Advanced management and control in 5G sliced networks

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- **Acknowledgement**
  - This overview and analysis is compiled and structured, based on several **public documents** like: 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**.

Advanced management and control in 5G sliced networks

- **Motivation of this talk**
  - **The 5G (fifth generation):** new generation of mobile networks to support dedicated use-cases and providing a large range of services to satisfy various customer demands.
  - **4G concept: "one-fit-all" type-architecture**
  - while 5G supports
    - diverse **business demands with different requirements** and separation between **logical slices**
    - service innovation and programmability through softwarization, open sources and open interfaces that allow access to third parties
  - **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
    - NGNM, 3GPP, 5GPPP, ETSI, ITU-T, GSMA, BBF, ONF, IETF, IEEE, etc.

Advanced management and control in 5G sliced networks

- **Motivation of this talk (cont'd)**
  - **5G Network slicing** – major concept, allowing resource sharing (w. logical isolation) among multiple tenants or network operators and/or services in multi-domain context
  - 5G slicing requirements : **multi-tenant, End-to-end (E2E), multi-domain, multi-provider/operator context** → many open research issues and challenges

  - **Management and control aspects**
    - Service/data model & mapping in a single or multi-domain environment
    - Slice stitching / composition in a single domain and cross-domain Coordination
    - E2E network orchestration
    - Network slice life cycle management
    - Customizable M&C for different tenants
    - Network slice monitoring and dynamic updating
    - Autonomic and cognitive slice management and operation
    - Seamless deployment , integrating 3G, 4G, …
    - ….

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1. 5G Network slicing – concepts, use cases and requirements

1.1 5G general aspects

- **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)
- **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 Network slicing – concepts, use cases and requirements

1.1 5G general aspects

- **5G Key technological characteristics**
  - Heterogeneous set of integrated air interfaces
  - Cellular and satellite solutions
  - Simultaneous use of different **Radio Access Technologies (RAT)**
    - **Seamless (vertical) 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)
  - **Optimized network management** operations, through
    - **cognitive features**
    - **advanced automation** of operation through proper algorithms
    - Data Analytics and Big Data techniques -> monitor the users' QoE

1. 5G Network slicing – concepts, use cases and requirements

1.1 5G general aspects

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. 5G Network slicing – concepts, use cases and requirements

1.2 5G Key Specific Requirements

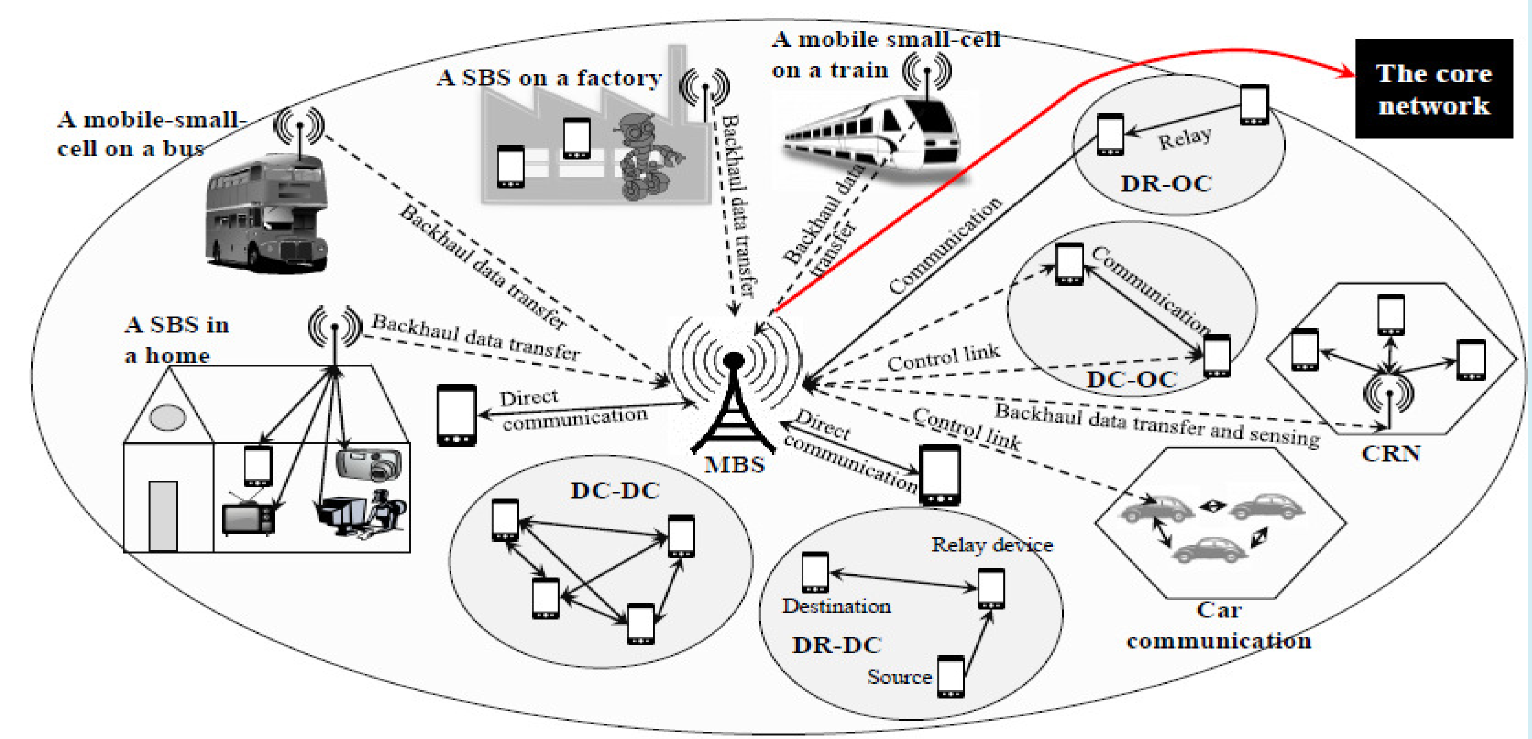
- **Summary of 5G figures - strong goals:**
  - **1,000 X in mobile data volume** per geographical area reaching a target ≥ 10 Tb/s/km2
  - **1,000 X in number of connected devices** reaching a density ≥ 1M terminals/km2
  - **100 X in user data rate** reaching a peak terminal data rate ≥ 10Gb/s
  - **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. 5G Network slicing – concepts, use cases and requirements

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

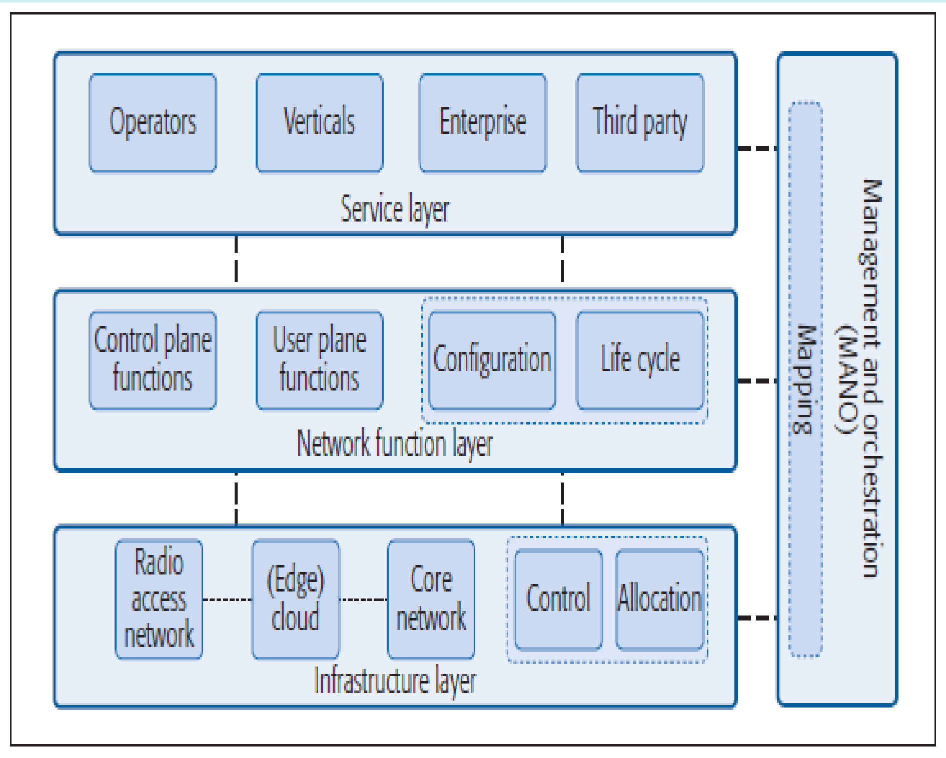


Source: Panwar N., Sharma S., Singh A. K. ‚A Survey on 5G: The Next Generation of Mobile Communication'. Accepted in Elsevier Physical Communication, 4 Nov 2015, http://arxiv.org/pdf/1511.01643v1.pdf

1. 5G Network slicing – concepts, use cases and requirements

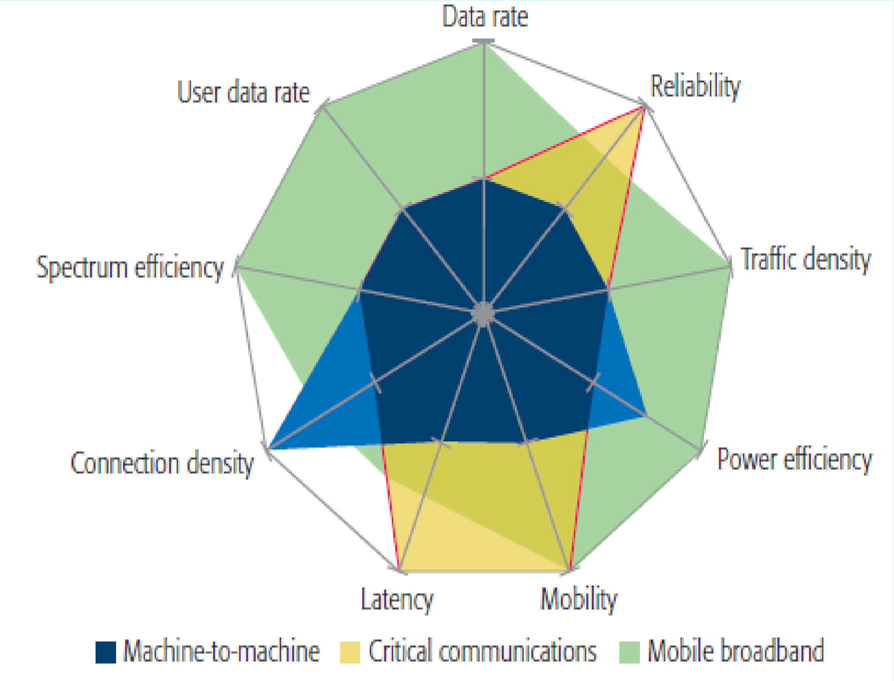
1.4 5G Layered Functional Architecture

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



Key 5G use cases and their requirements

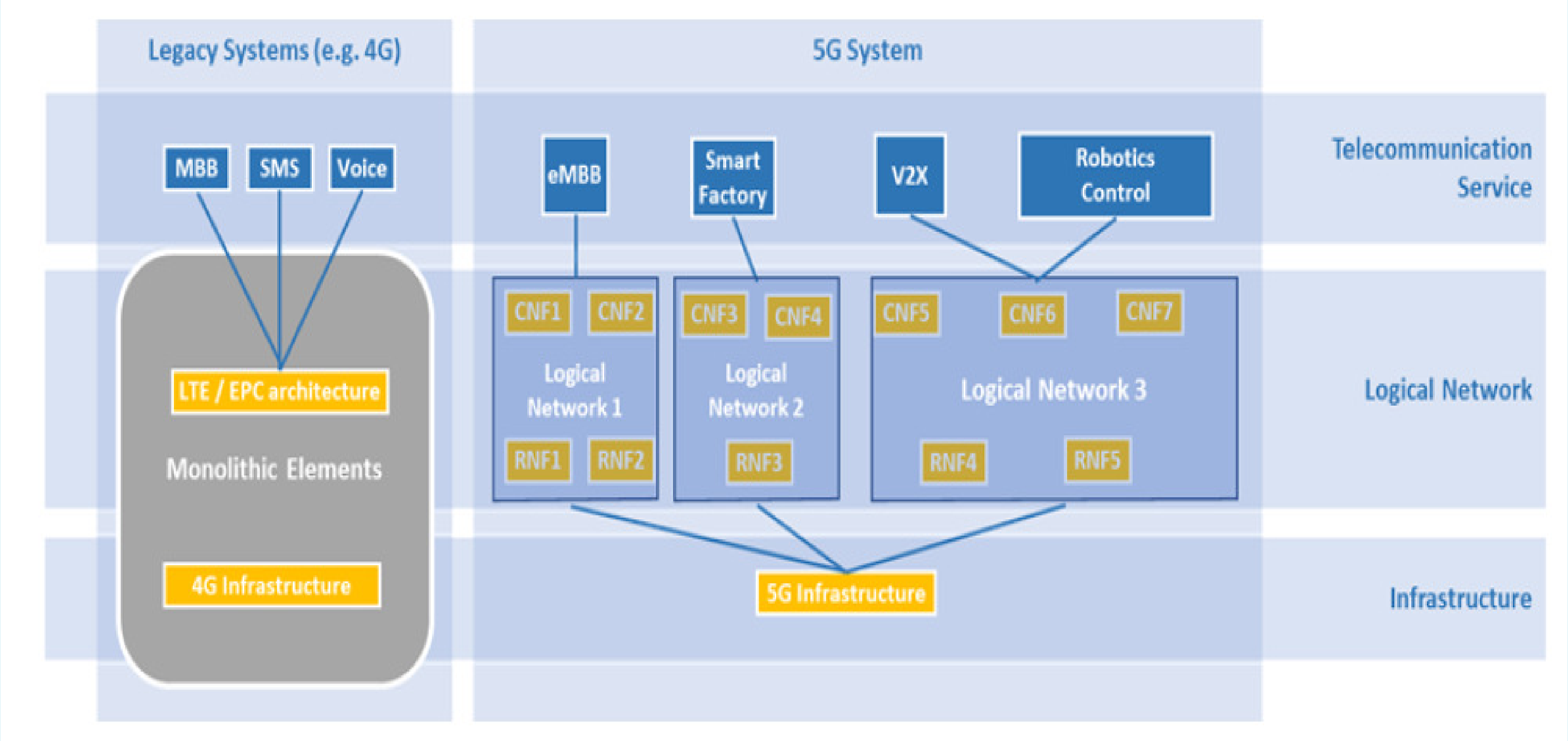
- difficult for a traditional unique arch to meet all of them
- **dedicated slicing can be the solution**



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. 5G Network slicing – concepts, use cases and requirements

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

1. 5G Network slicing – concepts, use cases and requirements

1.6 Network slicing concepts

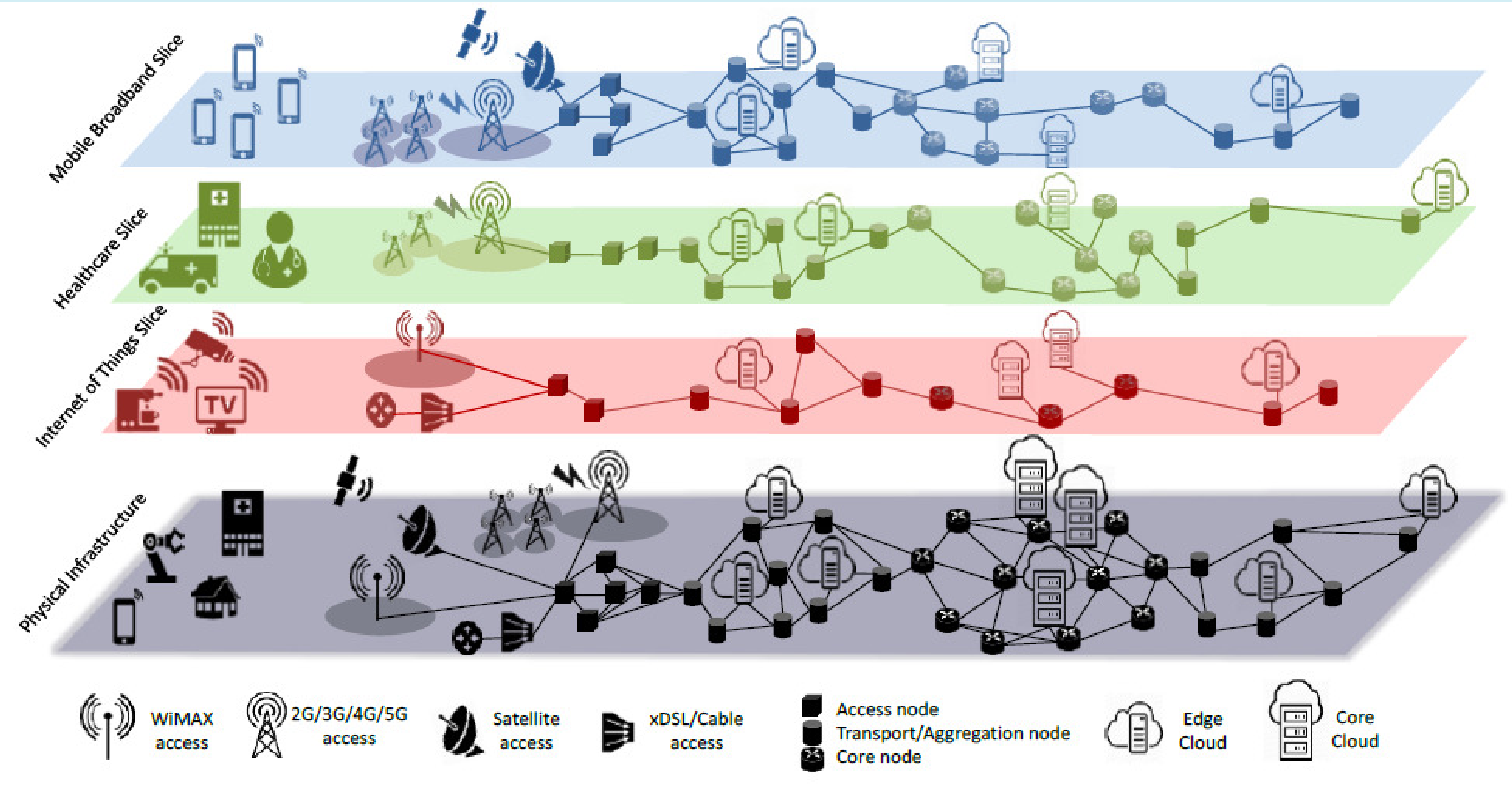
- **E2E concept:** covering all network segments : radio, access/edge, wire, core, transport and edge networks.
- **concurrent deployment of multiple E2E logical, self-contained and independent shared or partitioned networks** on a common infrastructure platform
- **Slices**
  - created **on demand**, running on a common underlying (P/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 virtualization, programmability, flexibility, and modularity to create **multiple network slices** each tailored for a given UC

1. 5G Network slicing – concepts, use cases and requirements

1.6 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

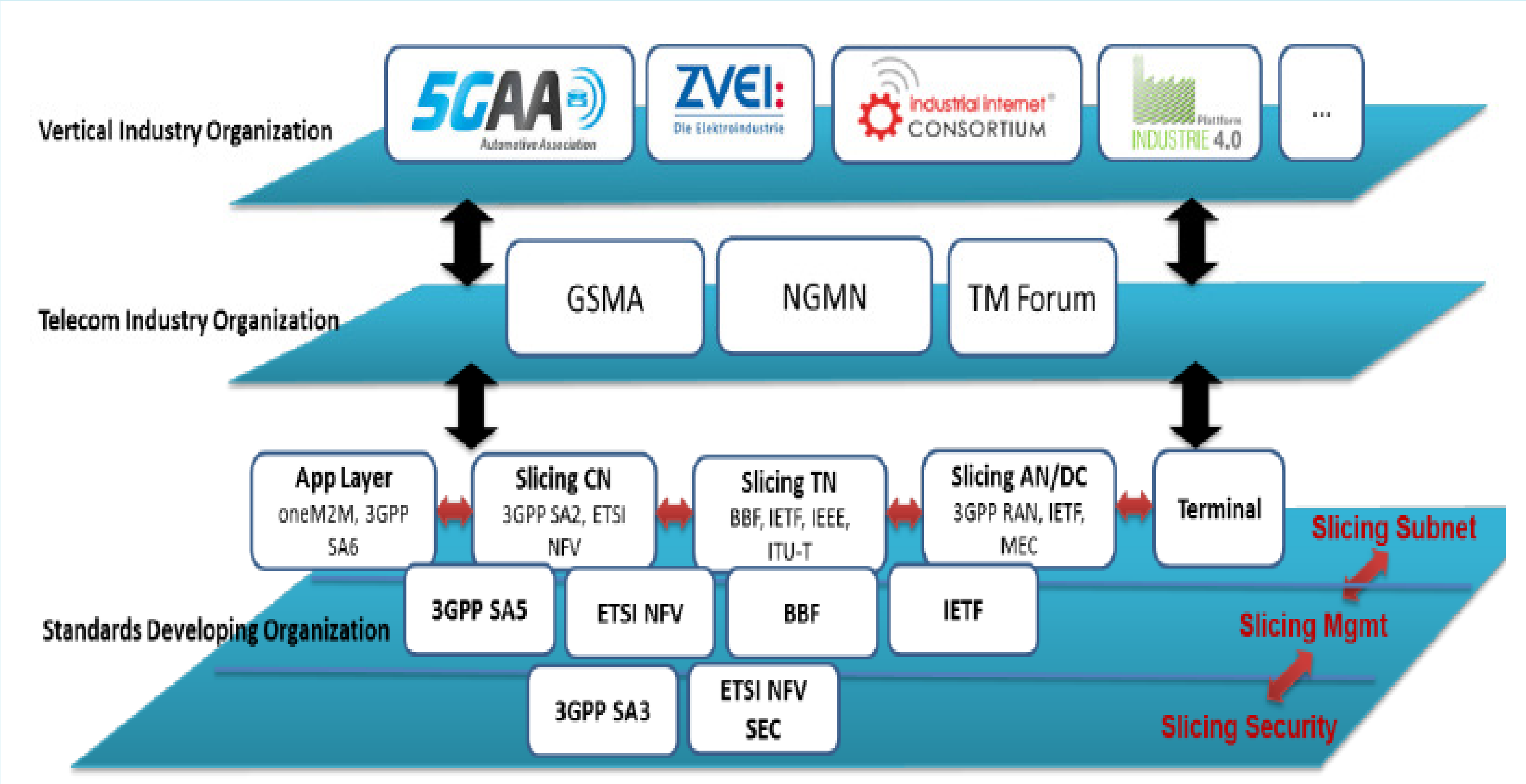
1. 5G Network slicing – concepts, use cases and requirements

1.7 Standardisation work oriented to slicing

- **European Telecom Std. Institute (ETSI)** –**Next Generation Protocols (NGP)** – Technology independent approach to slicing
  - **ETSI- Network Function Virtualization (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.

1. 5G Network slicing – concepts, use cases and requirements

1.7 Standardisation effort oriented to slicing (cont'd)



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

1. 5G Network slicing – concepts, use cases and requirements

1.8Terminology summary

For more details see also Backup slides BS1

- **Networking Servicing terms**
  - **Service, Network Service (NS), Service Instance**
  - **Administrative domain (AD)**
  - **Infrastructure domain**

  - **Tenant: one or more service users** sharing access to a set of P/V resources or service resources
  - **Multi-tenancy:** P/V or service resources are allocated to multiple tenants

  - **Tenant domain:** provides combinations of VNFs into Network Services, and is responsible for their M&O including 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

1. 5G Network slicing – concepts, use cases and requirements

1.8 Terminology summary (cont'd)

- **Network Resources**
  - **Resource, Logical Resource**
  - **Virtual Resource** - An abstraction of a P/L resource, maybe with different characteristics and extended capabilities w.r.t the original
  - **Network Function (PNF/VNF)**
  - **Network Element (NE)**

- **Network Slicing Terms**
  - **Resource Slice -** A grouping of P/V (network, compute, storage) resources

  - **Network Slice (NSL)**
    - 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)**

1. 5G Network slicing – concepts, use cases and requirements

1.8Terminology summary (cont'd)

- **Network Slicing Terms**
  - **End-to-end NSL (E2E-NSL)** - A cross-domain customized NS
    - it may consist of access (fixed or cellular), transport (mobile) core networks, etc.
  - **Network Slice Instance (NSLI)** - An activated NSL, created based on network template
    - complete instantiated logical network to meet the reqs. of the service instance(s)
    - **set of managed run-time NFs and resources** to run them;
    - **may be shared** across multiple service instances provided by the NO
  - **Network Slice Tenant (NSTn)** - is the user of specific NSLIs, who offer specific services to end customers
    - The operators' customers (e.g., vertical industries) or the operators themselves. They utilize the NSLIs to provide services to their end users
    - Tenants may have independent O&M reqs., uniquely applicable to the NSLIs
    - NSTn-s can request the creation of new NSLI
    - The NSP usually grants some management capability to NSTn

1. 5G Network slicing – concepts, use cases and requirements

1.8 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 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

1. 5G Network slicing – concepts, use cases and requirements

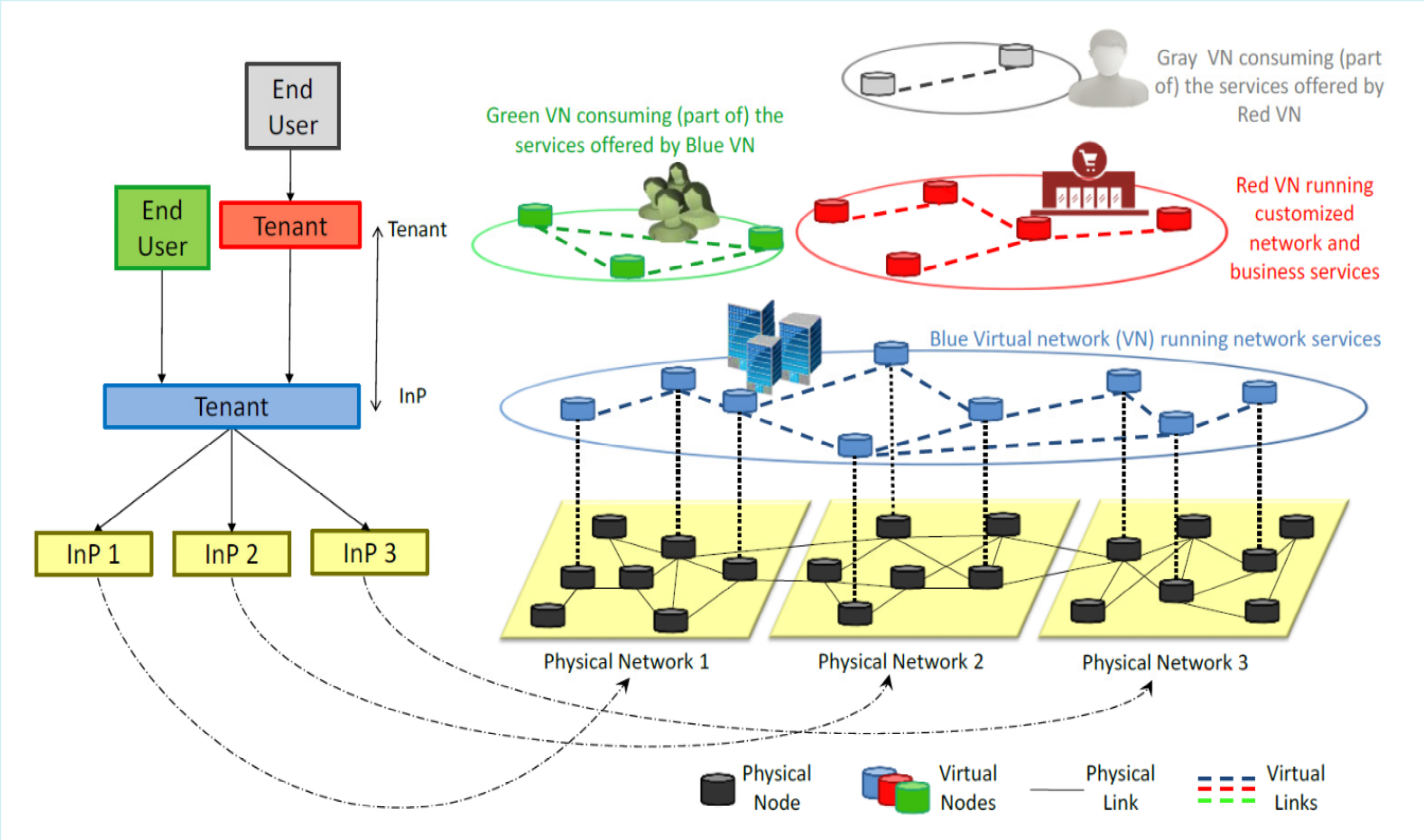
1.9 Business model (actors)- variant of definition

- **Infrastructure Provider (InP)**– owner of the PHY infrastructure (network/cloud/data center) and lease them to operators
  - It can become an SLP if it leases the infrastructure in slicing fashion
- **Slice Provider (SLP) –** typically a telecom SP, **owner or tenant** of the infrastructures from which network slices can be created
- **Slice Tenant (ST) -** the user of specific network/cloud/data centre slice, hosting customized services
  - STs can request creation of new slice through a service model
  - **ST** can **lease virtual resources from one or more SLP** 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 applicbility in mobile and fixed networks and clouds, v1.0, Network Slicing Tutorial – IEEE NetSoft 2018 – Montreal 29th June2018.

2. 5G slicing concepts, characteristics and use cases

1.9 Business model (actors)-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

1. 5G Network slicing – concepts, use cases and requirements

1.10 Categories of 5G fundamental scenarios

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

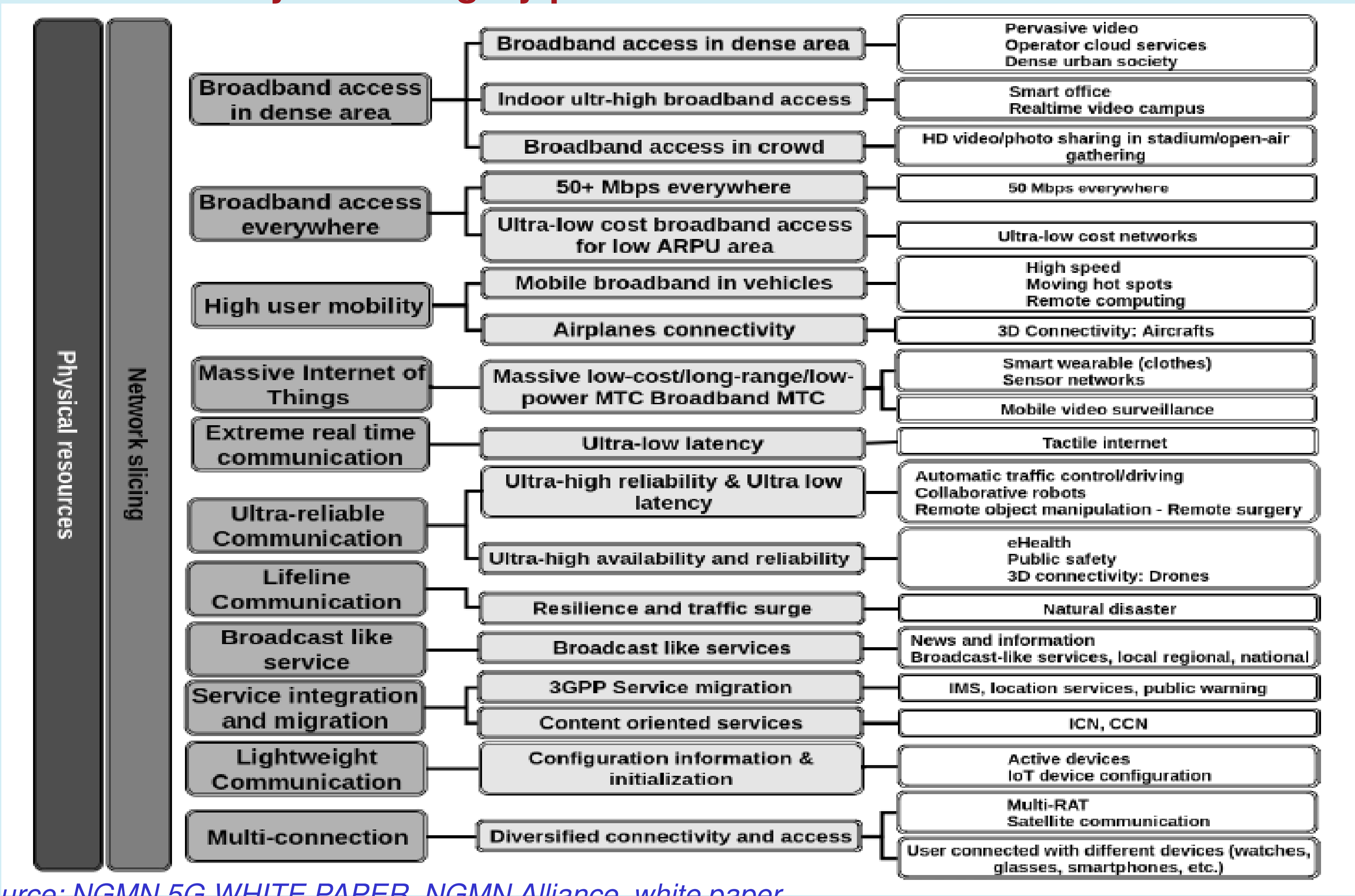
- **different requirements on 5G: functional** (e.g. priority, charging, policies, security, and mobility) and **performance** (e.g. latency, mobility, availability, reliability and data rates) -→ **dedicated slices can be constructed**

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

2. 5G slicing concepts, characteristics and use cases

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



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

1. 5G Network slicing – concepts, use cases and requirements

1.12 Summary of Network Slices - key requirements

- **User/tenant related**
  - **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.Galis and K.Makhijani, Network Slicing Landscape: A holistic architectural approach, orchestration and management with applicbility in mobile and fixed networks and clouds, v1.0, Network Slicing Tutorial – IEEE NetSoft 2018 – Montreal 29th June2018.

1. 5G Network slicing – concepts, use cases and requirements

1.12 Summary of Network Slices key requirements (cont'd)

- **User/tenant related**
  - **dynamic multi-service** support, **multi-domain, multi-tenant** (independent of 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
  - **NSs must be 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 applicbility in mobile and fixed networks and clouds, v1.0, Network Slicing Tutorial – IEEE NetSoft 2018 – Montreal 29th June2018.

1. 5G Network slicing – concepts, use cases and requirements

1.12 Summary of Network Slices key requirements (cont'd)

- **NSL Management and control**
  - **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**
  - NSL 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 applicbility in mobile and fixed networks and clouds, v1.0, Network Slicing Tutorial – IEEE NetSoft 2018 – Montreal 29th June2018.

1. 5G Network slicing – concepts, use cases and requirements

1.12 Summary of Network Slices key requirements (cont'd)

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

  - **programmability** allows to enrich the offered services
  - **OTT providers** and other **market players can use NSLs without changing the PHY infrastructure**
  - to simplify the provisioning of services, manageability, integration and operation
  - to create 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
A.Galis and K.Makhijani, Network Slicing Landscape: A holistic architectural approach, orchestration and management with applicbility in mobile and fixed networks and clouds, v1.0, Network Slicing Tutorial – IEEE NetSoft 2018 – Montreal 29th June2018.

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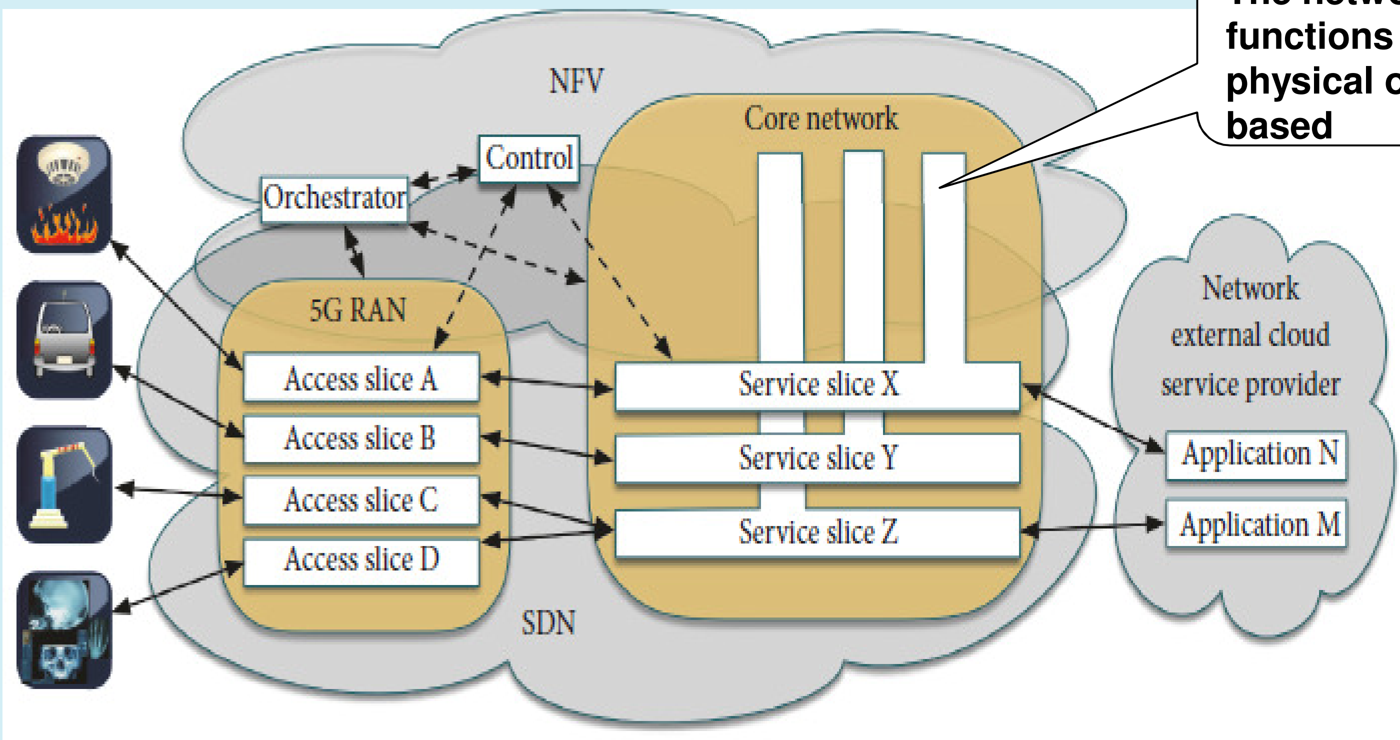
2. 5G slicing relevant architectures

2.1 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



The network functions can be physical or NFV-based

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/10.1155/2018/6923867https://www.hindawi.com/journals/wcmc/2018/6923867/

2. 5G slicing relevant architectures

2.2 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 NSLs** 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 NSLs , while **other functions reside in individual NSLs**
  - **Group C -** the **Control Plane is common between the slices,** while the User plane(s) (UPl/DPl) are handled as different NSLs

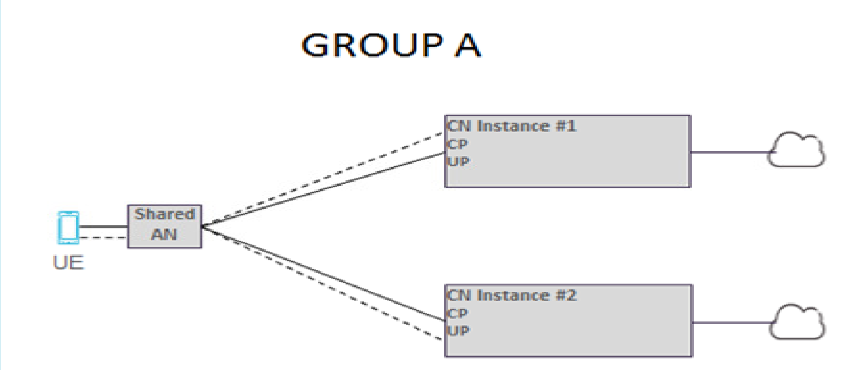
See: 3GPP, TR 23.799 V14.0.0 (2016-12), Study on Architecture for Next Generation System (Release 14)

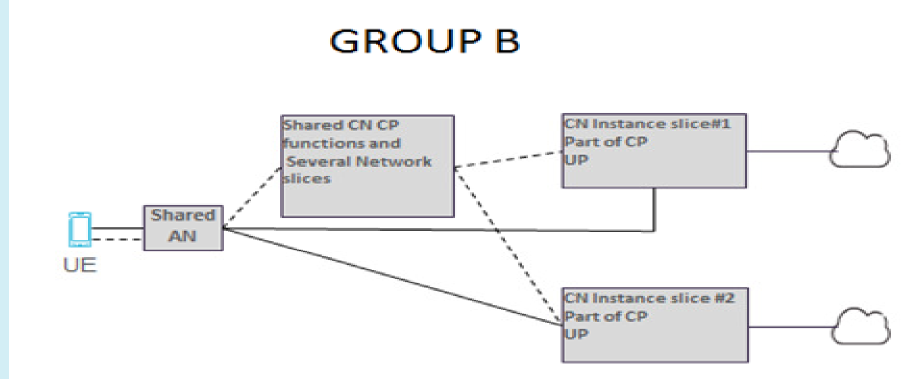
2. 5G slicing relevant architectures

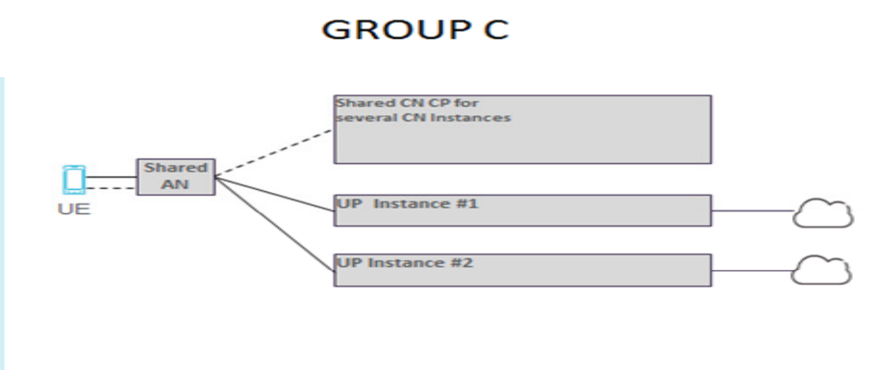
2.2 Slicing variants (cont'd)

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







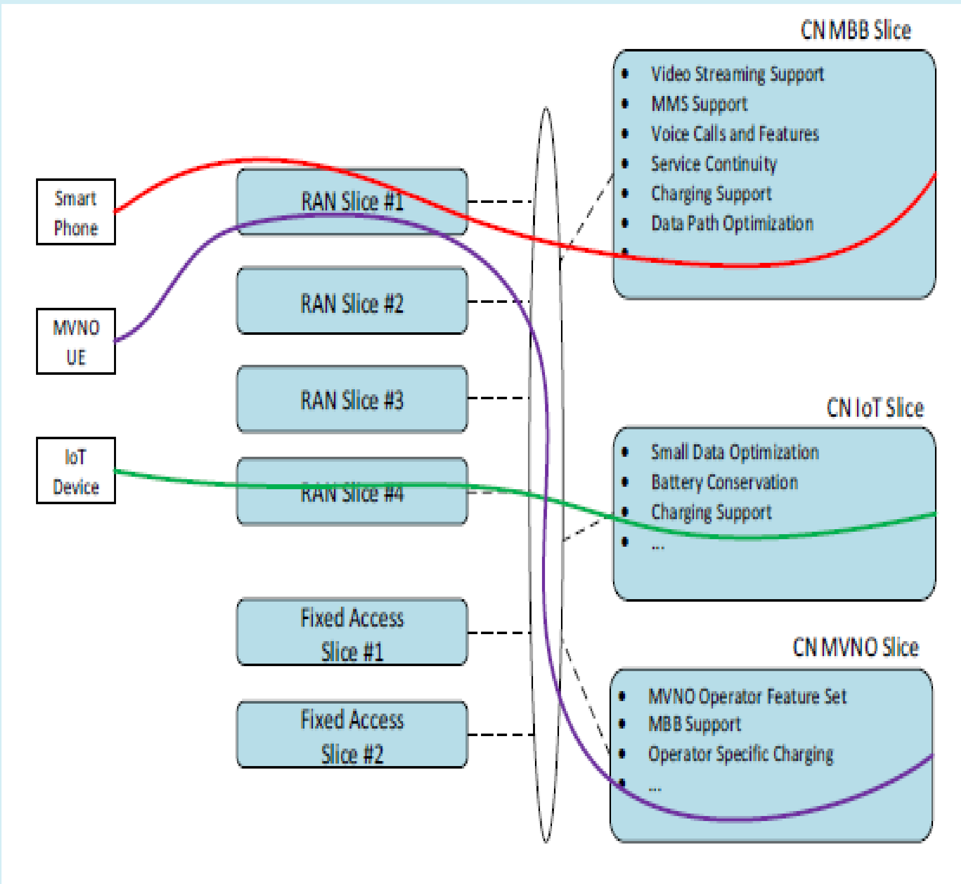
Note: This approach does not detail the slicing at AN premises

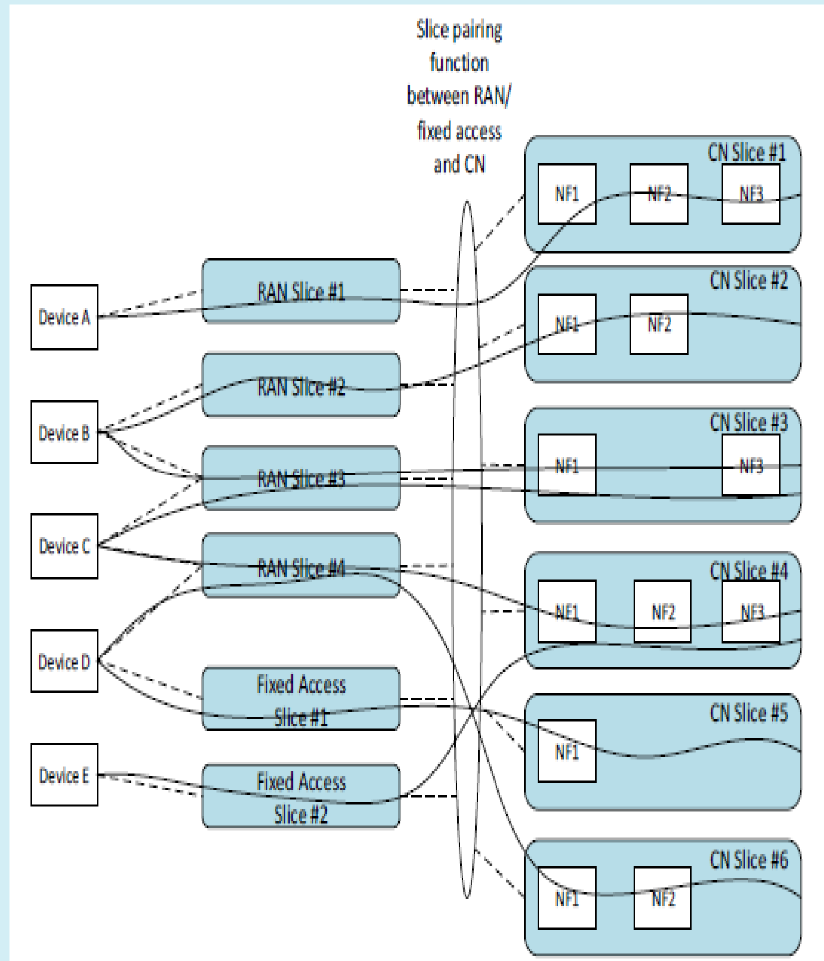
Source: 3GPP, TR 23.799 V14.0.0 (2016-12), Study on Architecture for Next Generation System (Release 14)

2. 5G slicing relevant architectures

2.2 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

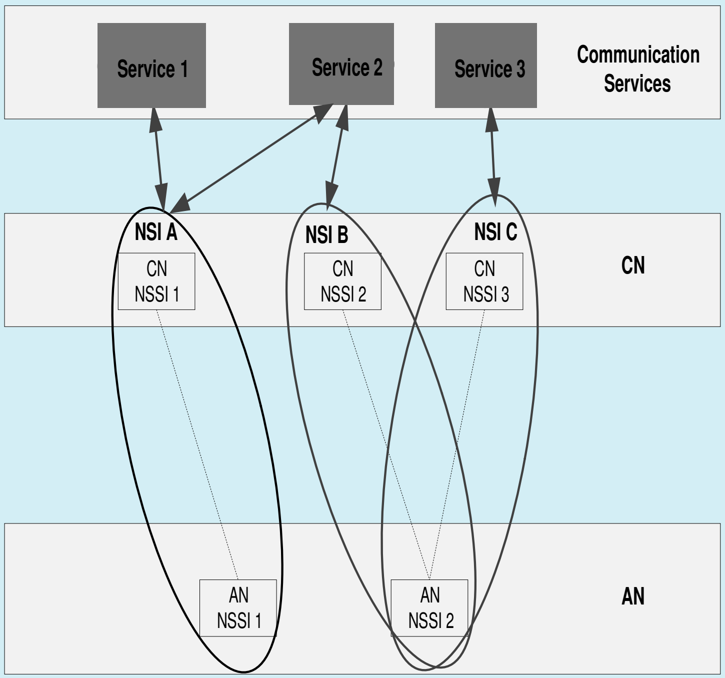
2. 5G slicing relevant architectures

2.2 Slicing variants (cont'd)

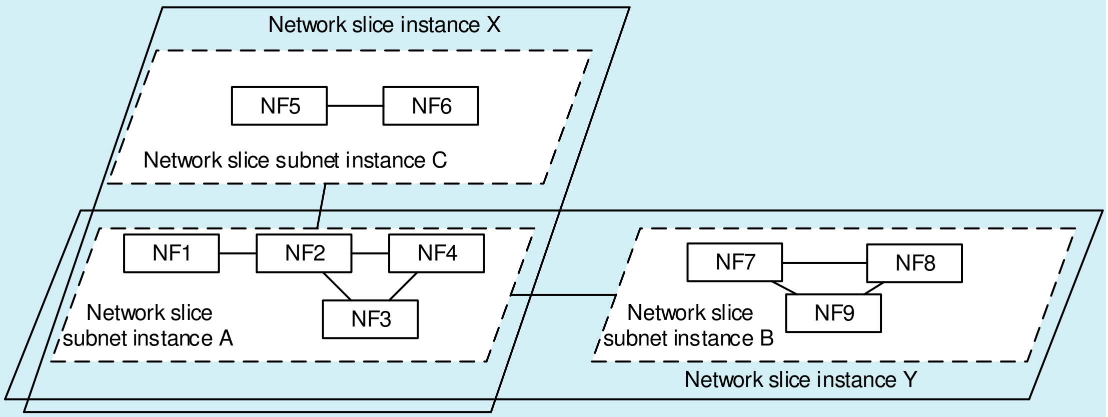
- **Previous slide: Flexible architecture for inter-connection between UEs, the Network Slices and Network Slice subnets**
  - Flexible interconnection between RAN/Fixed_access slices and CN slices
    - via - slice pairing function
      - between RAN and CN
      - between radio PHY and RAN
    - PHY 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 (NSLI)

2.2 Slicing variants - examples

End to End services provided by NSLI(s)



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



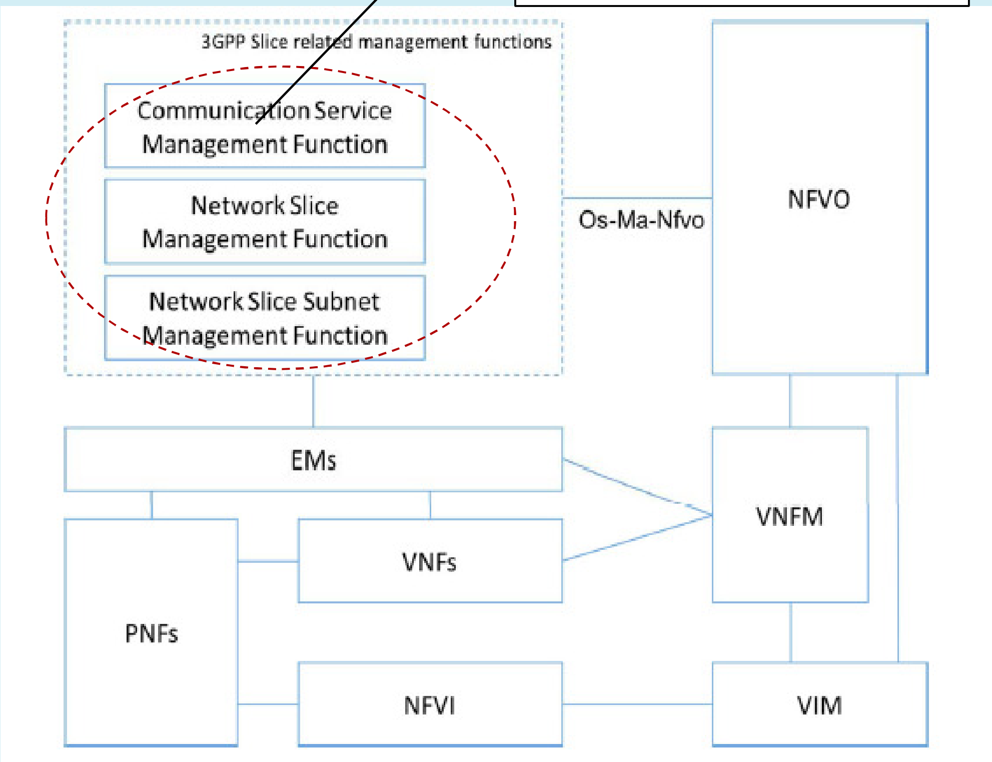
Source: 3GPP TR28.801 V15.1.0 (2018-01), Study on management and orchestration of network slicing for next generation network, (Release 15)

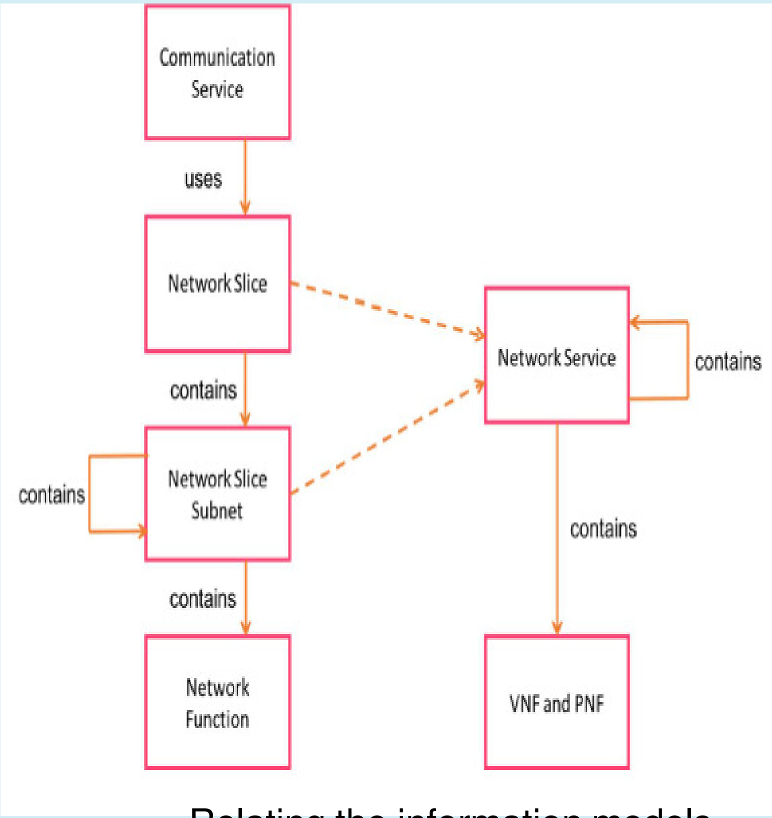
2. 5G slicing relevant architectures

2.3 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

2. 5G slicing relevant architectures

2.3 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 NSL requirements
    - I/F with **(NSMF)**
  - **Network Slice Management Function (NSMF) -** mgmt. (including lifecycle) of NSLIs. It derives NS subnet requirements from the NSL related requirements
    - I/F with NSSMF and the CSMF.
  - **Network Slice Subnet Management Function (NSSMF) –** mgmt (including lifecycle) of NSSIs.
    - I/F with the NSMF.
- The **Os-Ma-NFVO Reference Point** (RP) is the I/F with NFV-MANO.

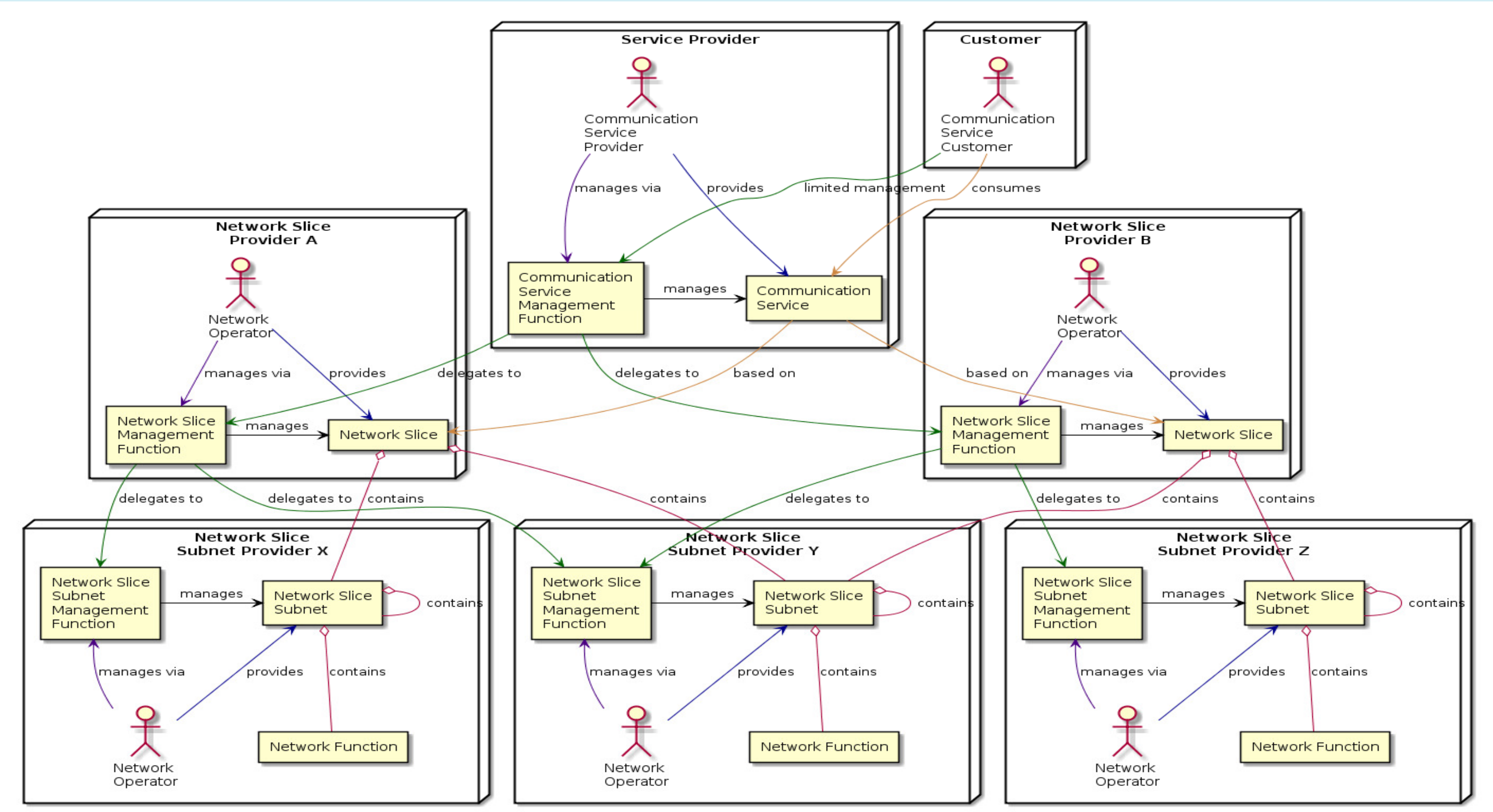
- The NSMF and/or NSSMF have to determine
  - the **type of NSL or set of NSLs, VNF and PNF** that can support the resource requirements for a NSLI or NSSI
  - and analyze if existing instances can be re-used, else need to create new instances of these NSLs, VNFs and the connectivity to the PNFs

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

2. 5G slicing relevant architectures-examples

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**



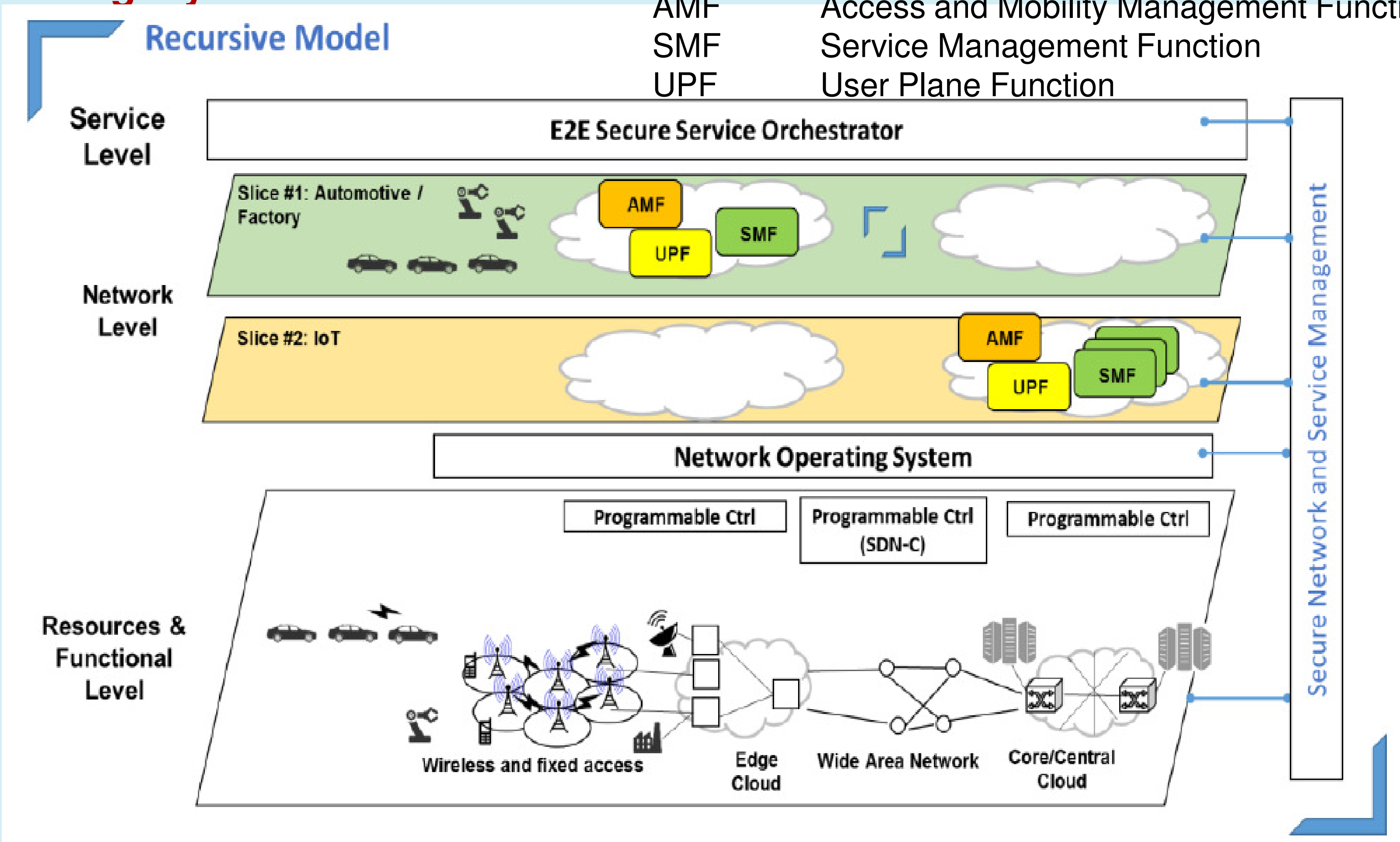
Source: 3GPP TR28.801 V15.1.0 (2018-01), Study on management and orchestration of network slicing for next generation network, (Release 15)

2. 5G slicing relevant architectures

2.3 ETSI and 3GPP functional architectures for slicing support

5G slicing layered architecture - 5GPPP vision

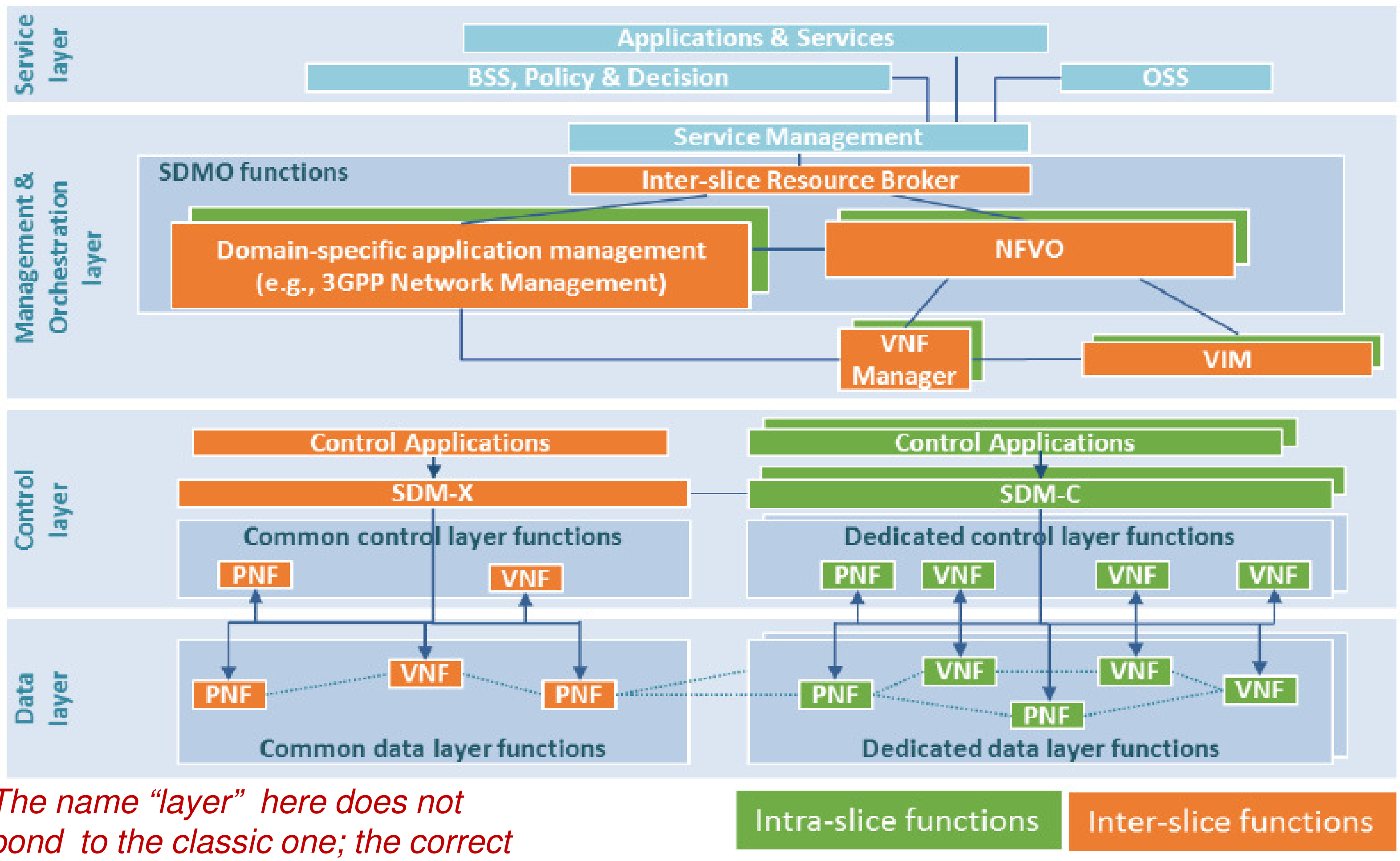
AMF Access and Mobility Management Function
SMF Service Management Function
UPF User Plane Function



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

2. 5G slicing relevant architectures

2.3 5G Layered Architecture - 5GPPP vision (cont'd)



Note: *The name "layer" here does not correspond to the classic one; the correct semantic would be rather - "plane"*

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

2. 5G slicing relevant architectures-examples

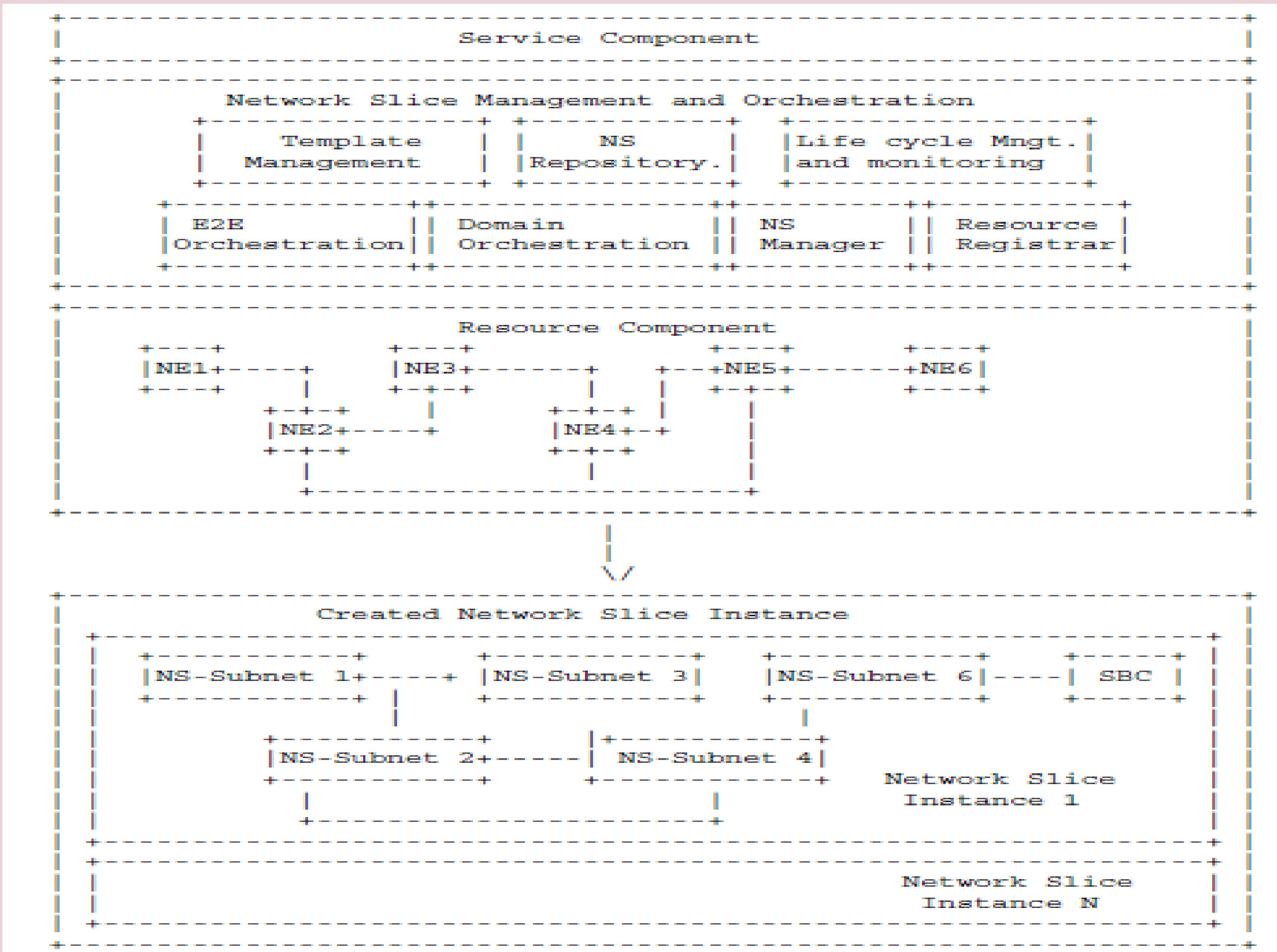
2.3 5G Layered Architecture - 5GPPP vision (cont'd)

- **Previous slide:**
- **Architecture based on ETSI-NFV and SDN**
- **Service layer** includes
  - **Apps. and services** operated by the tenant (includes the E2E orchestration system)
  - **Business Support Systems** (BSSs); **Business-level Policy** and Decision functions
- **Management and Orchestration layer**
  - **Service Management** (i.e. services offered by the slices)
  - **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

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

3. 5G slicing general architectures

3.3 IETF Slicing architecture



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

CONTENTS

1. 5G Network slicing – concepts, use cases and requirements
2. 5G slicing relevant architectures
3. ➡ Management, orchestration and control
4. Advanced cognitive management
5. Conclusions and research challenges

3. Management, orchestration and control

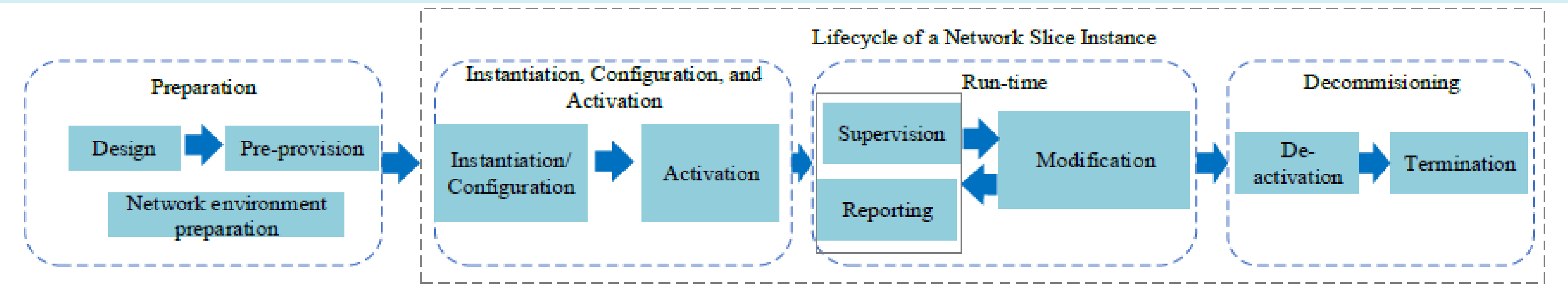
3.1 General Requirements/Objectives for 5G Slicing Network Management

- On demand slices
- Multi-tenant, multi-domain, multi-operator, E2E slices
- The Network Slice as a Service
- Management of Network (Virtual) Functions (LCM)
- Scalable solutions (horizontal and vertical)
- Quality of Service control and assurance
- Flexibility (resource allocation optimization, slice scaling, ..)
- Sustainability (including energy management)
- Context Awareness
- Security (including slice isolation)
- Flexible business model
- Open system (new components added)

3. Management, orchestration and control

3.2 Network slice instance life- cycle

- Functions provided by the NSM system in several phases for a NSLI life cycle
  - **Preparation phase**
  - **Instantiation, Configuration and Activation phase**
  - **Run-time phase**
  - **Decommissioning phase**



- Details:
  - **Preparation phase** (the NSLI does not exist yet)
    - creation and verification the feasibility of NSL template(s)
    - preparation of the necessary network environment to support the NSLIs lifecycle (e.g., provisioning databases)

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

3. Management, orchestration and control

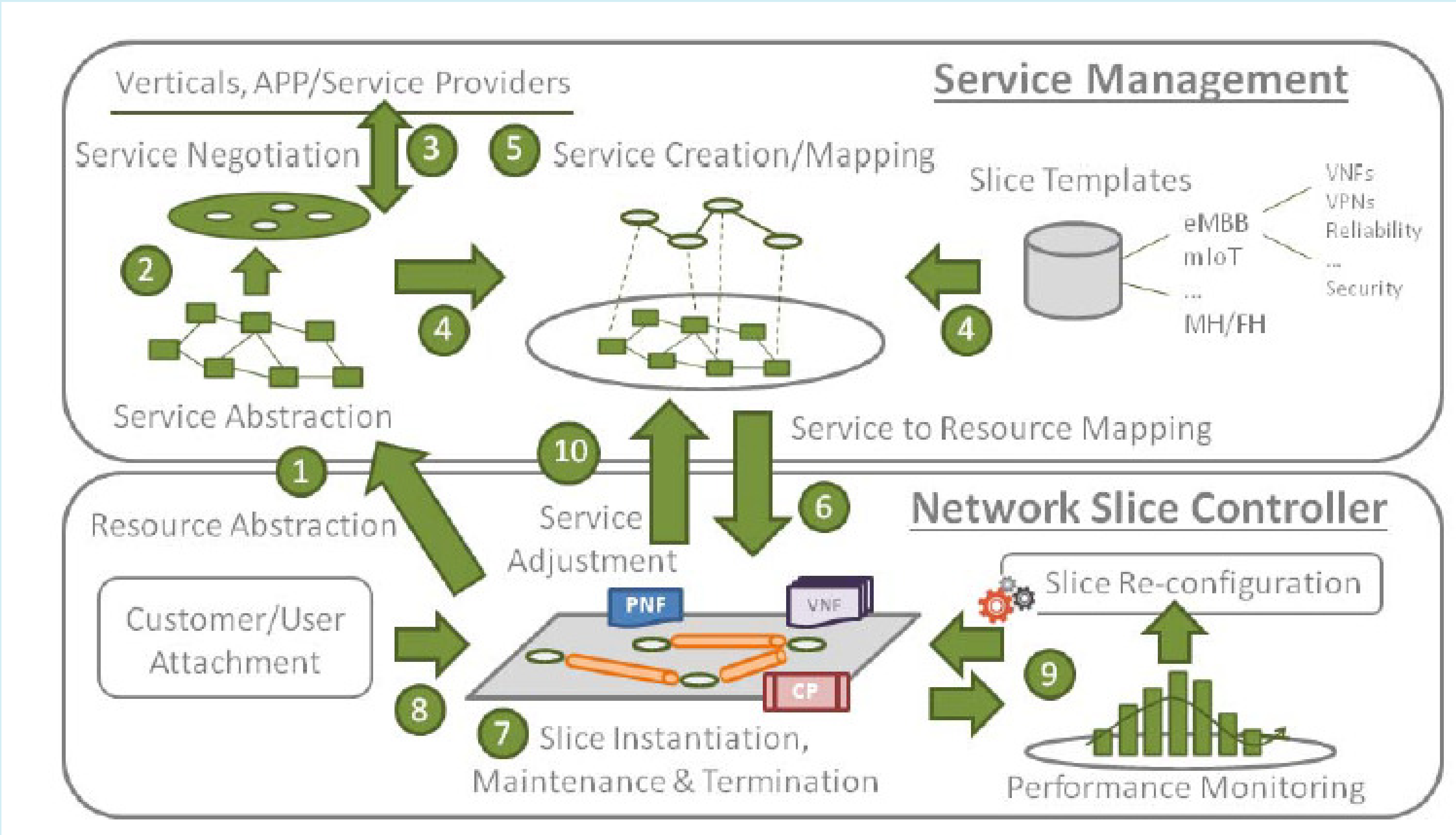
3.2 Network slice instance life- cycle (cont'd)

Functions provided by the NSM system in several phases for a NSLI life cycle

- **Instantiation / configuration**
  - It can include **instantiation, configuration and activation** of various shared and/or non-shared NFs
  - All resources shared/dedicated to the NSLI are created and configured, i.e. to a state where the NSLI is ready for operation
  - **Activation** : makes the NSLI active, e.g. diverting traffic to it
- **Run-time phase**
  - NSLI **handles traffic** to support services of certain type(s)
  - **Supervision/reporting** (e.g. for KPI monitoring)
  - **Modification** could be: upgrade, reconfiguration, NSI scaling, Possible **changes** of NSLI capacity, changes of NSLI topology, association and disassociation of NFs with NSLI
- **Decommissioning phase**
  - **Deactivation** (taking the NSLI out of active duty)
  - Release the dedicated resources (e.g. **termination** or re-use of NFs) and configuration of shared/dependent resources
  - Finally, the NSLI does not exist anymore

3. Management, orchestration and control

3.3 Generic service management and network slice control



Ibrahim Afolabi, Tarik Taleb , Konstantinos Samdanis, Adlen Ksentini, and Hannu Flinck,
Network Slicing and Softwarization: A Survey on Principles, Enabling Technologies, and Solutions
IEEE COMMUNICATIONS SURVEYS & TUTORIALS, VOL. 20, NO. 3, THIRD QUARTER 2018 2429

3. Management, orchestration and control

3.3 Generic service management and network slice control

- ***Plane roles***
- ***Service management plane***- performs service operations
  - **abstraction, negotiation, admission control and charging** for verticals and 3rd parties
  - **service creation** if admission control accepts the slice request
    - AC input parameters: {slice reqs., slice templates available}
  - The desired service combines
    - VNFs, PNFs, value added services,
    - data/control plane, and security mechanisms,
    - and exposes them to the underlying network
- ***Network slice management and control plane***
  - provides resource abstraction to service management
  - handles **NSL resource management** & **control plane** operations, including
    - instantiation of the slice resources based on the service mapping
    - performance maintenance via monitoring, analysis and slice re-configuration procedures
    - slice selection, attachment and support for multi-slice connectivity

3. Management, orchestration and control

3.3 Generic service management and network slice control (cont'd)

- ***Actions*** (related to previous slide)
  - (1) Network Slice M&C provides resource abstraction to service management
  - (2-3) abstraction, negotiation, admission control and charging for verticals and 3rd parties
  - (4-5) service creation after a slice request is accepted by AC
  - (6) Srv. Mgmt provides all information to network slice M&C plane
  - (7) Net M&C **instantiates the slice resources** based on service mapping
  - (8) Net M&C performs slice selection, attachment and support for multi-slice connectivity
  - (9) Net M&C - performance maintenance via monitoring, analysis and slice re-configuration procedures

3. Management, orchestration and control

3.4 Orchestration concepts

- ***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: unified vision and scope of orchestration- still in discussions**
  - **Open Network Foundation (ONF) definition/vision on orchestration**
    - **continuing** process of **selecting resources** to fulfil client service demands in an optimal manner
    - **optimization policies** can be applied
      - to meet all the specific policies and SLAs associated with clients (e.g. tenants or end users)
    - **"continuing"** means that the available resources, service demands and optimization criteria **may change in time**

3. Management, orchestration and control

3.4 Orchestration concepts (cont'd)

- *ONF vision on Orchestration* (cont'd)
    - orchestration is also a defining characteristic of an SDN controller
    - orchestrator functions include
        - client-specific service demand validation; resource configuration; event notification

- **Open issues:** in multi-domain 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**
- **Variant of proposals**
    - **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

3. Management, orchestration and control

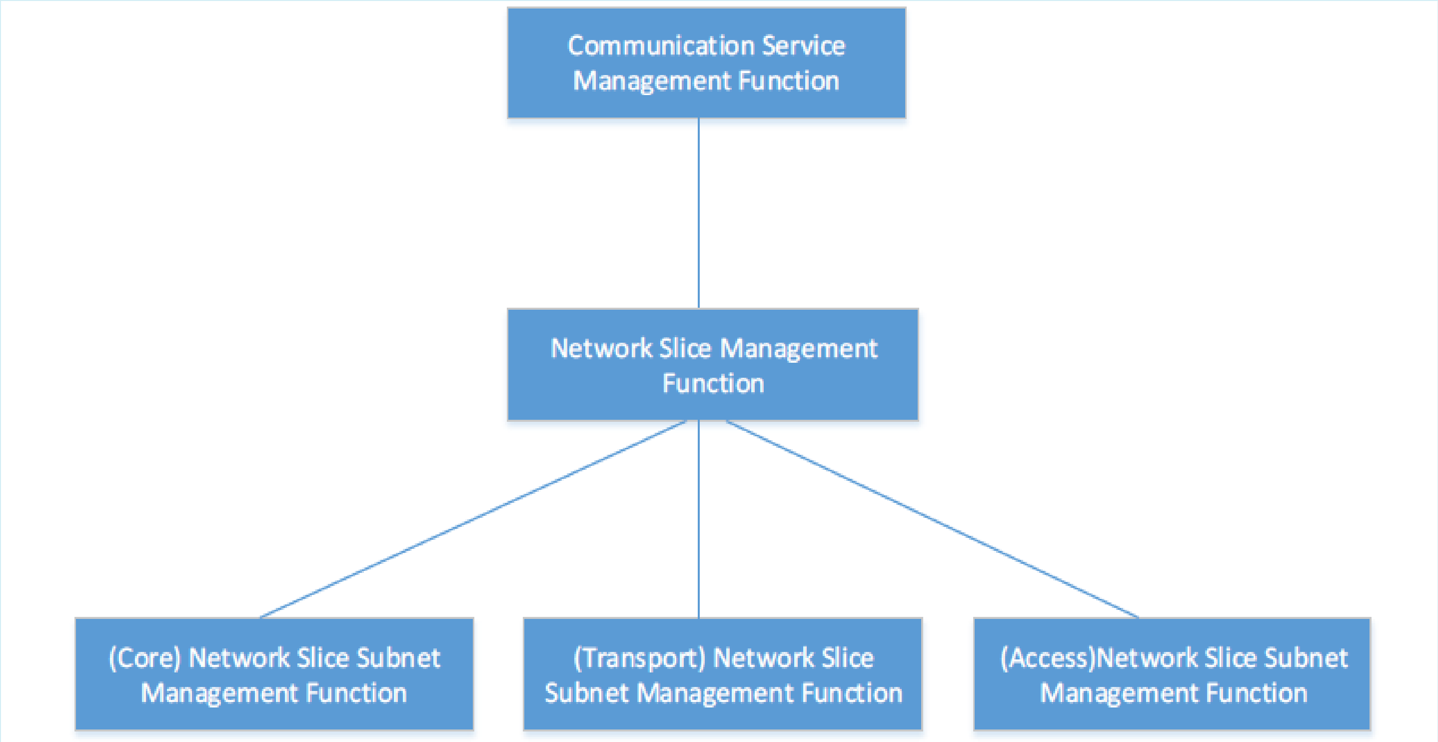
3.5 Network Slicing Management (NSM) Architectures

- **Network slicing design and management principles – in E2E context**

- **Separation of the NSL template (NST) design and the NSLI 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 NSLI is instantiated based on the NST- in the operation phase
- **Multi-domain management:** a given NSLI
  - can contain **multiple technical domains**
  - 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 NSL template design, O&M and NSLI 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

3.5 Network Slicing Management (NSM) Architectures (cont'd)

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

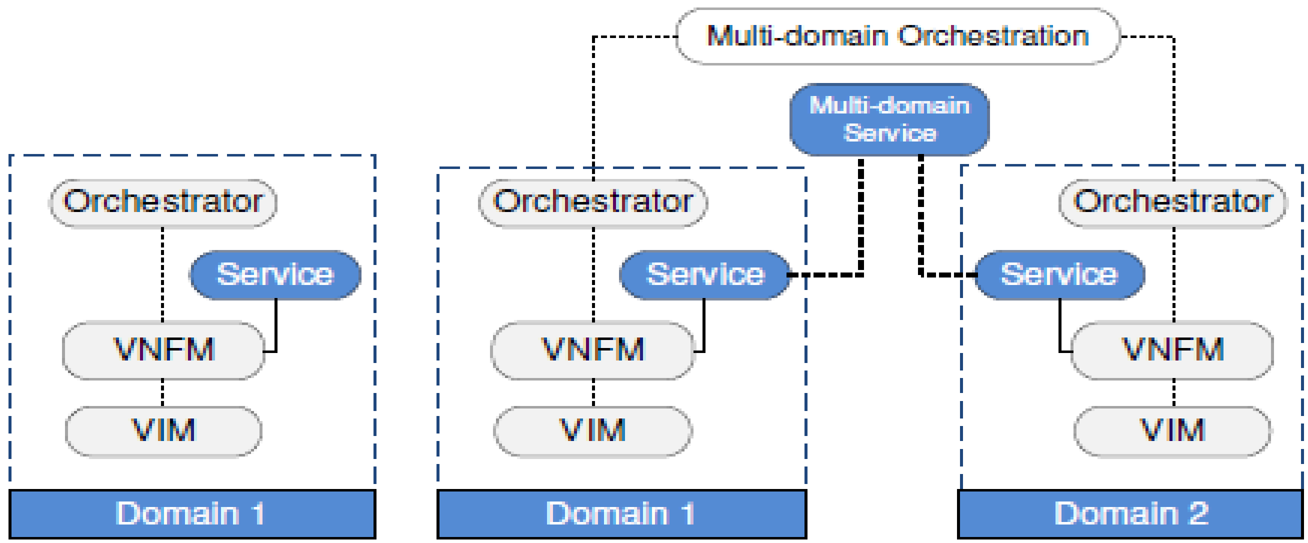


Source: End to End Network Slicing – White paper 3 Outlook 21, Wireless World , Nov 2017

3. Management, orchestration and control

3.5 Network Slicing Management (NSM) Architectures (cont'd)

- Single domain and multi-domain orchestration for NFV



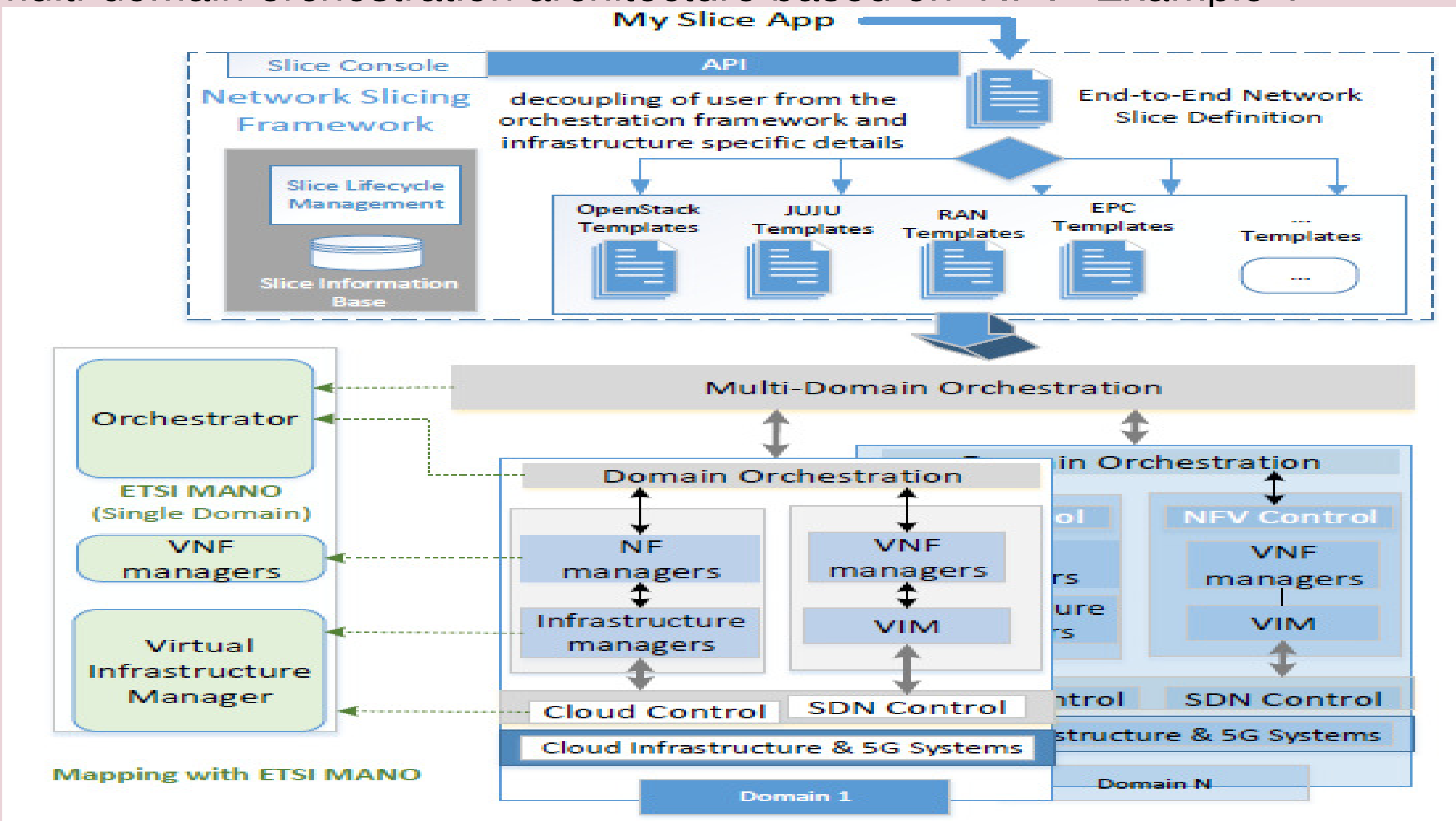
(a) Single Domain (b) Multi-Domain

VNFM- Virtual Network F8unction 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

3.5 Network Slicing Management (NSM) Architectures (cont'd)

A multi-domain orchestration architecture based on NFV- Example 1



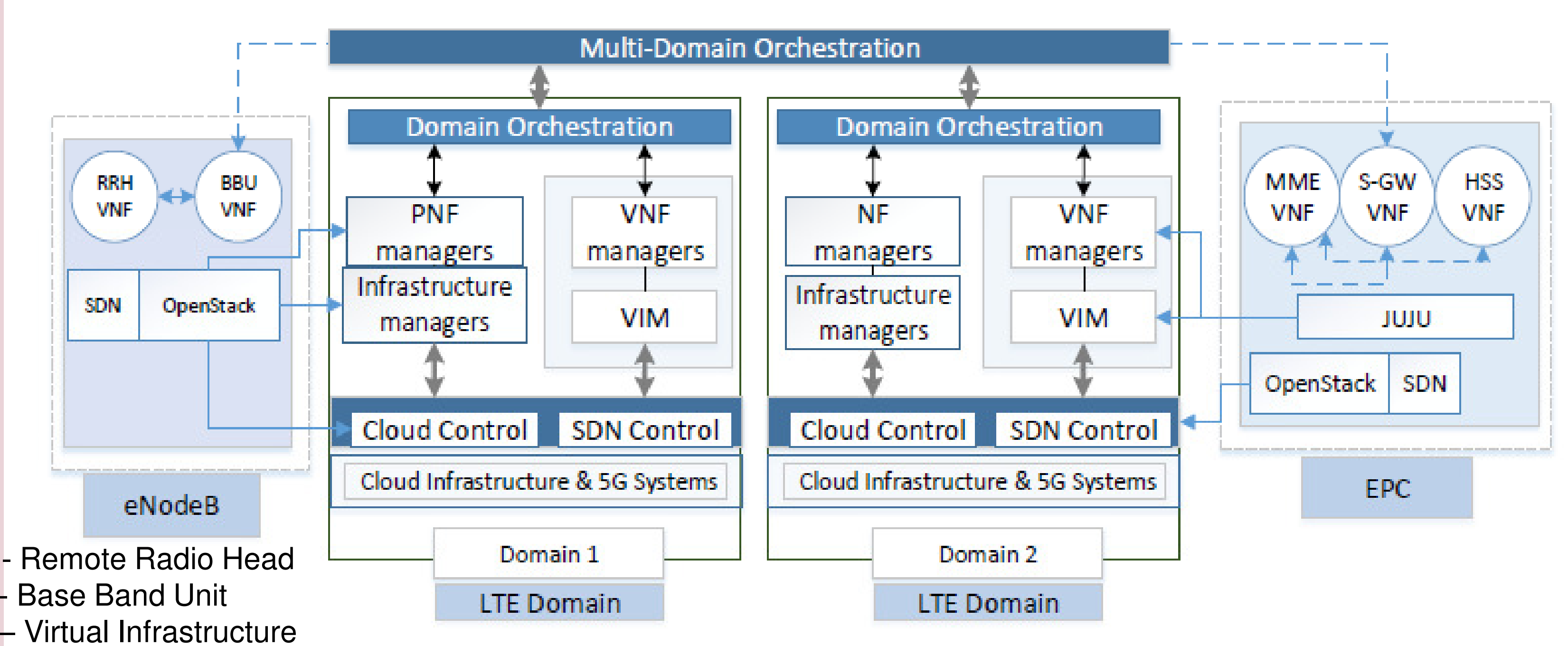
Source: K.Katsalis, N.Nikaein, Andy Edmonds, Multi-Domain Orchestration for NFV: Challenges and Research Directions, 2016 15th International Conference on Ubiquitous Computing and Communications and 2016 International Symposium on Cyberspace and Security (IUCC-CSS), https://ieeexplore.ieee.org/document/7828601

3. Management, orchestration and control

3.5 Network Slicing Management (NSM) Architectures (cont'd)

- Multi-domain NFV for 4G/LTE networks- Example 2
- 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 Sysrtem



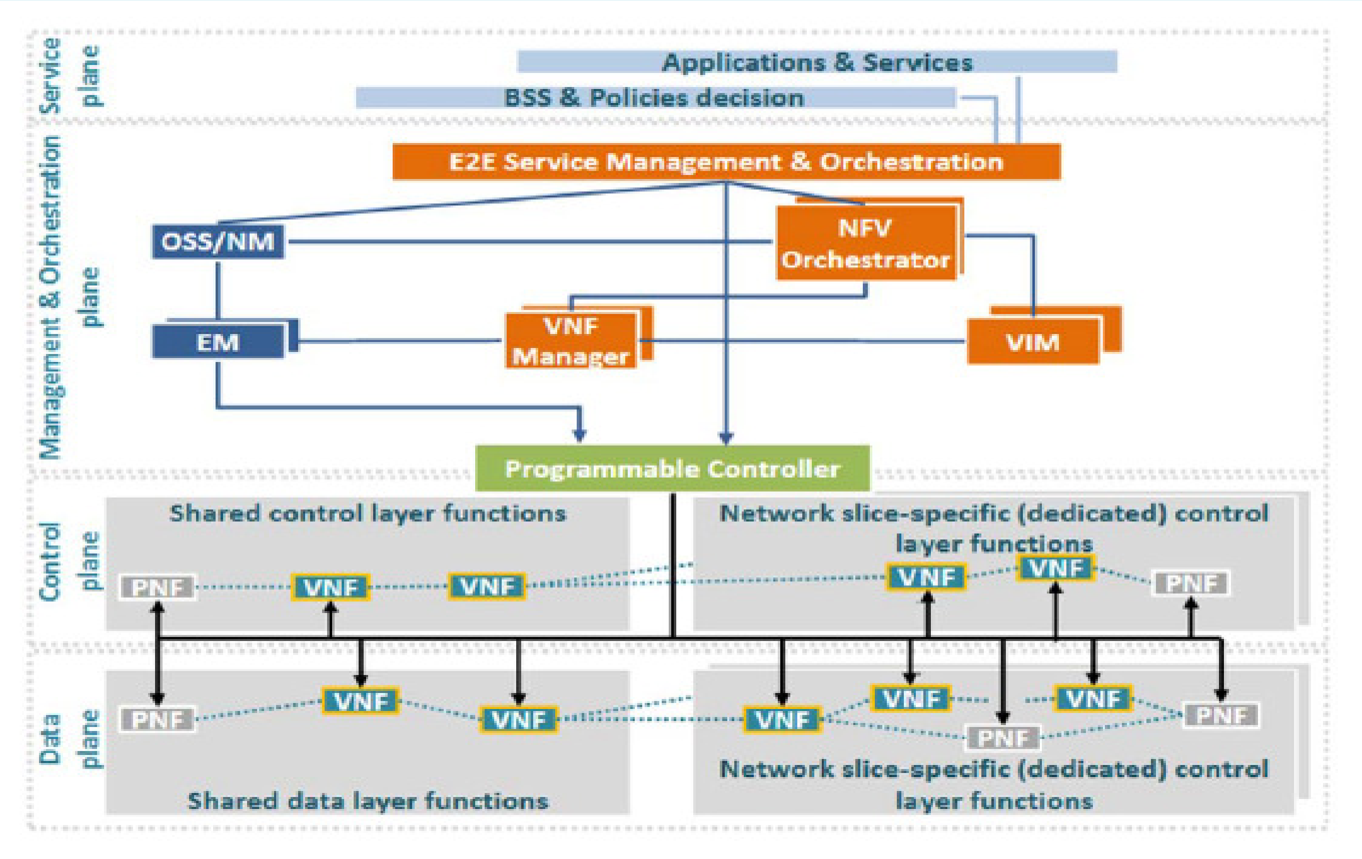
RRH- Remote Radio Head
BBU- Base Band Unit
VIM – Virtual Infrastructure Manager

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

3. Management, orchestration and control

3.5 Network Slicing Management (NSM) Architectures (cont'd) – Example 3

- 5GPPP network orchestration architecture



5GPPP, "View on 5G architecture," 5G PPP Architecture Working Group, EuCNC, Athens, Greece, Jul. 2016.

3. Management, orchestration and control

3.6 Multi-tenant – multi-domain management and control

- **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
  - **Elastic adaptation,** within minimum and maximum limits, of the slice capacity
  - Support for **slice prioritization**
  - Multi-slice/multi-service support for a given user equipment (UE)

3. Management, orchestration and control

3.6 Multi-tenant – multi-domain management and control
Multi-domain requirements

- **E2E NSL overall objective**: 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**
  - **NSL : complete network**, including RAN functions and CN functions
  - Capabilities are needed to:
    - define and update the set of services for a NSL
    - NSL-create/modify/ delete (maybe with different priorities)
    - identify UE and its service requirements and associate it to a NSL or remove it from a NSL

  - **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 NSL**

3. Management, orchestration and control

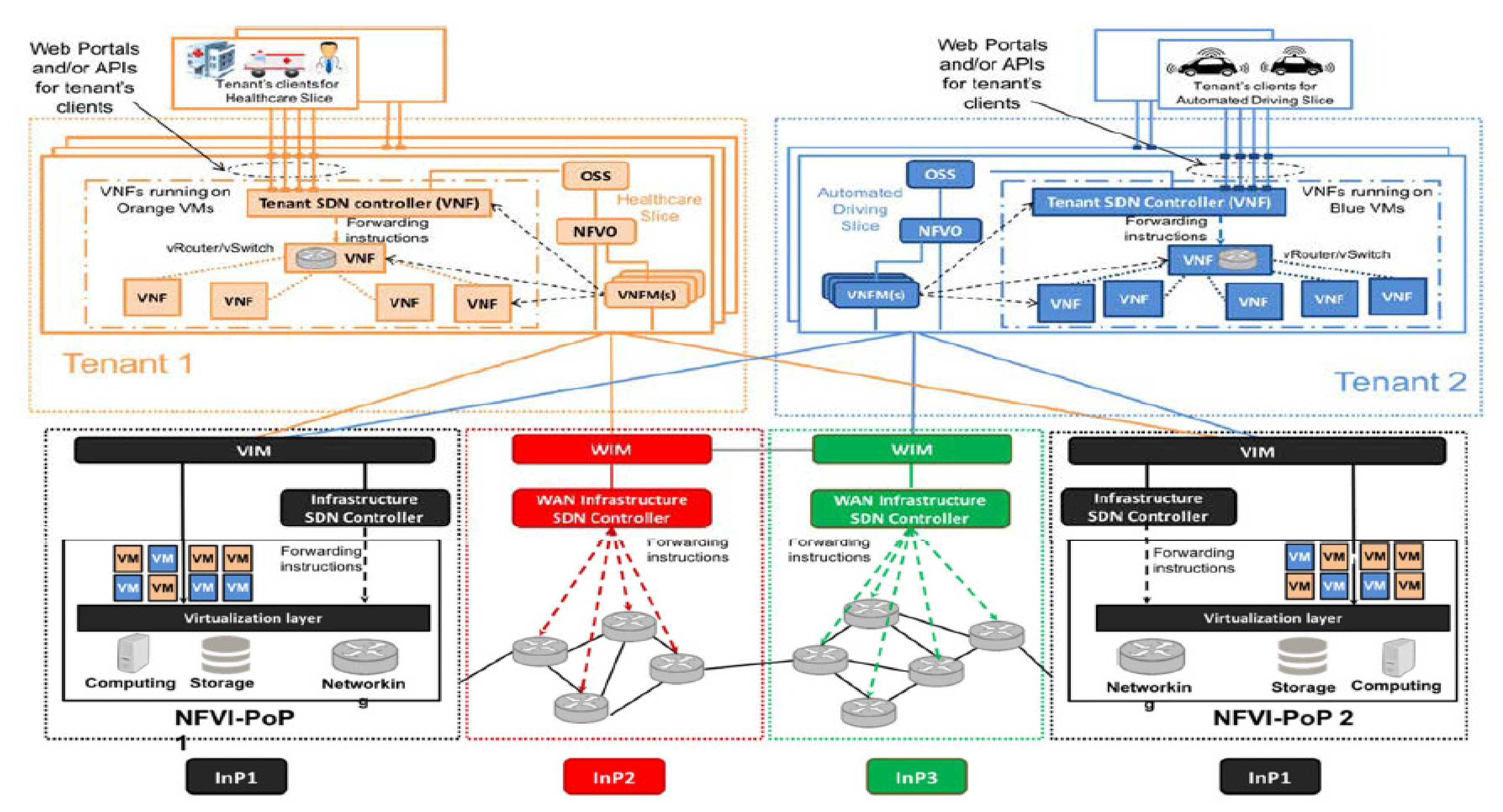
3.6 Multi-tenant – multi-domain management and control

Multi-domain requirements (cont'd)

- **Multi-tenancy** model should work in E2E and multi-domain context
- NSL 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

3. Management, orchestration and control

3.7 Multi-tenant – multi-domain architectures – **Example 1**



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. Management, orchestration and control

3.7 Multi-tenant – multi-domain architectures – Example 1 (cont'd)

- NSs are **mutually isolated: performance, resiliency, security, privacy and management**
  - (they run concurrently on top of a shared NFVI without (directly or indirectly) affecting each other
  - the infrastructure (and NFVI) is owned and managed by different (and potentially non-trusted) administrative domains (InP1, InP2, ..)
  - Details on how isolation properties can be achieved
    - e.g. : ETSI GS NFV-EVE 005, R NFV-IFA 022 and GR NFV-IFA 028
- Two types of **SDN controllers** : for **tenant** and for **infrastructure**
  - each one - logically placed in a particular admin domain
- 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

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. Management, orchestration and control

3.7 Multi-tenant – multi-domain architectures – **Example 1** (cont'd)

- The **infrastructure SDN controller (IC)**
  - M&C for the NFVI resources (placed in a NFVI-PoP or a WAN)
  - set up the connectivity to support the communication between the tenant VNFs in the infrastructure domain
  - performs M&C of the connectivity among the **virtualization containers** that host the tenant VNFs' software applications
  - the networking resources, supporting VM (and hence VNF) connectivity at the infrastructure level, are programmatically managed by the ICs following the managers VIM and the WIM commands
  - **VIMs and WIMs act as SDN applications**, delegating to ICs the M&C tasks related to networking resources
  - Implementation variant: to integrate ICs into their corresponding VIMs

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. Management, orchestration and control

3.7 Multi-tenant – multi-domain architectures – **Example 1** (cont'd)

- Each **NFVI-PoP** has a single VIM instance to configure and manage the virtualization containers and their underlying HW
  - Their connectivity is locally enforced by the infrastructure SDN controller (IC)
  - 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 scenario presented above is well-aligned with the **NFVI as a Service (NFVIaaS)** (ETSI GR NFV-IFA 028)
- Each tenant uses of the NFVI to get the performance needs of the slices in its domain
  - each **InP** plays the **NFVIaaS provider** role
  - each **tenant** acts as an **NFVIaaS consumer**

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. Management, orchestration and control

3.7 Multi-tenant – multi-domain architectures – Example 1 (cont'd)

- A **tenant,** with its own set of NSLs is **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
  - fault resilience features to support the tenant VNFs deployment
- **WIMs 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

3.7 Multi-tenant – multi-domain architectures – Example 1 (cont'd)

- **Each NSL** serving a tenant comprises
  - one NFVO
  - one (or several) VNFM(s)
  - a tenant SDN controller
  - one Operations Support System (OSS)

  - Each NSL has its own FBs as above → the tenant can preserve the required management isolation among slices
- **NFVO**
  - **manages the operative slices in its admin. domain**
  - perform **resource scheduling functions** in the tenant domain

  - capable to orchestrate resources **(provided by different InPs)** across different **multiple** administrative domains in the infrastructure

  - dynamically manages the lifecycle of the NSL constituent network service(s), including any associated VNF graph

- The VNFM(s) perform(s) LCM operations over the slice VNFs

- Variant: a single NFVO to control more than one slice

3. Management, orchestration and control

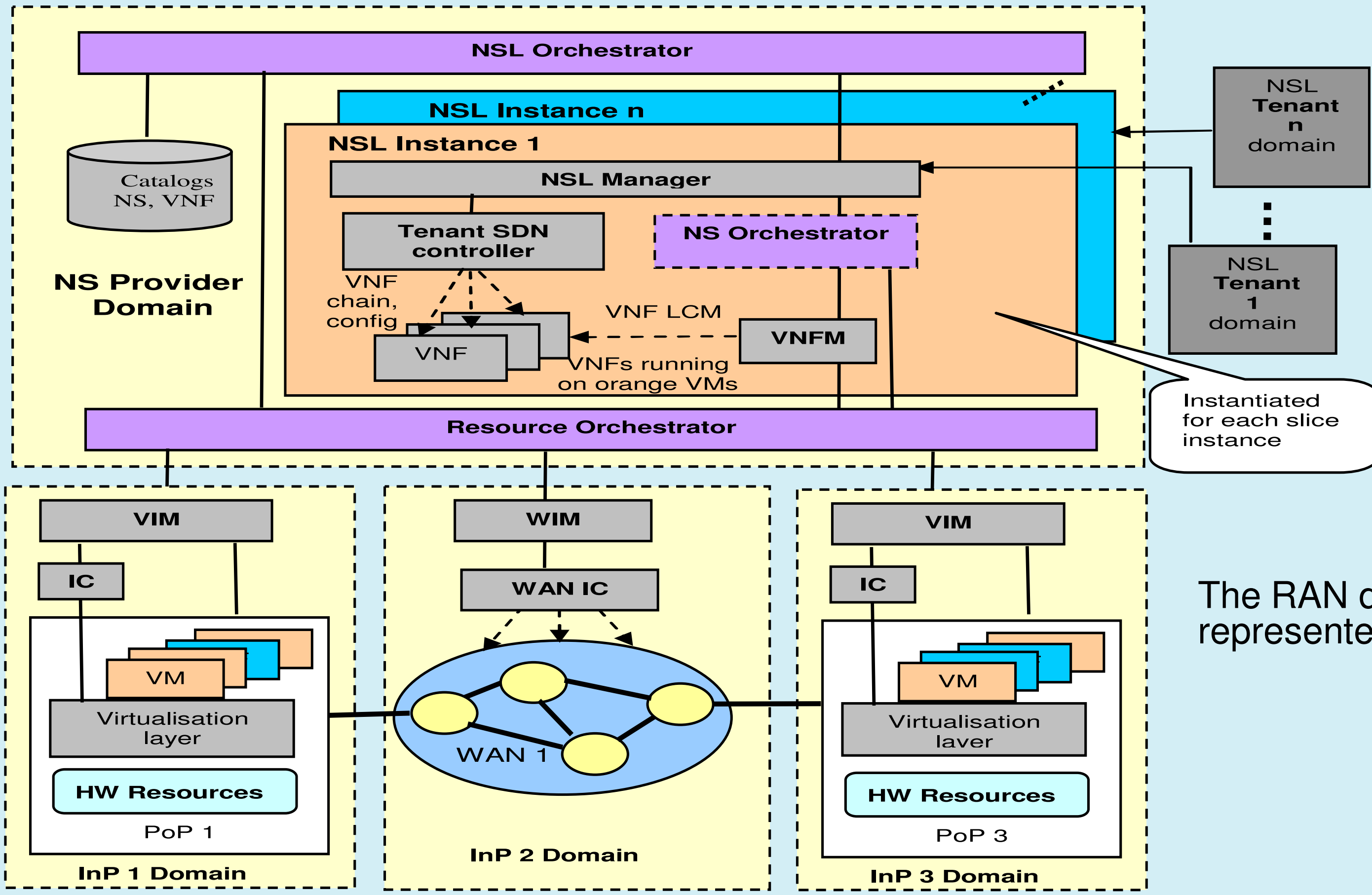
3.7 Multi-tenant – multi-domain architectures – Example 1 (cont'd)

- **Each NSL 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 app. 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.

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. Management, orchestration and control

3.7 Multi-tenant – multi-domain architectures – Example 2 - Variant of Example 1



The RAN domain is not represented in the figure

Adapted from source: J.Ordonez-Lucena, et.al., "The Creation Phase in Network Slicing: From a Service Order to an Operative Network Slice", European Conference on Networks and Communications (EuCNC), 2018, https://arxiv.org/abs/1804.09642

3. Management, orchestration and control

3.7 Multi-tenant – multi-domain architectures – **Example 2** (cont'd)

- **The NSL provider**
  - can simultaneously operate multiple NSLIs
  - rents the infrastructure resources owned by the InPs

- A NSL instance (NSLI) may be composed of one or more Network Service (NS) instances
  - The NSLI can consist
    - of an instance of a simple NS.
    - of an instance of a composite NS.
    - of a concatenation of simple and/or composite NS instances
- **A NSL instance**
  - can span several *Infrastructure Provider*s (InP) and/or admin. domains
  - has its own MPI plane and this provides isolation across NSIs
    - NSL Manager
    - Network Service Orchestrator (NSO)
    - Tenant SDN Controller
    - VNF Manager (VNFM)

  - The VNFM(s) and the NSO perform the required life cycle operations (e.g. instantiation, scaling, termination, etc.) over the instances of the VNFs and NS(s), respectively.

3. Management, orchestration and control

3.7 Multi-tenant – multi-domain architectures – Example 2 (cont'd)

- **NSL Orchestrator (NSLO)**
  - highest layer of the architecture
  - **key role in the creation** phase and also in the **run-time** phase

  - **NSLO- role at creation phase**
  - NSLO receives the order to deploy a NSLI for a tenant (or the Slice Provider decides to construct a slice)
    - NSLO needs to have information (including on multi-domain) as to be able to check the feasibility of the order
    - if feasible, then triggers the instantiation of the NSL
    - To accomplish this, NSLO interacts with RO, and accesses the VNF and NS Catalogues
    - The catalogues contain VNF and NS descriptors, exposing the capabilities of all the VNFs and NSs that an NSL provider can select for the NSLs.

  - **NSLO role at run-time**
  - NSLO performs policy-based inter-slice operations
    - e.g.: it analyzes the perf and fault management data received from the operative NSLIs instances to manage their SLAs)
    - If SLA violations, the NSLO decides modify/correct some NSLIs

3. Management, orchestration and control

3.7 Multi-tenant – multi-domain architectures – **Example 2** (cont'd)

- **The NSLO and Resource Orchestrators are multi-domain capable**
- **Resource Orchestration (RO)**
  - uses the resources (supplied by the VIMs/WIMs), and dispatches them to the NSL instances in **an optimal way**
  - knows the resource availability in each domain (**this supposes a set of inter-domain interactions**)
- **NFVI level**
  - NFV and SDN solutions are applied
  - M&C
    - VIM
    - WIM
    - SDN Infrastructure controllers

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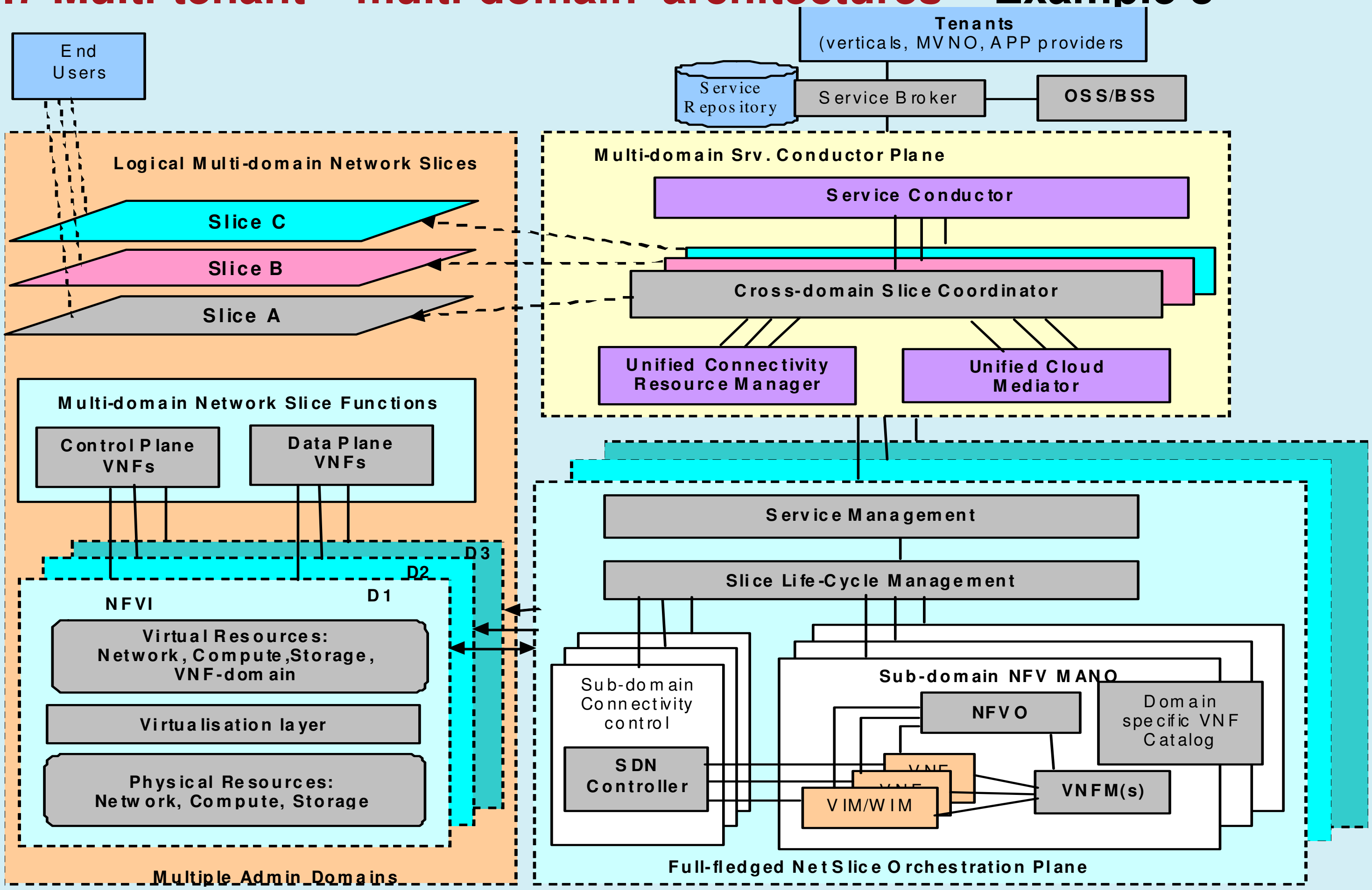
3. Management, orchestration and control

3.7 Multi-tenant – multi-domain architectures – Example 3



Adapted from source: T.Taleb, I.Afolabi, K.Samdanis, and F. Z.Yousaf, "On Multi-domain Network Slicing Orchestration Architecture & Federated Resource Control", http://mosaic-lab.org/uploads/papers/3f772f2d-9e0f-4329-9298-aae4ef8ded65.pdf

3. Management, orchestration and control

3.7 Multi-tenant – multi-domain architectures – Example 3 (cont'd)

- A **multi-domain NSLI** can combine several **Fully-Fledged NSLIs** belonging to distinct admin domains to get an **E2E multi-domain** (i.e., **federated NSLIs**)
  - The constituent Fully-Fledged NSLIs = NSSI of the multi-domain NSLI

- **A slice request received from a 3rd party→ general sequence of actions**
  - 1) **mapping** of the service requirements onto capability requirements
  - 2) **translating** the capability requirements into:
    - a. NSLI resource requirements (compute, storage, networking);
    - b. NSLI topology and connectivity type, policy, isolation and security requirements
  - 3) **identifying the infrastructure-domains** with the required resources, able to assure the E2E NSLI functional and operational requirements
  - 4) **instantiating NSSIs** in each infrastructure domain and then "stitching" them to create the federated NSI
  - 5) **run-time coordination management** operations across different domains for maintaining the E2E NSI service integrity.

The above processes → need to have several levels of controllers

3. Management, orchestration and control

3.7 Multi-tenant – multi-domain architectures – Example 3 (cont'd)

- **Novel top plane** - **Service Broker (SB)**
  - to handle incoming slice requests from **verticals**, **Mobile Virtual Network Operators (**MVNO), and **application providers**.

- **The main SB operations**:
  - collects abstracted service capability information regarding different admin. domains, creating a **global service support repository**
  - interacts with the Operating/Business Support System (OSS/BSS) in order to collect business, policy and admin information when handling slice requests
  - Involved in **admission control** and negotiation, considering service aspects
  - management of slice user/owner relationship enabling a direct tenant interface with the MSC plane
  - billing and charging

  - **NSLI scheduling,** i.e., start and termination time related with slice composition and decommission

3. Management, orchestration and control

3.7 Multi-tenant – multi-domain architectures – **Example 3** (cont'd)

- **Other specific functional blocks**
- **Multi-domain Service Conductor** (MSC) stratum
  - service management across federated domains
  - analyzes and maps the service reqs. of incoming slice requests onto appropriate admin domains
  - maintains the desired service performance during service life-cycle
- **Cross-domain Slice Coordinator** is **defined for each E2E slice**
  - It aligns cloud and networking resources across federated domains and carries out the (LCM) operations of a multi-domain slice
  - It also establishes and controls inter-domain transport layer connectivity assuring the desired performance.
- **Each domain will have a dedicated Orchestration plane**, involving the NFV style architecture for the management and control.

3. Management, orchestration and control

3.8 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**
  - **separate security domains** in the slice is should preserve security and privacy isolation between clients.
  - Examples: one security domain for each InP ; one security domain for each tenant; one (or more) security domain(s) for each slice
- The tenant SDN controller enables the **abstraction** and **isolation** with its northbound interfaces

- **Isolation aspects:**
  - **Performance:** service-specific performance reqs. (KPIs) must be always met on each slice, regardless of the congestion and perf. levels of other slices
  - **Security and privacy: Attacks/faults** in one slice must have no impact on other slices
    - each slice has its security functions to avoid unauthorized access to slice-specific configuration/management/accounting information

3. Management, orchestration and control

3.8 Isolation and security- summary (cont'd)

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 may want to 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

3. Management, orchestration and control

- **3.8 Isolation and security- summary** (cont'd)

- **Isolation aspects:**

  - **How to to achieve isolation**
    - **consistent policies** and **mechanisms** to be defined **at each virtualisation level**

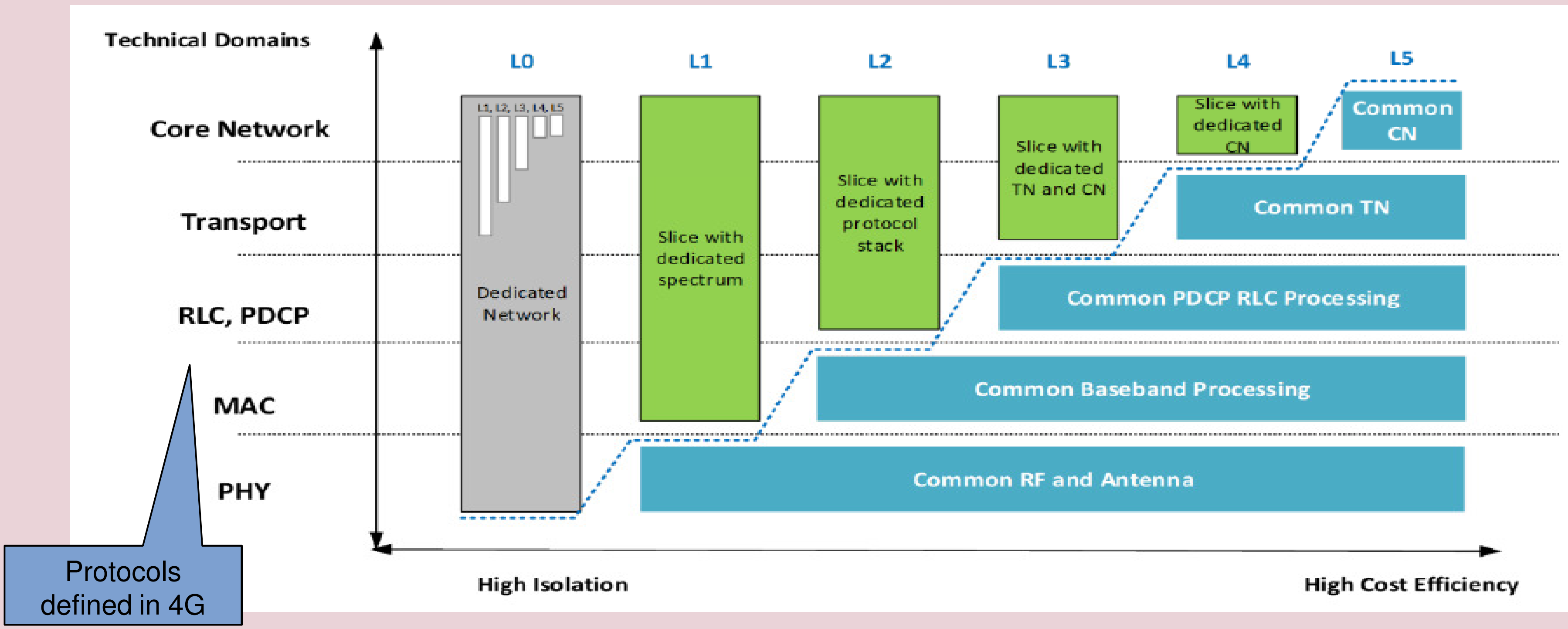
      - **policies** : lists of rules (***What?)*** - describe how different manageable entities must be properly isolated, without delving into how this can be achieved.
      - **mechanisms** (***How?*** it is to be done) - processes implemented to enforce the defined policies

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

3.8 Isolation and security- summary (cont'd)

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

CONTENTS

1. 5G Network slicing – concepts, use cases and requirements
2. 5G slicing relevant architectures
3. Management, orchestration and control
4. ➡ Advanced cognitive management
5. Conclusions and research challenges

4. Advanced cognitive management

4.1 Cognitive Management concepts

- 5G slicing – has complex management requirements related to multi – tenant/domain/operator character and softwarization of network resources

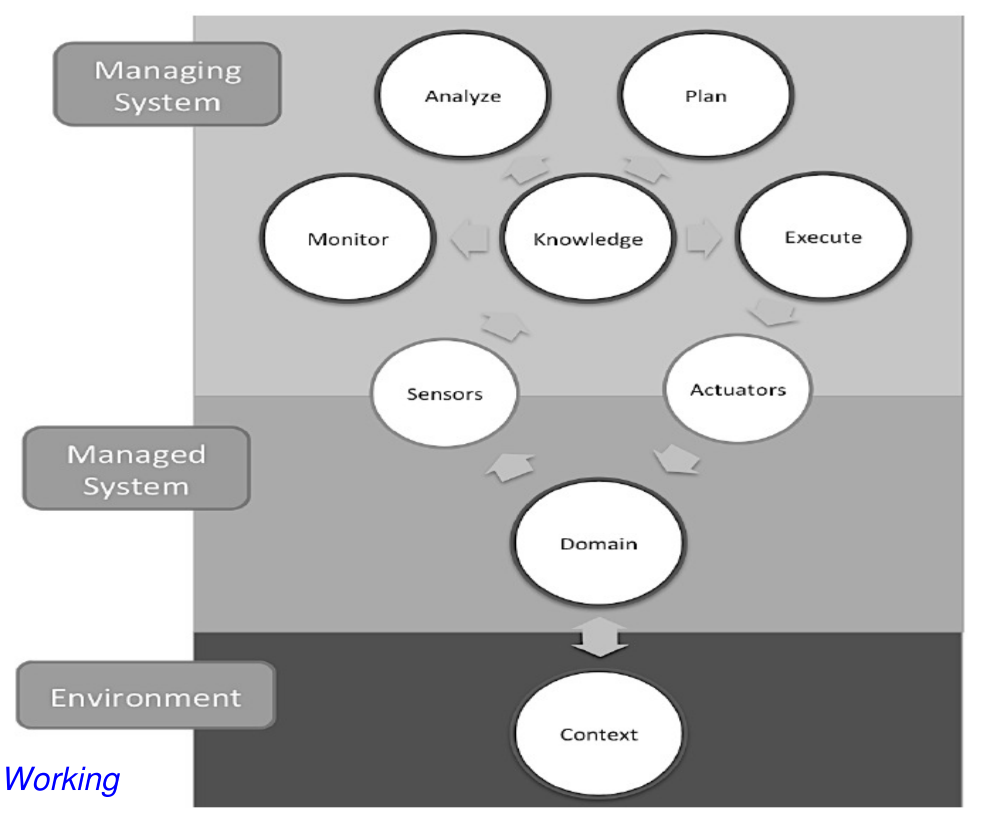
- Need of real-time mgmt. based on a hierarchy of complex decision making techniques that analyse *historical, temporal and frequency network data.*

- **Cognitive network management** – recent trend using **Artificial Intelligence (AI)** and in particular **Machine Learning (ML)** to develop **self-x**, (x= -aware, -configuring, -optimization, -healing and -protecting systems)
- Cognitive management– extension of **Autonomic Management (AM)** (coined by IBM ~ 2001)
  - **AM + Machine learning = Cognitive Management (CogM)**

- **Challenge:** to deploy the CogM and its orchestration across multiple heterogeneous networks: Radio & Other Access Networks, Core & Aggregation, Edge Networks, Edge and Computing Clouds and Satellite Networks

4. Advanced cognitive management

- **4.1 Cognitive Management concepts** (cont'd)
- **Autonomous Network Management (ANM) :** introduce self-governed networks for pursuing business and network goals while maintaining performance
- IBM original AM (~2001), later extended in networking domain → ANM
  - **Loop:** The **Monitor-Analyse-Plan-Execute** over a shared Knowledge
  - (**MAPE-K**) is a control theory-based feedback model for self-adaptive systems.
  - The environment has full-duplex communication with a ***managing systems*** controlling a ***managed system***
  - **AM –** hierarchical and recursive approach



Source: 5GPPP Network Management & Quality of Service Working Group, "Cognitive Network Management for 5G", 2017

4. Advanced cognitive management

4.1 Cognitive Management concepts (cont'd)

- **Autonomic Network Management functions**
  - **Monitoring**: active, passive, centralized, distributed, granularity-based, timing-based and programmable
  - **Analysis:** many approaches exist –relying, e.g., on probability and Bayesian models for anticipation on knowledge, timing, mechanism, network, user, app.
    - Challenge: to define a concentrated data set that comprehensively captures information across all anticipation points.
    - Recent solutions – **use learning and reasoning** to achieve such specific ends**.**
  - **Planning and Execution**
    - Dimensions of the network adaptation plan are: knowledge, strategy, purposefulness, degree of adaptation autonomy, stimuli, adaptation rate, temporal/spatial scope, open/closed adaptation and security.
    - Current status: the adaptation solutions differ broadly and there is no unanimity in defining proper planning and execution guidelines

4. Advanced cognitive management

4.1 Cognitive Management concepts (cont'd)

- **Autonomic Network Management functions** (cont'd)
  - **Knowledge base**
  - The network information is shared across the MAPE-K architecture
  - Many approaches exist - to build knowledge on network/topology, including models from learning and reasoning, ontology and DEN-ng models.
  - Integrated solution- able to capture knowledge on: structure , control and behaviour
  - **Typically:**
    - a knowledge-based framework processes input data from multiple sources
    - and extracts relevant knowledge, **through learning-based classification, prediction and clustering models**
    - to drive the decisions of **Self Organizing Network (SON)-type**, e.g., self-planning, self-optimization and self-healing.

4. Advanced cognitive management

4.2 Automation of 5G network slicing management with Machine Learning

- **Network functions requiring automation**
  - **Planning and design**: Requirements and environment analysis, topology determination; it provide inputs to
  - **Construction and deployment**: Static resource allocation, VNF placement, orchestration actions; it provide inputs to
  - **Operation, control and management**: Dynamic resource allocation, adjustment; policy adaptation; it interact bi-directionally with
    - **Fault detection**: Syslog analysis, behavior analysis, fault localization
    - **Monitoring**: Workload, performance, resource utilization
    - **Security:** Traffic analysis, DPI, threat identification, infection isolation

Adapted from source: V. P. Kafle, et. al., "Consideration on Automation of 5G Network slicing with Machine Learning" , ITU Caleidoscope Santafe 2018

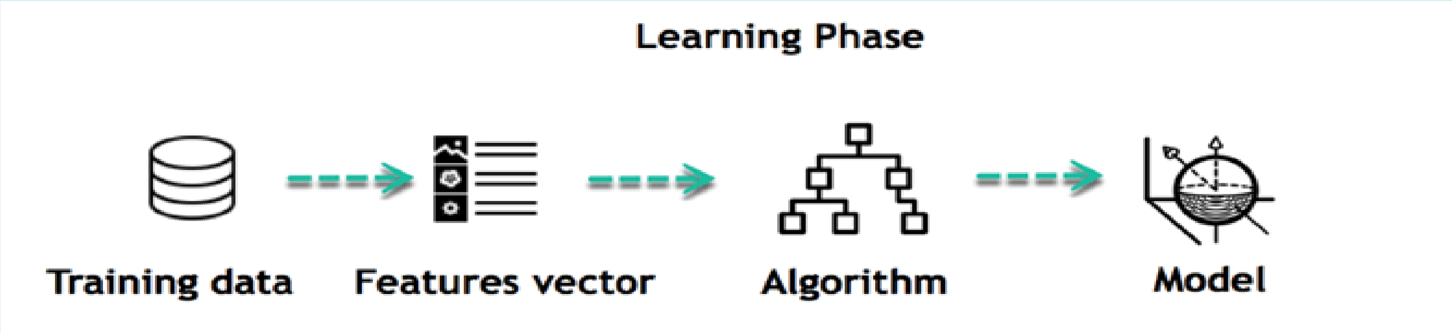
4.3 Machine Learning (ML) – basic summary

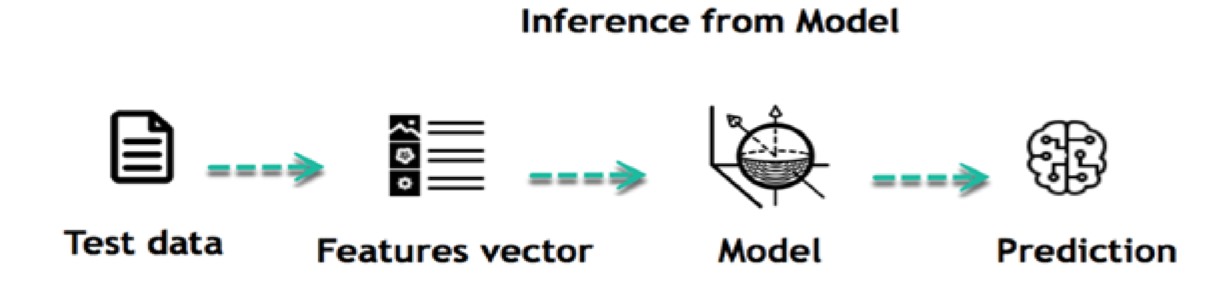
- **(ML) (subset of AI)**
- A machine can **learn from experience, by using algorithms and statistical models, i.e., not explicitly programmed to perform a given task**.
  - **ML algorithms build a math model** of sample data, known as "training data", in order to make predictions or decisions
  - The machine learns from experience, with respect to some task, and some perf. metric, if its task perf. improves with experience
  - **Traditional programming**
    - Input Data , Rules → **Computing Machine** →Output data
  - **Machine learning**
    - *Supervised learning*
      - Input (training) data, Output data → **Computing Machine** →Rules
    - *Unsupervised learning*
      - an algorithm explores input data without knowing an explicit output variable (e.g., explores demographic data to identify patterns)
    - *Reinforced learning*
      - software **agents** take **repeated actions** in an environment so as to maximize some notion of cumulative reward.

4. Advanced cognitive management

4.3 Machine Learning (ML) – basic summary (cont'd)

- **Phase (1) learning**: through the discovery of patterns thanks to the data
  - The list of attributes used to solve a problem is called a feature vector (subset of data that is used to tackle a problem)
  - Phase (1) is used to describe the data and summarize it into a model
- **Phase (2) Inference: using the model, test it on never-seen-before data**
  - The new data are transformed into a features vector, go through the model and give a prediction





Source: "Machine Learning Tutorial for Beginners", https://www.guru99.com/machine-learning-tutorial.html

4. Advanced cognitive management

4.3 Machine Learning (ML) – basic summary (cont'd)

- **Supervised machine learning (SML)**
  - SML alg. build a math model of a set of data that contains both the inputs and the desired outputs
  - The training data, consists of a set of examples (each having one or more inputs and a desired output)
  - **Example:** y_i is the output associated with the vector x_i

Given: Training data: $(x_1, y_1), \ldots, (x_n, y_n)$ / $x_i \in \mathbb{R}^d$ and y_i is the label.

example $x_1 \rightarrow$	x_{11}	x_{12}	...	x_{1d}	$y_1 \leftarrow$ label
...	...	...	...	...	...
example $x_i \rightarrow$	x_{i1}	x_{i2}	...	x_{id}	$y_i \leftarrow$ label
...	...	...	...	...	...
example $x_n \rightarrow$	x_{n1}	x_{n2}	...	x_{nd}	$y_n \leftarrow$ label

Source: Machine Learning Basic Concepts https://courses.edx.org/asset-1:ColumbiaX+CSMM.101x+1T2017+type@asset+block@AI_edx_ml_5.1intro.pdf

4. Advanced cognitive management

4.3 Machine Learning (ML) –basics- summary

- **Supervised learning** (cont'd)
- Given a set of N training examples of the form $\{(x_1, y_1),..(x_n,y_n)\}$ such that
  - x_i is the feature vector of the i-th example and
  - y_i is its label (i.e., class),
  - **a learning algorithm seeks a function g:X->Y where X is the input space and Y is the output space**
- The function g is an element of a space of possible functions G, usually called the hypothesis space
- It is convenient to represent g using a scoring function f: X x Y-->R
  - such that **g is defined as returning the y value that gives the highest score**: $g(x)=\arg\max_y f(x,y)$

- **SL algorithms-main applications: classification and regression**
  - Characteristics
    - **Classification** : outputs are restricted to a limited set of values
    - **Regression** : outputs may have any numerical value within a range

4. Advanced cognitive management

4.3 Machine Learning (ML) –basics- summary

- **Supervised learning** (cont'd)
- **Algorithms for supervised learning - examples**
  - **k-Nearest Neighbors** (k-NN) - can be used for classification and regression
    - k-NN is a non-linear method where the input consists of the k closest training samples in the input space. The predicted output is the average of the values of its k nearest neighbours
  - **Generalized Linear Models (GLM)-** it describes a linear relationship between the output and one or more input variables
  - **Naive Bayes (NB)** - used for classification and is based on Bayes theorem, i.e., calculating probabilities based on the prior probability. The main task is to classify new data points as they arrive

Source: Jessica Moysen and Lorenza Giupponi, "From 4G to 5G: Self-organized Network Management meets Machine Learning", arXiv:1707.09300v1 [cs.NI] 28 Jul 2017

4. Advanced cognitive management

4.3 Machine Learning (ML) –basics- summary

- **Algorithms for supervised learning-examples**
- **Support Vector Machines (SVMs)** - are inspired by statistical learning theory for estimating multidimensional functions
  - It can be used for classification and regression. This method is a math. optimization problem, which can be solved by known techniques
  - Problem: given m training samples ((x1; y1);…; (xm; ym)), the goal is to learn the parameters of a function which best fit the data

- **Artificial Neural Network (ANN)** is a statistical learning model where the interconnected nodes represent the neurons producing appropriate responses ANN supports both classification and regression
  - The basic idea is to efficiently train and validate a neural network. Then, the trained network is used to make a prediction on the test set.

- **Decision Trees (DT)** is a flow-chart model in which each internal node represents a test on an attribute. Each leaf node represents a response, and the branch represents the outcome of the test.
  - DTs can be used for classification and regression

4. Advanced cognitive management

4.3 Machine Learning (ML) - summary

- **Supervised learning** (cont'd)
  - **Similarity learning** is an area of SML closely related to regression and classification,
    - but the goal is to learn from examples using a similarity function that measures how similar or related two objects are
    - It has applications in ranking, recommendation systems, visual identity tracking, face/speaker verification

- **Unsupervised Machine Learning (UML)**
- The UML technique, receives **unlabelled input patterns** with the objective **to find a pattern in it**
  - The machine learns by itself, without providing it in the training phase the correct answer to the problem
  - The goal is to construct representation of inputs that can be used for predicting future inputs without giving the algorithm the right answer, as in turn we do in SML case.
  - The three most important families of algorithms **are clustering, dimensionality reduction** and **anomaly detection** techniques.

4. Advanced cognitive management

4.3 Machine Learning (ML) - summary

- **Unsupervised learning** (cont'd)
- **Clustering** - aims at **identifying groups** of data to build representation of the input
  - Methods to create clusters by grouping the data are: non-overlapping, hierarchical and overlapping clustering methods
  - Algorithms: K-means, Self-organizing Maps (SOMs), Fuzzy C-means, Gaussian mixture models

- **Dimensionality Reduction**
  - It is of interest for many problems to reduce the dimension of the original data.
  - Common methods:
    - Feature Extraction (FE) (e.g. Principal component analysis (PCA)
    - Feature Selection (FS) (e.g. Sparse Principal Component Analysis (SPCA)
  - They seek to reduce the number of features in the dataset

Source: Jessica Moysen and Lorenza Giupponi, "From 4G to 5G: Self-organized Network Management meets Machine Learning", arXiv:1707.09300v1 [cs.NI] 28 Jul 2017

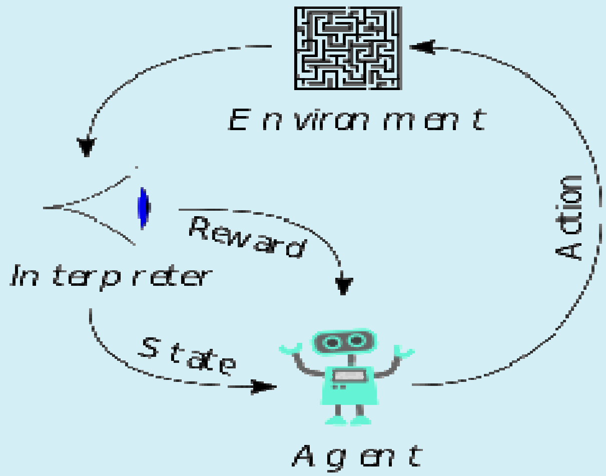
4. Advanced cognitive management

4.3 Machine Learning (ML) - summary

- **Unsupervised learning** (cont'd)
- **Anomaly Detection** - identifies events that do not correspond to an expected pattern. The machine selects the set of unusual events
  - Common methods
    - Rule based systems: (similar to DTs),
    - Pruning techniques: identify outliers, where there are errors in any combination of variables
- **Reinforcement learning (RL)**
  - Software **agents take actions** in an environment so as **to maximize some notion of cumulative reward**
  - RL is also is called approximate dynamic programming, or neuro-dynamic programming
  - The environment is typically formulated as a **Markov Decision Process (MDP)**, as many RL algorithms for this context utilize dynamic programming techniques
  - RL do not assume knowledge of an exact mathematical model of the MDP and they target large MDPs where exact methods become infeasible

4.3 Machine Learning (ML) - summary

- **Reinforcement learning (RL) (cont'd)**
  - RL is a general-purpose framework for decision-making
    - RL is for an agent with the capacity to act
    - Each action influences the agent's future state
    - Success is measured by a scalar reward signal
  - Goal: select actions to maximize future reward



4. Advanced cognitive management

4.3 Machine Learning (ML) - summary

- **Deep Learning (DL)**
- DL is a general-purpose framework for representation learning
  - Given an objective
  - Learn representation that is required to achieve objective
  - Directly from raw inputs, using minimal domain knowledge

  - **DL use a cascade of multiple layers of nonlinear processing units** for feature extraction and transformation. Each successive layer uses the output from the previous layer as input
  - learn in supervised (e.g., classification) and/or unsupervised (e.g., pattern analysis) manners
  - learn multiple levels of representations that correspond to different levels of abstraction; the levels form a hierarchy of concepts
- **Deep Reinforcement Learning**: **AI = RL + DL**
  - **RL defines the objective**
  - **DL gives the mechanism**
  - RL + DL = general intelligence

4. Advanced cognitive management

4.3 Machine Learning (ML) - summary

- **Q-learning**
  - It is a model-free RL algorithm.
  - The goal is to learn a policy, which tells an agent what action to take under what circumstances
  - It does not require a model (hence the connotation "model-free") of the environment, and it can handle problems with stochastic transitions and rewards, without requiring adaptations

4.3 Machine Learning (ML) - summary

Supervised Learning	
Classification	K-Nearest Neighbours Generalized Linear Model Support Vector Machines Naive Bayes Neural Networks
Regression	K-Nearest Neighbours Generalized Linear Regression Support Vector Regression Neural Networks Decision Trees
Unsupervised Learning	
Clustering	Non-overlapping clustering Hierarchical clustering Overlapping clustering
Dimensionality Reduction	Feature Extraction Feature Selection
Anomaly Detection	Pruning techniques Rule-based systems
Reinforcement Learning	
Model-based	Dynamic Programming Monte Carlo
Model-free	Temporal Difference

Source: Jessica Moysen and Lorenza Giupponi, "From 4G to 5G: Self-organized Network Management meets Machine Learning", arXiv:1707.09300v1 [cs.NI] 28 Jul 2017

4. Advanced cognitive management

- **4.4 Machine Learning algorithms –typical –generic- use cases**
- **Supervised learning** - used for
  - *regression computation*
    - algorithms: trees, neural networks (NN), deep NN
  - *classifications*
    - algorithms: trees, neural networks (NN), deep NNs, Bayesian classifier, support vector machine (SVM)
- **Unsupervised learning-** used for
  - *density estimation*
    - algorithms: Bolzmann machine, Kernel density, Gaussian mixtures
  - *dimensionality reduction*
    - algorithms: auto-associative NN, local linear embedding (LLE)
  - *clustering*
    - algorithms: Spectral clustering, K-means, Principal component analysis
- **Reinforcement learning** (RL) –used for real-time decisions

4. Advanced cognitive management

- **4.5 Network functions and relevant (possible to be used) ML techniques**
- **Planning and design**
  - **Functions**: Classification of service requirements; Forecasting trend; user behavior; Parameters Configuration
  - **ML techniques:** Support vector machine; Gradient boosting decision tree; Spectral clustering; Reinforcement learning

- **Operation and management**
  - **Functions:** Clustering cells, users, devices; Routing, forwarding, traffic control; Decision making for dynamic resource control, policy formulation; Reconfiguration of parameters
  - **ML techniques**: K-mean clustering; Deep neural network; Reinforcement learning

- **Monitoring**
  - Functions: Clustering of syslog data; Classification of operation modes; Forecasting resource utilization trend
  - **ML techniques** : Spectral clustering; K-mean clustering; Support vector machine; Deep neural network

4. Advanced cognitive management

- **4.5 Network function and relevant (possible to be used) ML techniques**
  - (cont'd)
- **Fault detection**
  - **Functions:** Classification of operation data; Detection of network anomaly; Predicting unusual behavior
  - **ML techniques:** Principal component analysis; Independent component analysis; Logistic regression; Bayesian networks
- **Security**
  - **Functions:** Clustering users and devices; Detecting malicious behaviour; - Intrusion detection
  - **ML techniques:** Deep neural network; Principal component analysis

4. Advanced cognitive management

- **4.5 Network function and relevant ML techniques**
  - Specific ML techniques appropriate for FCAPS- Examples

- BN - Bayesian networks
- NN - Neural networks
- K-NN – K Nearest Neighbors
- DT - Decision trees
- DL - Deep Learning
- SVM - Support vector machines
- DNN - Deep NN
- RL - Reinforcement Learning

Management area	Management function	Machine learning techniques
Fault	Fault prediction	NN, k-NN, k-Means, DT, BN, SVM
	Fault localization	NN, k-NN, k-Means, DT
	Automated mitigation	BN, SVM
Configuration	Adaptive resource allocation	Q-Learning, Deep
	Adaptive service configuration	Q-Learning
Accounting	–	–
Performance	Traffic load and metrics prediction	(Ensemble) NN, BN, SVM,
	QoE-QoS correlation	DT, BN, SVM, Q-learning
Security	Misuse detection	NN, DT, BN, SVM
	Anomaly detection	(Ensemble) NN, DNN, *k*-NN, *k*-means, (Ensemble) DT, Ensemble BN, SVM

Source: Sara Ayoubi, et.al., Machine Learning for Cognitive Network Management, IEEE Comm.Magazine , January 2018, pp.158-165

4. Advanced cognitive management

- **4.5 Research challenges related to ML techniques for FCAPS- examples**
- **Failure Prevention:**
  - ML- Proactive mitigation (e.g using RL) combined with fault prediction can prevent upcoming failures
    - To select the mitigation step, the root cause of the predicted fault has to be identified
    - But, existing ML-based localization approaches: poor scalability for the high-dimensional device log attributes in moderate-size networks.
    - Dimensionality reduction is needed
- **Fault Management in Cloud and Virtualized Environments**
  - The multi-tenancy in cloud/NFV environment raise the complexity and dimensions of the fault space in a network
  - DNNs can model complex multi-dimensional state spaces- -- > used to predict and locate faults in such networks
  - Any automated mitigation within a Virtual Network (VN) should not affect other coexisting VNs
    - RL combined with DNNs can learn to optimize mitigation steps.

Adapted from : Sara Ayoubi, et.al., Machine Learning for Cognitive Network Management, IEEE Comm.Magazine , January 2018, pp.158-165

4. Advanced cognitive management

- **4.5 Research challenges related to ML techniques for FCAPS** (cont'd)
- **Configuration Management:**
  - Mapping High-Level Requirements to Low-Level Configurations:
    - There is a gap between high-level requirements and low-level configurations (e.g., resources to be provisioned)
    - RL techniques can be applied
    - The reward for selecting a configuration setting of a given network element can be seen as the utility of that particular setting in delivering the high-level req. under a given network condition
  - **Configuration Verification**
    - Configuration changes (e.g., access control lists, routing tables) should comply with high-level reqs. and not adversely affect the expected network behavior
    - Interest exists in applying DL-aided verification, code correction, and theorem proving

Source: Sara Ayoubi, et.al., Machine Learning for Cognitive Network Management, IEEE Comm.Magazine , January 2018, pp.158-165

4. Advanced cognitive management

- **4.5 Research challenges related to ML techniques for FCAPS (cont'd)**
- **Performance Management**
  - **Adaptive Probing**
    - Large number of devices, parameters, small time intervals to log data → increase the amount of measuring traffic overhead
    - Regression, mostly based on time series data, can predict the value of the measured parameters to optimize probing.
    - Objective: to set probing rates that keep traffic overhead enough low, while minimizing perf. degradation and providing high prediction accuracy
  - **Detecting Patterns of Degradation**
    - Need to detect the characteristic patterns of degradation before the quality drops below an acceptable level
    - Elastic resource allocation can dynamically accommodate user demands for achieving optimum perf. while maximizing resource utilization
    - SML has been already used to predict the value of network perf.
    - However, employing perf. prediction for autonomic tuning of the network behavior remains is an open challenge.

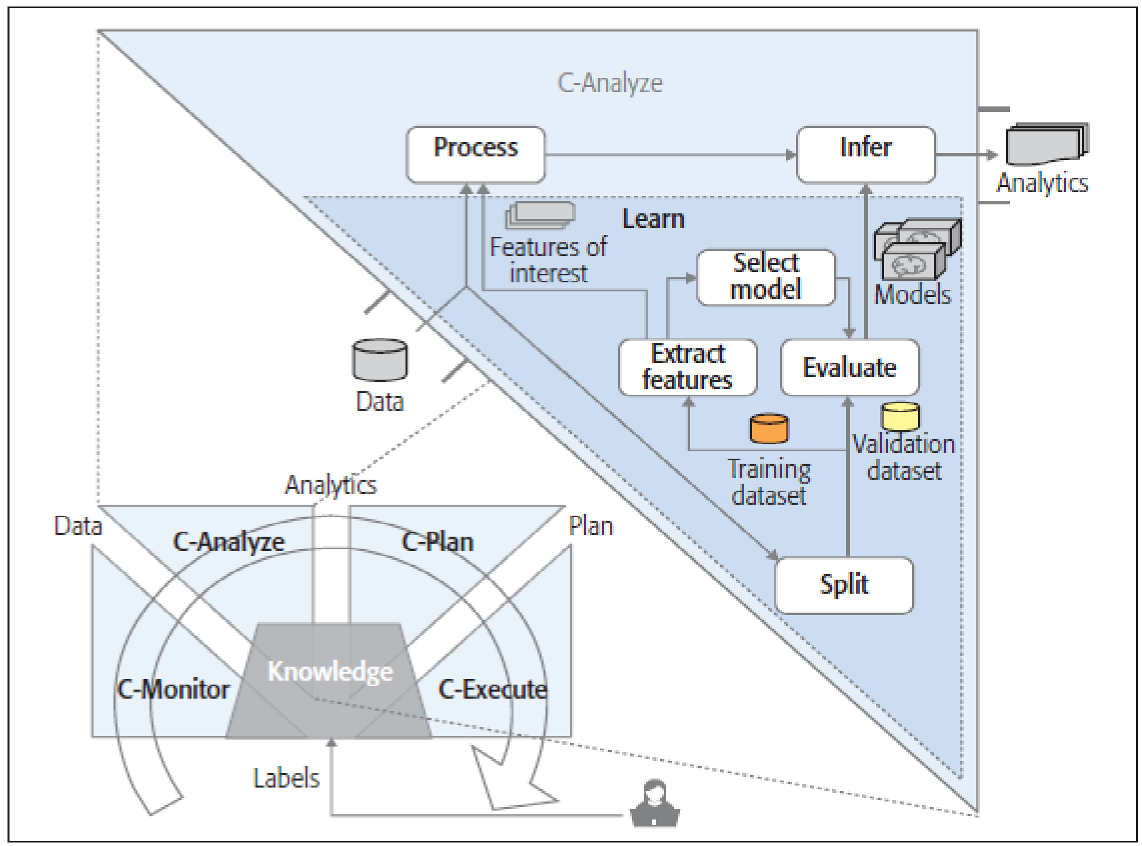
4. Advanced cognitive management

4.6 Examples of architectures embedding cognitive management

- **MAPE- full cognitive loop**

Source: Sara Ayoubi, et.al., Machine Learning for Cognitive Network Management, IEEE Comm.Magazine , January 2018, pp.158-165

- Traditional – MAPE: only Analyze Phase included cognitive properties
- **Proposal : to introduce ML in all phases**
- ML: introducing **learning** and **inference** in every function.



4. Advanced cognitive management

4.6 Examples of architectures embedding cognitive management

- **MAPE- full cognitive loop** (cont'd)
- **C-Monitor: intelligent probing** (e.g., if overloaded network, the C-Monitor function may decide to reduce the probing rate and instead perform regression for data prediction
- **C-Analyze**: **detects or predicts changes** in the network environment (e.g., faults, policy violations, frauds, low performance, attacks).
- **C-Plan:** can leverage ML to develop an **intelligent automated planning** (AP) engine that reacts to changes in the network by selecting or composing a change plan.
- **C-Execute:** schedules the generated plans and determine the course of action should the execution of a plan fail.
  - RL is –naturally- applied: C-Execute agent could exploit past successful experiences to generate optimal execution policies, and explore new actions in case the execution plan fails
- **Closing the control loop** : monitoring the state of the network to measure the impact of the change plan

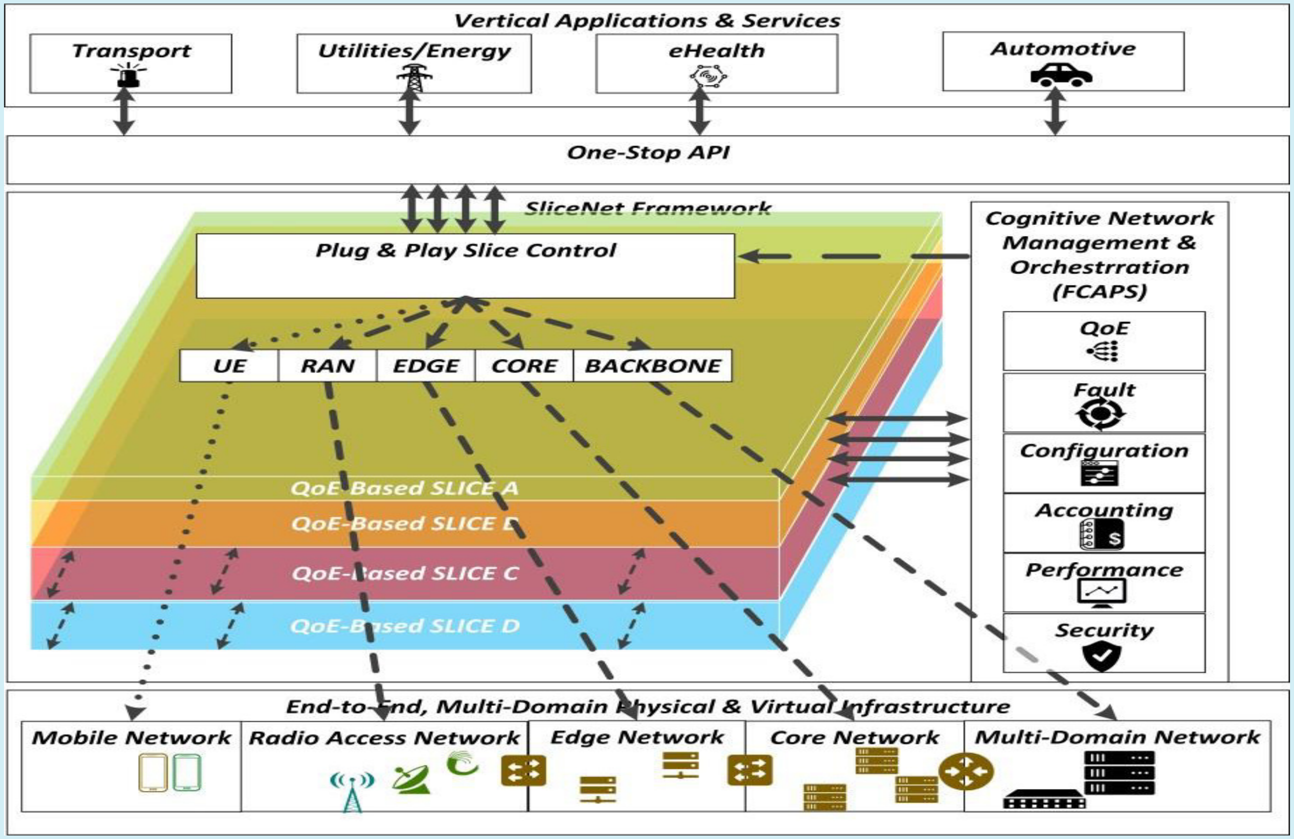
Source: Sara Ayoubi, et.al., Machine Learning for Cognitive Network Management, IEEE Comm.Magazine , January 2018, pp.158-165

4. Advanced cognitive management

4.6 Examples of architectures embedding cognitive management

- SLICENET H2020 Phase 2 project : *End-to-End Cognitive Network Slicing and Slice Management Framework in Virtualised Multi-Domain, Multi-Tenant 5G Networks. (2016)*

- *SLICENET vision*

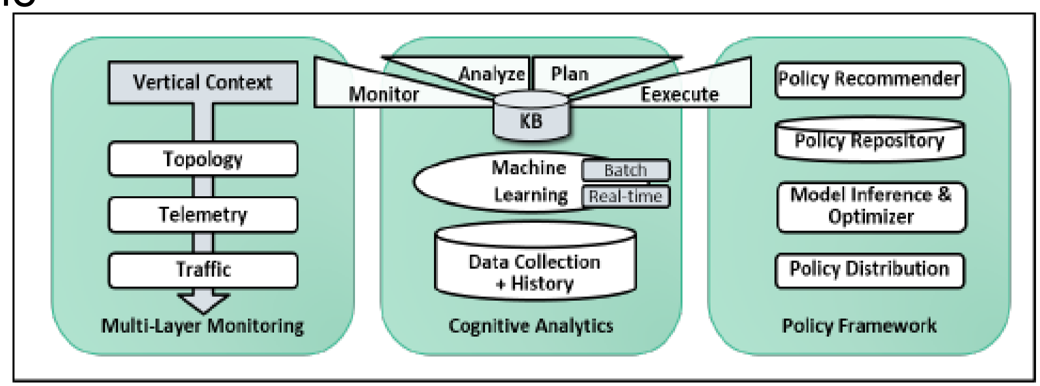


Source: *https://5g-ppp.eu/slicenet*

4. Advanced cognitive management

4.6 Examples of architectures embedding cognitive management

- SLICENET H2020 Phase 2 project : *End-to-End Cognitive Network Slicing and Slice Management Framework in Virtualised Multi-Domain, Multi-Tenant 5G Networks. (2016) https://5g-ppp.eu/slicenet*
- SliceNet mgmt. takes a “verticals in the whole loop” approach, integrating the vertical perspective into the slice management process
- SliceNet: fully automated slice M&O through AI/ML and utilizing the autonomous computing MAPE loop model, a vertically-informed multilayer QoE monitoring sub-plane, and a slice-centric policy framework.
- The vertical is integrated into the CogM process by providing
  - the perceived QoE: it enables *supervised ML* methods.
  - context: used to collect context-aware cross-layer information



Source: D. Lorenz, et. al., “SliceNet – Cognitive Slice Management Framework for Virtual Multi-Domain 5G Networks”, https://www.systor.org/2018/pdf/systor18-21.pdf

CONTENTS

5. Conclusions and research challenges

- **General Research challenges**
- **Cross-Domain Coordination(CDC)**
  - Service/data model & mapping in a single domain and coordination in multi-domain
  - Slice stitching / composition in a single domain and coordination for multi-domain
- **Network Slicing Management**
  - Uniform Network Slice life cycle management
  - Network Slice Discovery
  - Autonomic slice management and operation (including C-MAPE-K for FCAPS)
  - E2E Sliced Network Orchestration, Multi-tenancy aspects
- **Performance Guarantee and Isolation**
  - Guarantees for network slice isolation
  - Isolation vs. Sharing issues
- **Slicing Resource & Requirement**
  - Uniform Reference Template, Capability exposure and APIs
  - Business models, Deployment and Economic Challenges

Adapted from A.Galis, "Network Slicing Tutorial" - IEEE CNSM 2018 - Rome 5th November 2018

5. Conclusions and research challenges

- **Challenges in Using Machine Learning**
  - Representative Datasets
  - Speed vs. Accuracy
  - Ground truth (refers to the accuracy of the training set's classification for SML techniques)
  - Selection of the most convenient ML techniques for networks
  - Incremental Learning
  - Security of Machine Learning

- **Challenges in Autonomic Network Management in cognitive context**
  - Orchestration of Cognitive Management Functions
  - Cooperation between Cognitive Mgmt and SDN, NFV environment

- Thank you !
- Questions?

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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
BN	Bayesian Networks
CA	Certificate Authority
CaaS	Cooperation as a Service
CAPIF	Common API Framework for 3GPP northbound APIs
CC	Cloud Computing
CP	Control Plane
CRAN	Cloud based Radio Access Network
D2D	Device to Device communication
DLk	Downlink
DL	Deep Learning
DN	Data Network
DNN	Deep Neural Network
DoS	Denial of Services
DP	Data Plane (User Plane UP)

Advanced management and control in 5G sliced networks

- **List of Acronyms**

DT	Decision Tree
ENaaS	Entertainment as a Service
ePDG	evolved Packet Data Gateway
FC	Fog Computing
GPS	Global Positioning System
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
k-NN	k-Nearest Neighbours
LADN	Local Area Data Network
LLC	Logical Link Control
LMF	Location Management Function
MANET	Mobile Ad hoc Network
M&C	Management and Control
MCC	Mobile Cloud Computing
MEC	Multi-access (Mobile) Edge Computing
ML	Machine Learning
N3IWF	Non-3GPP InterWorking Function
NaaS	Network as a Service
NAI	Network Access Identifier

Advanced management and control in 5G sliced networks

- **List of Acronyms**

NEF	Network Exposure Function
NF	Network Function
NFV	Network Function Virtualization
NGAP	Next Generation Application Protocol
NN	Neural Networks
NRF	Network Repository Function
NSL	Network Slice
NSLI	Network Slice Instance
NS	Network Service
NSLID	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
QFI	QoS Flow Identifier
QoE	Quality of Experience
RAN	Radio Access Network

Advanced management and control in 5G sliced networks

- **List of Acronyms**

RL	Reinforcement Learning
RRH	Remote Radio Head
RSU	Road Side Unit
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
SLA	Service Level Agreement
SM	Service Management
SMF	Session Management Function
SML	Supervised Machine Learning
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
SVM	Support Vector Machine
TNL	Transport Network Layer
TNLA	Transport Network Layer Association
TSP	Traffic Steering Policy

- **List of Acronyms**

UDM	Unified Data Management
UDR	Unified Data Repository
UML	Unsupervised Machine Learning
UL	Uplink
UPF	User Plane Function
V2X	Vehicle-to-everything
VANET	Vehicular Ad hoc Network
VID	VLAN Identifier
VLAN	Virtual Local Area Network
VM	Virtual Machine
WAT	Wireless Access Technologies
WSN	Wireless Sensor Network

- Backup slides

BS1: 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

BS1: 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.a;., 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

BS1: 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

BS1: 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

BS1: 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

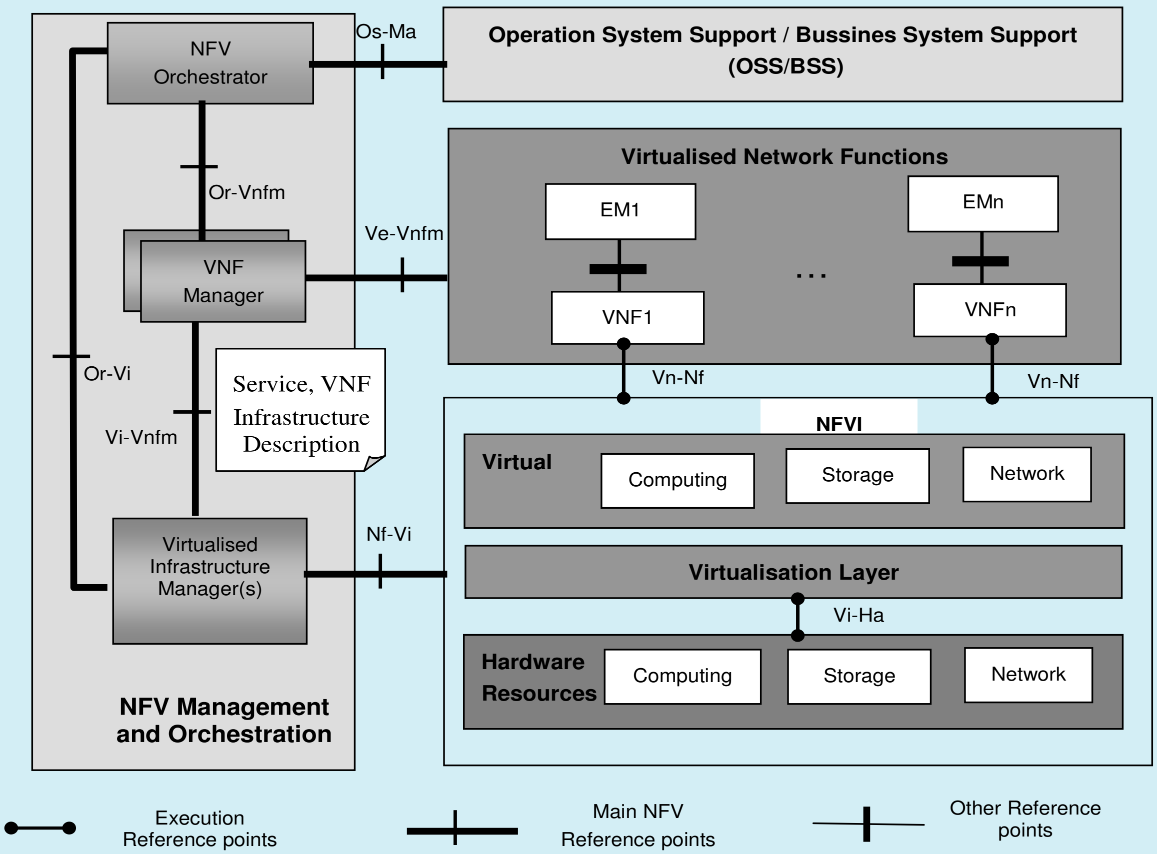
BS1: Terminology summary

(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

BS2: ETSI and 3GPP functional architectures for slicing support

- **Network Function Virtualization – 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

BS2: 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

BS2: ETSI and 3GPP functional architectures for slicing support

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

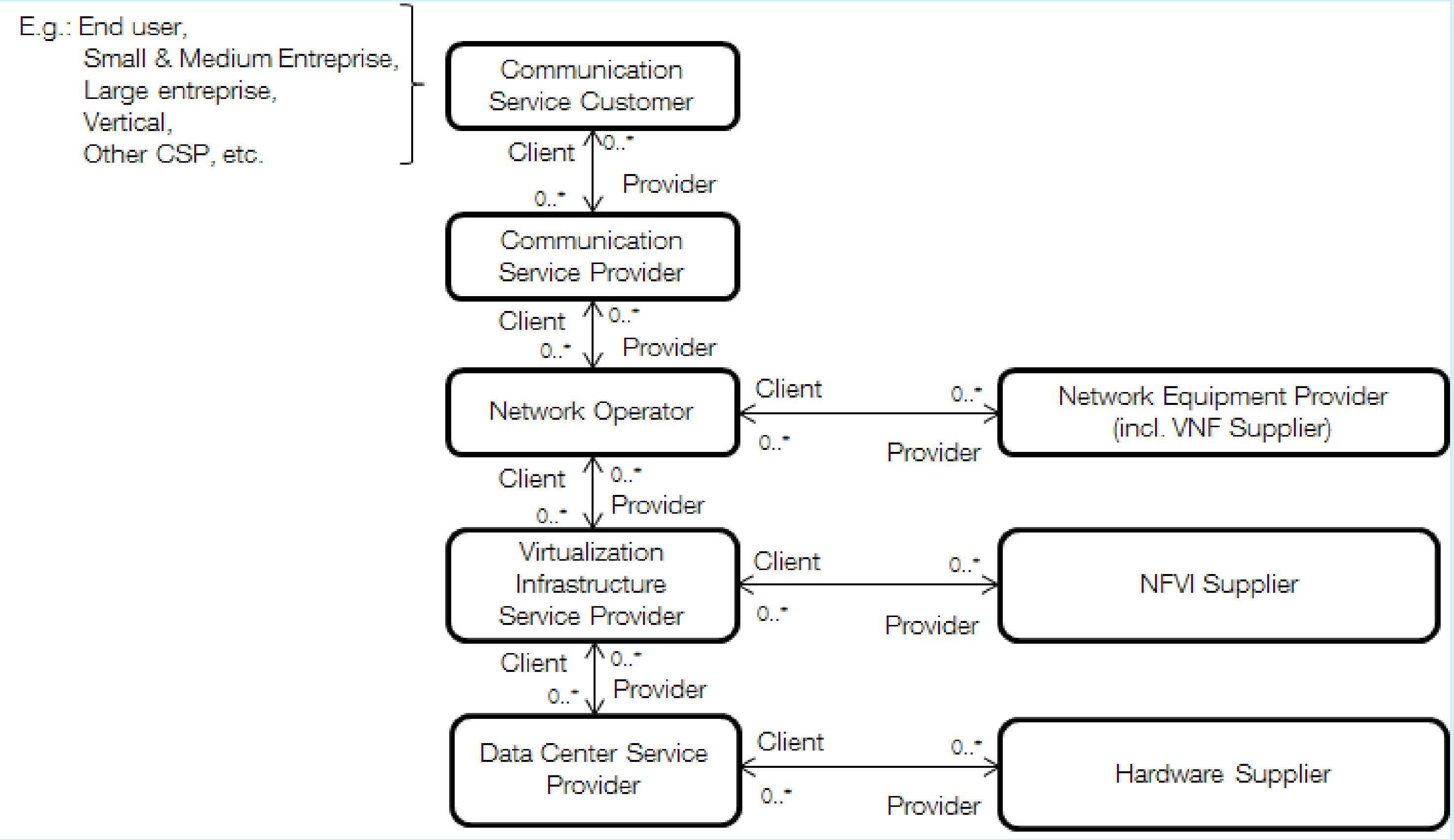
- **NFV Management and Orchestration Architectural Framework (NFV-MANO Architectural Framework):**
  - collection of all FBs (those in NFV-MANO and others interworking with NFV-MANO), data repositories used by these FBs , and RPs and interfaces for the purpose of managing and orchestrating NFV

- **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

BS2: 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)

BS3 SDN and NFV- complementary

- **SDN and NFV**
  - they can be developed independently
  - however they are complementary and can efficiently cooperate