capabilities to support particular service(s) demanded by each use case; generally implemented as
 - **SW instances** running on infrastructure resources
 - **Physical NFs** (a combination of vendor-specific HW+ SW defining a traditional purpose-built physical appliance)
 - **and/or virtualised NFs** (NF software is decoupled from the HW it runs on)
- **(2) Infrastructure Resources:** heterogeneous [HW + SW] for **hosting** and **connecting** NFs.
 - **Computing, storage and networking resources** (e.g. links and switching/routing devices enabling network connectivity)
 - physical assets for radio access
- The resources and their attributes are abstracted and logically partitioned
 - leveraging virtualisation mechanisms
 - defining virtual resources usable in the same way as physical ones

2. 5G slicing concepts, characteristics and use cases

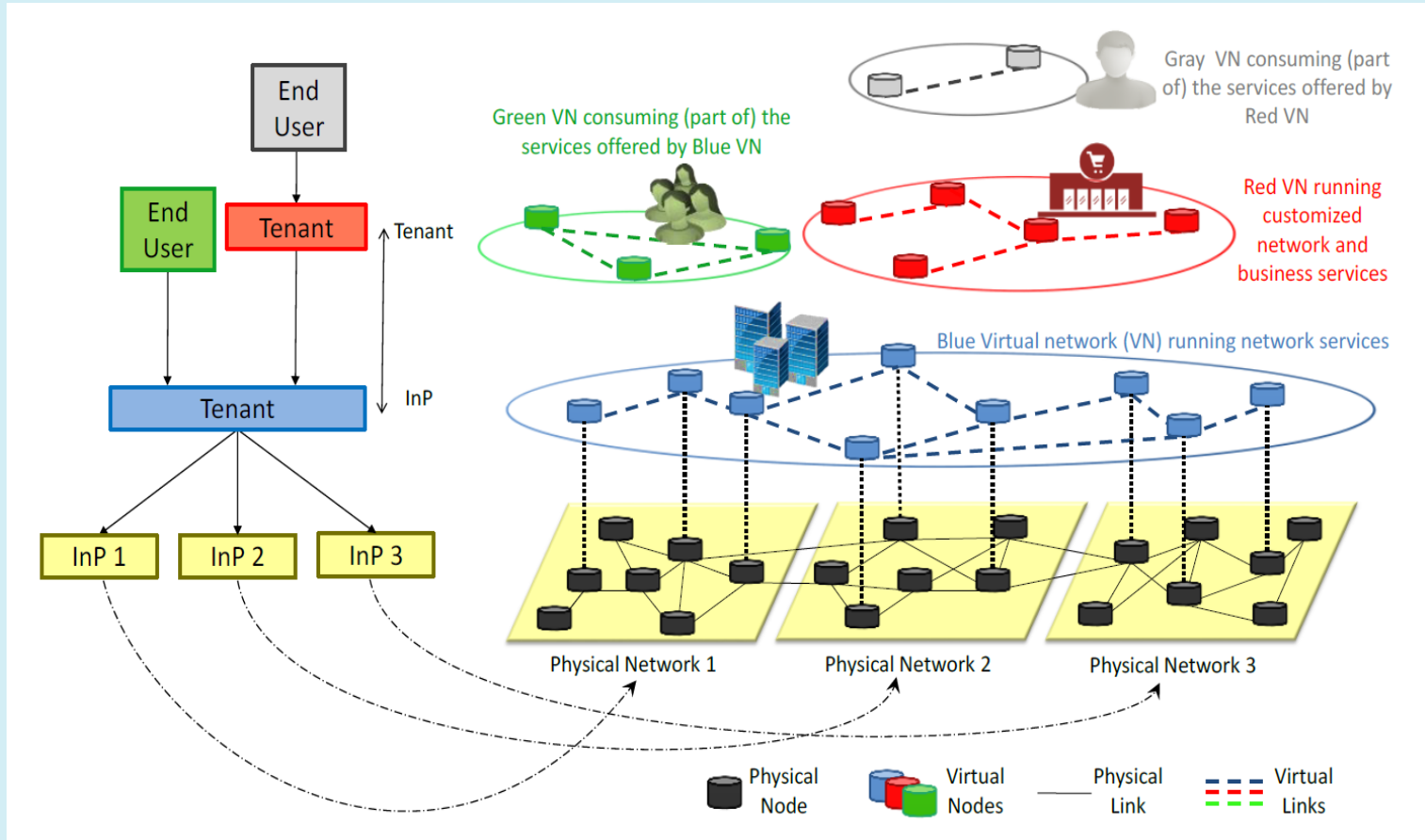
■ 2.6 Network slicing components (cont'd)

■ **Virtualisation**

- It is based on :
 - **resource abstraction** : representation of a resource in terms of attributes that match predefined selection criteria while hiding or ignoring aspects that are irrelevant to such criteria
- Resources to be virtualised : **physical or already virtualised**, supporting a **recursive** pattern with different abstraction layers.
- **Network virtualisation**: creation of multiple isolated virtual networks, completely decoupled from the underlying PHY network
- **InPs and tenants can act as virtualisation actors** (recursion principle is valid)
 - **Recursion**:
 - a tenant at one layer can acts as the InP for an upper layer
 - a tenant can provide network services to an end user, but also to another tenant

2. 5G slicing concepts, characteristics and use cases

2.6 Network slicing components (cont'd)



Source: J. Ordonez-Lucena, P. Ameigeiras, D. Lopez, J.J. Ramos-Munoz, J. Lorca, J. Folgueira, Network "Slicing for 5G with SDN/NFV: Concepts, Architectures and Challenges", IEEE Communications Magazine, 2017

2. 5G slicing concepts, characteristics and use cases

2.6 Network slicing components (cont'd)

- **Orchestration** - key process for network slicing
 - **General definition : bringing together and coordinating disparate things into a coherent whole**
 - an orchestrator coordinates seemingly disparate network processes for creating, managing and delivering services.
 - **Open issue: a unified vision and scope of orchestration has not been fully agreed upon (2016-17)**

- **Open Network Foundation (ONF) definition/vision on orchestration**
 - **continuing** process of **selecting resources** to fulfil client service demands in an optimal manner
 - **optimization policy** can be applied to govern orchestrator behaviour
 - to meet all the specific policies and SLAs associated with clients (e.g. tenants or end users) that request services
 - **“continuing”** meaning : available resources, service demands and optimization criteria **may change in time**

2.6 Network slicing components (cont'd)

■ **Orchestration (cont'd)**

- ONF: orchestration is also a defining characteristic of an SDN controller
- orchestrator functions include
 - client-specific service demand validation; resource configuration; event notification
- **Open issue:** in network slicing orchestration cannot be performed by a single centralized entity;
- Reasons:
 - **complexity** and broad scope or orchestration tasks
 - need to preserve **management independence** of the domains
 - need to support the possibility of **recursion**.
- **Some proposal [Ordonez]**
 - **Each virtualisation actor should have an orchestration entity**
 - The entities should **exchange information** and delegate functionalities between them
 - to ensure that the services delivered at a certain abstraction layer
 - satisfy the required performance levels
 - with optimal resource utilisation

2. 5G slicing concepts, characteristics and use cases

- **2.6 Network slicing components (cont'd)**
- **Isolation** - requirement for **parallel slices** running on a shared underlying substrate
- **Isolation aspects:**
 - **Performance:**
 - each slice is defined to meet particular service reqs. (KPIs)
 - service-specific performance reqs. **should be always met on each slice**, regardless of the congestion and performance levels of other slices.
 - **Security and privacy:**
 - **Attacks/faults** in one slice **must not have an impact on other slices**
 - **mgmt issues:** each slice must have independent security functions
 - to prevent unauthorized entities to have r/w access to slice-specific configuration/management/accounting information
 - to record any of access attempts, whether authorized or not



2. 5G slicing concepts, characteristics and use cases

- **2.6 Network slicing components (cont'd)**

- *Isolation (cont'd)*
- Isolation aspects:
 - **Management**: each slice must be independently managed as a separate network.
 - **How to to achieve isolation**
 - **consistent policies** and **mechanisms** to be defined **at each virtualisation level**
 - **policies** : lists of rules (*What?*) - describe how different manageable entities must be properly isolated, without delving into how this can be achieved.
 - **mechanisms** (*How?* it is to be done) - processes implemented to enforce the defined policies

 - **Interplay of virtualisation and orchestration is needed**

- **2.7 Network slicing- design choices**
- **Virtualisation of radio resources**
 - **Dedicated:** (+) ensures resource isolation, ease of realizing VBSes and multiple RATs
 - (-) Inefficient utilization of radio resources
 - **Shared:** (+) efficient use of radio resources
 - (-) more sophisticated techniques to isolate of radio resources
- **Granularity of NFs**
 - **Coarse-grained:** (+) easier deployment and management of NFs
 - (-) less flexible and adaptive to changing network conditions
 - **Fine-grained:** (+) flexible and easier to conform to SLAs
 - (-) complex -service chaining and interoperability of NFs
- **Service description**
 - **Human-readable format**
 - (+) Easier to express service requirements
 - (-) complex MANO role in mapping requirements to network components
 - **Set of functions and network components**
 - (-) Non-intuitive way to express service requirements
 - (+) Simpler realization of network slices

2.8 Categories of 5G fundamental scenarios

- Massive machine type communication (mMTC)
- Ultra reliability low latency communication (URLLC)
- Enhanced mobile broadband (eMBB)

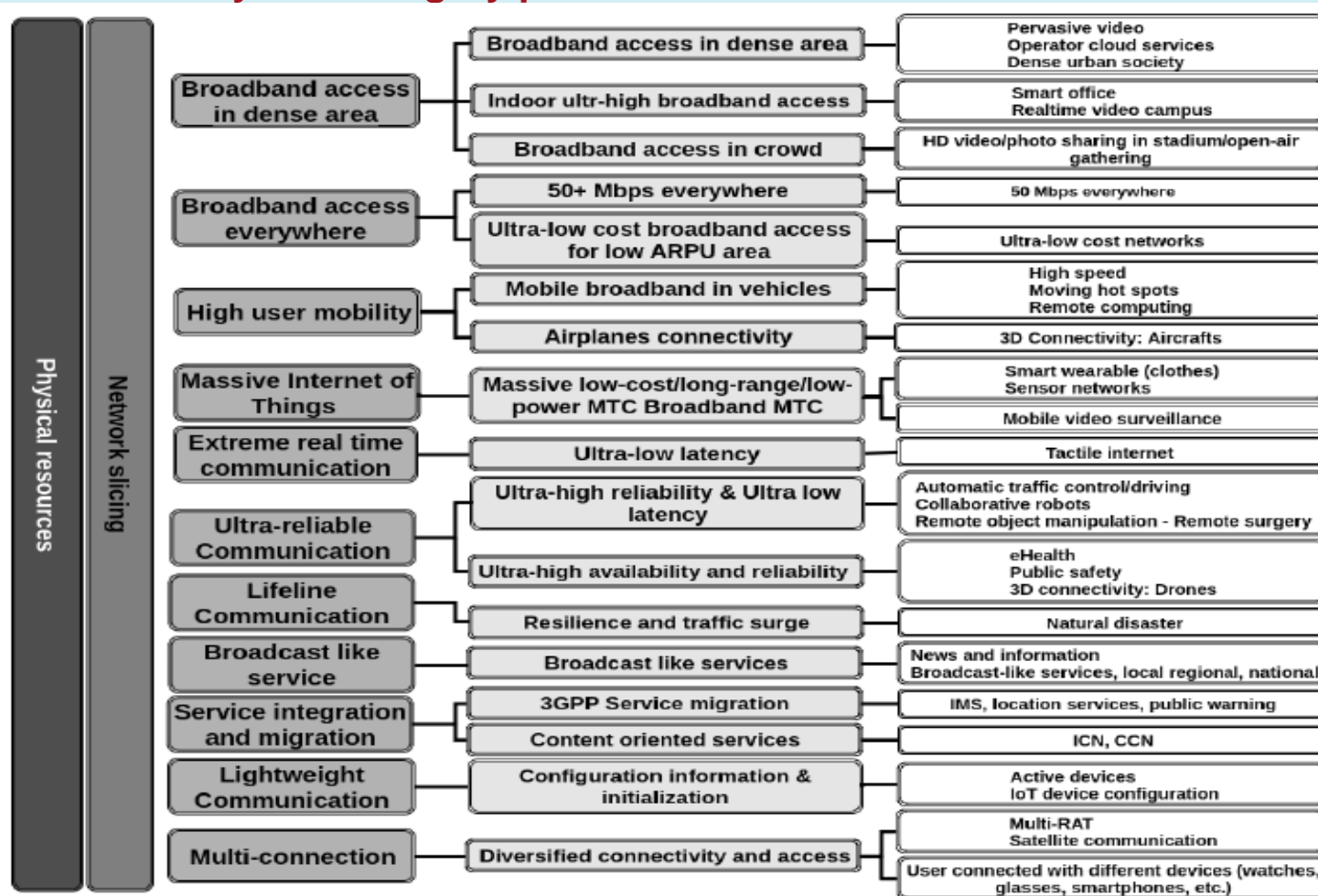
- **different requirements on 5G: functional** (e.g. priority, charging, policies, security, and mobility) and **performance** (e.g. latency, mobility, availability, reliability and data rates) -> **dedicated slices can be constructed**

Characteristics	mMTC	URLLC	eMBB
Availability	Regular	Very High	Regular (baseline)
E2E latency	Not highly sensitive	Extremely sensitive	Not highly sensitive
Throughput type	Low	Low/med/high	Medium
Frequency of Xfers	Low	High	High
Density	High	Medium	High
Network coverage	Full	Localized	Full

Source: End to End Network Slicing – White paper 3 Outlook 21, Wireless World , Nov 2017

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2.8 Use-cases family and category per 3GPP and NGMN



Source: *MGMN 5G WHITE PAPER, NGMN Alliance, white paper, https://www.ngmn.org/uploads/media/NGMN_5G_White_Paper_V1_0.pdf, Feb. 2015.*

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2. 5G slicing concepts, characteristics and use cases

- **2.9 Verticals and Use cases**

- **Augmented Reality (AR)/ Virtual Reality (VR)**
 - Strong-Interactive VR: Audio-visual interaction
 - Strong-Interactive VR: Low-delay speech and video coding
 - Strong-Interactive AR: Use Cases

- **Automotive (CV2X)**
 - Infotainment
 - Telematics
 - Road Safety and Efficiency:
 - road warning, information sharing
 - Advanced Driving Service
 - Cooperative driving
 - Platooning
 - Tele-operation

- **Energy**
 - Smart-grids, Micro-grids
 - Smart meters and aggregator gateways
 - Electricity traffic scheduling



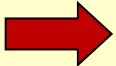
2. 5G slicing concepts, characteristics and use cases

- **2.9 Verticals and Use cases (cont'd)**
- **Healthcare**
 - Hospitals, Rehabs and care homes
 - Health and wellness monitoring
 - Remote healthcare, Remote surgery
- **Industry 4.0, Manufacturing**
 - Augmented reality, Control-to-control (C2C)
 - Motion control, Mobile robots and mobile platforms
 - Mobile Control Panels with Safety Functions, Closed-loop control
 - Process monitoring, Plant asset management
- **Internet of Things for Low Power Wide Area Applications**
 - Asset Tracking and monitoring, Waste management, Smart parking, Smart manhole, Water metering, Gas Metering
- **Public Safety**
 - Mission critical : Push-To-Talk, data, video, IoT
- **Smart Cities**
 - Intelligent lighting
 - Public safety
 - Emergency service management



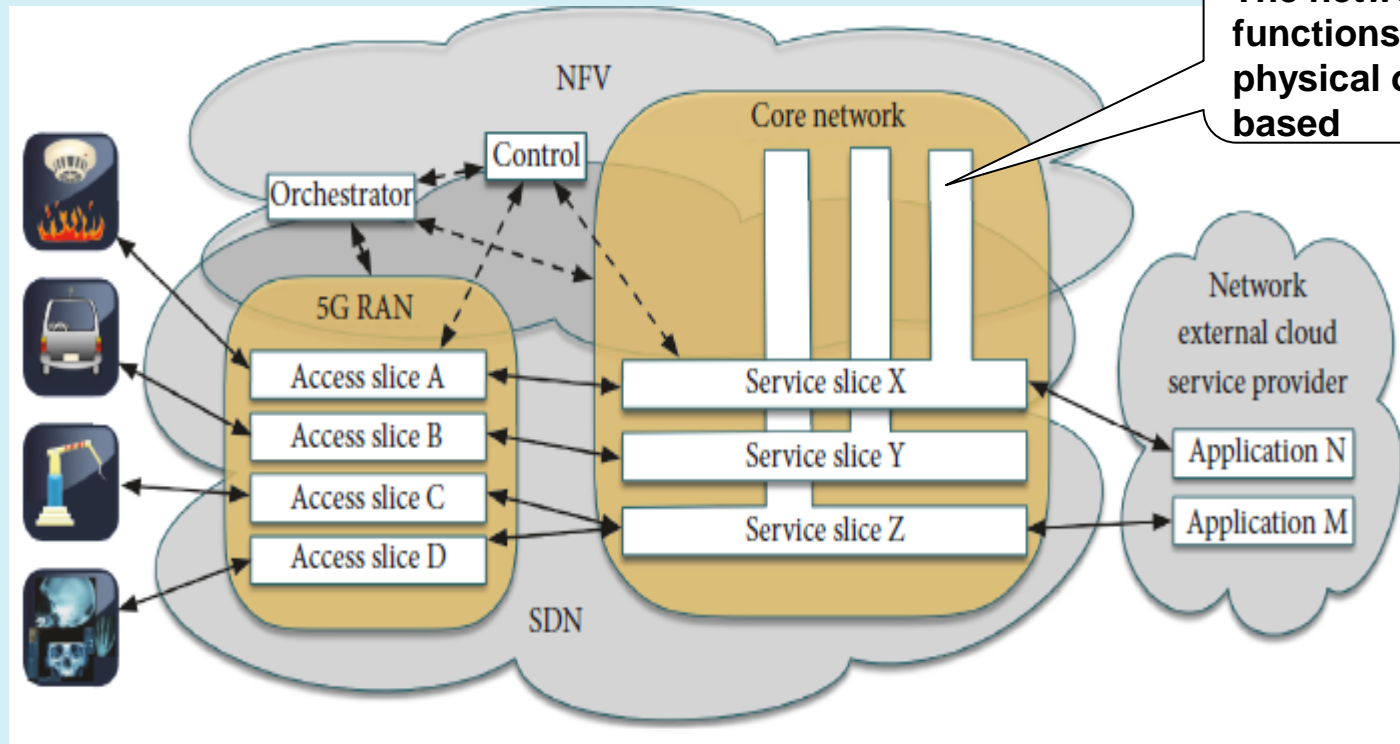
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3.  5G slicing general architectures
4. Multi-tenant 5G slicing
5. Multi-domain and end to end 5G slicing
6. Conclusions

3.1 Generic slicing architecture with SDN and NFV support

- Potential solution scenarios for support of multiple slices per UE
 - Three groups of solutions defined by 3GPP



Source: G. Nencioni et al., *Orchestration and Control in Software-Defined 5G Networks: Research Challenges*, Wiley, *Wireless Communications and Mobile Computing Volume 2018*, Article ID 6923867, pp. 1-19, <https://doi.org/10.1155/2018/6923867><https://www.hindawi.com/journals/wcmc/2018/6923867/>

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3. 5G slicing general architectures

3.1 Generic slicing variants 3GPP, TR 23.799 V14.0.0 (2016-12)

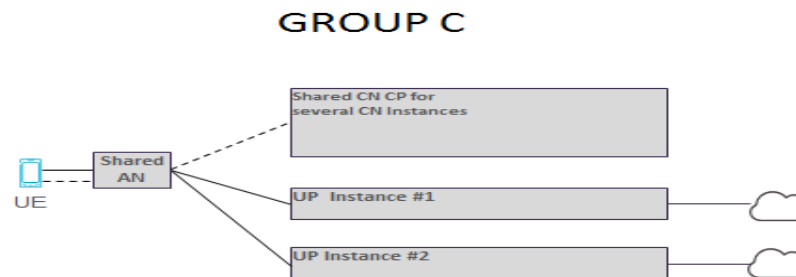
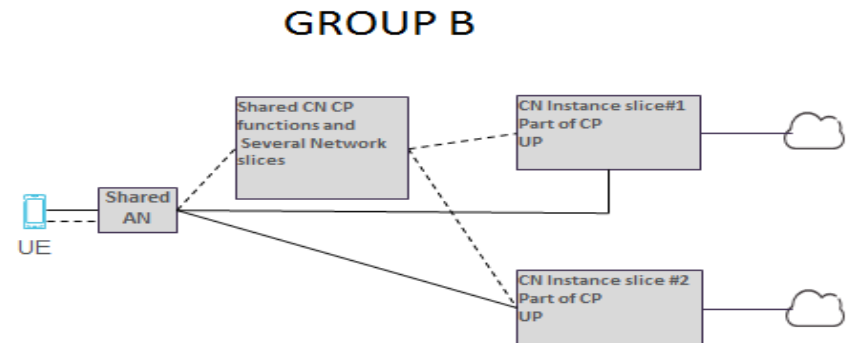
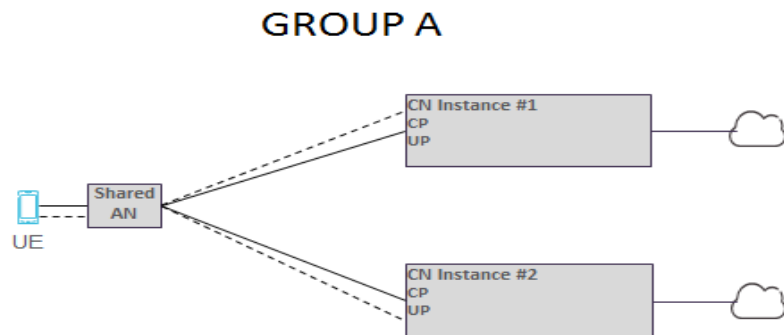
- **Potential solution scenarios for support of multiple slices per UE**
 - Three groups of solutions defined by 3GPP-for **Core Network (CN)** slicing
 - **Group A** - the UE gets services from **different NSs** and **different CN instances**
 - (+) **easiest logical separation/isolation** between the CN instances
 - independent subscription management/mobility management for each network slice handling the UE
 - (-) **potential side effects** of additional signalling in the network and over the air
 - **Group B** - **some NFs are common** between the NSs , while **other functions reside in individual NSs**
 - **Group C** - the **Control Plane is common between the slices**, while the User plane(s) (UPI/DPI) are handled as different NSs

See: *3GPP, TR 23.799 V14.0.0 (2016-12), Study on Architecture for Next Generation System (Release 14)*
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3.1 Generic slicing variants (cont'd)

3GPP, TR 23.799 V14.0.0 (2016-12)

- Potential solution scenarios for support of multiple slices per UE (cont'd):** Three groups of solutions defined by 3GPP

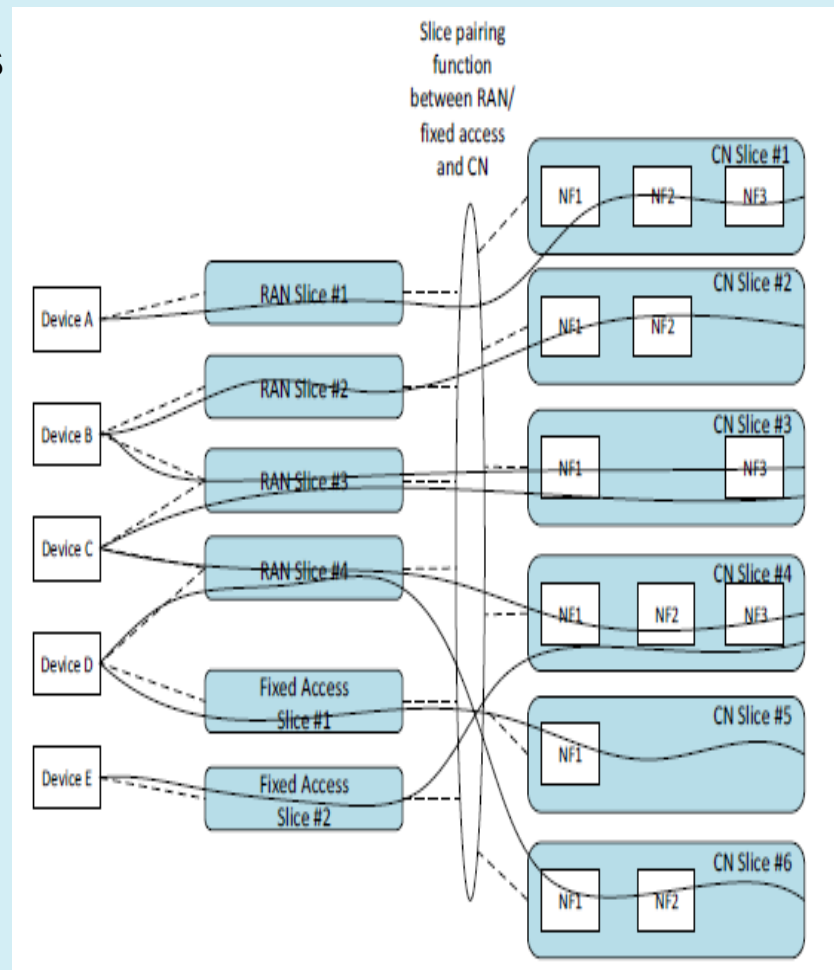
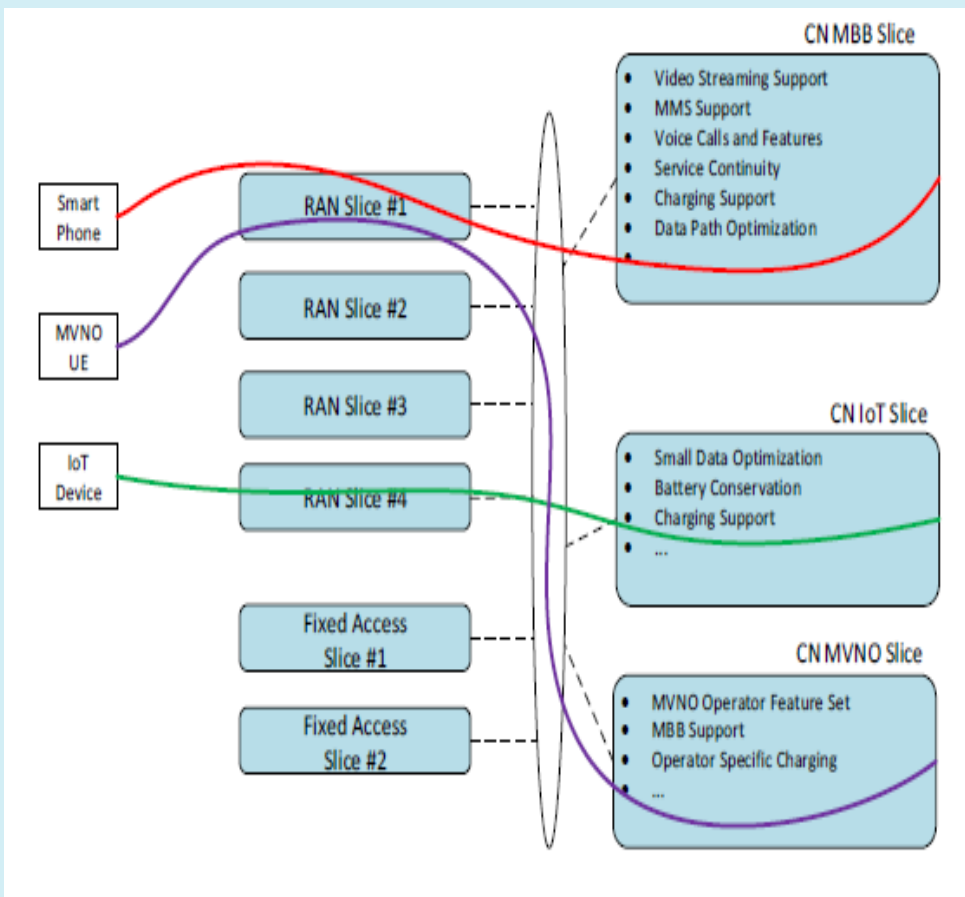


Note: This approach does not detail the slicing at AN premises

Source: 3GPP, TR 23.799 V14.0.0 (2016-12), Study on Architecture for Next Generation System (Release 14)

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- **3.1 Generic slicing variants (cont'd)**
- **UE Connection with the Network Slices**

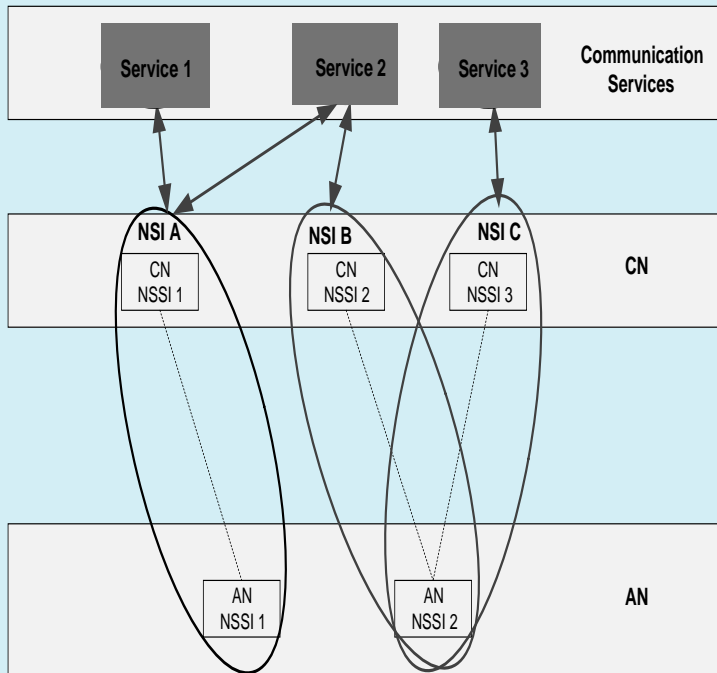


Source: 5G Americas, *Network Slicing for 5G Networks & Services*, 2016,
http://www.5gamericas.org/files/3214/7975/0104/5G_Americas_Network_Slicing_11.21_Final.pdf

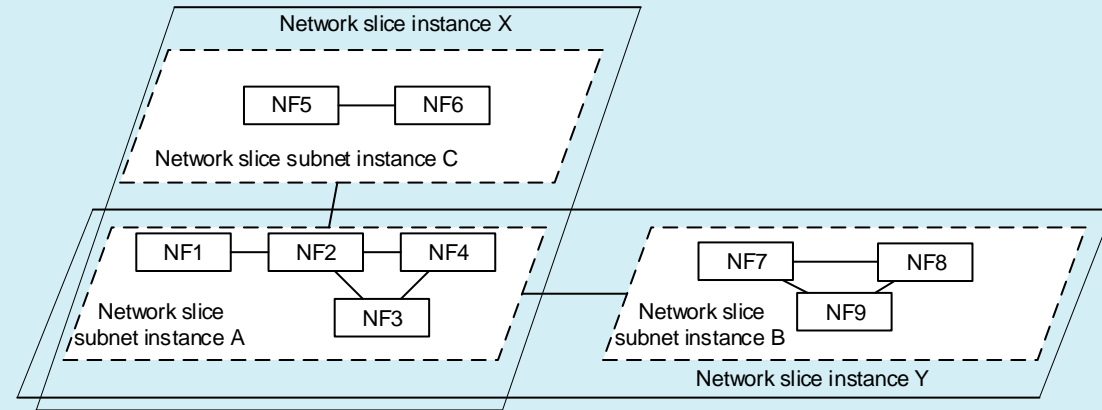
- **3.1 Generic slicing variants (cont'd)**
- **Previous slide: Flexible architecture w.r.t. inter-connection between UEs, the Network Slices and Network Slice subnets**
 - Interconnection between RAN/Fixed_access slices and CN slices – flexible
 - via - slice pairing function
 - between RAN and CN
 - between radio PHY and RAN
 - PHY can also be sliced
 - The same UE can connect simultaneously to several different slices
 - RAN and CN slices are customised (e.g., CN-MBB, CN-MVNO, CN-IoT)
 - A given type of NF can be used in several different slice instances
 - NFs can be appropriately chained cf. NFV technologies
 - The same **Network Slice Subnet Instance (NSSI)** can be shared by several Network Slice Instances (NSI)

3.1 Generic slicing variants - examples

End to End services provided by NSI(s)



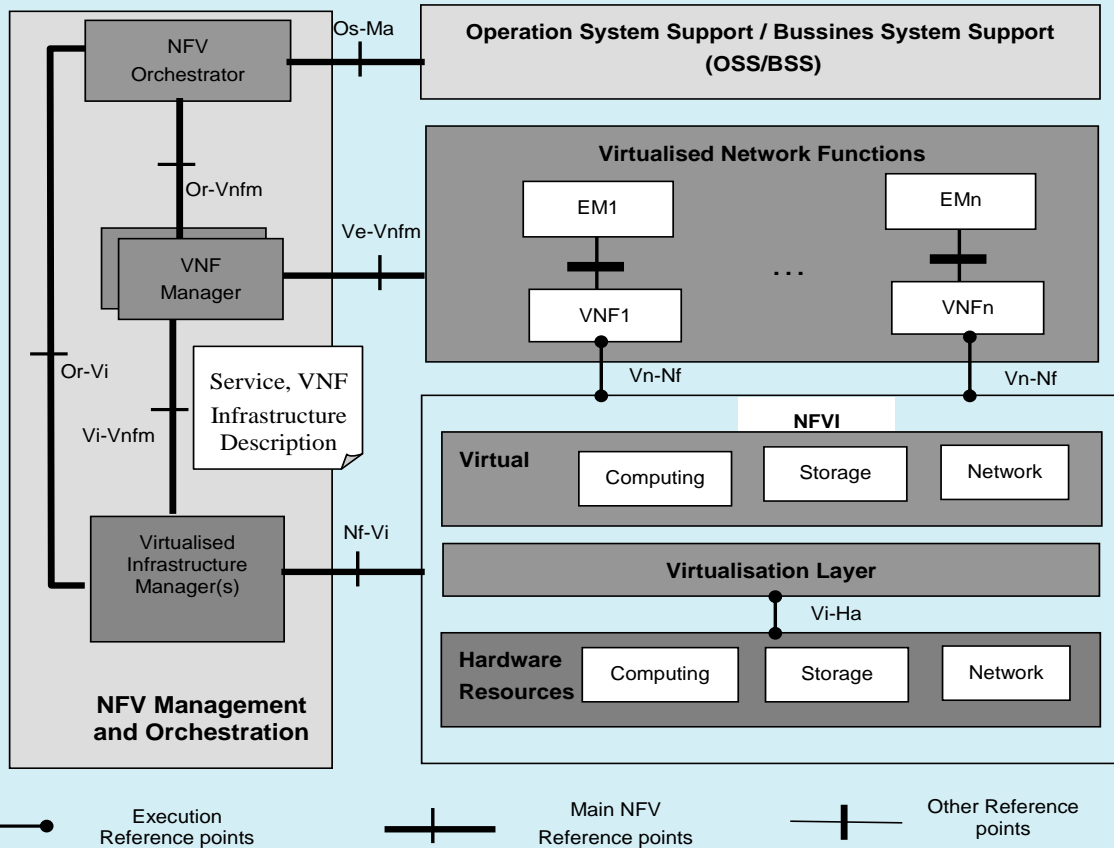
One NSSI can contribute to several NSIs
E.g., NSI X and Y composed by NSSI A, B and C



Source: 3GPP TR28.801 V15.1.0 (2018-01), Study on management and orchestration of network slicing for next generation network, (Release 15)

3.2 ETSI and 3GPP functional architectures for slicing support

- Network Function Virtualisation – ETSI- summary
- Reference architecture



EM Element Manager
 MANO Management and Orchestration
 NFV NF Virtualization
 NFVI NF Virtualization Infrastructure
 NS Network Service
 OSS Operations Support System
 VNF Virtual Network Function
 VIM Virtual Infrastructure Manager

Source: ETSI GS NFV 002 v1.2.1 2014-12, NFV Architectural Framework

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3. 5G slicing general architectures



3.2 ETSI and 3GPP functional architectures for slicing support

- **Network Function Virtualisation – ETSI- summary**
- **High level view of NFV framework**
- **Working domains** composed of
 - **VNF** -SW implementation of a NF which is running over the NFVI
 - **NFV Infrastructure (NFVI)**, including the diversity of physical resources and virtualisation tools
 - NFVI supports the execution of the VNFs
 - The **Virtualisation Layer (VL)** abstracts the HW resources and decouples the VNF software from the underlying hardware, thus ensuring a HW independent lifecycle for the VNFs
 - **NFV Management and Orchestration (NFV-MANO)**
 - **orchestration and lifecycle management (LCM)** of physical and/or SW resources that support the infrastructure virtualisation, and the VNFs lifecycle management
 - NFV MANO focuses on management of all virtualisation-specific tasks

See: *ETSI GS NFV 002 v1.2.1 2014-12, NFV Architectural Framework*

3. 5G slicing general architectures

3.2 ETSI and 3GPP functional architectures for slicing support

- **Network Function Virtualisation – ETSI- summary (cont'd)**

- **NFV Management and Orchestration Architectural Framework (NFV-MANO Architectural Framework):**
 - collection of all FBs (those in NFV-MANO and others interworking with NFV-MANO), data repositories used by these FBs , and RPs and interfaces for the purpose of managing and orchestrating NFV

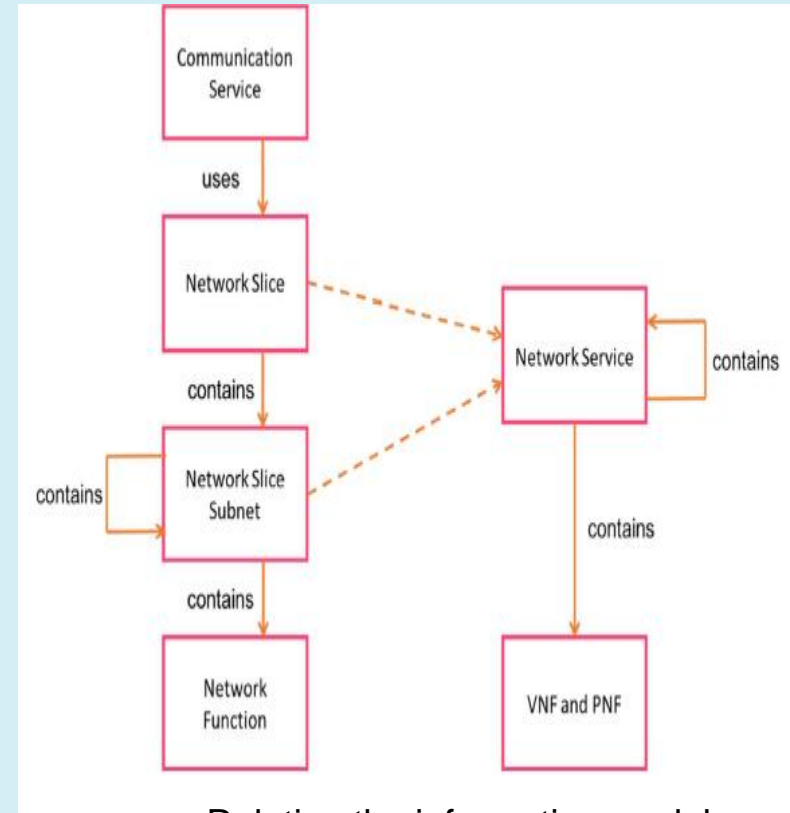
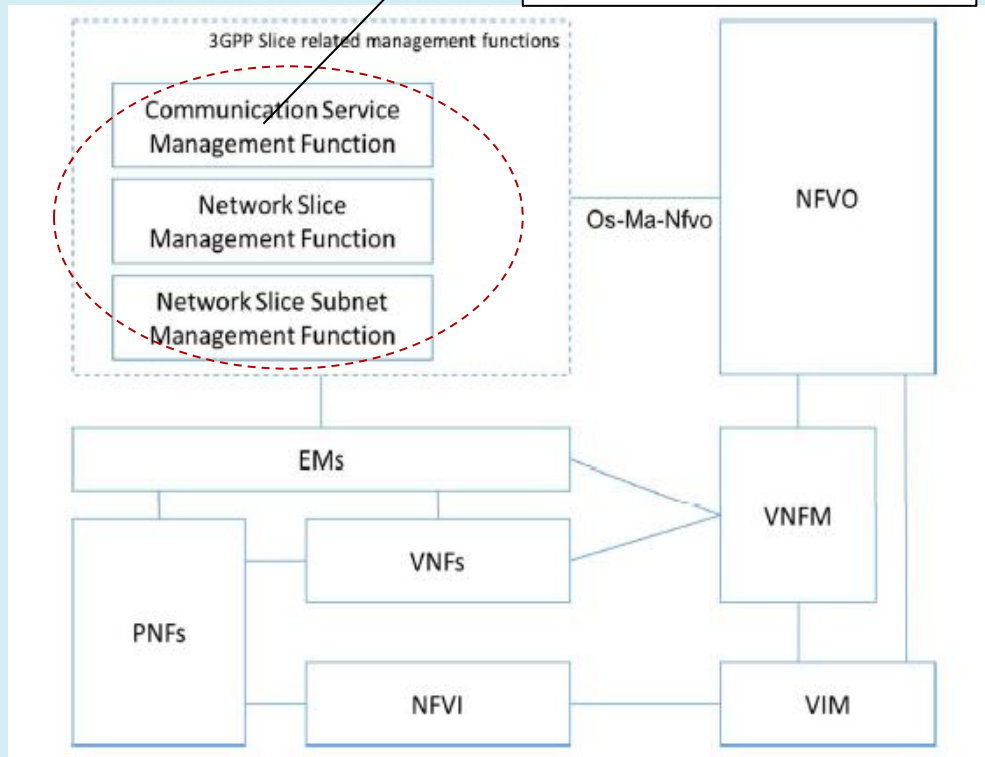
- **Network Functions Virtualisation Orchestrator (NFVO):**
 - FB that manages the **Network Service (NSrv)** lifecycle and coordinates
 - the management of NSrv lifecycle,
 - VNF lifecycle (supported by the VNFM) and
 - NFVI resources (supported by the VIM)
 - to ensure an optimized allocation of the necessary resources and connectivity

See: *ETSI GS NFV 002 v1.2.1 2014-12, NFV Architectural Framework*

3.2 ETSI and 3GPP functional architectures for slicing support

Network slice management (NSM) in NFV framework

New slicing mgmt. components added to NFV framework



Relating the information models

Source: ETSI GR NFV-EVE 012 V3.1.1 (2017-12), Release 3; NFV Evolution and Ecosystem; Report on Network Slicing Support with ETSI NFV Architecture Framework



3. 5G slicing general architectures



3.2 ETSI and 3GPP functional architectures for slicing support

- **Network slice management (NSM) in NFV framework (cont'd)**

- **Three layered functions** related to NS mgmt.
 - **Communication Service Management Function (CSMF)**: translates the communication service requirements to NS requirements
 - The CSMF has I/F with **(NSMF)**
 - **Network Slice Management Function (NSMF)** - mgmt. (including lifecycle) of NSIs. It derives NS subnet requirements from the NS related requirements
 - NSMF has I/F with NSSMF and the CSMF.
 - **Network Slice Subnet Management Function (NSSMF)** – mgmt (including lifecycle) of NSSIs.
 - The NSSMF communicates with the NSMF.

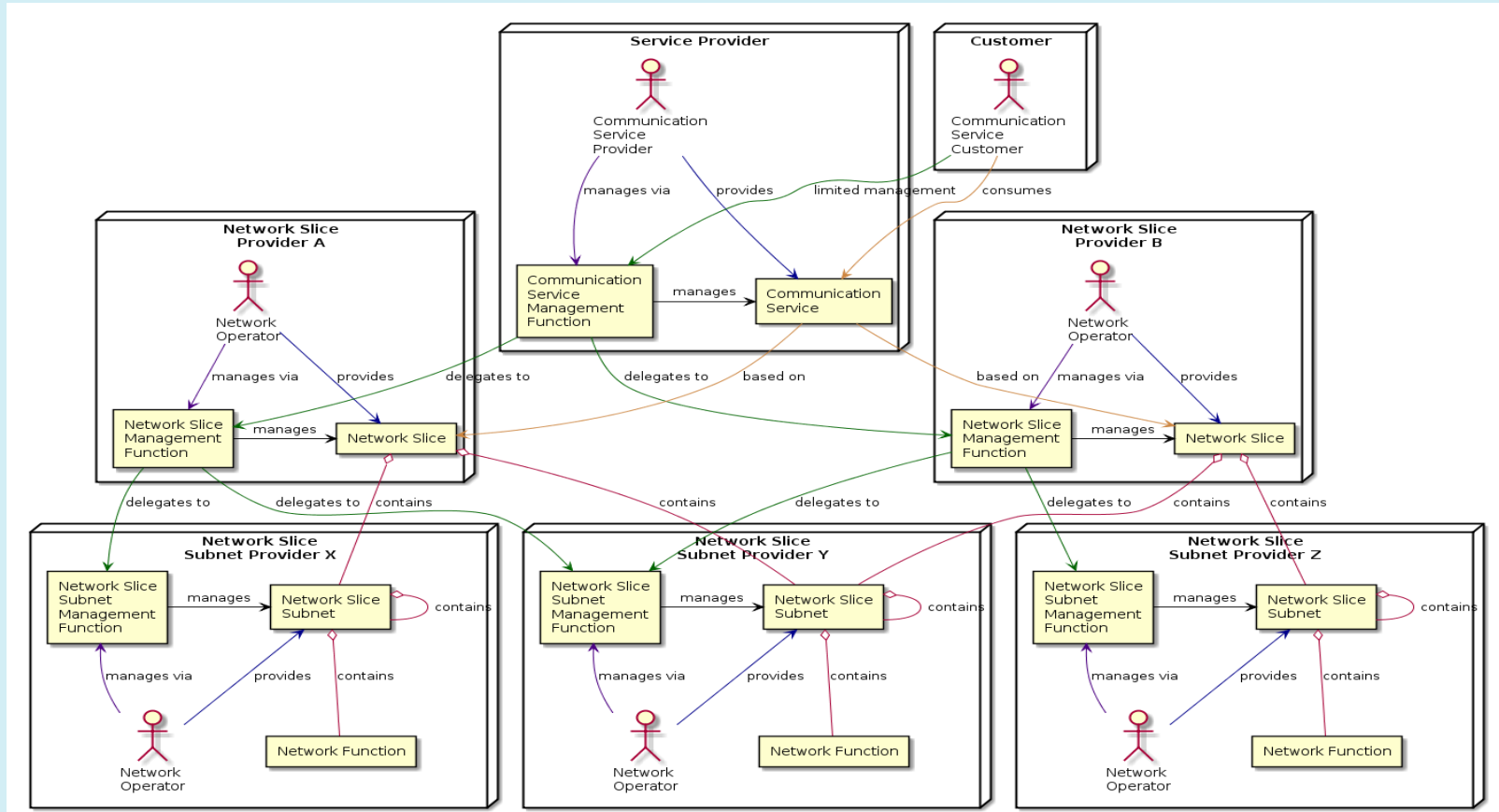
- The **Os-Ma-NFVO Reference Point (RP)** is the I/F with NFV-MANO.

- The NSMF and/or NSSMF need to determine
 - the **type of NS or set of NSs, VNF and PNF** that can support the resource requirements for a NSI or NSSI,
 - and whether new instances of these NSs, VNFs and the connectivity to the PNFs need to be created or existing instances can be re-used

See ETSI GR NFV-EVE 012 V3.1.1 (2017-12), Release 3; NFV Evolution and Ecosystem; Report on Network Slicing Support with ETSI NFV Architecture Framework

3.2 ETSI and 3GPP functional architectures for slicing support

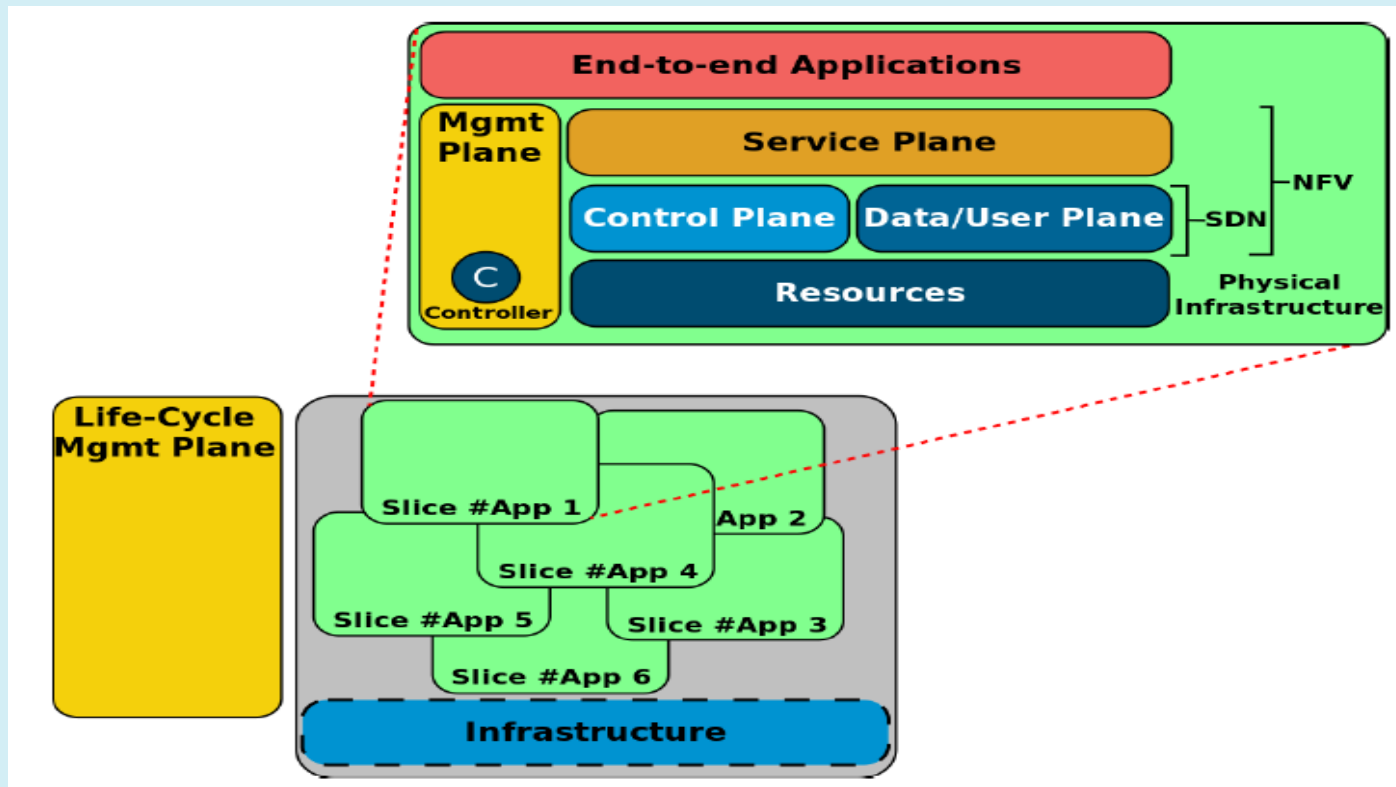
- Network slice management in NFV framework (cont'd)
- General example of network slicing management functions



Source: 3GPP TR28.801 V15.1.0 (2018-01), Study on management and orchestration of network slicing for next generation network, (Release 15)

3.3 Network slice management in SDN and NFV framework

- Generic example of slices instantiated from a template, on top of a common infrastructure (with SDN and NFV control and management)



Source: I. Afolabi, et al., *Towards 5G Network Slicing over Multiple-Domains*, *IEICE Trans. Commun.*, Vol.E100-B, No.11 Nov. 2017

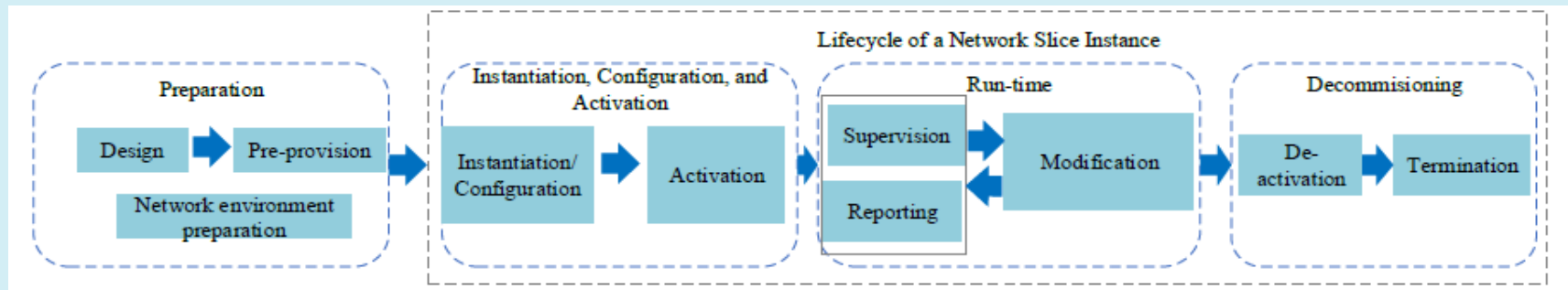
3.3 Network slice management (NSM) in SDN and NFV framework (cont'd)

- Functions provided by the NSM system in several phases for a NSI life cycle
 - **Preparation phase**
 - **Instantiation, Configuration and Activation phase**
 - **Run-time phase**
 - **Decommissioning phase**
- Details:
 - **Preparation phase** (the NSI does not exist yet)
 - creation and verification of NS template(s)
 - preparation of the necessary network environment to support the NSIs lifecycle (e.g., provisioning databases)
 - **Instantiation / configuration**
 - It can include **instantiation, configuration and activation** of other shared and/or non-shared NFs
 - All resources shared/dedicated to the NSI are created and configured, i.e. to a state where the NSI is ready for operation.
 - Activation : makes the NSI active, e.g. diverting traffic to it

See: End to End Network Slicing – White paper 3 Outlook 21, Wireless World , Nov 2017

3.3 Network slice management (NSM) in SDN and NFV framework (cont'd)

- Functions provided by the NSM system in several phases for a NSI life cycle
 - **Run-time phase**
 - NSI handles traffic to support services of certain type(s)
 - **Supervision/reporting** (e.g. for KPI monitoring)
 - **Modification** could be: upgrade, reconfiguration, NSI scaling, changes of NSI capacity, changes of NSI topology, association and disassociation of network functions with NSI
 - **Decommissioning phase**
 - **Deactivation** (taking the NSI out of active duty)
 - Free the dedicated resources (e.g. **termination** or re-use of network functions) and configuration of shared/dependent resources
 - Finally, the NSI does not exist anymore

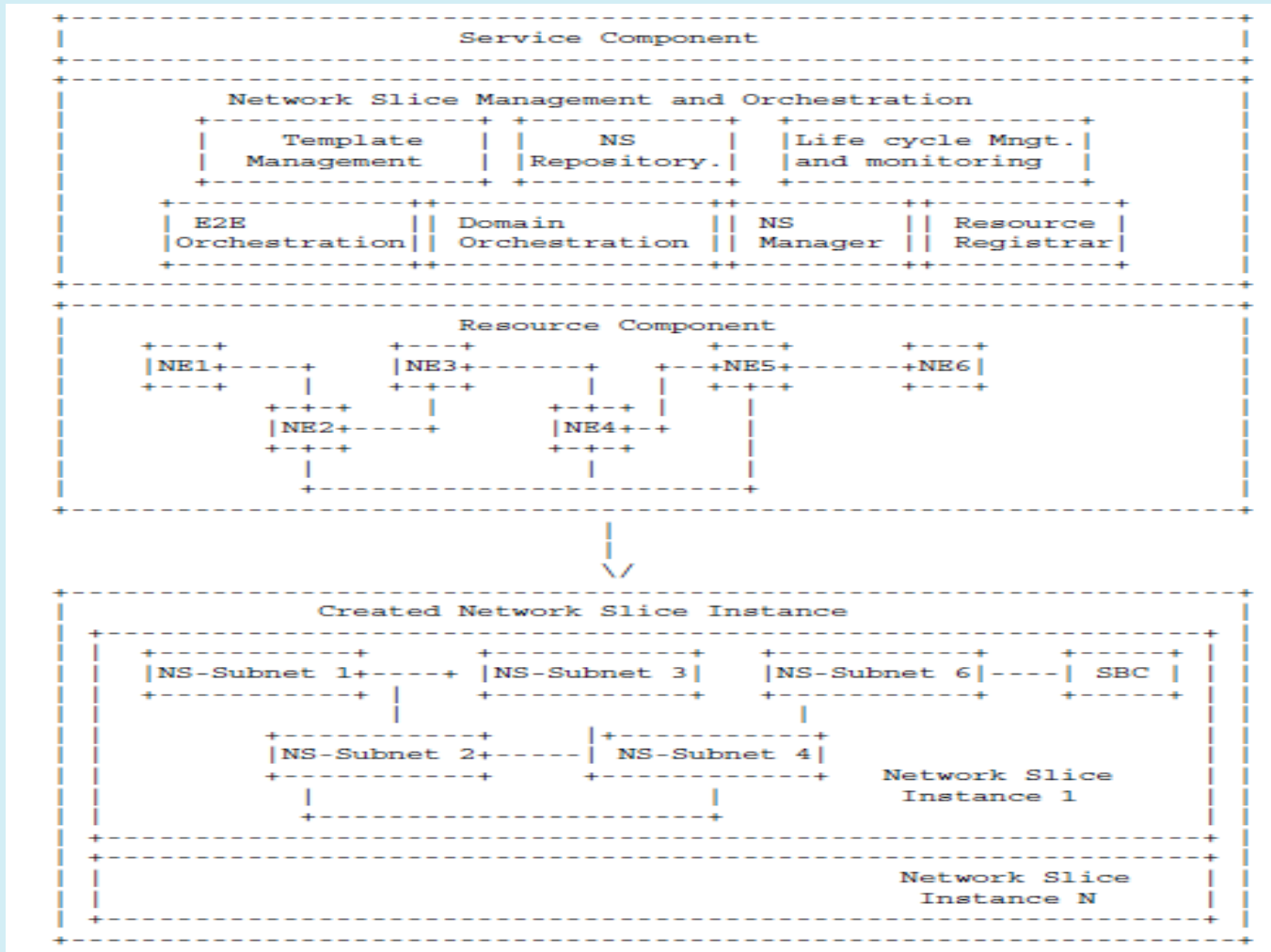


Source: End to End Network Slicing – White paper 3 Outlook 21, Wireless World, Nov 2017

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3. 5G slicing general architectures

3.3 IETF Slicing architecture

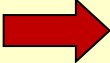


Source: IETF Network Slicing Architecture draft-geng-netslices-architecture-02, 2017



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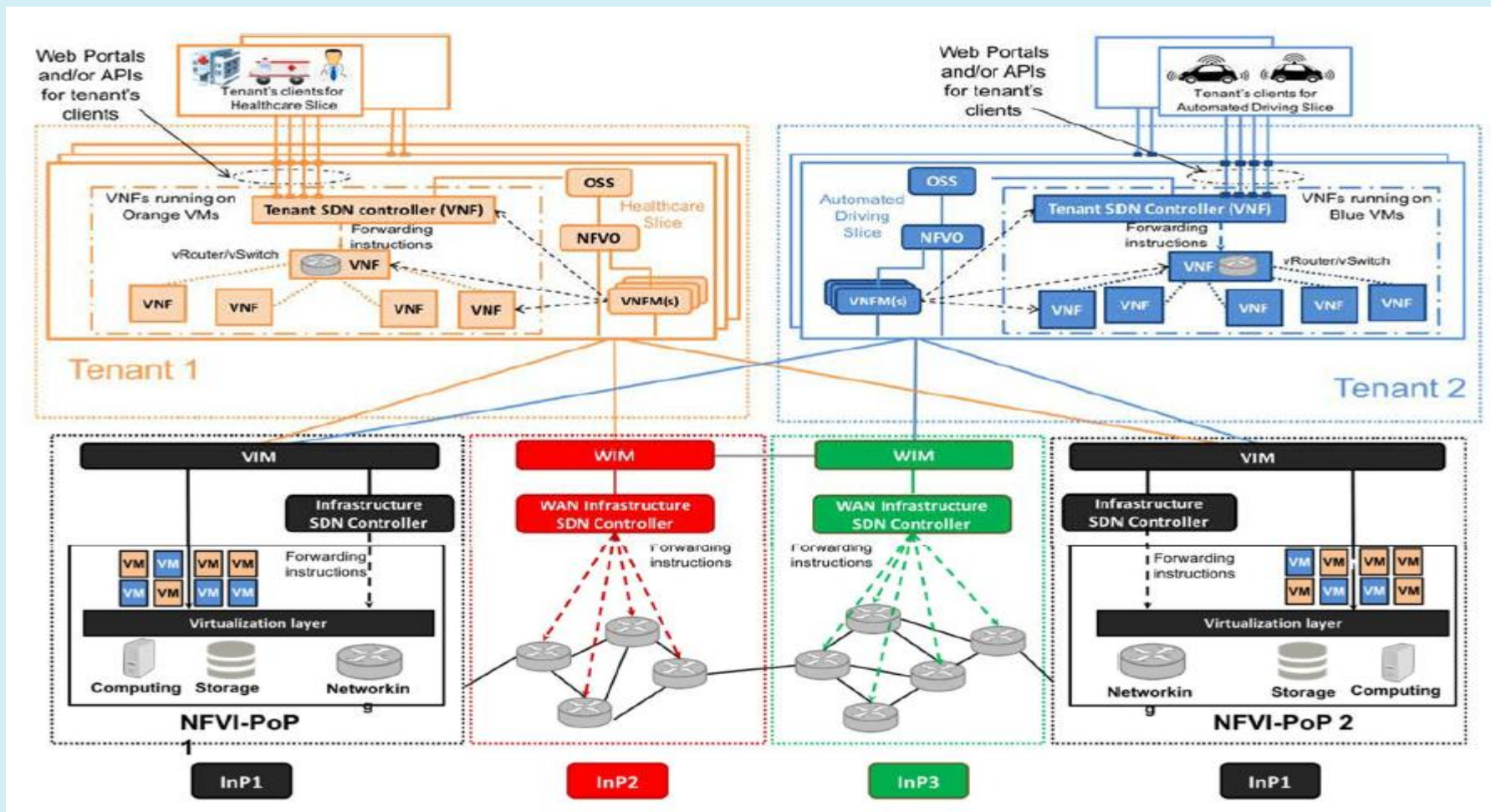
4. Multi-tenant 5G slicing



4.1 5G Slicing - Multi-tenant requirements

- **On-demand slice creation, allocation, modification, and deletion** guaranteeing **isolation** from each other
- Slices allocated to **different tenants** should run **concurrently** on top of a common shared infrastructure without (directly or indirectly) affecting each other
- Provision of **suitable APIs** to third parties (tenants) for slice monitoring and management
- The **elastic adaptation**, within minimum and maximum limits, of the slice capacity
- The support for **slice prioritization**
- Multi-slice/multi-service support for a given user equipment (UE)

4.2 Multi-tenant Network slicing example with NFV and SDN control



Source: ETSI GR NFV-EVE 012 V3.1.1 (2017-12), Release 3; NFV Evolution and Ecosystem; Report on Network Slicing Support with ETSI NFV Architecture Framework

4. Multi-tenant 5G slicing

4.2 Multi-tenant Network slicing example with NFV and SDN control (cont'd)

- *Ref.: slide - example*
- NSs should be **mutually isolated** performance, resiliency, security, privacy and management
 - (they run concurrently on top of a common shared infrastructure without (directly or indirectly) affecting each other.
 - The infrastructure : owned and managed by different (and potentially non-trusted) admin. domains
 - Details on how isolation properties can be achieved by applying current ETSI NFV concepts:
 - e.g. : ETSI GS NFV-EVE 005, R NFV-IFA 022 and GR NFV-IFA 028
- **Previous slide:** example of the application of the concepts to achieve isolation properties.
 - Note: the presented set of NFs SDN and NFV-MANO functions comprising the tenancy entities is not exhaustive; other examples are possible
- Two types of **SDN controllers** : **tenant** and **infrastructure** SDN controllers each logically placed in different admin domains.

See: ETSI GR NFV-EVE 012 V3.1.1 (2017-12), Release 3; NFV Evolution and Ecosystem; Report on Network Slicing Support with ETSI NFV Architecture Framework

4. Multi-tenant 5G slicing

4.2 Multi-tenant Network slicing example with NFV and SDN control (cont'd)

- *Ref.: slide example*
- The **tenant SDN controller** dynamically configures and chains VNFs to realize network services in the tenant domain
 - It only controls the SW apps. of the VNFs for configuration and chaining purposes, but **not their underlying NFVI** resources
- The **infrastructure SDN controller**
 - manages and controls the NFVI network resources (placed in a NFVI-PoP or a WAN)
 - to set up the connectivity that is required for communicating the tenant VNFs in the infrastructure domain
 - It is in charge of managing and controlling the connectivity among the **virtualisation containers** that host the tenant VNFs' software applications
- The **NSs run in parallel** on a shared underlying NFVI.
- The NFVI resources are owned and managed by three different InPs, each defining a different infrastructure domain.

See: *ETSI GR NFV-EVE 012 V3.1.1 (2017-12), Release 3; NFV Evolution and Ecosystem; Report on Network Slicing Support with ETSI NFV Architecture Framework*

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4. Multi-tenant 5G slicing

4.2 Multi-tenant Network slicing example with NFV and SDN control (cont'd)

- *Ref.: slide example*
- Each **NFVI-PoP** has a single VIM instance to configure and manage the virtualisation containers and their underlying HW
 - Their connectivity is locally enforced by the infrastructure SDN controller, which manages the NFVI-PoP network resources under the supervision of the VIM.
 - To connect NFVI-PoPs, each WAN domain relies on a **WAN Infrastructure Manager (WIM)** instance, (as the model in ETSI GR NFV-IFA 022)
- The NFVI resources owned and managed by the InPs are delivered to the tenants logically placed on top of them.
- Each tenant uses of the NFVI to serve the performance needs of the slices in its domain.
- The scenario presented above is well-aligned with the **NFVI as a Service (NFVlaaS)** (ETSI GR NFV-IFA 028)

See: *ETSI GR NFV-EVE 012 V3.1.1 (2017-12), Release 3; NFV Evolution and Ecosystem; Report on Network Slicing Support with ETSI NFV Architecture Framework*

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4. Multi-tenant 5G slicing

4.2 Multi-tenant Network slicing example with NFV and SDN control (cont'd)

- *Ref.: slide example*
- In the example above:
 - each InP takes the NFVlaaS provider's role
 - each tenant acts as an NFVlaaS consumer
- A tenant, with its own set of NSs , need to be isolated from others
 - **both VIMs and WIMs support multi-tenancy, by offering separate NFVI resources to subscribed tenants through dedicated I/Fs**
- VIMs has a **resource pooling mechanisms** to provide subscribed tenants with isolated resource environments endowed with high availability and fault resilience features for tenant VNFs deployment
- WIMs should have similar mechanisms (e.g., those of the ONF TR 527) to simultaneously manage a number of virtual topologies in the WAN with different levels of abstraction

See: *ETSI GR NFV-EVE 012 V3.1.1 (2017-12), Release 3; NFV Evolution and Ecosystem; Report on Network Slicing Support with ETSI NFV Architecture Framework*

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4. Multi-tenant 5G slicing

4.2 Multi-tenant Network slicing example with NFV and SDN control (cont'd)

■ *Ref.: slide example*

- **One NFVO in each tenant-** logically placed in the tenant domain
 - **Each tenant manages the slices that are operative in its admin. domain** by means of its NFVO
 - NFVOs perform resource scheduling functions in the tenant domain
 - The NFVO should need to orchestrate resources (**provided by different InPs**) across different administrative domains in the infrastructure
 - In the example above: **each of the NSs** serving a tenant comprises
 - one NFVO
 - one (or several) VNFM(s)
 - a tenant SDN controller
 - one Operations Support System (OSS)
 - Each NS has these FBs functional → the tenant can preserve the required management isolation among slices
 - **Note: Other combinations of number of NFVO/VNFM are also possible depending on the level of isolation and other reqs., e.g. ,when an NFVO can be used to fulfill more than one slice.**

4. Multi-tenant 5G slicing

4.2 Multi-tenant Network slicing example with NFV and SDN control(cont'd)

■ *Ref.: slide example*

- The NFVO dynamically manages the lifecycle of the NS constituent network service(s), including any associated VNF graph
- The VNFM(s) perform(s) LCM operations over the slice VNFs
- **Each NS has a tenant SDN controller**
 - Deployed as a VNF itself
 - It **dynamically configures the (other) inner network slice's VNFs**, and chains them to build up the NSrvs to be supported by the slice for a given use case
 - **NSrvs and VNF operations are highly correlated** → after NFVO decision that a NSrv has been instantiated, there is a need for the OSS(an SDN application from the tenant SDN controller's perspective), to interact with the controller and instruct it to perform the VNF configuration and chaining tasks
 - The tenant SDN controller also offers a set of **dedicated northbound I/Fs** that allows slice's clients (and thus tenant's clients) to interact with the slice.

4. Multi-tenant 5G slicing

4.2 Multi-tenant Network slicing example with NFV and SDN control (cont'd)

- **Isolation and security- summary**
- Trust relationships is needed between the different actors (e.g. InPs, tenants, tenant's clients, etc.), → **each admin. domain may have its own security domain**
 - E.g., one security domain for each InP, i.e. one security domain
 - for each tenant
 - one (or more) security domain(s) for each slice
- The slice's clients may come from different organizations, so,
 - the slice-specific mgmt. actions (resp. data) these organizations can perform (resp. access) may be potentially different.
 - the definition of **separate security domains** in the slice is required to preserve security and privacy isolation between clients.
- The **abstraction** and **isolation** that the tenant SDN controller enables with its northbound interfaces helps to accomplish this

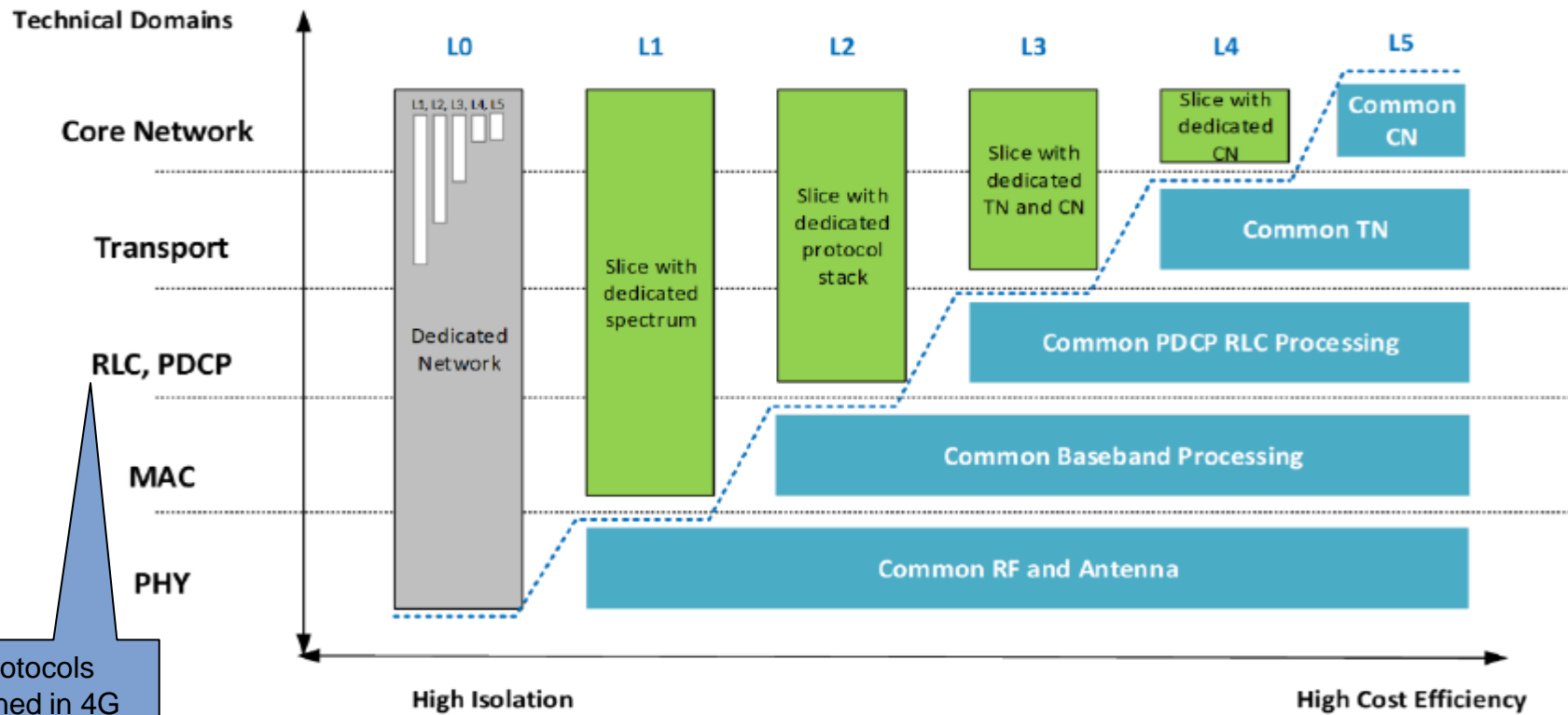
4.3 Different Levels of Network Slices Isolation

- **Operational isolation vs. network level isolation**
 - **operational isolation**
 - vertical customers could have **independent** monitoring, control, configuration, or even full operation capability of the NS
 - **network level isolation**
 - Vertical customers do not share NFs or resources with the other customers
 - different sub-categories exist, e.g.: shared RAN but isolated core, or isolated RAN as well as core, etc.
- Operators can provide operational isolation w/wo very weak network isolation
 - E.g.: the system could use IDs to differentiate the users belonging to different tenants who share the infrastructure.
 - Example : NB-IoT, which can be treated as a preconfigured NS, with many different IoT tenants sharing the same NB-IoT network.

See: GSMA, Network Slicing, - Use Cases and Requirements , April 2018

4.3. Different Levels of Network Slices Isolation

- Different levels of isolation will have different costs
- Most expensive mode will be dedicated RAN (L0 or L1)



Source: GSMA, Network Slicing, - Use Cases and Requirements , April 2018

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1. Introduction
2. 5G slicing concepts, characteristics and use cases
3. 5G slicing general architectures
4. Multi-tenant 5G slicing
5. **➔ Multi-domain and end to end 5G slicing**
6. Conclusions

5.1 Objectives and requirements

- **E2E NS overall objective**: to provide logical isolation and independent operations including: the **terminal, RAN resource, core network (CN), transport network (TN)** and network management for different scenarios, service and vertical industry
- **General requirements for E2E multi-domain slices**
 - **NS : complete network**, including RAN functions and CN functions.
 - Capabilities are needed to:
 - define and update the set of services for a NS
 - NS-create/modify/ delete
 - identify UE and its service requirements and associate it to a NS or remove it from a NS
 - NSes may have different **priorities**
 - **E2E isolation** between slices should be ensured
 - The **slice modification** operation may **redefine the max/min capacity** or **add and remove NFs to the slice**
 - An **user equipment (UE)** may have **access more than one NS**

5.1 Objectives and requirements (cont'd)

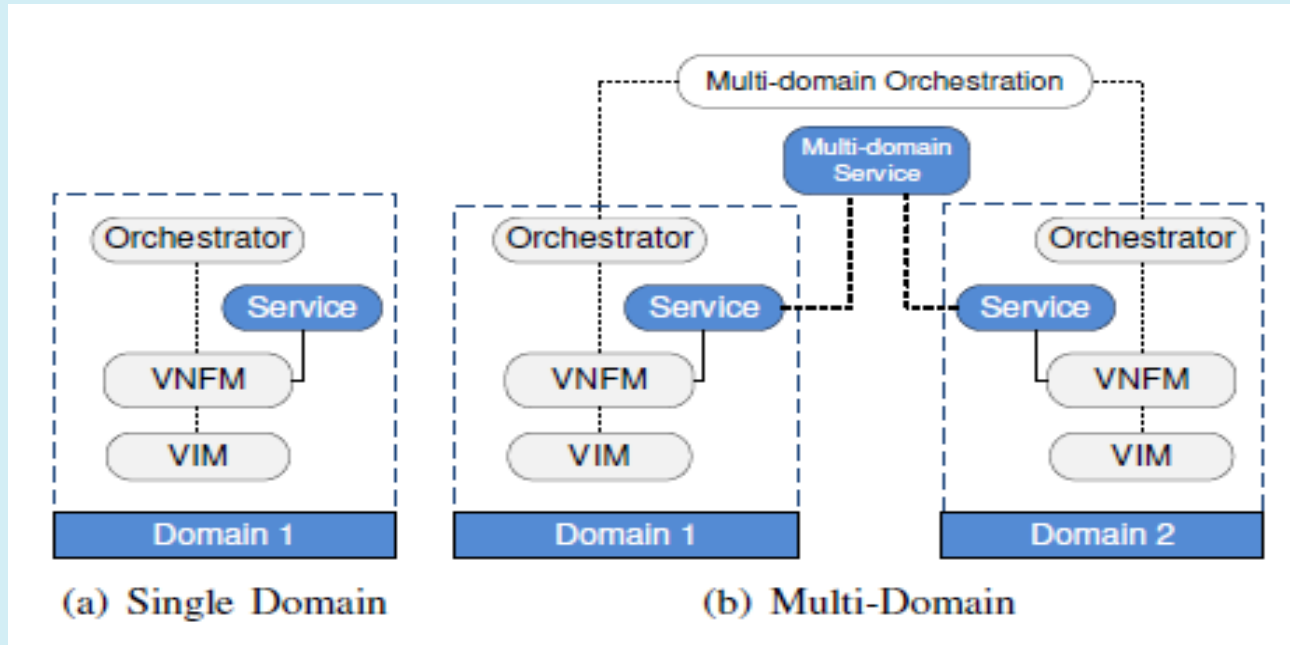
- **Multi-tenancy** model should work in E2E and multi-domain context
- NS should meet **Service Level Agreement (SLA)** requirements for each tenancy
- **Plurality of devices** to be admitted
 - with diverse sets of
 - QoS/QoE ranging over E2E latency
 - throughput
 - types of data transferred between end point devices and application servers
 - frequency of data transfers among other dependencies

5.2 Network Slicing Management (NSM) Architecture

- **Network slicing design and management principles – in E2E context**
- **Separation of the NS template (NST) design and the NSI operation**
 - The NST is created based on the network capability of each technical domain and a tenant's particular reqs - in the design phase
 - An NSI is instantiated based on the NST- in the operation phase
- **Multi-domain management**
 - a NSI contains **multiple technical domains**
 - a NSI may involve multiple tech/admin domains belonging to different operators
- **On-demand customization**
 - This could be different within each technical domain
 - **NSM system - coordinator role** during the process of network slice template design, O&M and NSI deployment.
 - **design** schemes should **balance architectural complexity** versus **simplicity/cost**
- **Common infrastructure** - among tenants from the same operator
 - It reduces the service time to market (TTM) and acquires higher resources utilization efficiency

5.2 Network Slicing Management (NSM) Architecture

- Single domain and multi-domain orchestration for NFV

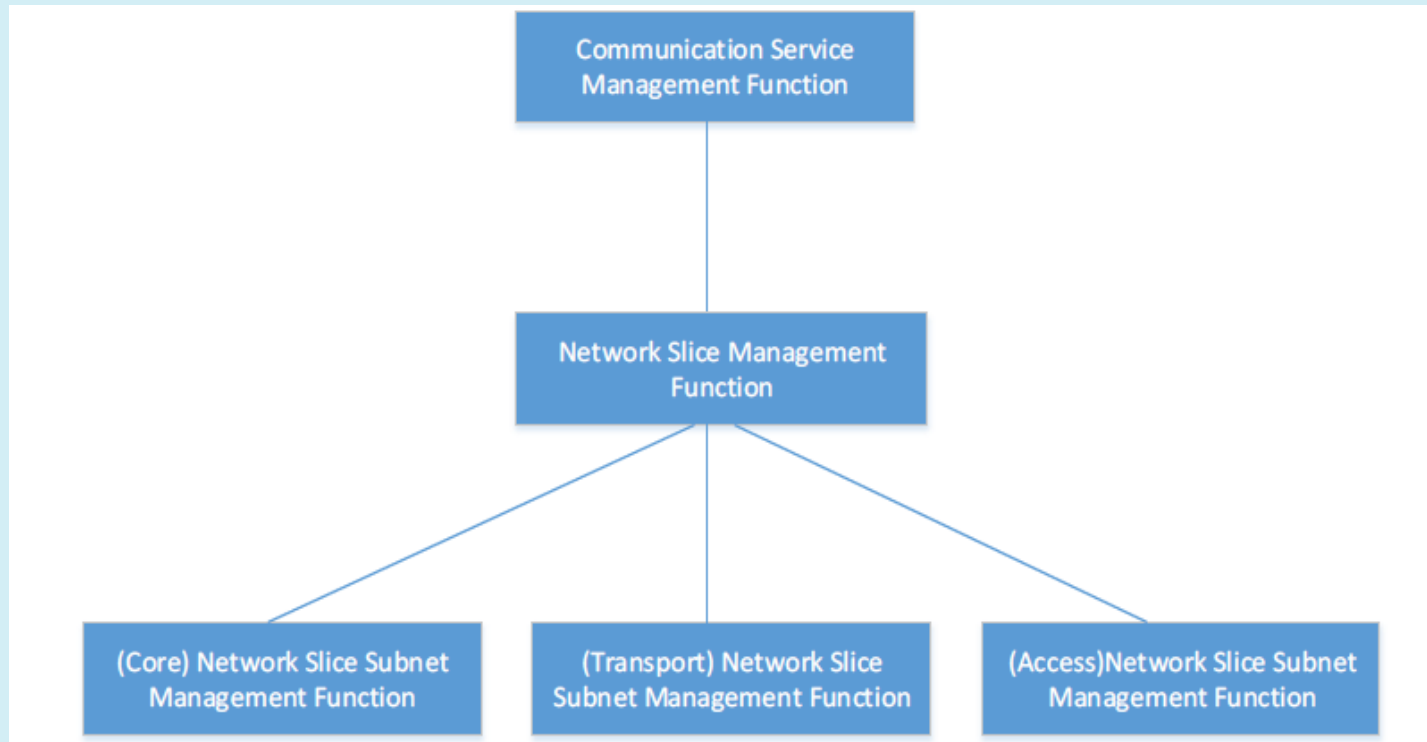


VNFM- Virtual Network Function Manager
VIM – Virtual Infrastructure Manager

Source: K.Katsalis, N.Nikaein, Andy Edmonds, *Multi-Domain Orchestration for NFV: Challenges and Research Directions*, [2016 15th International Conference on Ubiquitous Computing and Communications and 2016 International Symposium on Cyberspace and Security \(IUCC-CSS\)](https://ieeexplore.ieee.org/document/7828601), <https://ieeexplore.ieee.org/document/7828601>

5.2 Network Slicing Management (NSM) Architecture

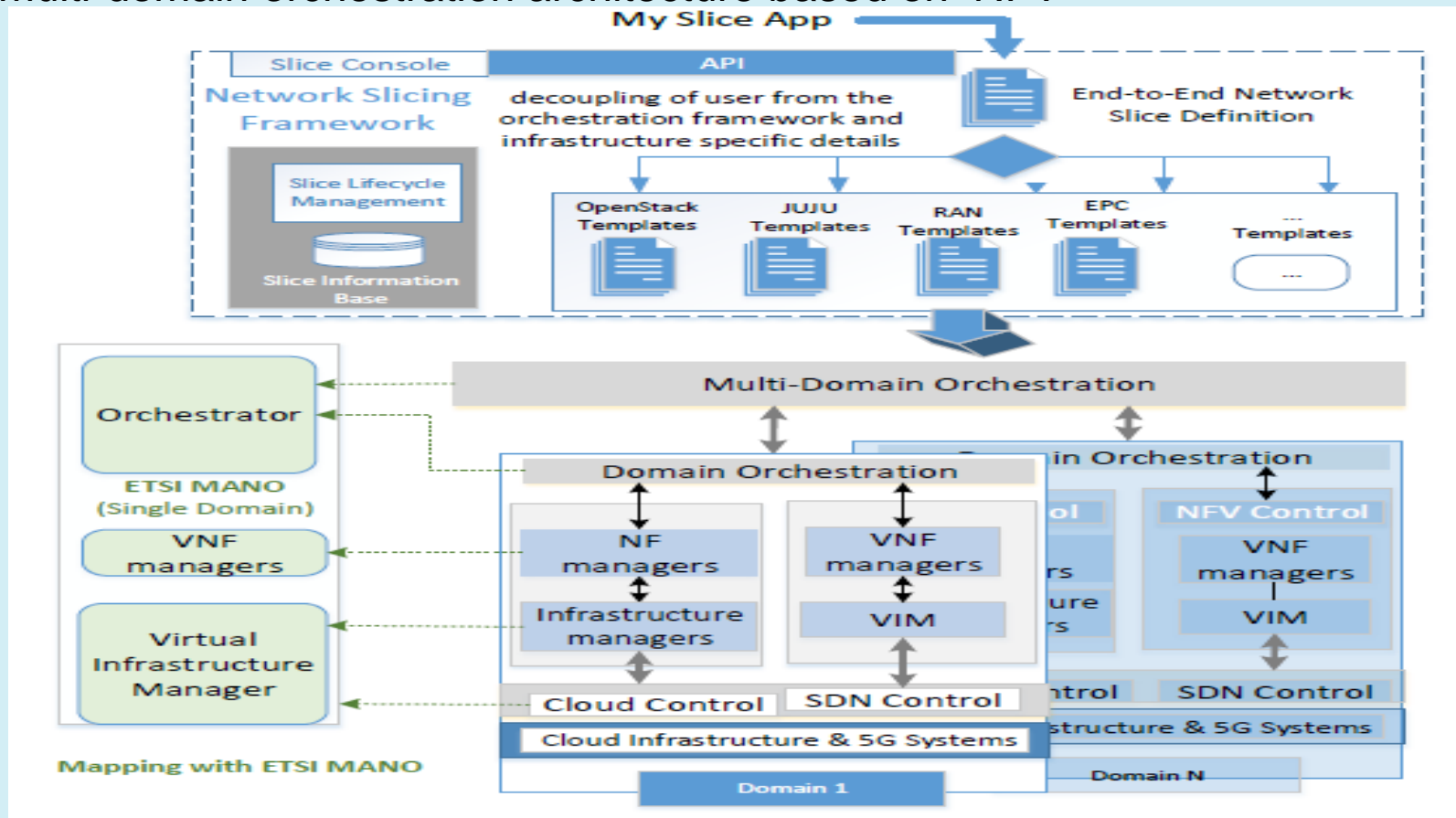
- General split of the management entities in a multi-domain context



Source: *End to End Network Slicing – White paper 3 Outlook 21, Wireless World, Nov 2017*

5.2 Network Slicing Management (NSM) Architecture

A multi-domain orchestration architecture based on NFV



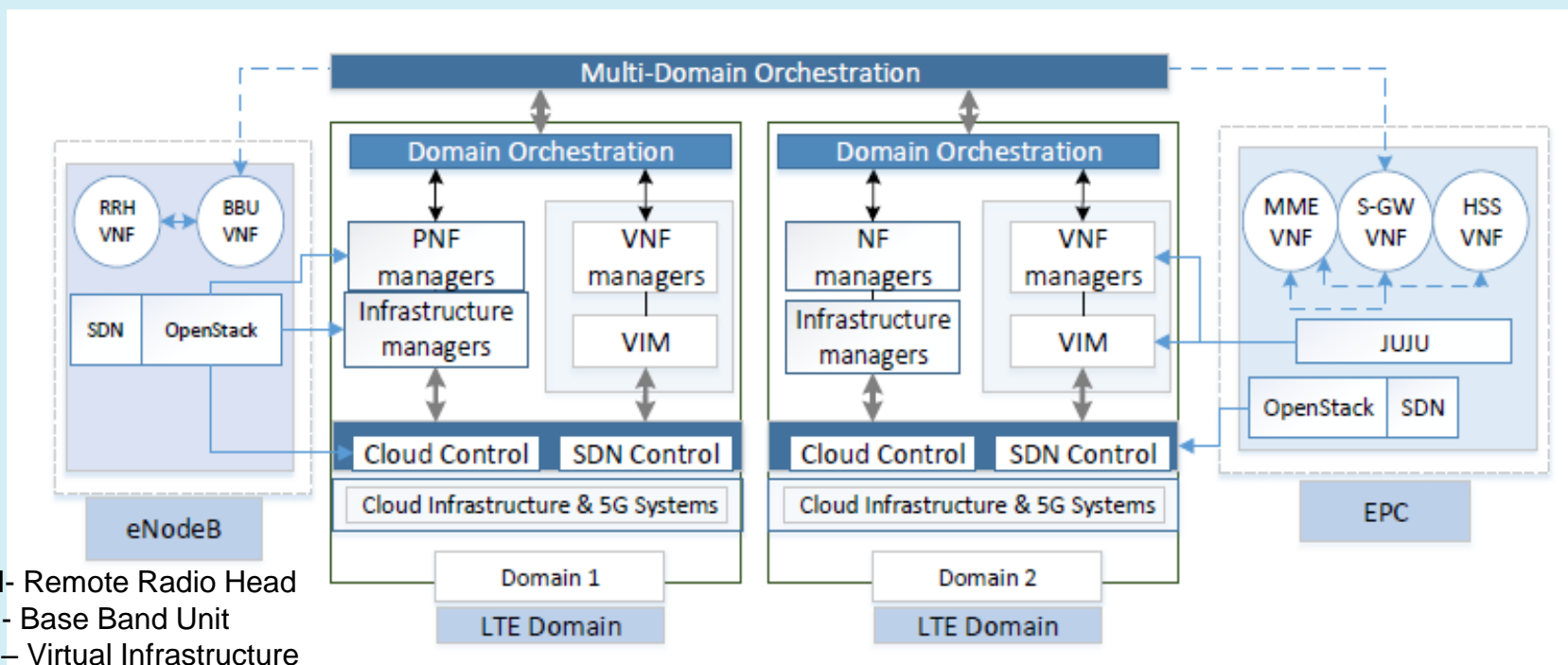
Source: K.Katsalis, N.Nikaein, Andy Edmonds, *Multi-Domain Orchestration for NFV: Challenges and Research Directions*, [2016 15th International Conference on Ubiquitous Computing and Communications and 2016 International Symposium on Cyberspace and Security \(UCC-CSS\)](https://ieeexplore.ieee.org/document/7828601), <https://ieeexplore.ieee.org/document/7828601>

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5.2 Network Slicing Management (NSM) Architecture

- Multi-domain NFV for 4G/LTE networks- Example
- E.g.: eNodeB resides in domain 1
- EPC resides in domain 2.

EPC- Evolved Packet Core
MME – Mobility Mgmt Entity
S-GW – Serving Gateway
HSS- Home Subscriber System



RRH- Remote Radio Head
BBU- Base Band Unit
VIM – Virtual Infrastructure Manager

Source: K.Katsalis, N.Nikaein, Andy Edmonds, Multi-Domain Orchestration for NFV: Challenges and Research Directions, [2016 15th International Conference on Ubiquitous Computing and Communications and 2016 International Symposium on Cyberspace and Security \(IUCC-CSS\)](https://ieeexplore.ieee.org/document/7828601), <https://ieeexplore.ieee.org/document/7828601>

5.3 Vertical and horizontal slicing concept

■ Vertical slicing (VS)

- **main solution**, for different needs of vertical industry and markets resource sharing among services and applications
- simplifies the QoS problem due to slice customisation
- each slice – based on air interface, RAN, CN, TN, hardware

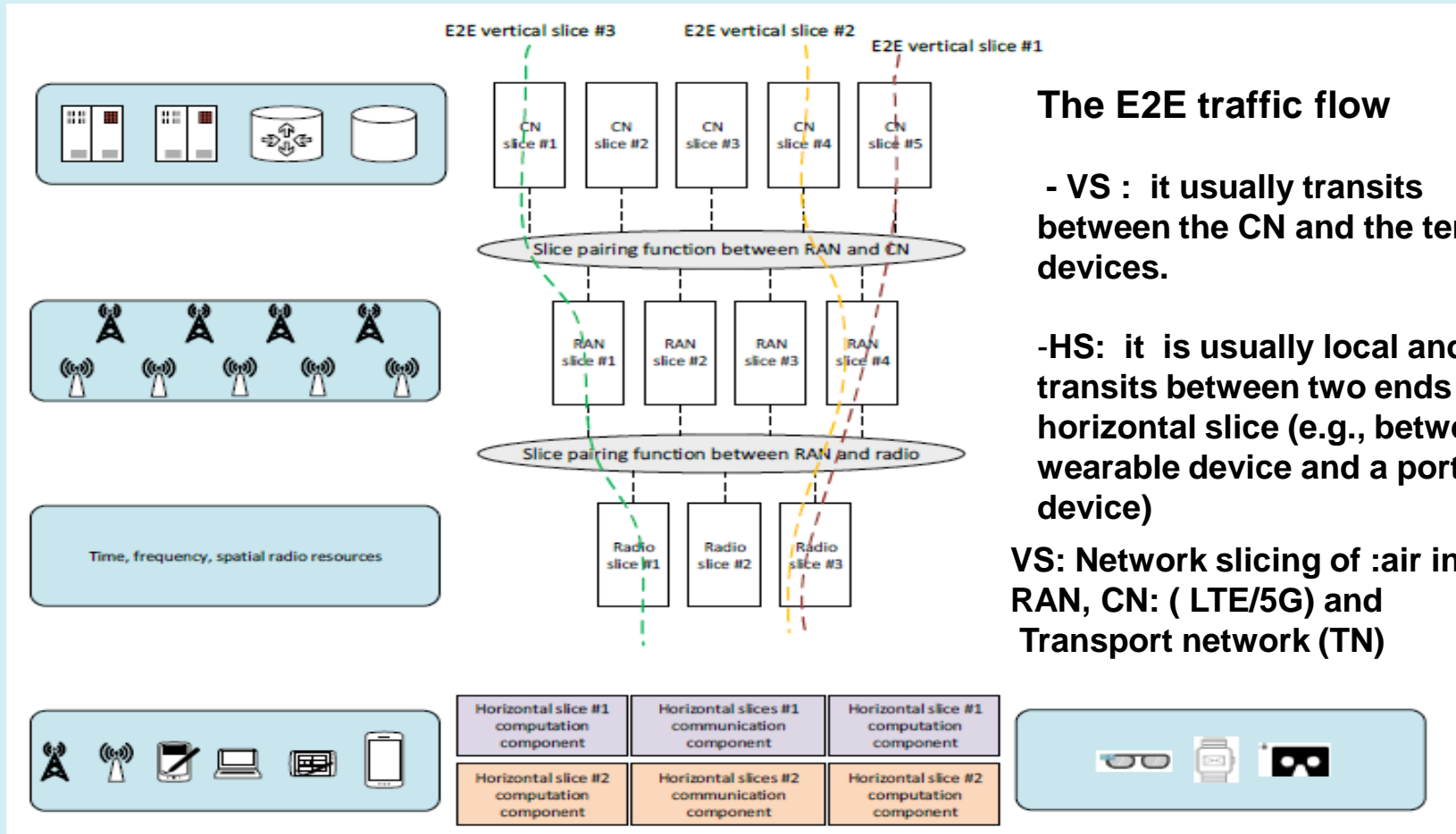
■ Horizontal slicing (HS) - extends the mobile devices capabilities

- **goes across and beyond platforms physical boundaries**
- resource sharing among network nodes and devices
 - high capable network nodes/devices share their resources (e.g., computation, communication, storage)
- **enhances the capabilities of less capable network nodes/devices**
- moving network clusters, with terminals becoming moving net nodes
- requires over-the-air resource sharing across network nodes

- **New definition of E2E** : the traffic flow terminates within the HS built among devices with direct communication link (i.e., not mandatory crossing the CN)

Source: Q. Li, G. Wu, A. Papathanassiou, U. Mukherjee , *An end-to-end network slicing framework for 5G wireless communication systems*, <https://arxiv.org/abs/1608.00572>

5.3 Vertical (VS) and Horizontal slicing (HS) concept (cont'd)



Source: Q. Li, G. Wu, A. Papathanassiou, U. Mukherjee, An end-to-end network slicing framework for 5G wireless communication systems, <https://arxiv.org/abs/1608.00572>

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5.3.1 Vertical slicing

a. Air interface slicing (Physical (PHY) and Medium access (MAC) layers)

■ Procedure:

- flexible partition of the PHY resources + abstraction into PHY subsets (logical resources) each for one slice
- Build MAC and higher layers operations on the PHY resource subsets

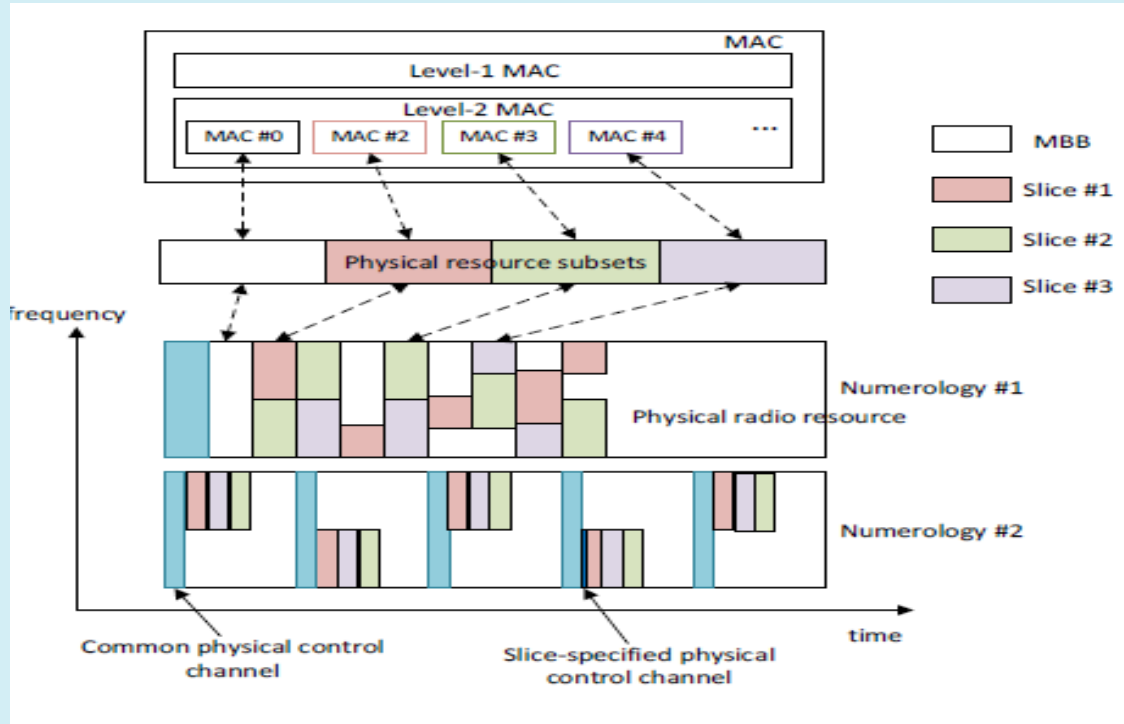
■ Details

- The PHY radio resource is partitioned into multiple segments
 - each is defined by one numerology to meet certain communication requirement (latency, coverage, etc.)
- numerology refers to the values of the basic PHY parameters defining the radio link (e.g., waveform, sampling rate, symbol duration, the frame/subframe length, etc.)
- A (NS) is assigned an ID (*sNetID*) known by devices accessing the NS
 - The *sNetID* can be
 - used to address all the devices in the NS
 - broadcast system info to indicate whether the slice is active in the BS

Source: Q. Li, G. Wu, A. Papathanassiou, U. Mukherjee, An end-to-end network slicing framework for 5G wireless communication systems, <https://arxiv.org/abs/1608.00572>

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5.3.1 a. Air interface slicing (cont'd)



Each slice occupies a subset of PHY resources taken from **one or multiple numerology segments**

Two layers MAC partition:
Level-1 MAC - intra-slice traffic multiplexing and scheduling
Level-2 MAC - inter-slice resource allocation

PHY channels in the air interface: downlink (DL) and uplink (UL) control channels, the physical random access channel and the physical shared channel, can be allocated

- as slice-specific dedicated PHY channels,
- as well as common PHY channels (usable by all slices)

Source: Q. Li, G. Wu, A. Papathanassiou, U. Mukherjee, An end-to-end network slicing framework for 5G wireless communication systems, <https://arxiv.org/abs/1608.00572>

5.3.1 b. RAN vertical slicing

- Optimal configuration of the CPI and UPI considering the specificity of slice.
- To be considered :
 - **Radio Access Type (RAT)** to support the services provided by a slice
 - Proper configuration of RAN capabilities with interfaces. It applies also to a correct cell deployment in every slice based on requirements
 - **Proper tailoring of each slice** is needed based on factors such as QoS requirements, traffic load, or type of traffic, etc.
 - Example :
 - slice 1 uses only macro cells,
 - slice 2 only small cells,
 - slice 3 uses both macro and small cells
 - This working mode (association) can be changed during functioning
- Each slice can have its own RAN arch.: mobile association, access control and load balancing will be slice-specific (traditionally there is - cell-specific characteristic)
- At each BS or access point slice on/off operation can be enabled

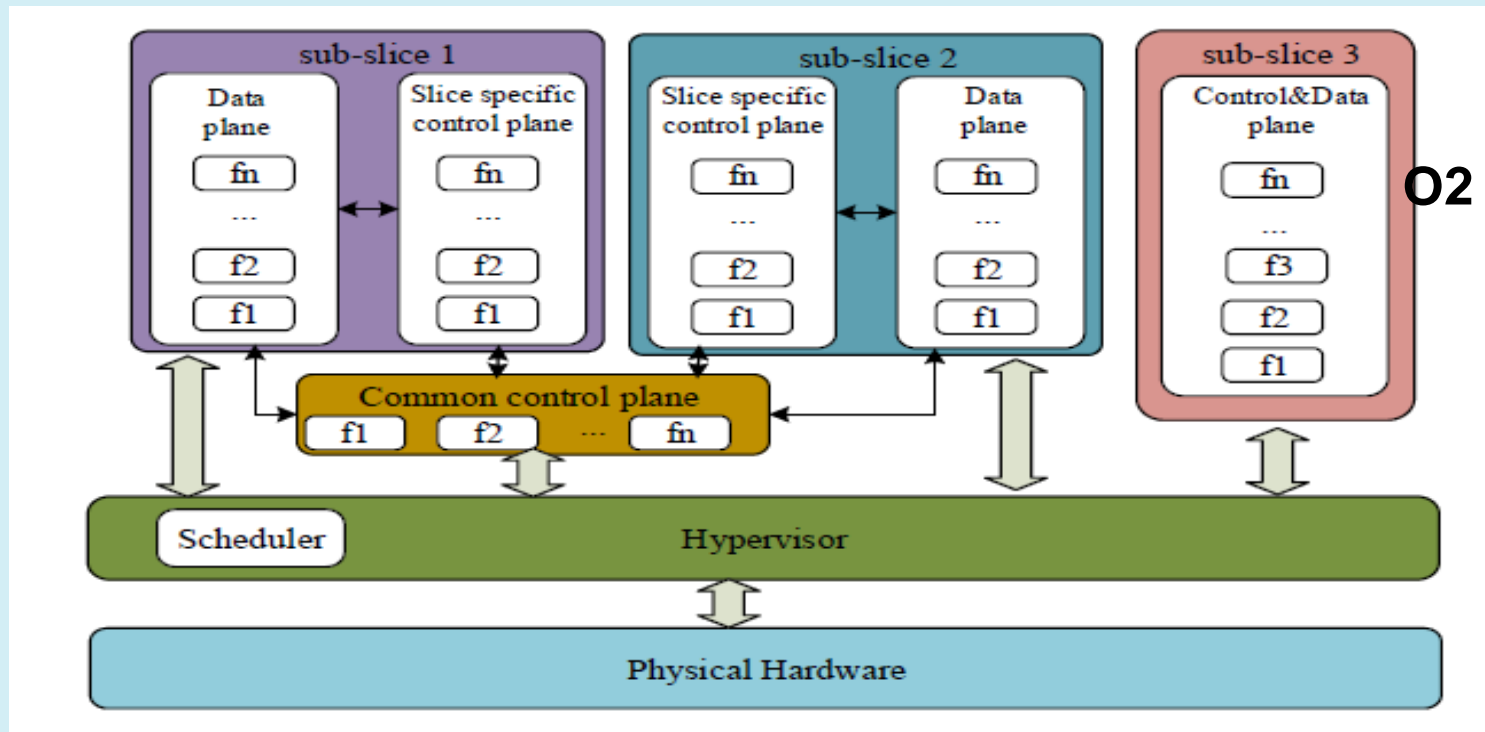
5.3.1 b. RAN vertical slicing (cont'd)

- CPI and UPI can be configured for slice-specific operation
- The RAN arch. of a slice can be dynamically configured depending on traffic type/load, QoS requirement, etc.
- The slice-specific RAN arch. needs slice-specific operation functions
 - control-plane/user-plane operation
 - slice on/off operation
 - slice-based **admission control (AC)** and **load balancing (LB)**
- **CPI/UIP options**
 - **O1**: common CPI across network slices and dedicated UPI for each of the slices
 - less design effort but lack the CPI flexibility
 - **O2**: dedicated CPI and UPI for each of the slices
 - slice-specific C-plane, but more costly
 - **O3**: common CPI for all slices and dedicated C/U-plane for each of the slices
 - Average solution in terms of flexibility/cost

5.3.1 b. RAN vertical slicing (cont'd)

- RAN slicing implementation via virtualization- example (option O3 and O2)

O3



Source: Jinjin Gong, Lu Ge, Xin Su, Jie Zeng, Radio Access Network Slicing in 5G, in *Advances in Intelligent Systems and Computing* · March 2017 , <https://www.researchgate.net/publication/315848047>

5.3.1 b. RAN Vertical slicing (cont'd)

■ Function categories

- **Common CPI slice functions** : *idle mode* (e.g., paging, cell reselection, tracking area update)
- **Slice-specific CPI functions**: *connected mode* (e.g., handover, dedicated bearer setup)

■ Examples of triggers for turning on a slice at an access point (AP):

- 1) Traffic load of that slice goes beyond a certain threshold
- 2) The number of active devices operating on that slice goes beyond a certain threshold
- 3) Need to keep service continuity
- 4) Need to meet certain QoS requirements

■ When turning on a slice

- an access point (AP) allocates RR for the slice and enable all radio and network functions associated with the slice

■ Slice-on at an AP can be triggered by a device or by the network.

- when triggered by a device, the network can decline the device slice-on request (various tech/business reasons)

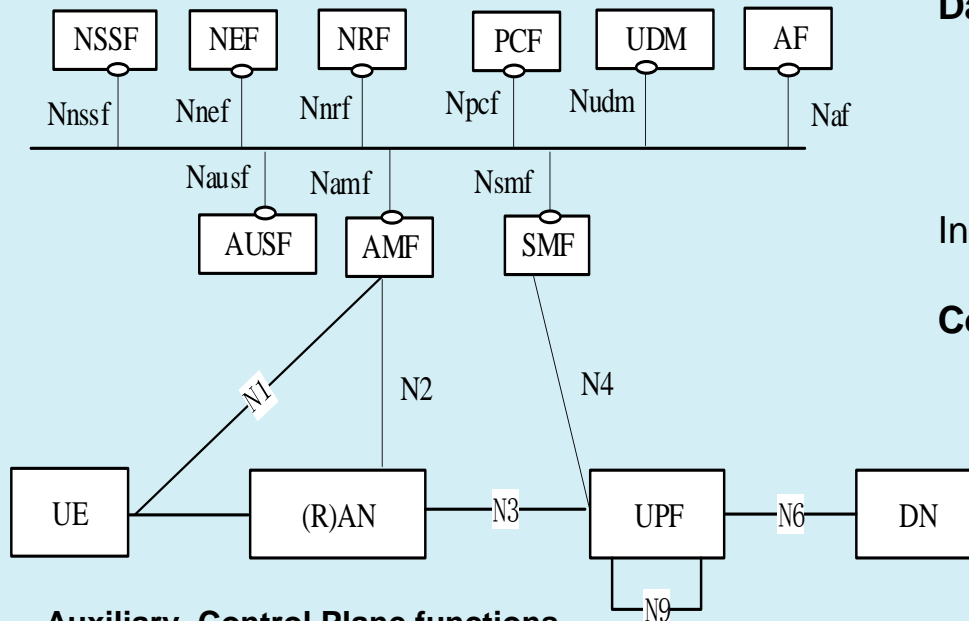
5.3.1 b. RAN Vertical Slicing (cont'd)

- **Operational details**
- AC and LB are based on the availability of the requested slice at the BS or APs well as the load conditions and the overall system performance.
 - The BS/AP system information indicates the active slices in the BS or AP
 - Based on the system information, a device can start the random access procedure with a BS that has the intended slice actively running
 - If the intended slice is not supported by a BS, the UE may still start the random access procedure considering factors such as link condition, QoS requirements, traffic load of the neighboring cells, etc.
 - If the device makes the access request but the slice is not currently active in the BS/AP, and the BS accepts the access request, then the BS/AP turns on the slice

5.3.1 c. Core Network Vertical Slicing (CN as defined in 4G, 5G specs)

3GPP 5G functional architecture

- Non-roaming reference arch. Service-based interfaces are used within the Control Plane.



Notations:

Data Path

UE User Equipment

(R)AN (Radio) Access Network

UPF User Plane Function

DN Data Network e.g. operator services, Internet access or 3rd party services

Control Plane

Main Control Plane functions

AUSF Authentication Server Function

AMF Access and Mobility Mgmt. Function

SMF Session Management Function

Auxiliary Control Plane functions

UDSF Unstructured Data Storage Function

NEF Network Exposure Function

NRF Network Repository Function

NSSF Network Slice Selection Function

PCF Policy Control Function

UDF Unified Data Management

UDR Unified Data Repository

SEPP Security Edge Protection Proxy

NWDAF Network Data Analytics Function

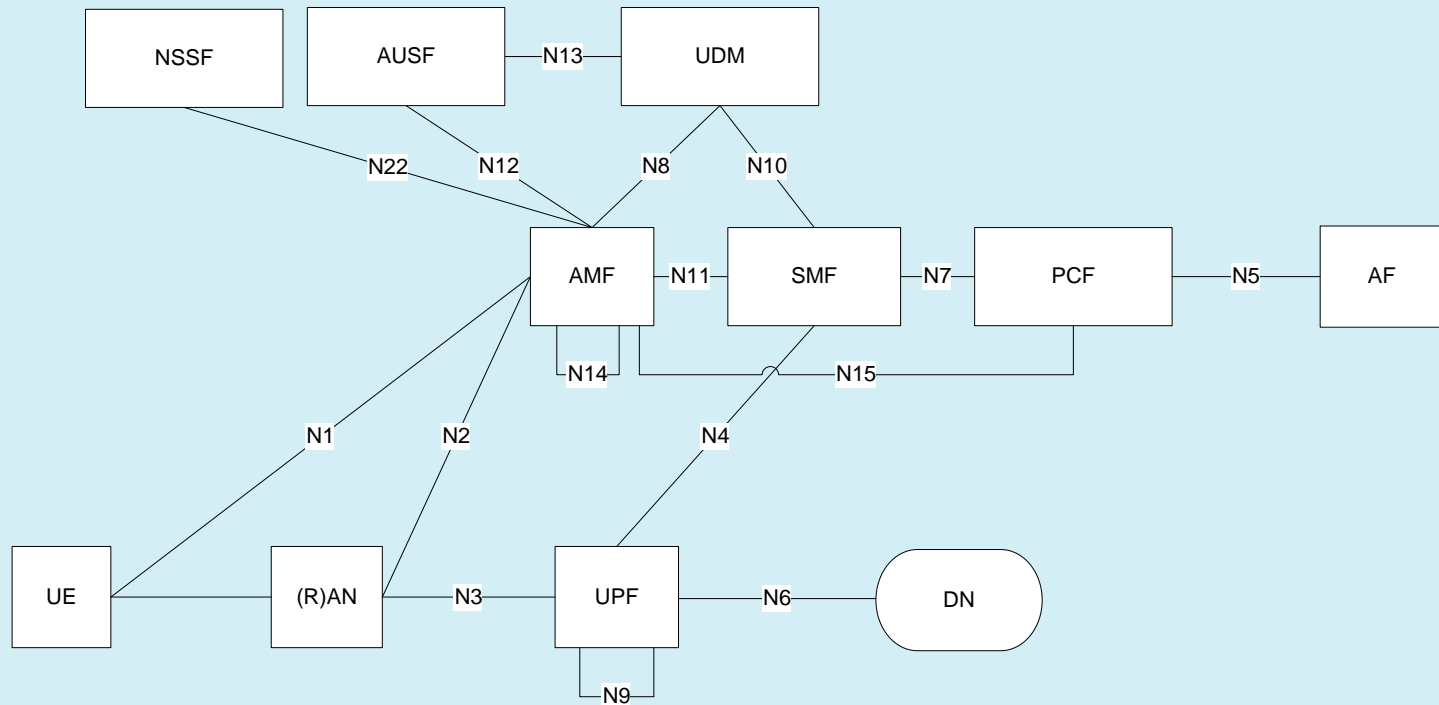
3GPP TS 23.501 V15.2.0 (2018-06), System Architecture for the 5G System; Stage 2, (Release 15)

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5.2.1 c. Core Network Vertical Slicing (cont'd)

3GPP 5G functional architecture

- Non-roaming reference architecture in **reference point (RP)** representation
-



3GPP TS 23.501 V15.2.0 (2018-06), System Architecture for the 5G System; Stage 2, (Release 15)

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5.3.1 c. Core Network Vertical Slicing (cont'd)

- **3GPP 5G functional architecture**
 - Each logical slice provides complete CN capability
 - **Separation of UP and CP enables**
 - Slice common or independent CP
 - Slice based independent UP
 - Selective choice of CP functions for different NSs
 - Distribution of UP closer to the network edge
- **UP functions** - examples: forwarding, encapsulation, de-capsulation, associated transport level specifics
- **CP functions**- examples: session mgmt., access authentication, policy negotiation/mgmt., user data storage , etc.
- **Actions:**
 - CN slicing selection
 - CN slicing registration
 - CN slicing PDU session establishment

Source: End to End Network Slicing – White paper 3 Outlook 21, Wireless World , Nov 2017

5.3.1 c. Core Network Vertical Slicing (cont'd)

- 3GPP 5G functional architecture
 - Example: network slicing for 5G CN

Two groups:

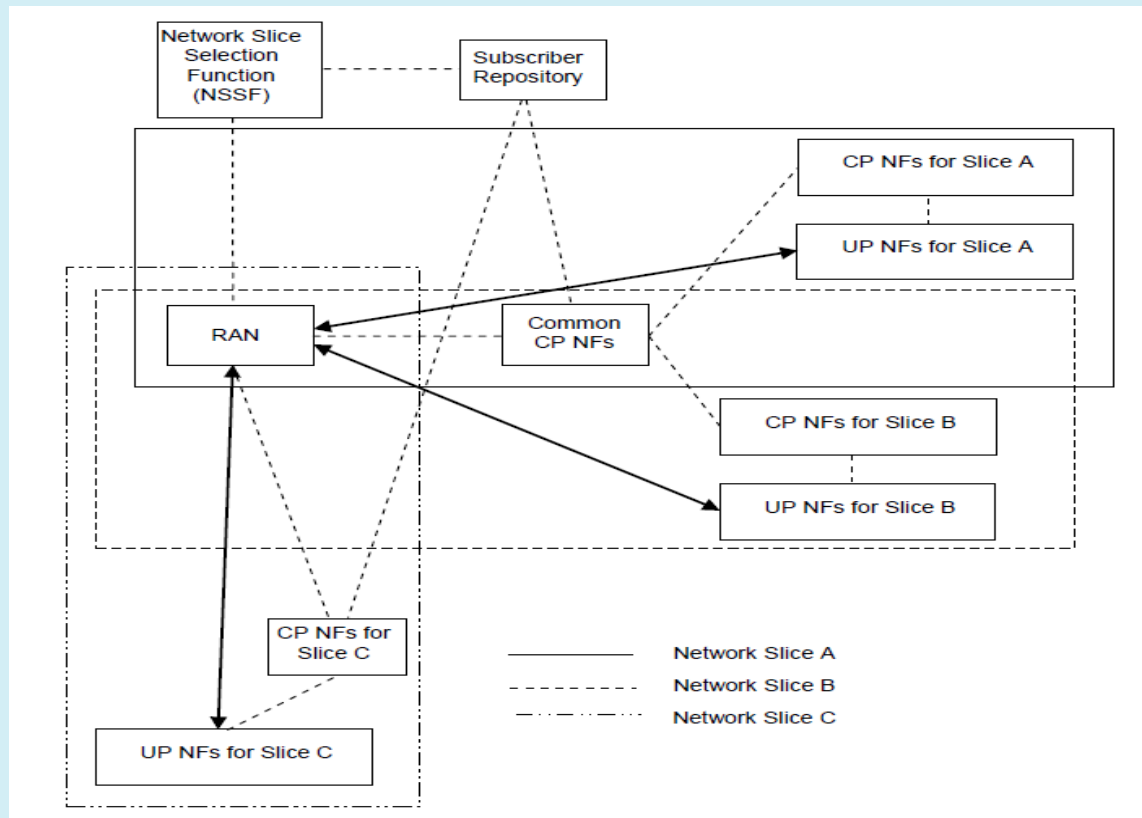
- dedicated network slice
- NSs sharing common CP NFs

Global NFs across multiple slices

e.g.,
 UE subscription repository
 NSSF- common fct. for all NSs
 in a PLMN

Common CP NFs for multiple NSs with UE simultaneously connected

The minimum set of common CP NFs
 should include AMF
 - this will reduce the signaling
 related to mobility between slices

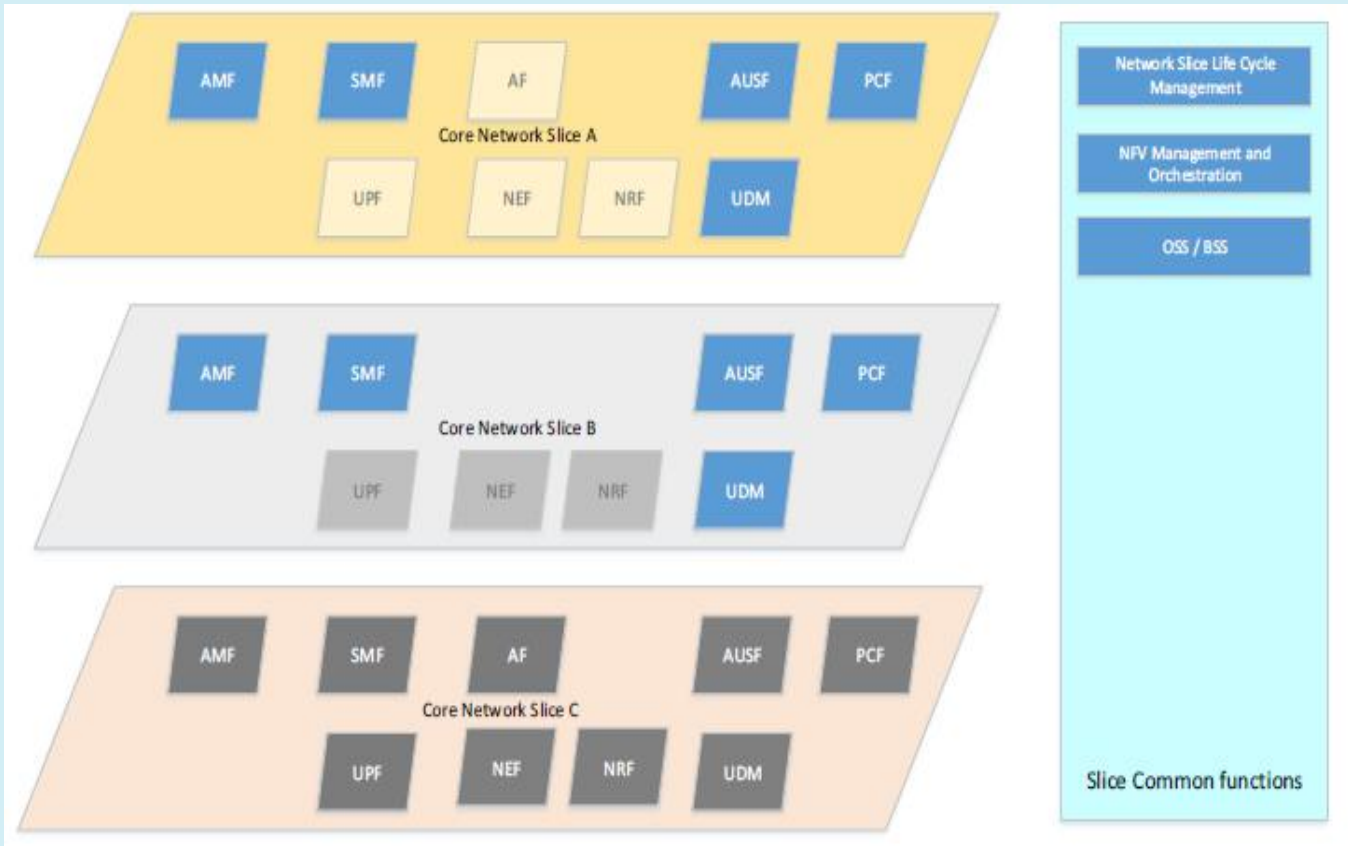


Source: End to End Network Slicing – White paper 3 Outlook 21, Wireless World, Nov 2017

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5.3.1 c. Core Network Vertical Slicing (cont'd)

- **3GPP 5G functional architecture**
 - Example: network slicing for 5G CN



Each NS has dedicated NFs), e.g.: SMF, UPF, NEF, NRF & AF nodes

One can implement shared NF for AMF, AUSF, PCF & UDM (e.g. same operator implementing different NS for MBB & mMTC use cases)

An entirely dedicated set of all NFs are implemented for Slice C

Source: End to End Network Slicing – White paper 3 Outlook 21, Wireless World, Nov 2017

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5. Multi-domain and end to end 5G slicing



5.3.1 d. Transport Network (TN) Vertical Slicing (Wide area network)

- **Requirements for TN** –to support 5G-based E2E development
 - High bandwidth, low latency, virtualisation and slicing capabilities,
 - flexible scheduling of services
 - inter-cloud connectivity
 - connection oriented carrier grade transport

- **Four- layer** architecture can be defined – w.r.t transport
 - **Physical** : racks, ports and fiber links, etc.
 - **Hard Pipe** : Layer 1 channels (Optical Transport Network (OTN), or FlexEthernet
 - **Soft Pipe** : L2 or L3 network (e.g., Ethernet or IP)
 - **Service** : client layer network of transport network

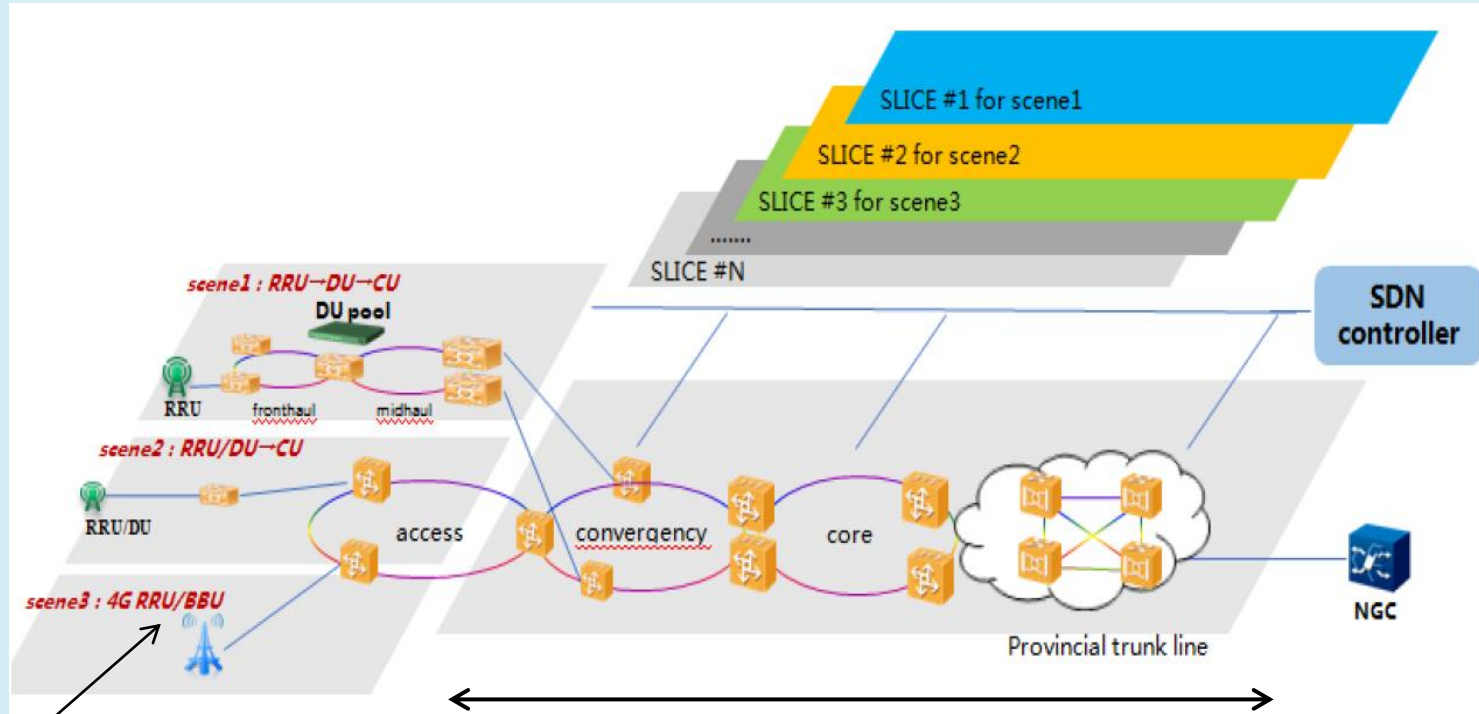
Source: End to End Network Slicing – White paper 3 Outlook 21, Wireless World , Nov 2017

5.3.1 d. Transport Network (TN) Vertical Slicing (cont'd)

- TN slicing may happen inside each layer network:
 - **Physical Slicing:** slicing of the network resource (e.g., assignments for network elements, ports, links, racks etc.)
 - **Hard Pipe Slicing:** L1 channel slicing (e.g., the channels of WDM, OTN, FlexE)
 - **Soft Pipe Slicing:** Ethernet / IP virtual network segment (e.g., L2 VPN, L3 VPN, L2 / L3 Bridge)
 - **Service Slicing:** service type slicing (e.g., URLLC, eMBB, mMTC)
- **Mapping** between Service slices (e.g., URLLC, eMBB, mMTC) on the lower layer is needed - directly on L1, or on top of L2/L3- depending on Service slice requirement

5.3.1 d. Transport Network Vertical Slicing (cont'd)

- Transport technologies



CRAN- Cloud RAN

RRU -remote radio unit

BBU - base band unit

CU/DU - 5G Centralized Unit/Distributed Unit

TN slices

Adapted from source: End to End Network Slicing – White paper 3 Outlook 21, Wireless World , Nov 2017

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5.3.1 d. Transport Network Vertical Slicing (cont'd)

■ Control plane (CP) slicing

- CP provides encapsulating and scheduling capabilities for the services
- Technologies: **SDN centralised control** and **Segment Routing (SR)**
 - **SDN** : routing control and flexible programming, policies, to achieve flexible scheduling of the service
 - **SR** (SDN- controlled)
 - decouples services from transport network.
 - service establishment only operates at the edge node, and can be seamlessly connected with the under SDN control
 - provides CO/CL pipeline to meet connectivity requirements

■ Forwarding plane (FP) slicing

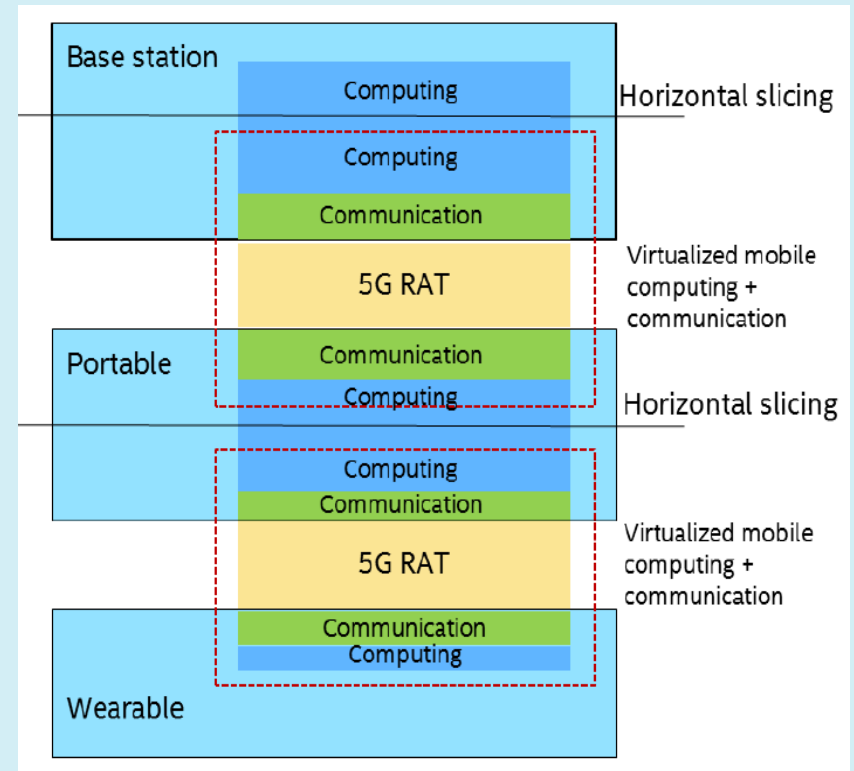
- double plane switching: **packet switching + slot switching** (similar to the traditional circuit switching techniques)
- Hard isolation
- Capability expansion
 - combined DWDM with the traditional physical electrical layer interface

See: End to End Network Slicing – White paper 3 Outlook 21, Wireless World , Nov 2017

5.2.2 Horizontal Slicing

- **Concepts**
- **Relationship with edge computing (EC)**
 - **Communication and computation cooperates at the network edge** (moving computation and storage to the edge)
 - The comm. link between the source and the destination is shortened
 - The user experience can be improved by HS
 - the **network nodes slice out part of their computation resources** to help computation at the portable device
 - the **portable devices slice out part of their computation resources** to help the computation at the wearable devices

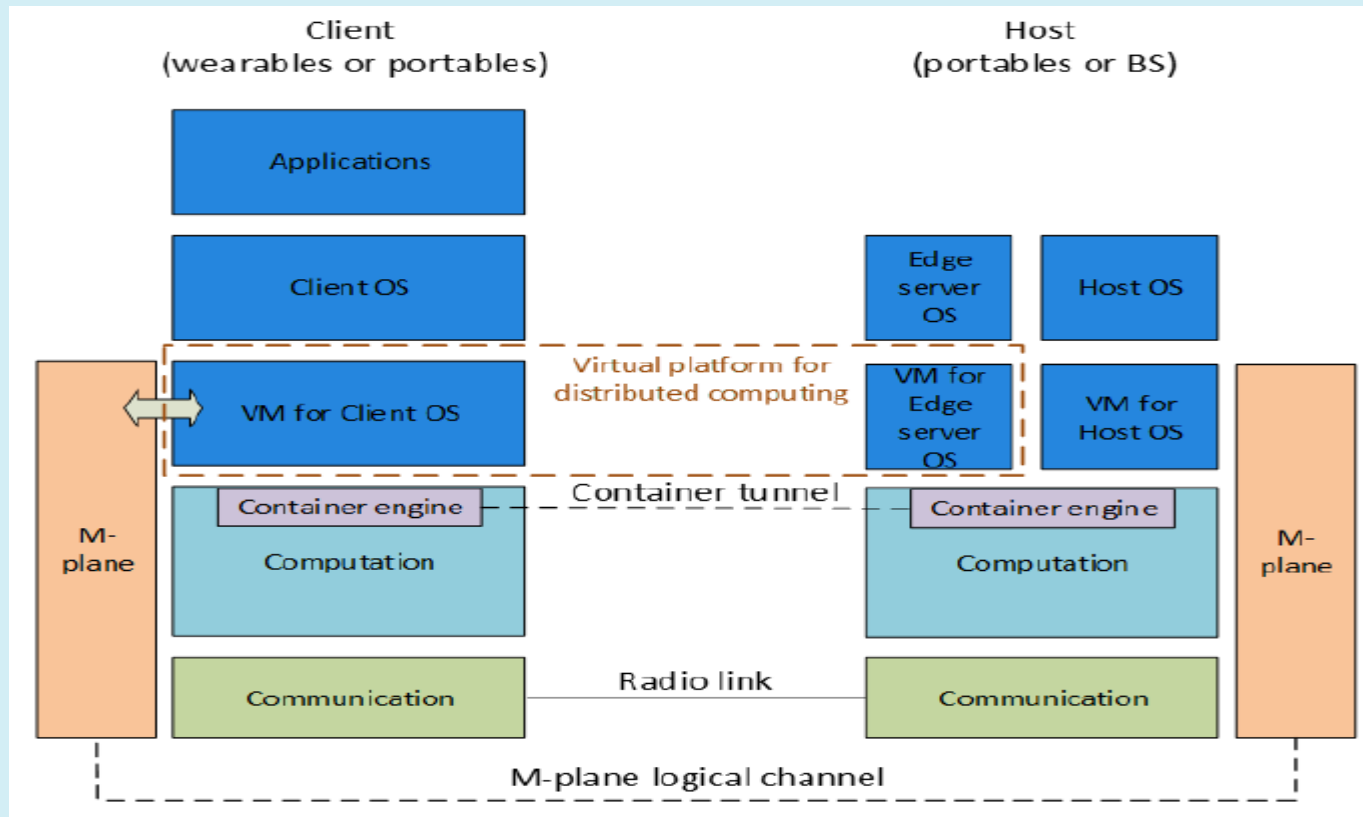
Horizontal slicing concept



See: Q. Li, G. Wu, A. Papathanassiou, U. Mukherjee, *An end-to-end network slicing framework for 5G wireless communication systems*, <https://arxiv.org/abs/1608.00572>

5.2.2 Horizontal Slicing (cont'd)

- Computation resource sharing example



Source: Q. Li, G. Wu, A. Papathanassiou, U. Mukherjee, An end-to-end network slicing framework for 5G wireless communication systems, <https://arxiv.org/abs/1608.00572>

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5.2.2 Horizontal Slicing (cont'd)

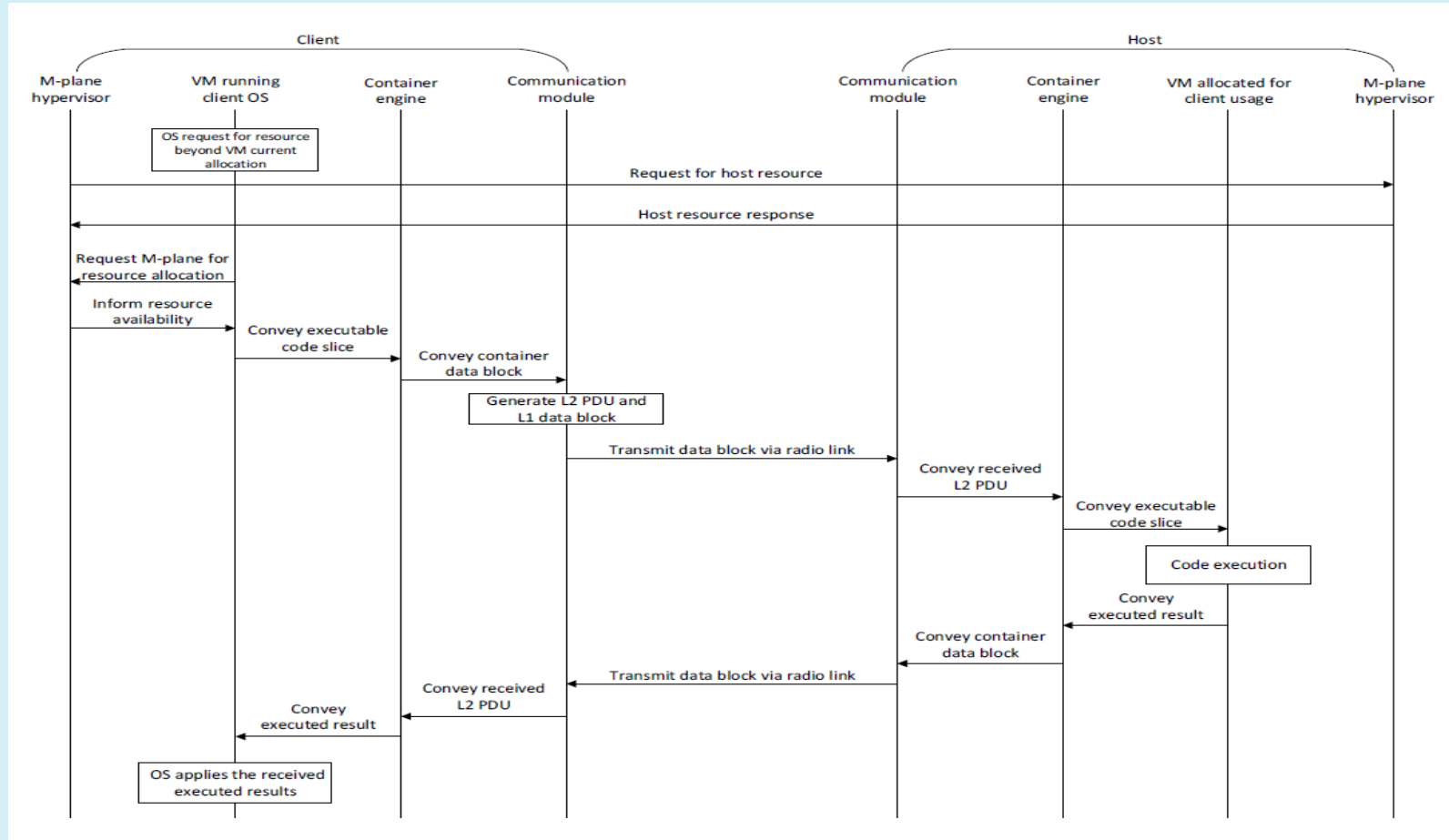
- **Computation resource sharing example (cont'd)**
- Computation slicing is managed by the M-plane
- The M-planes monitors the system resource usage and the radio link condition
- **Summary of the procedure**
 - **When**
 - the **M-plane of the client (C) sees benefit (perf., costs, etc.) of computation offloading**
 - or the **client OS requests resource beyond the client comp.** can support
 - it asks the host M-plane for sharing computation resource.
 - The **signaling between the M-plane@C<--> M-plane@H: air I/F L3 messages**
 - If the H accepts the client's request for resource the M-plane@C informs the client VM on the availability of the resource
 - The client VM then **slices the sliceable app.** based on the information from the M-plane and convey the generated executable code to the container engine
 - The **container engine packs the sliced executable code** into container and convey the data packet carrying the container to the comm. Module

5.2.2 Horizontal Slicing (cont'd)

- **Computation resource sharing example (cont'd)**
- **Summary of the offloading procedure (cont'd)**
 - The **Comm Module packs the container data into L2 PDU**, generate L1 data block and transmit to the H via the selected radio link.
 - The **H Comm. module decodes** the received data blocks and convey to the container engine
 - The **H container engine unpacks** the received container and **hands the executable code to the edge server VM**
 - Upon computation end, the **H container engine packs the results in the container and deliveries it back to the C container engine**
 - The C container unpacks the executed result
 - The **client OS then applies the received executed results**

5.2.2 Horizontal Slicing (cont'd)

- Summary of the offloading procedure (cont'd)



Source: Q. Li, G. Wu, A. Papathanassiou, U. Mukherjee, An end-to-end network slicing framework for 5G wireless communication systems, <https://arxiv.org/abs/1608.00572>

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5.3 Example of E2E architecture – NORMA EU H2020 project

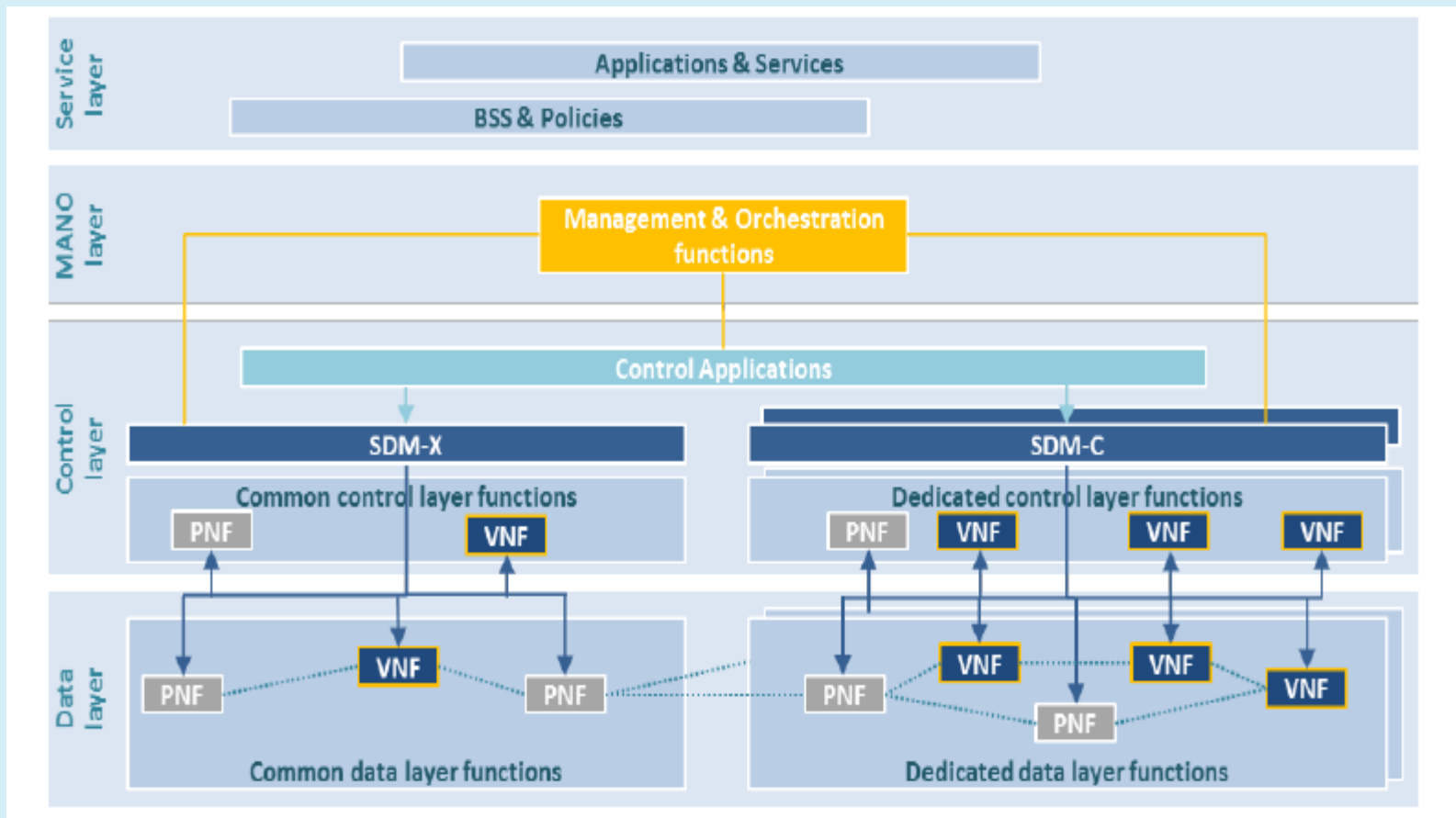
■ Two kind of functions

- **dedicated NFs**, combined in **dedicated sub-slices** and controlled by the **Software-Defined Mobile network Controller (SDM-C)**.
- **shared NFs** are aggregated in **common sub-slices** controlled by the **SDM Coordinator (SDM-X)**,
 - SDM-X
 - coordinates and, if necessary, define priorities for the QoS requirements of multiple slices.
 - realizes resource efficiency while guaranteeing individual SLAs.
 - resides on the common control layer; it also includes P/VNFs that the NSs rely on.
 - **Dynamic adjustments of common resources** (versus static one) brings multiplexing gains at the expense of less determinism.
 - So, SMD-X should balance between flexible/dynamic and static resource assignments, by taking into account sharing policies set by the service provider

See: *P. Rost et al, Network Slicing to Enable Scalability and Flexibility in 5G Mobile Networks, IEEE Communication Magazine, 2017*

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- CG slicing NORMA architecture

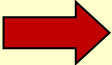


Source: P. Rost et al, Network Slicing to Enable Scalability and Flexibility in 5G Mobile Networks, IEEE Communication Magazine, 2017



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6.  Conclusions

- **Network slicing in the context of 5G offer virtual networks**
 - **on demand, concurrent, self-contained, independent, multiple-logical shared or partitioned** on top of a common infrastructure
 - **abstracted and isolated** w.r.t. the underlying physical network resources
 - compatible with cloud/edge/fog computing
 - **Multi-tenant, multi-domain, and End to end capabilities**
 - Large variety of verticals (including OTT) can be served in a large set of configurations
 - **Services provisioning** : flexible way, with customisation and isolation of the slices for different tenants
 - **Operators and Providers** can benefit from
 - powerful (automated) management and orchestration
 - programmability
 - novel cooperative business models

- **Open research issues/challenges summary (not-exhaustive list)**
- Still many resarch/development efforts are needed to improve solutions for
 - **Network slicing management**
 - Multi-tenant management
 - Multi-domain (cross-domain coordination) and E2E slicing management
 - Network slice discovery and monitoring
 - Life cycle management- including slice modification during run-time
 - Autonomic and cognitive slice management
 - Services mapping on slices, data models
 - Slice isolation and stitching, security
 - Cooperation with SDN, NFV, Clod/fog/edge computing
 - Infrastructure resources management
 - Performance and E2E QoS
 - **Business models development**
 - Multi-domain, multi-operator, multi-tenant
 - Large variety of third parties
 - **Implementation and deployment options**
 - Disruption related and backward compatibility challenges
 - Economy of scale in slicing
 - Interaction with vertical customers



End-to-end, multi-domain and multi-tenant in 5G network slicing



- Thank you !
- Questions?



End-to-end, multi-domain and multi-tenant aspects in 5G network slicing



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- List of Acronyms

5G CN	Core Network
5G-AN	5G Access Network
5GS	5G System
5QI	5G QoS Identifier
AF	Application Function
AI	Artificial Intelligence
AMF	Access and Mobility Management Function
AS	Access Stratum
AUSF	Authentication Server Function
BBU	Baseband Unit
BSF	Binding Support Function
CA	Certificate Authority
CaaS	Cooperation as a Service
CAPIF	Common API Framework for 3GPP northbound APIs
CC	Cloud Computing
CP	Control Plane
CP	Control Plane
CRAN	Cloud based Radio Access Network
D2D	Device to Device communication
DL	Downlink
DN	Data Network
DNAI	DN Access Identifier
DNN	Data Network Name
DoS	Denial of Services
DP	Data Plane (User Plane UP)



End-to-end, multi-domain and multi-tenant in 5G network slicing



- List of Acronyms

ENaaS	Entertainment as a Service
ePDG	evolved Packet Data Gateway
FAR	Forwarding Action Rule
FAST	Fast Application and Communication Enabler
FC	Fog Computing
FQDN	Fully Qualified Domain Name
GMLC	Gateway Mobile Location Centre
GPS	Global Positioning System
GUAMI	Globally Unique AMF Identifier
HR	Home Routed (roaming)
IaaS	Infrastructure as a Service
INaaS	Information as a Service
INS	Insurance
IoT	Internet of Things
IT&C	Information Technology and Communications
ITS	Intelligent Transportation Systems
LADN	Local Area Data Network
LLC	Logical Link Control
LMF	Location Management Function
LRF	Location Retrieval Function
MANET	Mobile Ad hoc Network
MCC	Mobile Cloud Computing
MEC	Multi-access (Mobile) Edge Computing
MPS	Multimedia Priority Service
N3IWF	Non-3GPP InterWorking Function
NaaS	Network as a Service



End-to-end, multi-domain and multi-tenant in 5G network slicing



- List of Acronyms

NAI	Network Access Identifier
NEF	Network Exposure Function
NF	Network Function
NFV	Network Function Virtualisation
NGAP	Next Generation Application Protocol
NR	New Radio
NRF	Network Repository Function
NSI ID	Network Slice Instance Identifier
NSSAI	Network Slice Selection Assistance Information
NSSF	Network Slice Selection Function
NSSP	Network Slice Selection Policy
NWDAF	Network Data Analytics Function
OBU	On Board Unit
OIF	Optical Internetworking Forum
ONF	Open Networking Foundation
PaaS	Platform as a Service
PCF	Policy Control Function
PEI	Permanent Equipment Identifier
PKI	Public Key Infrastructure
PSA	PDU Session Anchor
QFI	QoS Flow Identifier
QoE	Quality of Experience
RAN	Radio Access Network
RRH	Remote Radio Head
RSU	Road Side Unit
SA NR	Standalone New Radio



End-to-end, multi-domain and multi-tenant in 5G network slicing



- List of Acronyms

SaaS	Software as a Service
SBA	Service Based Architecture
SBI	Service Based Interface
SD	Slice Differentiator
SDN	Software Defined Networking
SEAF	Security Anchor Functionality
SEPP	Security Edge Protection Proxy
SM	Service Management
SMF	Session Management Function
S-MIB	Security Management Information Base
SMSF	Short Message Service Function
S-NSSAI	Single Network Slice Selection Assistance Information
SSC	Session and Service Continuity
SSE	Smart Safety and Efficiency
SST	Slice/Service Type
TNL	Transport Network Layer
TNLA	Transport Network Layer Association
TSP	Traffic Steering Policy
UDM	Unified Data Management
UDR	Unified Data Repository
UDSF	Unstructured Data Storage Function
UL	Uplink
UPF	User Plane Function
URSP	UE Route Selection Policy



End-to-end, multi-domain and multi-tenant in 5G network slicing



- List of Acronyms

V2X	Vehicle-to-everything
VANET	Vehicular Ad hoc Network
VID	VLAN Identifier
VLAN	Virtual Local Area Network
VM	Virtual Machine
WAT	Wireless Access Technologies
WAVE	Wireless Access for Vehicular Environments
WSN	Wireless Sensor Network



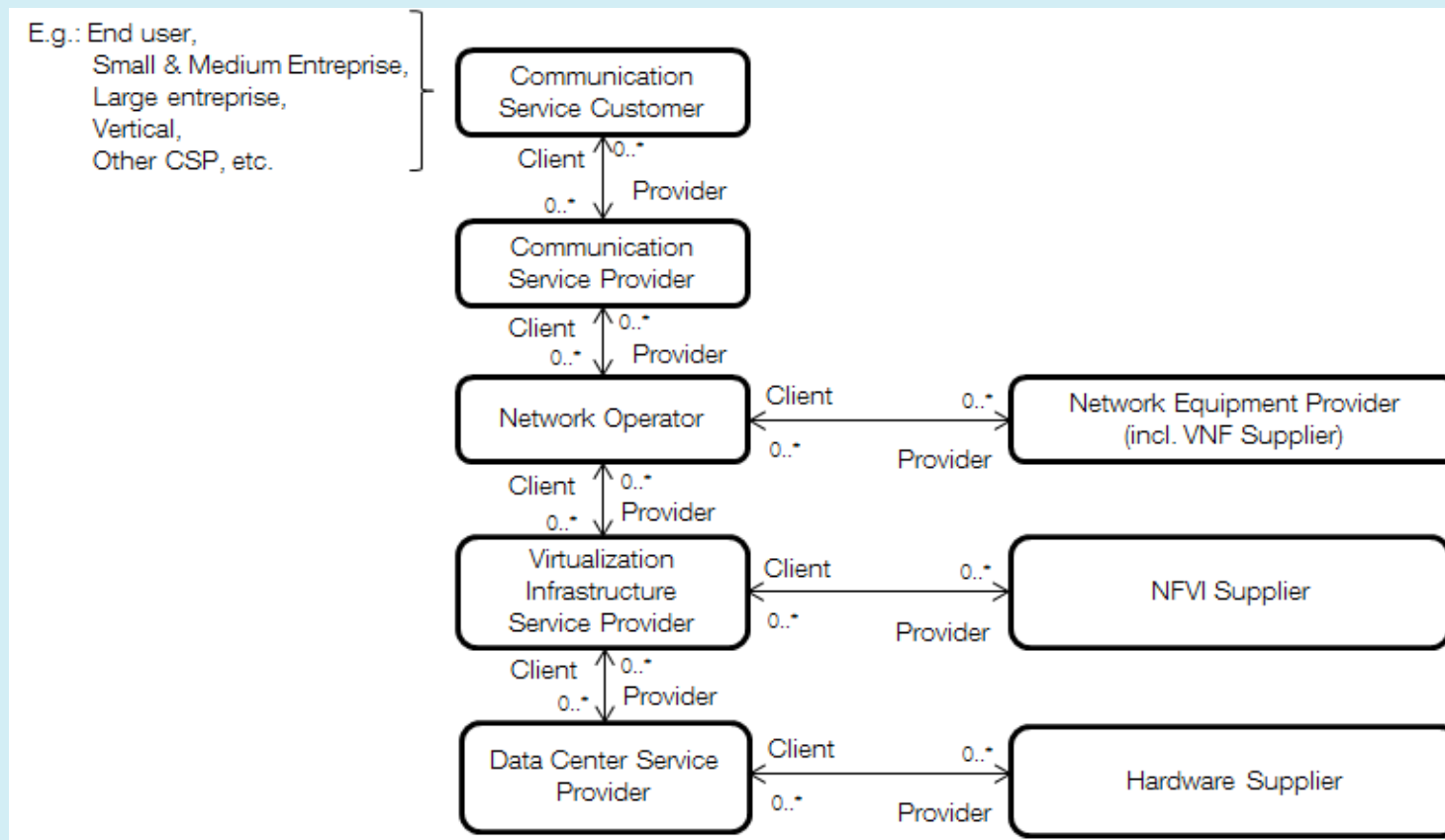
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- Backup slides

3.2 ETSI and 3GPP functional architectures for slicing support

- Business model interactions – in NFV context



Source: 3GPP TR28.801 V15.1.0 (2018-01), Study on management and orchestration of network slicing for next generation network, (Release 15)