Programmability, Softwarization and Management in 5G smart networking

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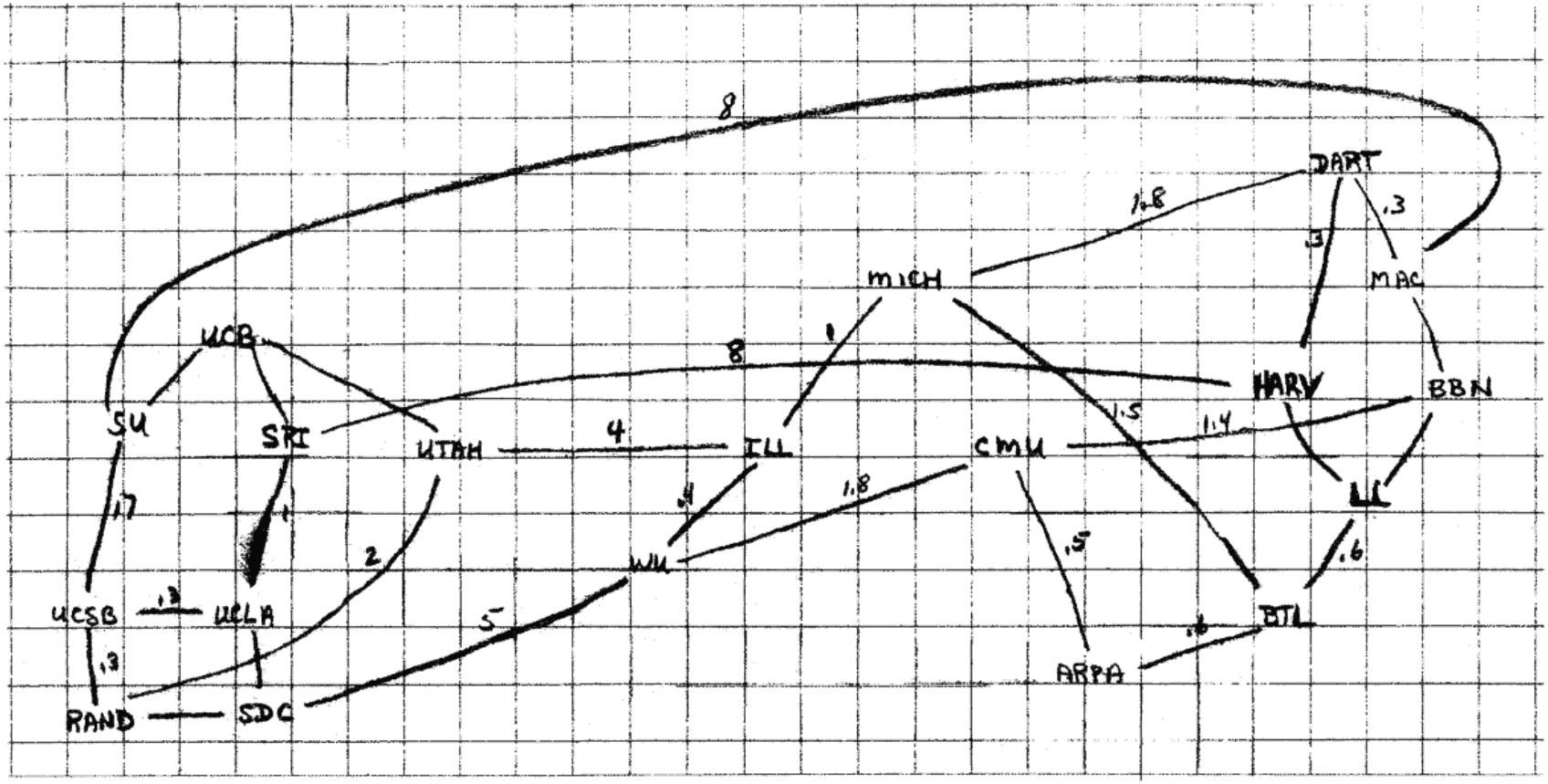
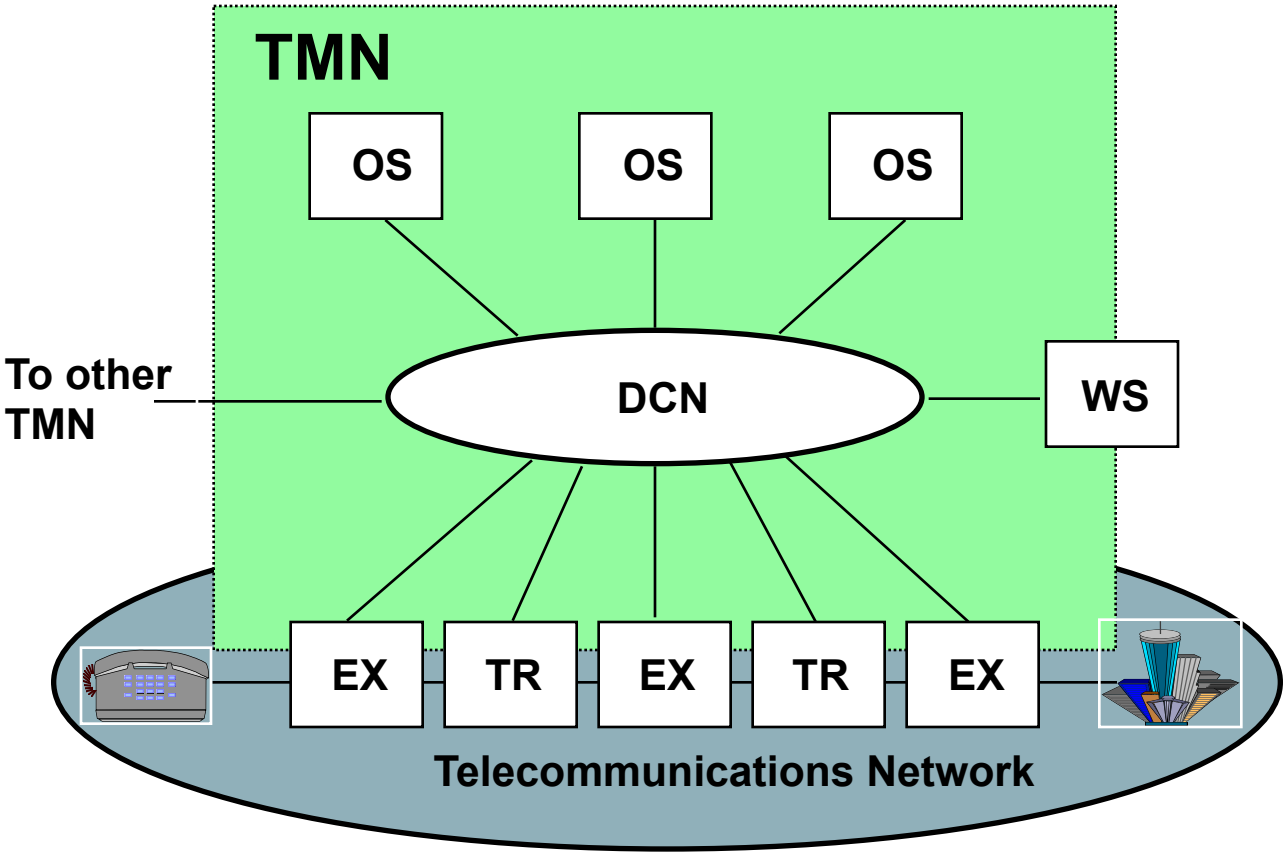
Rough sketch by Larry Roberts



Telecommunication Management Network

Networks today:

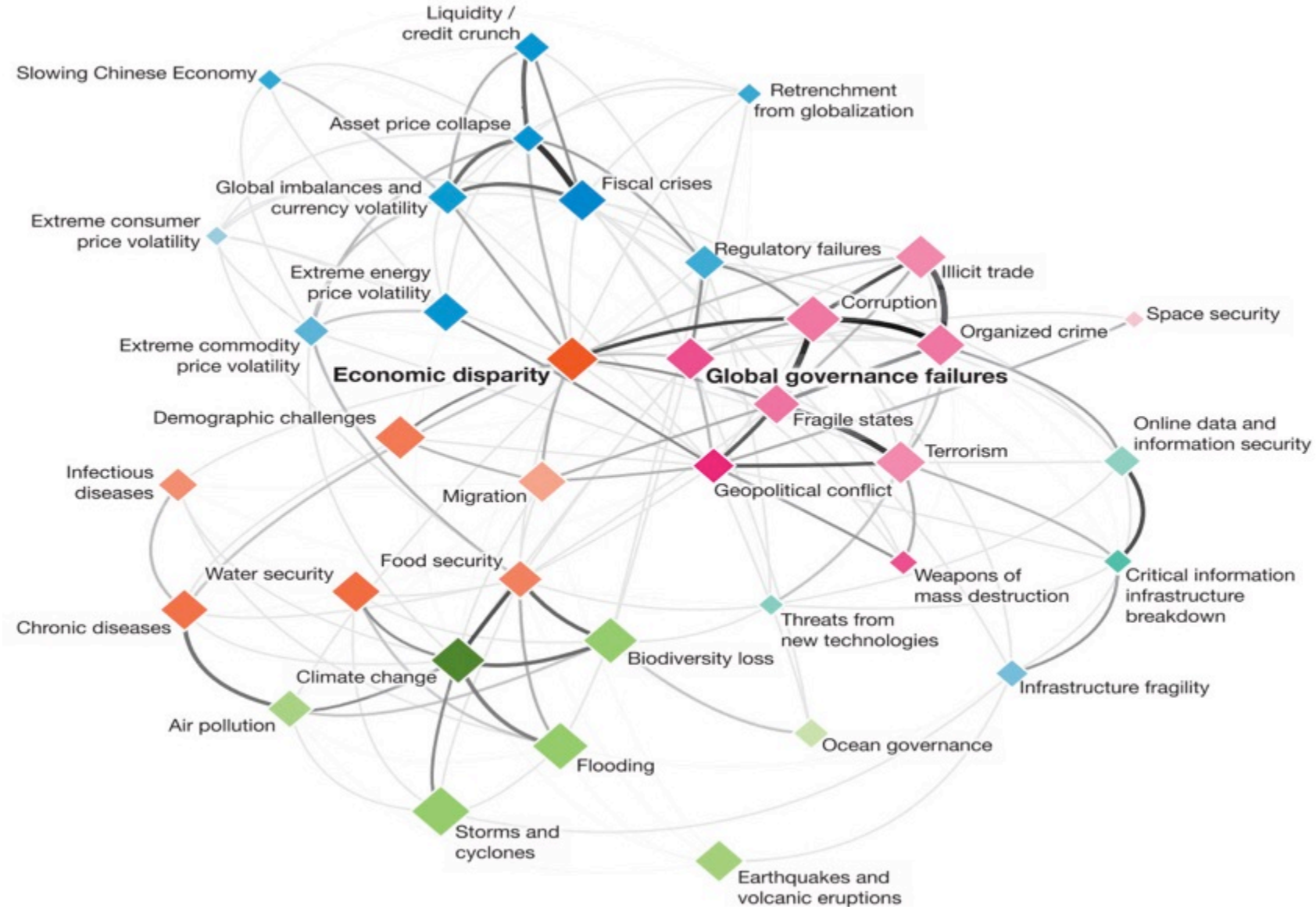
- ***Out of Band Management***
- ***Static & configured & managed as silos (i.e. multi technology, multi- vendor silos)***



EX: Exchange
TR: Transmission
DCN: Data Communication Network

OS: Operations System
WS: Work Station

A highly joint with interdependencies World and moving towards hyper connectivity



Systemic interdependencies of the socio-economic variables of the highly connected world (i.e.: reference: World Economic Forum)

Content

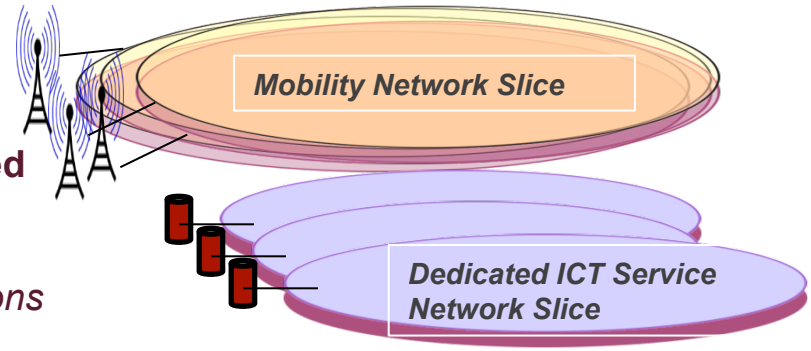
- Review of the 5G Smart Network Architecture
- Key Challenges in E2E Management
- Key Challenges in Network Slices
- Key Challenges in Smart Network Fabric
- Concluding Remarks

Smart Networks

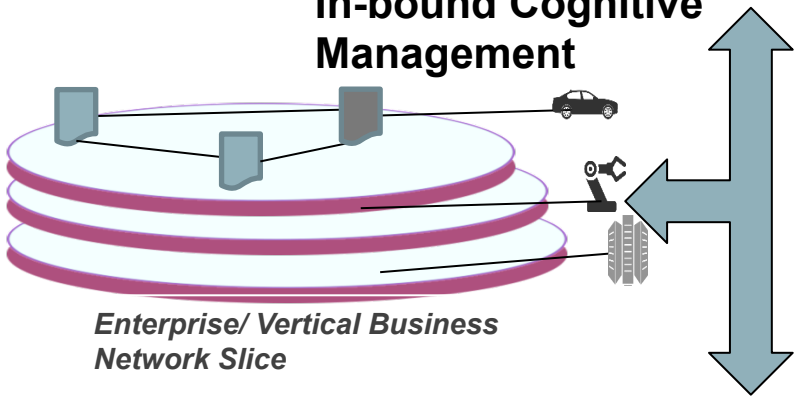
- Transition from network devises to network functions and virtual network functions with inbound management
- Dynamically adapting the network to meet future demands requires
- Creating the dynamic, configurable, programmable, resilient, cost effective E2E network
- A programmable network operating system with simple interface to the network (smart network fabric)

E2N Multi-Domain Orchestration
E2E coordination, conflict resolution, multi-domain information exchange

Service Adapted Network Slices
Enabled by Network Functions Including NFV

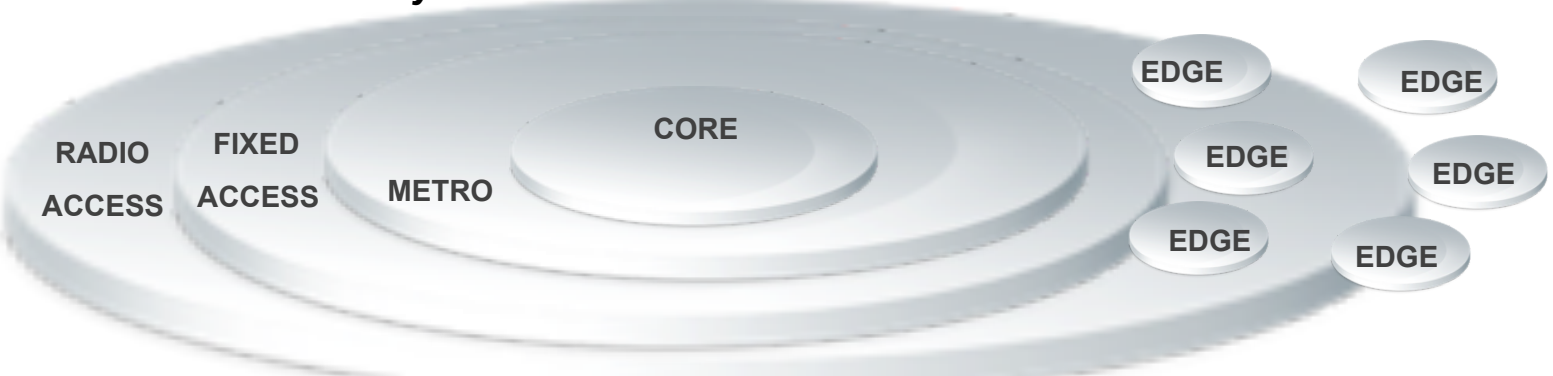


In-bound Cognitive Management



Smart Network Fabric: E2E Multi-Domain Network Operating System Facilities
Network Abstraction, Allocate (virtual) network resources, Maintain network state, Ensure network Reliability in a multi domain environment

Smart Cloud & Network Fabric
Enabled by Programmability Including SDN



Smart Networks (1)

5G Networking is driven by

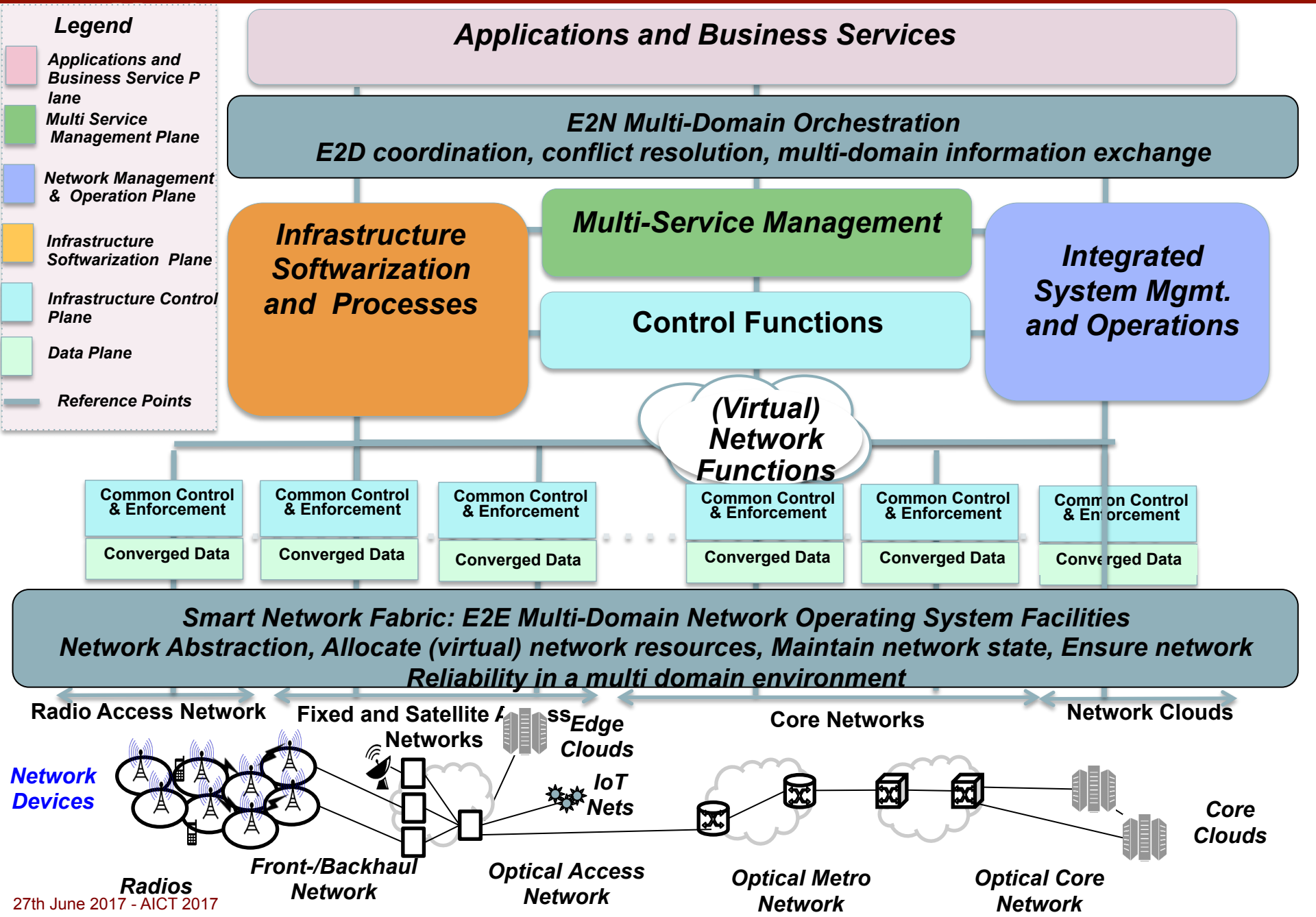
- an evolution in terms of **higher capacity, performance and spectrum access in radio network segments**; and
- an evolution of **native higher flexibility and programmability conversion in all non-radio 5G network segments**: Fronthaul and Backhaul Networks, Access Networks, Aggregation Networks, Core Networks, Mobile Edge Networks, Edge Clouds Software Networks, Software-Defined Cloud Networks, Satellite Networks and IoT Networks.

Smart Networks (2)

5G Networking is dependent logically and functionally on the followings key separation of concerns:

- **Serving at best high diversity types of communications (Human & Machines & Devices & Sensors & Edge Systems) with different performance attributes.**
- **Separation of concerns between control/management/softwarization/services**
- **Separation of concerns between logical / physical resources functions (i.e. connectivity, compute and storage resources) and network capabilities**
- **A shift in networking and a transition form "network of entities", as in current systems, to "network of (virtual) functions / capabilities". As such "network (virtual) functions" are units of networking.**
- **Network softwarization is not equated with network slicing. Hosting services executions in one (or more) Slices.** Network softwarization includes functions for programmability of
  - (1) network devices;
  - (2) network (virtual) functions;
  - (3) network slices;
  - (4) network services and applications;
  - (5) data, control, management planes.
- Supporting on demand **composition of network functions and network capabilities**
- **Leveraging natively Network Softwarization technologies in all network segments and network components**.

Revised Smart Network Functional Architectural



Smart Network Planes - Scope and Functionality (I)

Application and Business Service Plane – It **defines and implements the business processes of the services along specific value chains**.

- A service in the 5G context is a piece of software that performs one or more functions, provides one or more APIs to applications or other services of the same or different planes to make usage of those functions, and returns one or more results.
- Services can be combined with other services, or called in a serialized manner to create a new service.
- An application in the 5G context is a piece of software that utilizes the underlying services to perform a function.
- Application operation can be parameterized, for example, by passing certain arguments at call time, but it is meant to be a standalone piece of software; an App does not offer any interfaces to other applications or services.

Smart Network Planes - Scope and Functionality (II)

Control Plane - *The collection of functions responsible for controlling one or more network functions.*

- Control Plane instructs network devices, network elements, and network functions with respect to processing elementary data units (packets, frames, symbols, bits, etc.) of the user/data/forwarding plane.
- The control of (virtual) network functions include Control of Network (Virtual) functions, Control of Orchestration functions, Control of Mobility functions, Cloud Control functions, Mobile Edge Computing Control functions and adaptors to different enforcement functions.
- The control of (virtual) network functions is generally 5G-applicable, and they are separated from the control and enforcements functions which are network segment-specific. The control plane interacts primarily with the forwarding plane and, to a lesser extent, with the management plane.

Forwarding Plane / Data Plane - *The collection of resources across all network devices responsible for forwarding traffic.*

Smart Network Planes - Scope and Functionality (III)

Integrated Network Management & Operations Plane

It enables the creation, deactivation, operation, control and coordination (orchestration) of

- Dedicated management functions operating on top of a 5G E2E smart infrastructure;
- The collection of resources required for managing the overall operation and coordination of individual network devices.
- It guarantees the creation the dynamic, configurable, resilient, cost effective software networks

It further includes E2E Network segments management, FCAPS functionality, Monitoring operations, Network Information Management, In-network data and operations processing and Multi domains management operations.

Smart Network Planes - Scope and Functionality (IV)

Multi-Service Orchestration and Management Plane – *The functions and interfaces in this plane are used to set up and manage groups of network instances and/or nodes*.

- More specifically, the setup consists of creating/installing/arranging/deactivation/ coordinating NFs and interfaces according to the available physical and virtual resources.
- It also comprises the set of functions associated with the network operations, such as fault management, performance management and configuration management.
- It further includes Slice – Service Mapper functions, Resources, Domain and Service Orchestration functions, Service Information Management functions and Network Capability Discovery functions.
- It also includes the lifecycle management of individual network functions and mobile network instances as a whole. In current mobile networks, this role is often performed by the Operations Support System (OSS). The idea is to enable the creation, operation, and control of multiple dedicated communication service networks running on top of a 5G E2E infrastructure.

Smart Network Planes - Scope and Functionality (V)

Infrastructure Softwarization Plane – Enables the **provisioning and operation of software and service networks**. It facilitates the operation of end-to-end heterogeneous networking and distributed cloud platforms, including physical and logical resources and devices. It includes functions for designing, implementing, deploying, managing and maintaining network equipment, network components and/or network services by programming. It further includes functions for the provision of software and service networks, application driven network softwarization, programmability of Software Networks, dynamic deployment of new network and management services (i.e. which could be executed in data, control, management, service plane), network capability exposure, and E2E slice provisioning. It includes functions for dynamic programmability of

(1) network devices;

(2) network (virtual) functions;

(3) network slices,

(4) network services and applications;

(5) Data, control, management planes.

The software utilize features such as flexibility and rapidity all along the lifecycle of network equipment/components/services, in order to create conditions that enable the re-design of network and services architectures, optimize costs and processes, allow self-management and bring added value to network infrastructures.

Smart Network Planes - Scope and Functionality (VI)

Infrastructure Softwarization Plane interacts / interworks with the other planes though a set of ***Programmability APIs*** including:

(1) allowing the functionality of some of their network elements to be dynamically programmable. The behaviour of network elements and resources can then be customized and changed through such programming interfaces ;

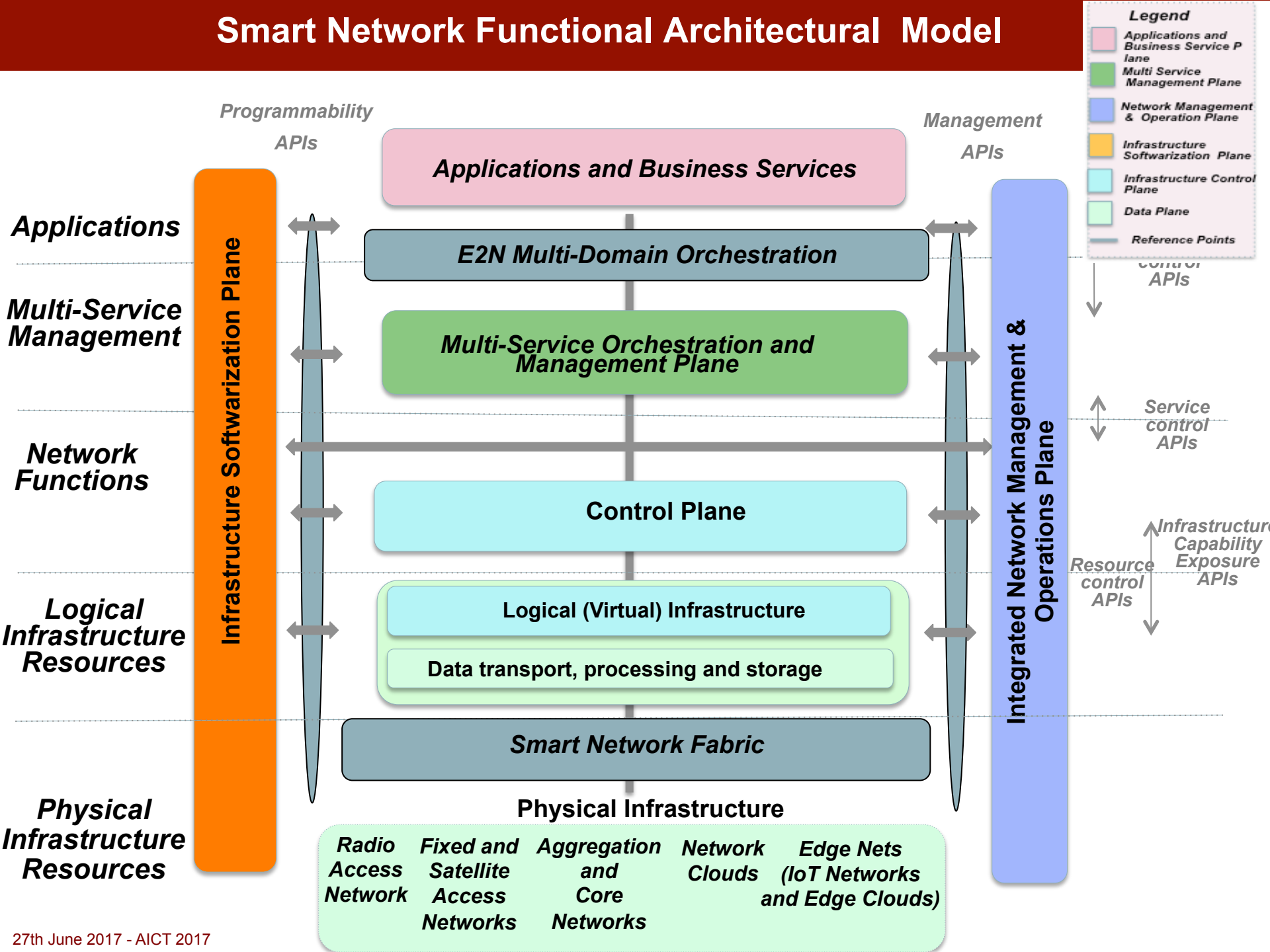
(2) enabling the fast, flexible setting-up of new network services, new slice-services, new software networks and new management services by dynamic programmability of the network resources executed as groups of virtual machines in the data plane, control plane, management plane and service plane in all segments of the network;

(3) enabling dynamic re-deployment and/or dynamic changes to elasticity characteristics for network services, slice services, software networks and management services.;

(4) enabling injection of executable code into the execution environments of network elements in order to create the new functionality at run time;

(5) enable trusted third parties (some end users, operators, and service providers) to inject application-specific services (in the form of code) into the network and/or slices. Applications may utilize this network support in terms of optimized network resources and, as such, they are becoming network aware.

Smart Network Functional Architectural Model



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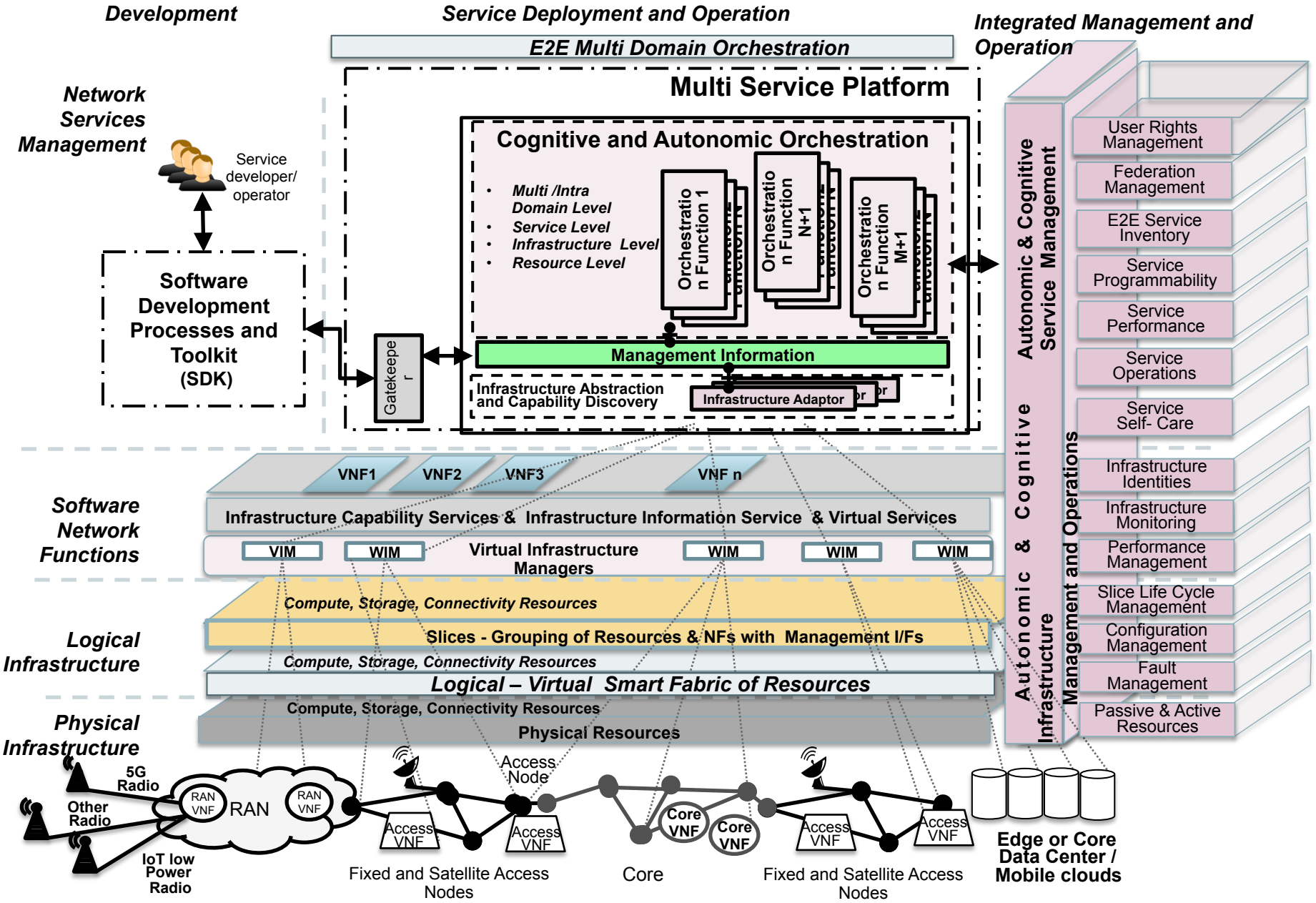
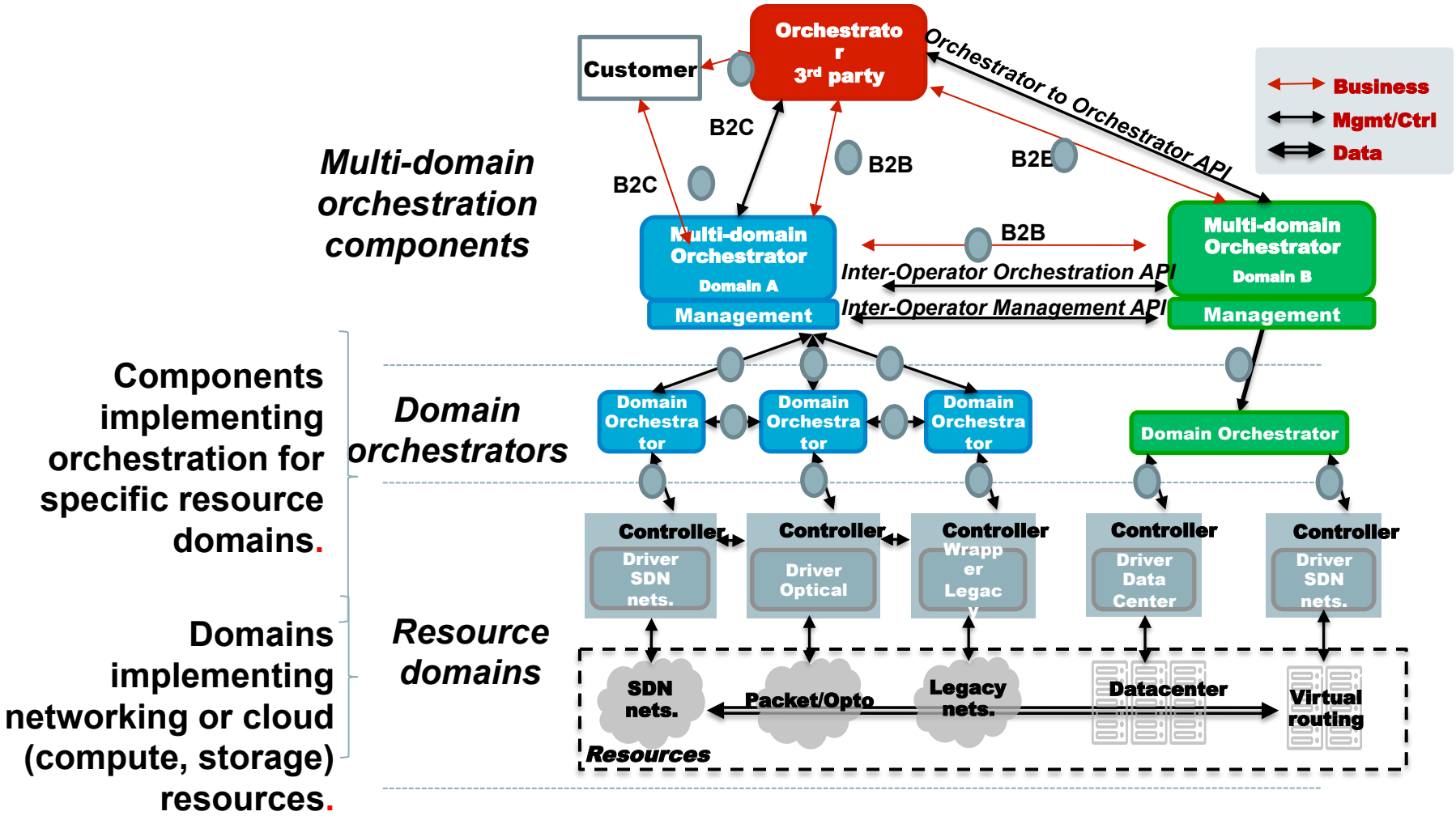
5G Management Functional Architectural Model and Issues



Multi-domain Management and Orchestration issues



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Definitions of Network Slicing & References (I)

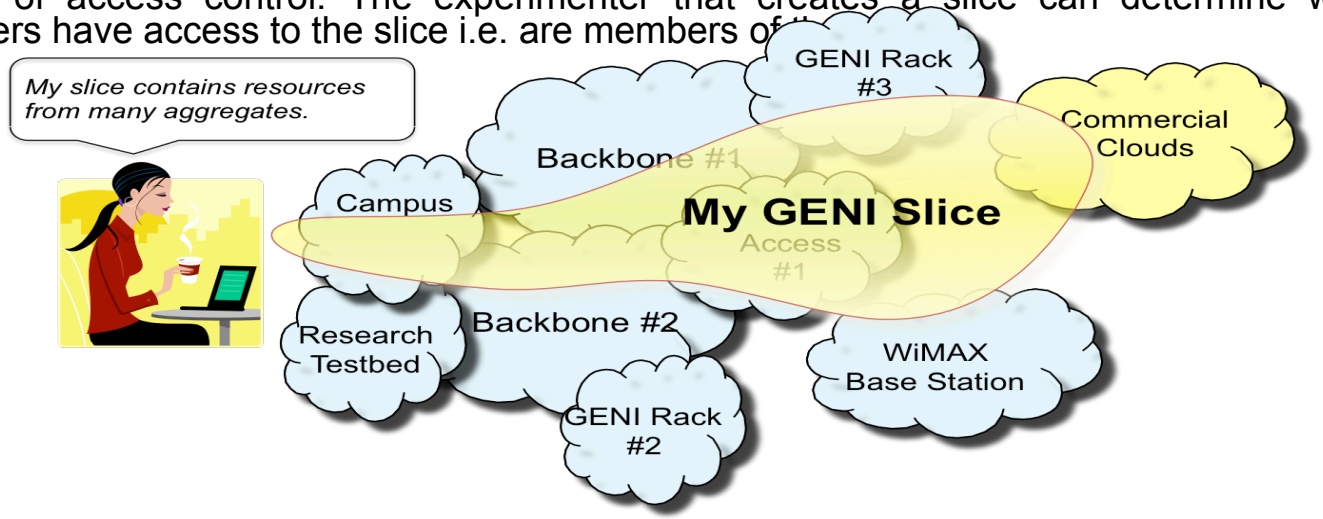
I - Slicing Resources:

Active / Programmable Networks research: node operating systems & resource control frameworks (1995 -2005) (*)

Federated Testbed research : Planet Lab USA (2002), PlanetLab EU (2005), OneLab EU (2007), PlanetLab Japan (2005), OpenLab EU (2012)

GENI Slice (2008): "GENI is a shared network testbed i.e. multiple experimenters may be running multiple experiments at the same time. A GENI slice is:

- The unit of isolation for experiments.
- A container for resources used in an experiment. GENI experimenters add GENI resources (compute resources, network links, etc.) to slices and run experiments that use these resources.
- A unit of access control. The experimenter that creates a slice can determine which project members have access to the slice i.e. are members of it.



(*) Galis, A., Denazis, S., Brou, C., Klein, C. (ed) –"Programmable Networks for IP Service Deployment" ISBN 1-58053-745-6, pp 450, June 2004, Artech House Books, http://www.artechhouse.com/International/Books/Programmable-Networks-for-IP-Service-Deployment-1017.aspx

Definitions of Network Slicing & References(II)

I - Slicing Resources:

Slice capabilities (2009) "Management and Service-aware Networking Architectures (MANA) for Future Internet" – A. Galis et all - Invited paper IEEE 2009 Fourth International Conference on Communications and Networking in China (ChinaCom09) 26-28 August 2009, Xi'an, China, http://www.chinacom.org/2009/index.html

3 Slices Capabilities

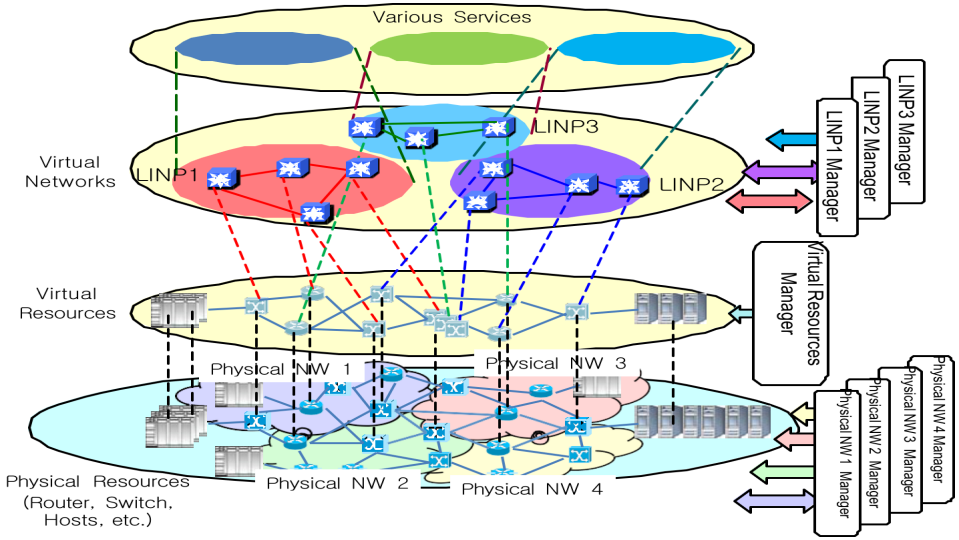
- "Resource allocation to virtual infrastructures or slices of virtual infrastructure."
- "Dynamic creation and management of virtual infrastructures/slices of virtual infrastructure across diverse resources."
- "Dynamic mapping and deployment of a service on a virtual infrastructure/slices of virtual infrastructure."

17 Orchestration capabilities

19 Self-functionality mechanisms

14 Self-functionality infrastructure capabilities

ITU-T Slicing (2011) as defined in [ITU-T Y.3011], [ITUTY.3012] is the basic concept of the Network Softwarization. Slicing allows logically isolated network partitions (LINP) with a slice being considered as a unit of programmable resources such as network, computation and storage.

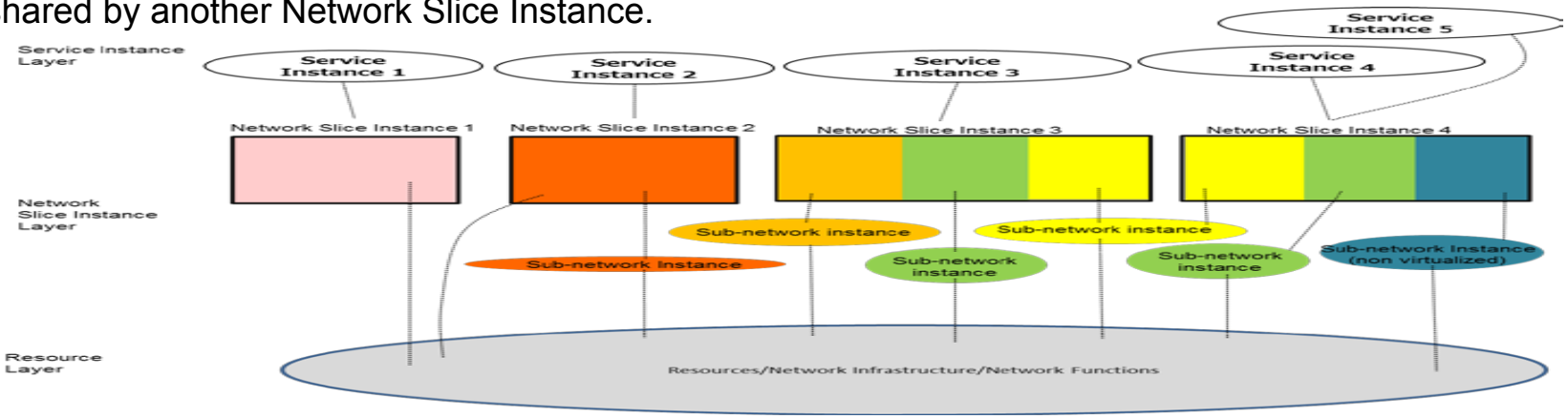


Definitions of Network Slicing & References(III)

II- Network Slicing :

NGMN Slice capabilities (2016) - consist of 3 layers: 1) Service Instance Layer, 2) Network Slice Instance Layer, and 3) Resource layer.

- The Service Instance Layer represents the services (end-user service or business services) which are to be supported. Each service is represented by a Service Instance. Typically services can be provided by the network operator or by 3rd parties.
- A Network Slice Instance provides the network characteristics which are required by a Service Instance. A Network Slice Instance may also be shared across multiple Service Instances provided by the network operator.
- The Network Slice Instance may be composed by none, one or more Sub-network Instances, which may be shared by another Network Slice Instance.



3GPP TR23.799 Study Item "Network Slicing' **2016**

ONF Recommendation TR-526 "Applying SDN architecture to Network Slicing" **2016**

IETF Draft draft-gdmb-netslices-intro-and-ps-02 2016- 2017

EU 5GPPP

- **15 Large Scale Research projects – all based on Network Slicing** (https://5g-ppp.eu) **(2015- 2018+)**
- **White Paper on 5G Architecture centered on network slicing** (https://5g-ppp.eu/wp-content/uploads/2014/02/5G-PPP-5G-Architecture-WP-July-2016.pdf) **(2016)**

(Proposal) Unified Slice definition

Slice as a union of subsets of resources & NFVs at a given time

(1) The Service Instance component

- represents the end-user service or business services.
- an instance of an end-user service or a business service that is realized within or by a NS.
- would be provided by the network operator or by 3rd parties.

(2) A Network Slice Instance component

- represented by a set of network functions, and resources
- forms a complete instantiated logical network to meet certain network characteristics required by the Service Instance(s).
- provides network characteristics which are required by a Service Instance.
- may also be shared across multiple Service Instances

(3) Resources component – it includes: *Physical, Logical & Virtual resources*

- *Physical & Logical resources* - An independently manageable partition of a physical resource, which inherits the same characteristics as the physical resource and whose capability is bound to the capability of the physical resource. It is dedicated to a Network Function or shared between a set of Network Functions;
- *Virtual resources* - An abstraction of a physical or logical resource, which may have different characteristics from that resource, and whose capability may not be bound to the capability of that resource.

(4) Slice Capability exposure component

- allow 3rd parties to access via APIs information regarding services provided by the slice (e.g. connectivity information, QoS, mobility, autonomicity, etc.)
- allow to dynamically customize the network characteristics for different diverse use cases within the limits set of functions by the operator.
- it includes a description of the structure (and contained components) and configuration of the slice instance.

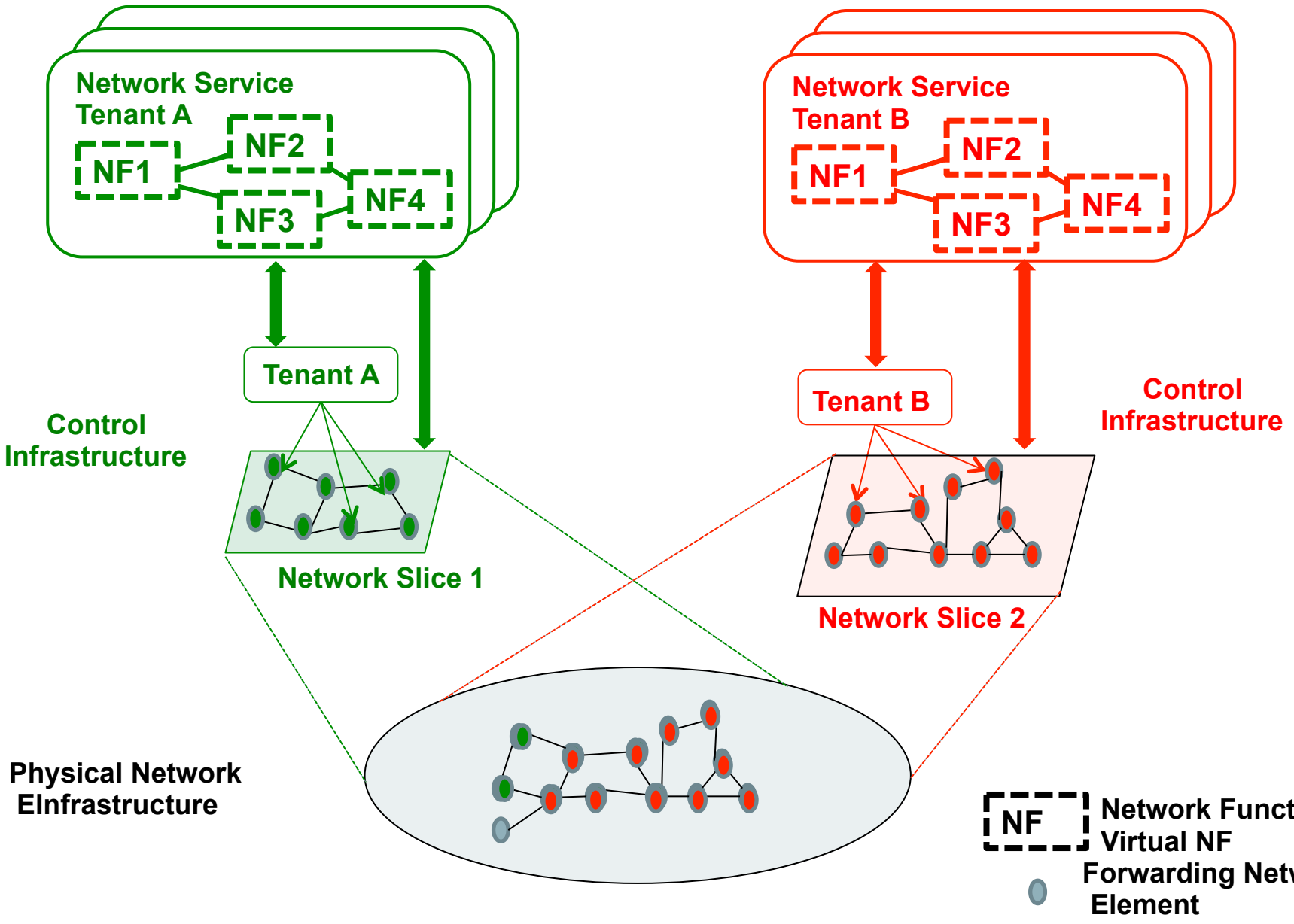
NS Key Characteristics - No1 Engineering Priority in 5G

- **A managed group of infrastructure resources, network functions and services** (e.g. Service Instance component, A Network Slice Instance component, Resources component , Slice Capability exposure component).
- **NS is programmable and has the ability to expose its capabilities**. The behaviour of the network slice realized via network slice instance(s).
- Concurrent deployment of **multiple logical, self-contained and independent, shared or partitioned networks on a common infrastructure platfor**m.
- Supports **dynamic multi-service support, multi-tenancy** and the integration means for vertical market players.
- **Service customized Network Slices (enabled by NFV principles) + Smart Network Fabric for coordinating/orchestration, control of network resource**
- **NSs** simplifies the provisioning of services, manageability of networks and integration and operational challenges especially for supporting communication services.
- **Network operators/ ISP can exploit network slicing** for
  - reducing significantly operations expenditures, allowing also programmability necessary to enrich the offered tailored services.
  - means for network programmability to OTT providers and other market players without changing the physical infrastructure.
- **Considerably transform the networking perspective** by
  - abstracting, isolating, orchestrating and separating logical network behaviors from the underlying physical network resources.

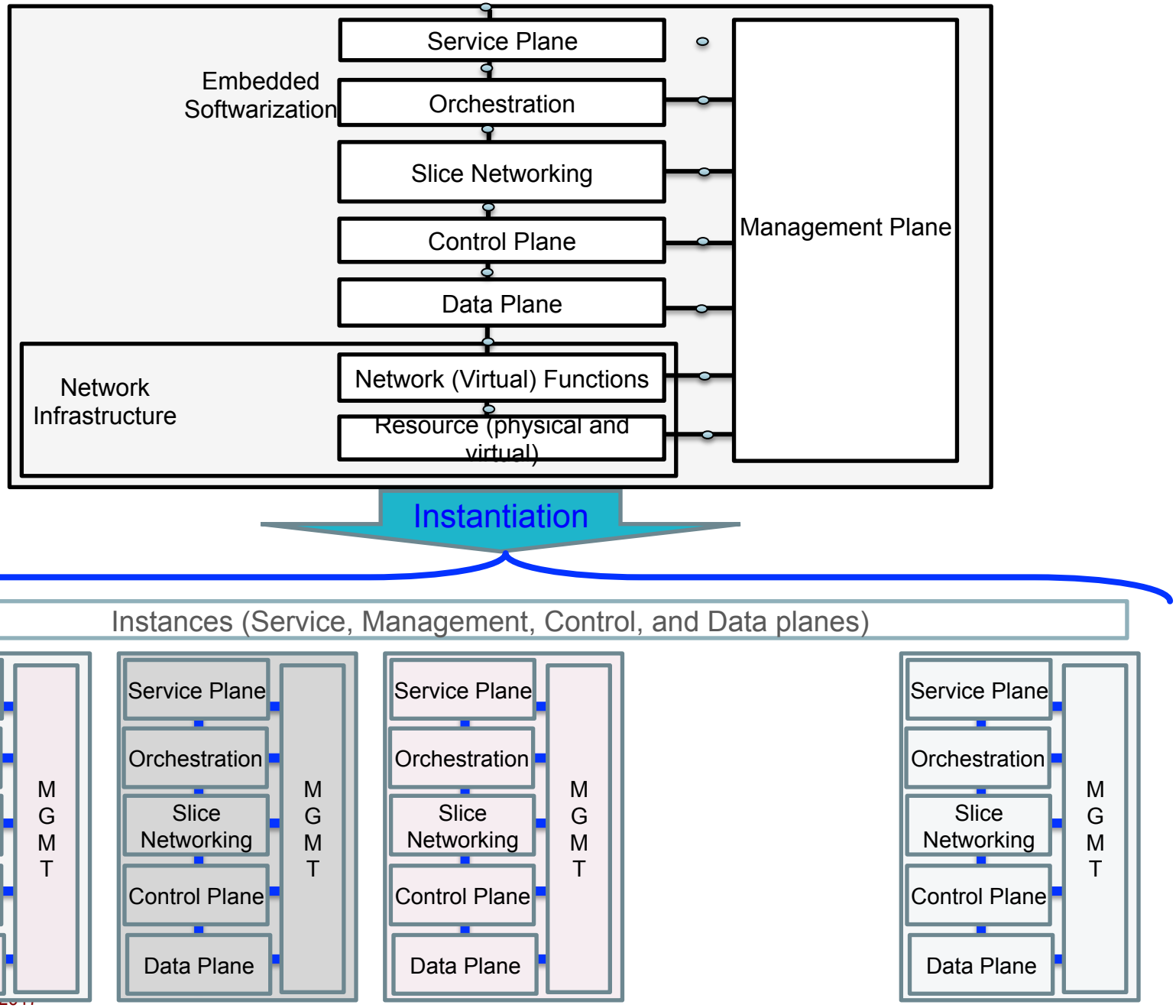
Network Slice Usage Scenarios

- Mission-critical Ultra low latency communication
- Massive-connectivity machine communication (e.g. Smart metering, Smart grid and sensor networks)
- Extreme QoS
- Independent QoS isolation design
- Independent operations and management
- Independent autonomic management functionality
- Independent cost and/or energy optimisation
- Independent multi-topology routing
- Sharing Infrastructure: Enablers for sharing infrastructure safely and efficiently (Multi-tenant)

Network Slice Representation



Network Slice Life Cycle Management



Network Slicing Key Challenges

(1) Uniform Reference NFV Model for Network Slicing (Architecture document): Describes all of the functional elements and instances of a network slice in NFV. Describes shared non-sliced network parts. Establishes the boundaries to the basic network slice operations

(2) Review common scenarios / Use Cases from the requirements for operations and interactions point of view. Describes the roles (owner, operator, user) which are played by entities with single /multiple entities playing different roles.

(3) Network Slice capabilities in NFV environment :

- Enablers for **safe, secure and efficient multi-tenancy in slices**.
- Methods to **guarantee/manage for the end-to-end QoS of service in a slice**.
- Recursion: methods for **NS segmentation allowing a slicing hierarchy** with parent - child relationships.
- Optimisation: **Mapping algorithms & methods for network resources automatic selection for NS ;** global resource view formed; global energy view formed; Network Slice deployed based on global resource and energy efficiency.
- **Monitoring status and behaviour of N**S in a single and/or muti-domain NFV environment.

5) Network slice operations in an NFV environment:

- **Slice life cycle management** including creation, activation / deactivation, protection, elasticity, extensibility, safety, sizing and scalability of the slicing model per network and per network clouds.
- **Slice management and operation**: namely configuration, composition, monitoring, optimisation, elasticity are carried as part of the slice protocols.
- **E2E Slice stitching / composition in an NFV environment**: having enablers and methods for efficient stitching /composition/ decomposition of slices:
  - vertically (service + management + control planes) and/or
  - horizontally (between different domains part of access, core, edge segments) and /or
  - vertically + horizontally.

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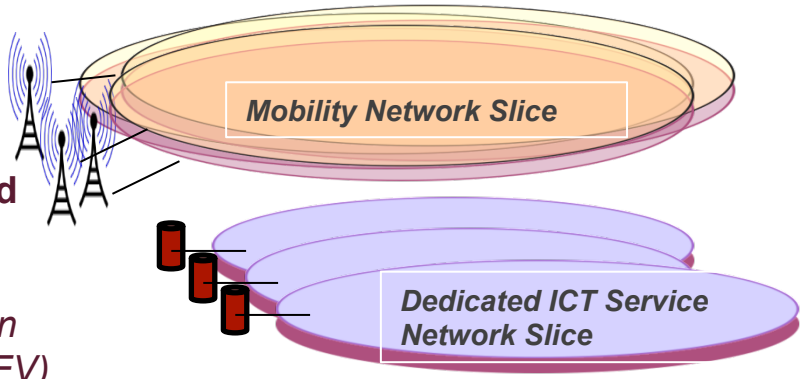
Future Smart Management Network

- **Dynamically adapting the network to meet future demands requires**
- **Creating the dynamic, configurable, resilient, cost effective network**
- **A programmable network operating system with simple interface to the network (smart network fabric)**
- **Transition from network devises to network functions and virtual network functions with inbound management**

E2N Multi-Domain Orchestration
E2D coordination, conflict resolution, multi-domain information exchange

Service Adapted Network Slices
Enabled by Network Function Virtualization (NFV)



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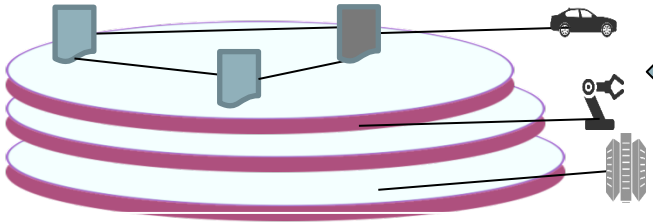

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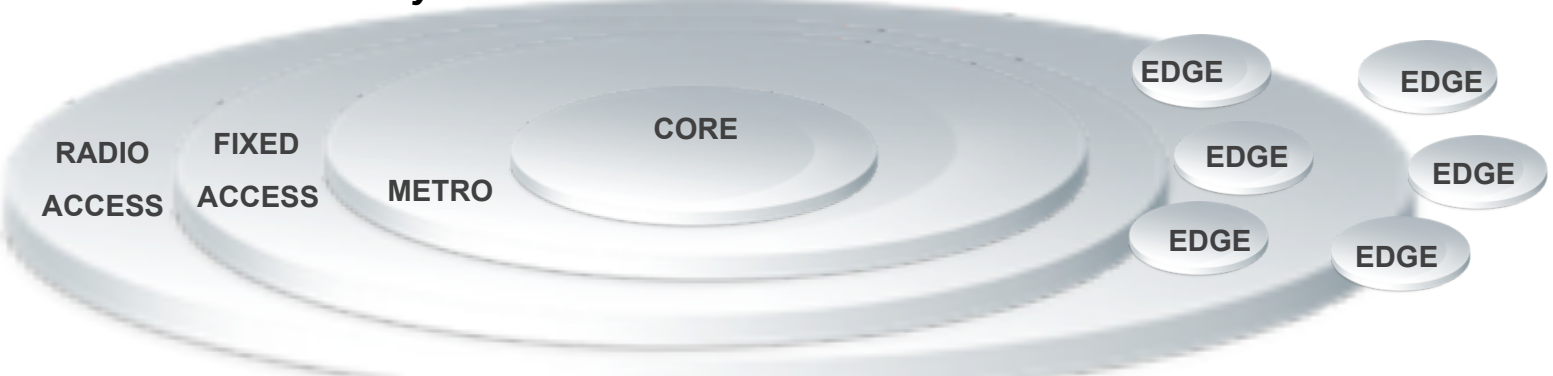


Smart Infrastructure Issues and chnallenges

E2N Multi-Domain Network Operating System Facilities

- ***Allocate (virtual) network resources, maintain network state, ensure network reliability in a multi domain environment***

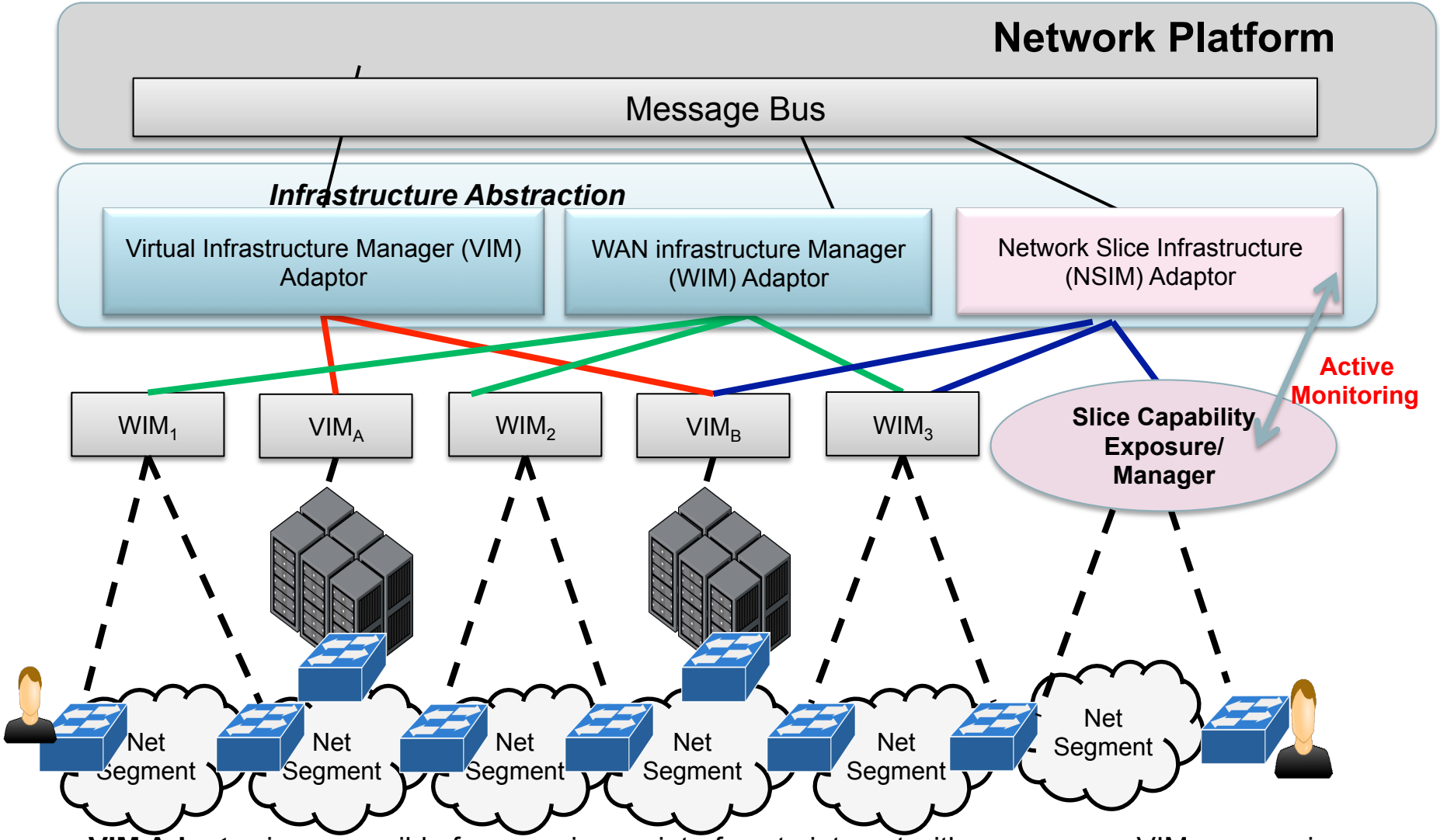
Infrastructure Abstraction plays the role of an abstraction layer between the MANO framework and the underlying (virtualised) infrastructure.

The Infrastructure Abstraction allows the orchestrator's entities to interact with the infras- tructure, regardless of the specific technology used to manage it. It exposes interfaces to manage service and VNF instances, retrieve monitoring information about the infrastructure status, reserve resources for services deployment.

It is composed of two main modules, the Virtual Infrastructure Manager Adaptor (VIM Adaptor) and the WAN infrastructure Manager Adaptor (WAN Adaptor). The VIM Adaptor is responsible for exposing an interface to interact with one or more VIMs, managing computational, network or storage resource in one or more Points of Presence to the Sonata MANO framework . The WIM Adaptor allows the service platform to manage network resources connecting different NFVI-PoPs in a vendor agnostic fashion, in order to provide connectivity to the deployed services.

These wrappers hide states, congurations, functions and implementations which are specicfic for each technology (OpenStack, OpenVIM, vCloud, OpenDaylight, VTN, etc...).

Network Abstraction – Work at UCL



- **VIM Adaptor** is responsible for exposing an interface to interact with one or more VIMs, managing computational, network or storage resource in one or more Points of Presence.
- **WIM Adaptor** allows the higher level capabilities to manage network resources connecting different NFVI-PoPs in a vendor agnostic fashion, in order to provide connectivity to the deployed services.
- **NSIM Adaptor** allows the higher level capabilities to manage network slices

Concluding Remarks

- Some of the Key Challenges in Realising 5G Smart Architecture were presented
- Network Programmability empowers the fast, flexible, and **dynamic deployment of new network and management services** executed as groups of virtual machines/ containers/ unikernels in the data plane, control plane, management plane as service plane in all segments of the network.
- Programmability in networks enables **dynamic changing the functionality and configuration** of network elements and/or network (virtual) functions and/or network ed dynamically. As such the behaviour of network resources can be customized and changed through programming interfaces for network control, management and servicing planes.
- Dynamic programming refers to **executable code that is injected and activated into the execution environments of network elements or the network containe**rs in order to create the new functionality/configuration at run time. The basic approach is to enable trusted third parties (operators, service providers, trusted management servers) to activate application-specific network functions or services (in the form of code) into the network.
- The key question is: how to exploit this potential flexibility for the benefit of both the operator and the end user. The answer lies in the promising potential that emerges with the advent of programmability in the following aspects:
  - Rapid deployment of large number of new services and applications;
  - Customization of existing service features;
  - Scalability and operational cost reduction in network and service management;
  - Additional independence of network equipment manufacturer;
  - Information network and service integration;
  - Diversification of services and business opportunities

Summary

- **Smart Networking is potentially No1 Engineering Priority in 5G**
  - **Service customized Network Slices enabled by NFV principles**
  - **Smart Network Fabric with Programmable Network OS Facilities for control of network resource**
  - **E2E Muti-domain Orchestration for coordinating network slices**

- **Slice and Smart Networking** would considerably ***transform the networking perspective*** **and** ***enhance architecture*** by
  - **abstracting,**
  - **Isolating at a sub-network level,**
  - **separating logical network behaviours from the underlying physical network resources**.
  - **dynamic management of network resources by managing resource-relevant slice configuration; simplification and reduction of operations expenditures**
  - **Support for rapid service provisioning**
  - **Support NFV deployment**

Acknowledgement - 5GPPP EU Research Projects

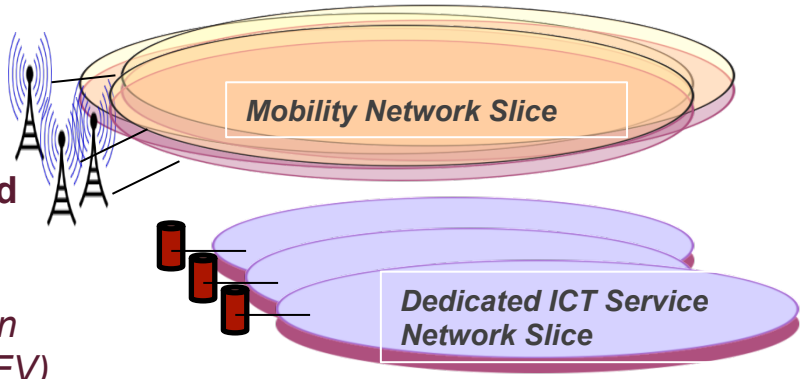
- **5GEx – "5G Multi-Domain Exchange" https://5g-ppp.eu/5gex/**
- **5G SONATA – "Service Programming and Orchestration for Virtualized Software Networks in 5G" https://5gppp.eu/sonata/.**

Future Smart Management Network

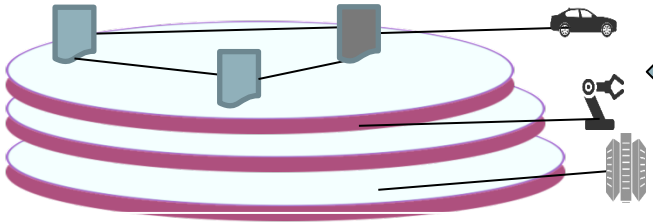
- **Dynamically adapting the network to meet future demands requires**
- **Creating the dynamic, configurable, resilient, cost effective network**
- **A programmable network operating system with simple interface to the network (smart network fabric)**
- **Transition from network devises to network functions and virtual network functions with inbound management**

E2N Multi-Domain Orchestration
E2D coordination, conflict resolution, multi-domain information exchange

Service Adapted Network Slices
Enabled by Network Function Virtualization (NFV)

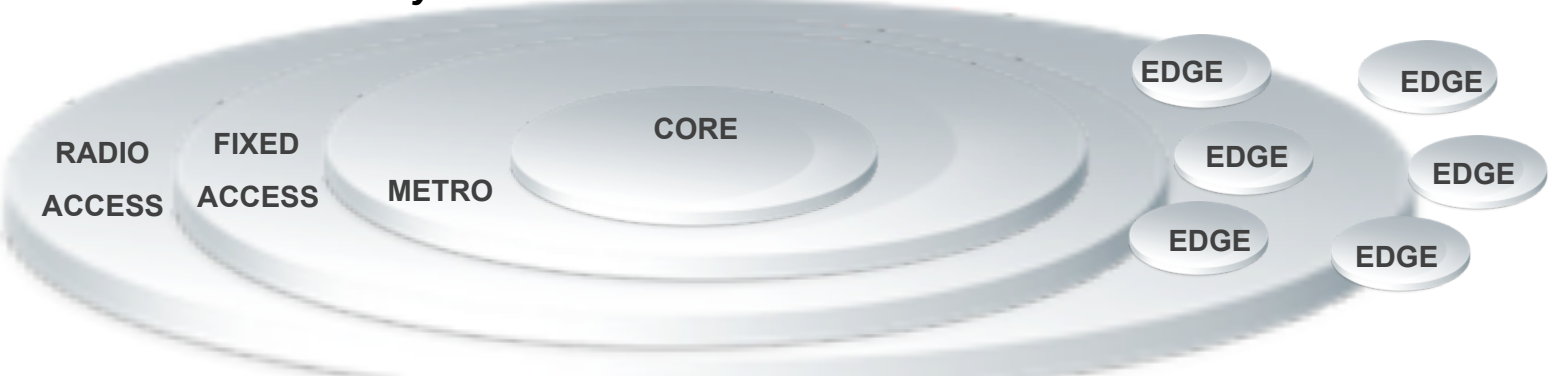


In-bound Cognitive Management



Smart Network Fabric: E2E Multi-Domain Network Operating System Facilities
Network Abstraction, Allocate (virtual) network resources, Maintain network state, Ensure network Reliability in a multi domain environment

Smart Cloud & Network Fabric
Enabled by Programmability Including SDN



Thank You

Confucius

“Ability will never catch up with the demand for it.”