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# In-Network 2030 Computing and Programmability
# Some Results and Research

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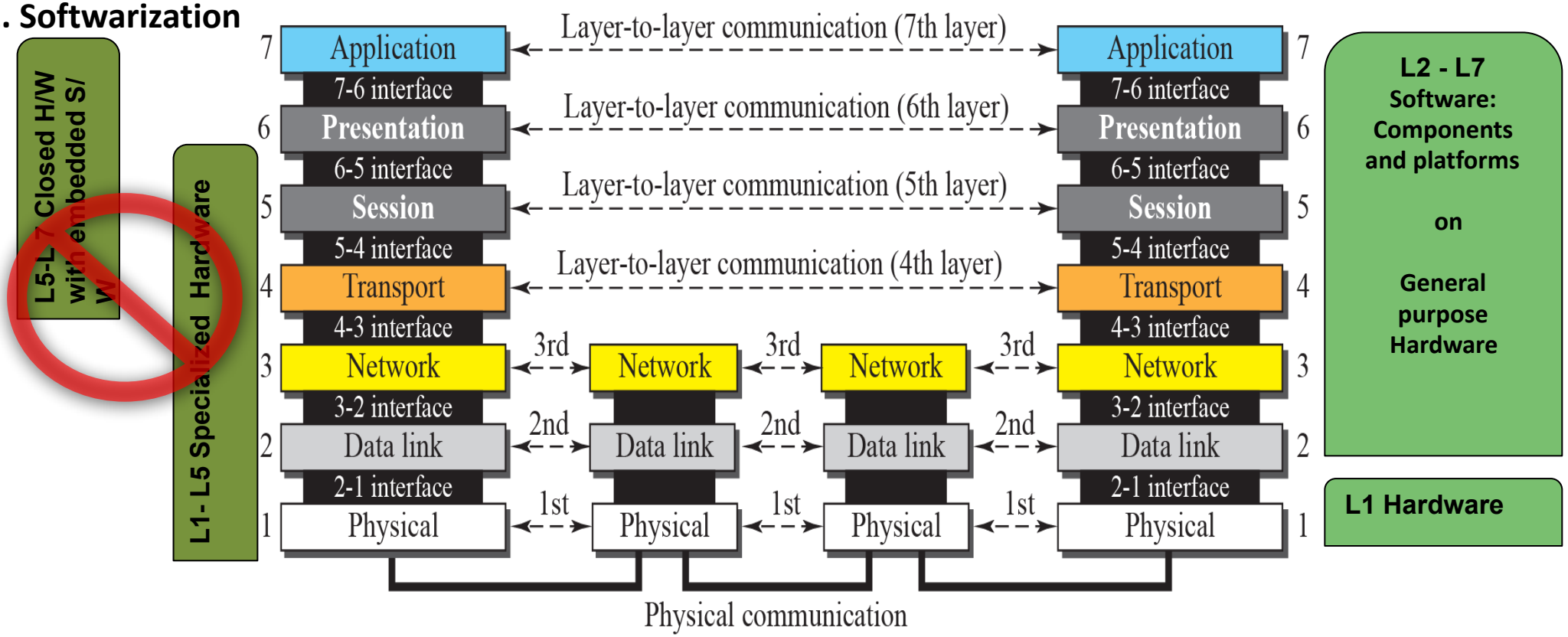
# Network 2030 Context & Trends

**1. Network 2030 -** an integrated, highly automated and intelligent infrastructure (In-Network communication, compute, storage and network services/applications paradigm), which contain a number of operational domains in all network segments (wire/wireless access, core, edge, space or mixture of segments) , that may be accessed by a user from one or more locations.

**2. Softwarization**



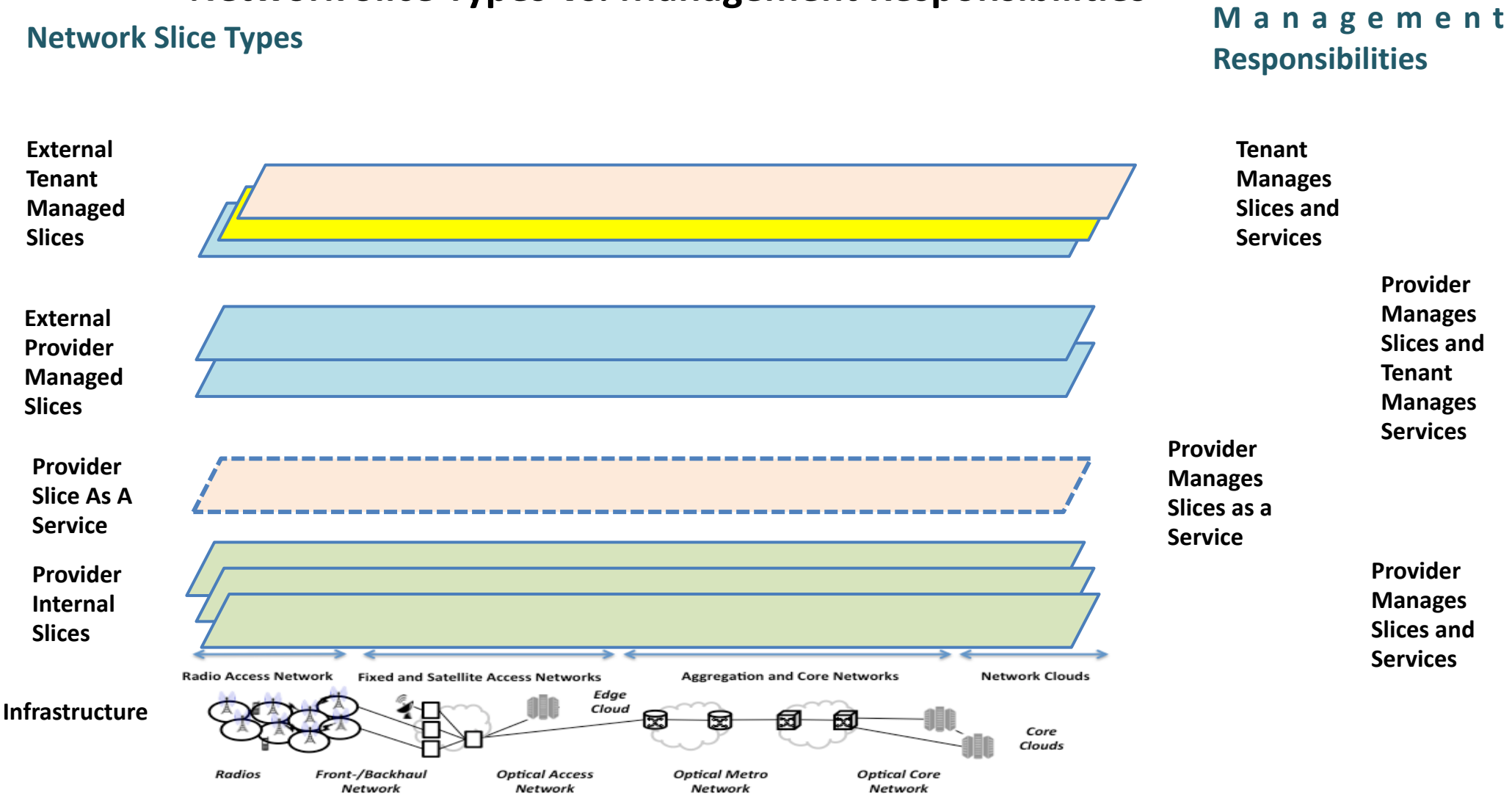

3. **Dynamic Interaction** between groups of communication, compute, storage and network services/ applications elements/devices in all network segments (edge, core, wire/wireless access, space)

4. **Cross Layers new requirements /characteristics**: different and very stringent non-functional requirements including the strict low latency and high data exchange requirements and guaranties for KPIs and/or SLA characteristics per parts of the infrastructure (slices).

# Network 2030 Context & Trends (Network Slicing)

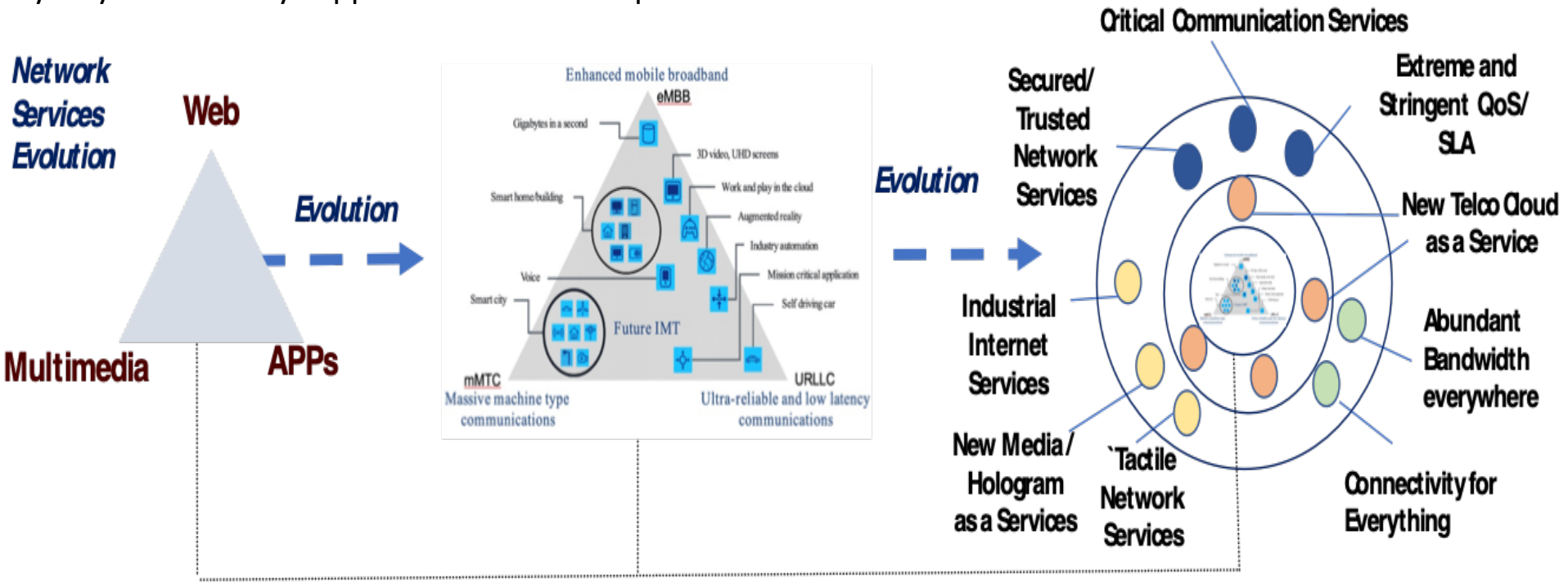
**Network Slice** – A Network Slice is a **managed group of subsets of resources, network functions / network virtual functions at the data, control, management/orchestration, and service planes at any given time.** The behaviour of the network slice is realized via network slice instances (i.e. activated network slices, dynamically and non-disruptively re-provisioned). A network slice is programmable and has the ability to expose its capabilities.

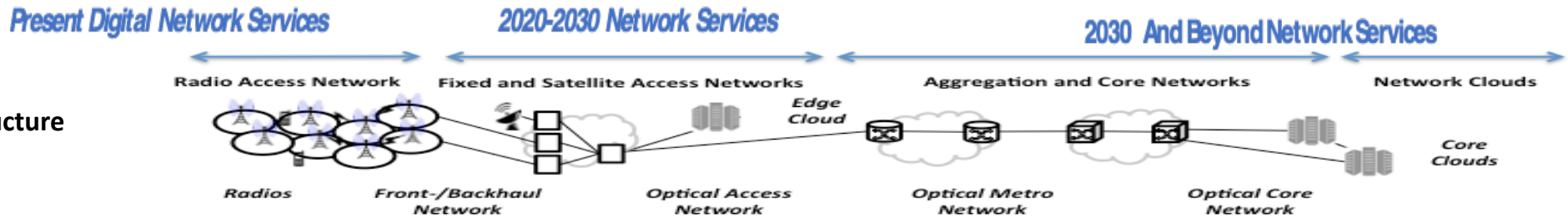
## Network Slice Types Vs. Management Responsibilities



# Network 2030 Context & Trends (Network Services Evolution)

- Delivery of stringent KPIs / SLAs per service (e.g. Gbps →Tbps, less than 20 ms for round trip latency)
- Guarantees and monitor mission critical services;
- New Telco Precision Service Cloud, Industrial Internet Services, Hologram as a Service, New Secure Network Services
- Integration at Hyper Scale of elements for service de livery (i.e. network devices, network (virtual) functions, edge elements and digital objects)
- Agility & Programmability (service functional change on demand)
- Anonymity and security support for all service operations



# In-Network Computing and Programmability – Key Terms

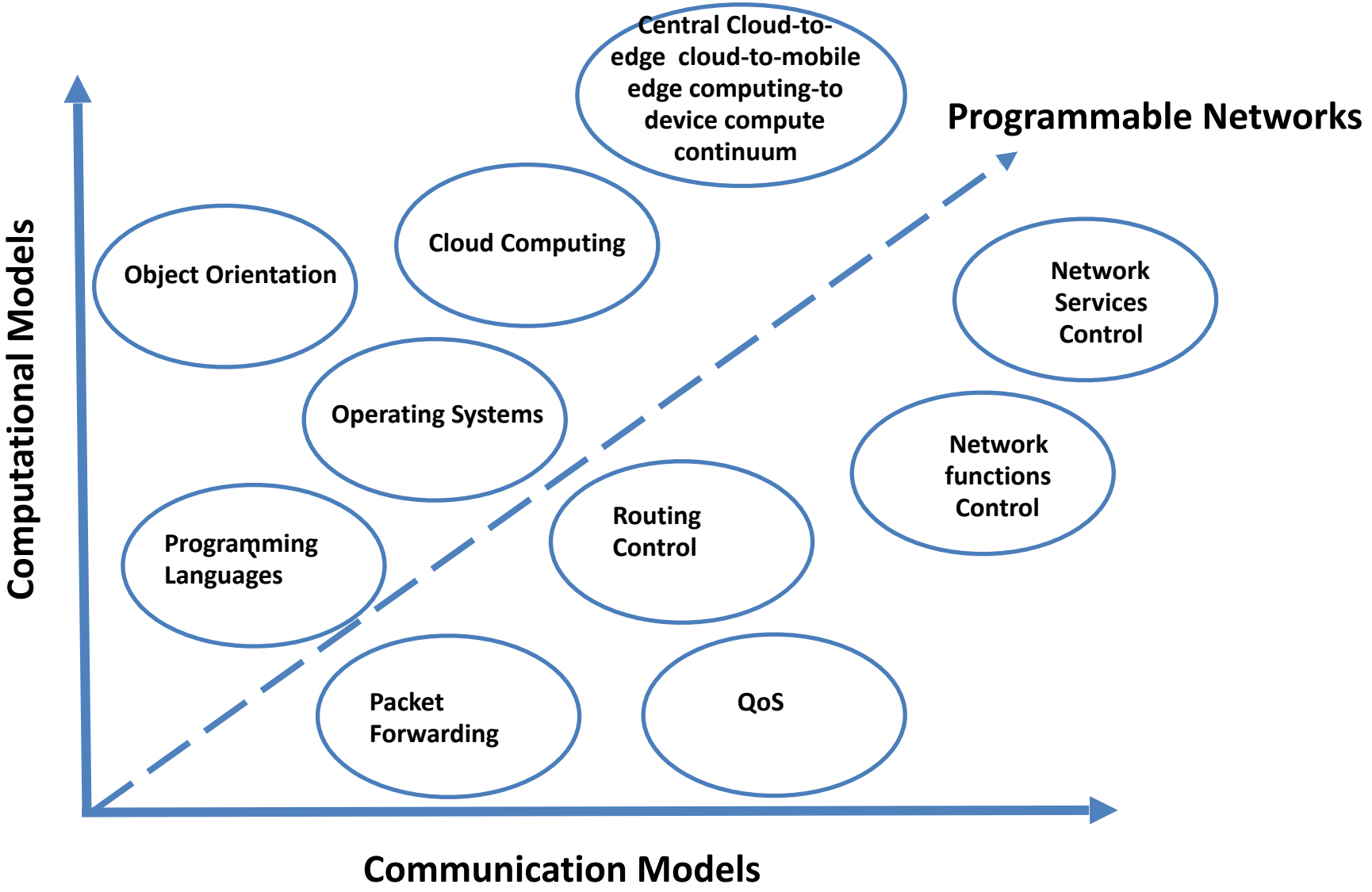
Network soft re-architecture is conceived as extremely flexible and highly programmable capability with native softwarisation infrastructures. As such **In-Network Computation and Programmability represents an evolution of native flexibility and programmability conversion in all network segments** (wireless/wire access, core, edge, space).

In **In-Network Computation and Programmability the decomposition of current monolithic network entities** into network functions or network virtual functions would be necessary and these functions should be able to be composed in an "on-demand", "on-the-fly" basis.

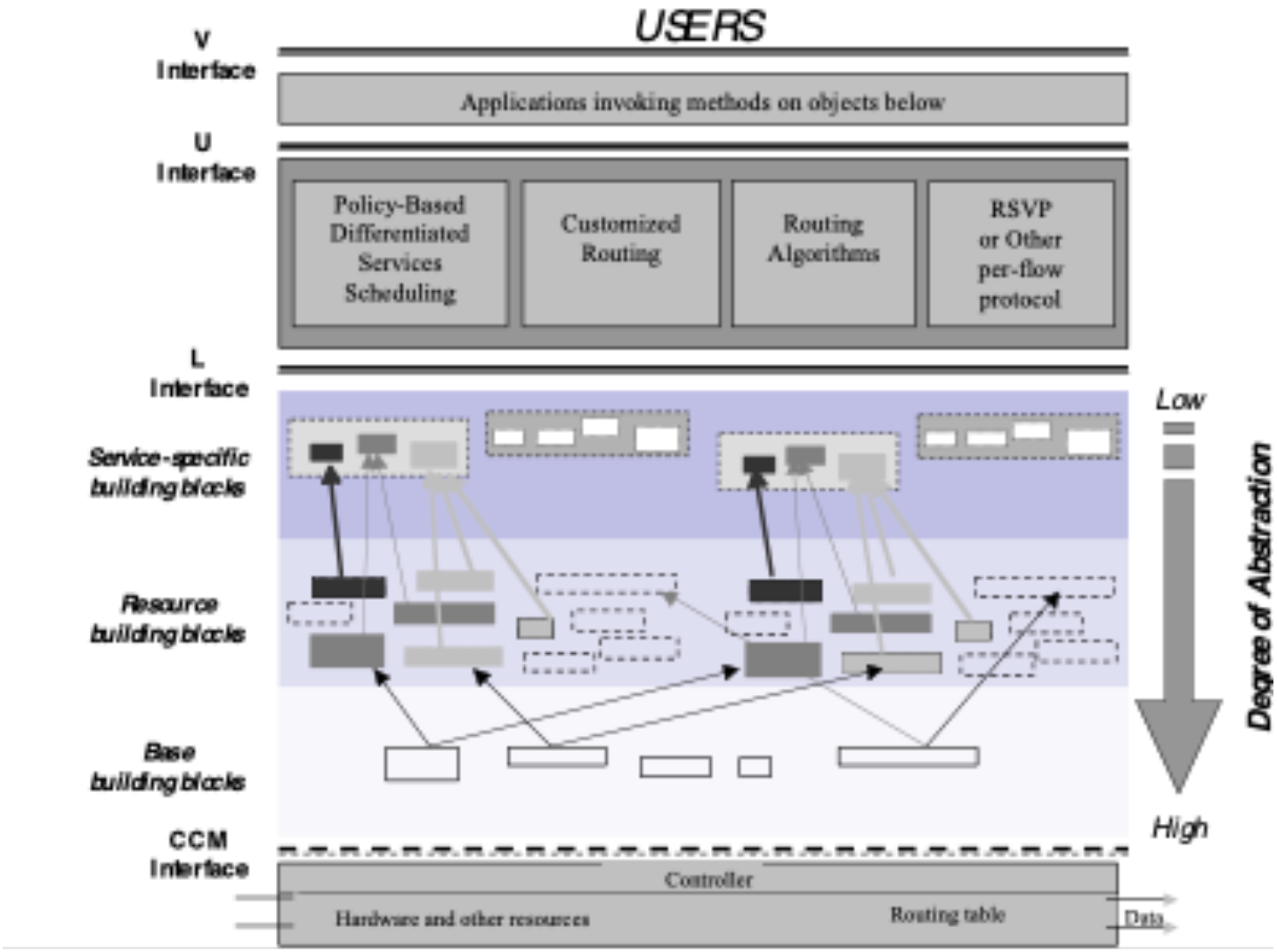
**Programmability in Networks enables the functionality of some of their network elements to be dynamically changed**. These networks aim to provide easy introduction of new network services by adding dynamic programmability to network devices such as routers, switches, and applications servers. Network Programmability empowers the fast, flexible, and dynamic deployment of new network functions and management services executed as groups of virtual machines in the data, control, management and service planes in all segments of the network infrastructure (i.e. wireless and wire access, core, edge and network cloud segments).

**Programmability in Networks refer to executable code that is injected into the execution environments of network elements in order to create the new functionality at run time with security characteristics**. The basic approach is to enable trusted third parties (end users, operators, and service providers) to inject application-specific services (in the form of code) into the network. Network services may utilize this network support in terms of optimized network resources and, as such, they are becoming network aware. The behavior of network resources can then be customized and changed through a standardized programming interface for network control, management and servicing functionality.

# Network Computing & Programmability – Evolution Space



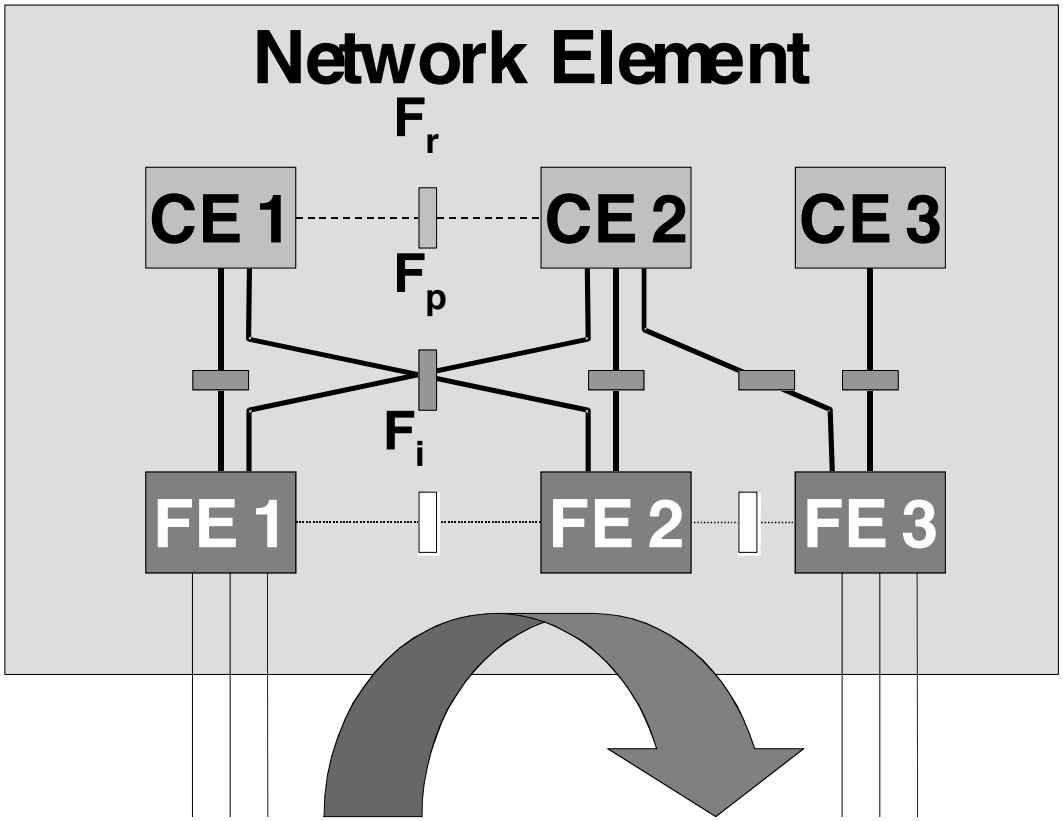
# Network Programmability Evolution – IEEE P1520 (1998)




Biswas, J., et al., "The IEEE P1520 Standards Initiative for Programmable Network Interfaces," IEEE Communications, Special Issue on Programmable Networks, Vol. 36, No 10, October 1998. http://www.ieee-pin.org/.

# Network Programmability Evolution – IETF ForCES (2002)

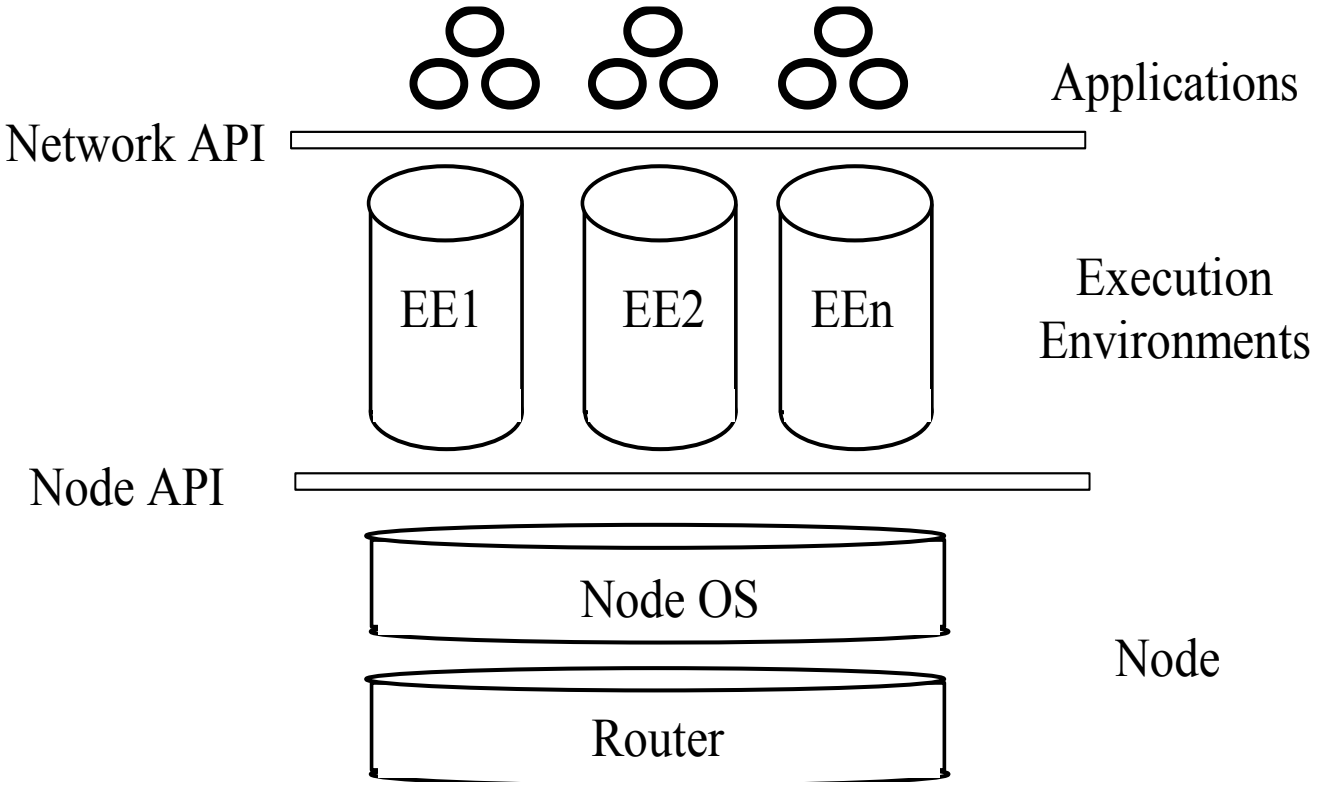
**ForCES – Separation of Forwarding (FE) and Control (CE) Elements in a Network Element**




IETF ForCES, draft-ietf-forces-framework-04.txt, December 2002. http://www.ietf.org/Internet-drafts/draft-ietf-forces-framework-04.txt

# Network Programmability Evolution – DARPA Active Networks (1999+)

## Active Node Architecture

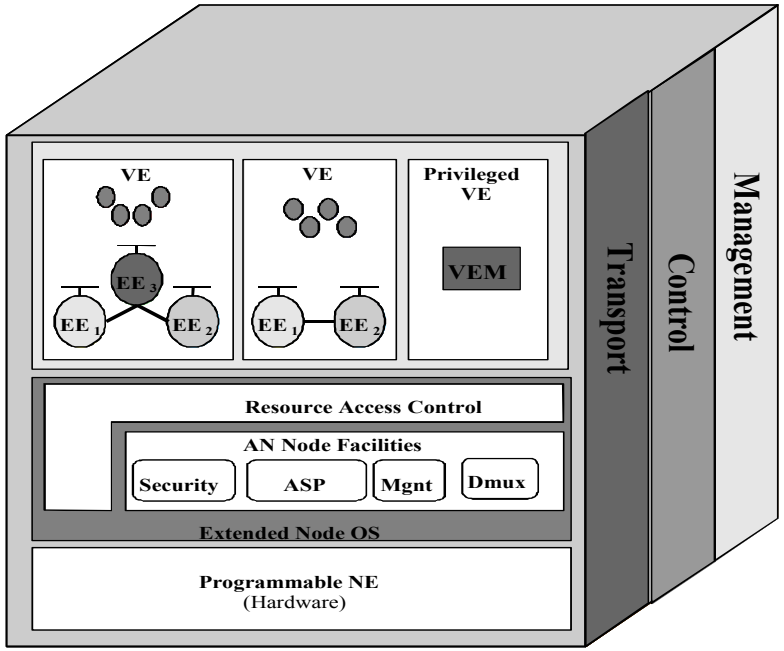



Calvert, K. L. (ed.), Architectural Framework for Active Networks, Draft version 1.0, July 27, 1999, http://protocols.netlab.uky.edu/~calvert/arch-latest.ps.

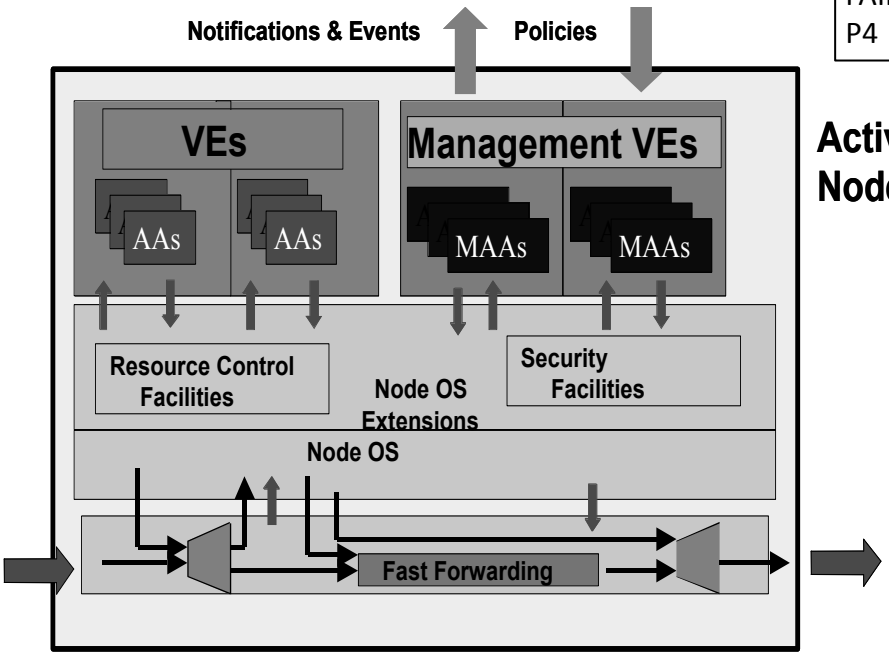
# Network Programmability Evolution – Node Operating Systems and Execution Environments (1999 - 2019)

| *Add-ons to Linux, NetBSD and MS Windows:* | *Proprietary NodeOS:* |
|---|---|
| ○ Pronto<br>○ Bowman<br>○ SILK<br>○ PromethOS<br>○ Crossbow/ANN<br>○ Lara++ | ○ Scout<br>○ Nemesis<br>○ Exokernel<br>○ Moab/Janos |

| Execution Environments |
|---|
| ANTS<br>ALIEN<br>PLAN<br>SNAP<br>CANES<br>ASP<br>Tamanoir<br>SwitchWare<br>FAIN EE<br>P4 |




FAIN Integrated Model

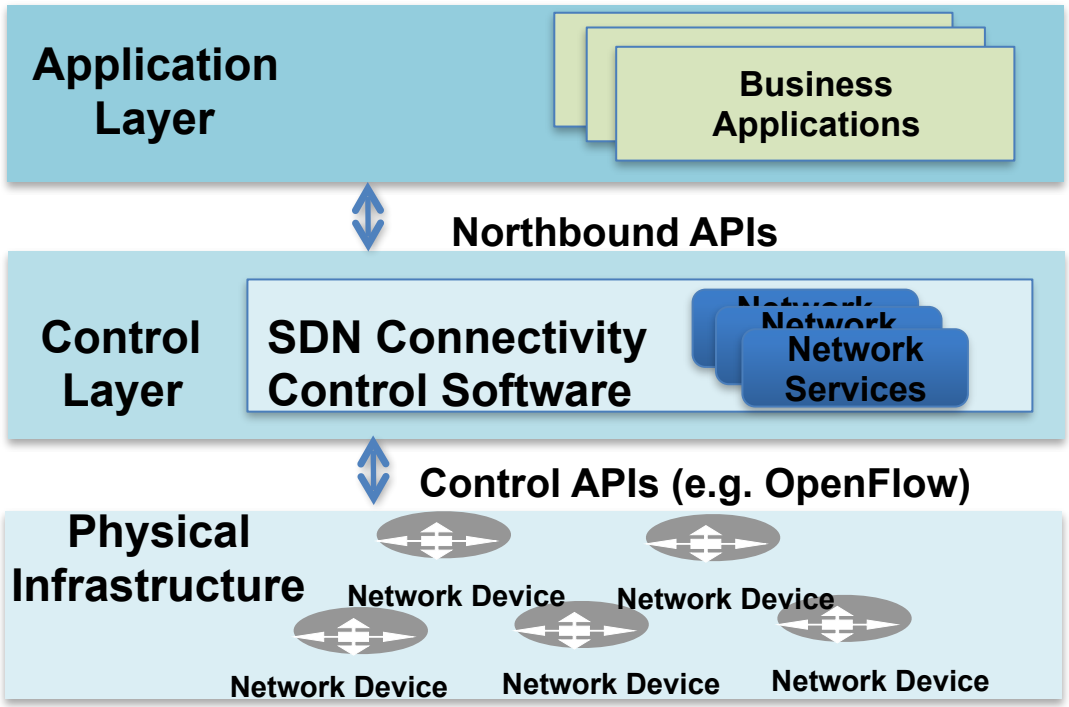



**Active Node**

**A Galis, S. Denazis, C Brou, C. Klein – Programmable Networks for iP Service Deployment – Research Book Arteck House, ISBN I-58053=745-6; 425 pp**

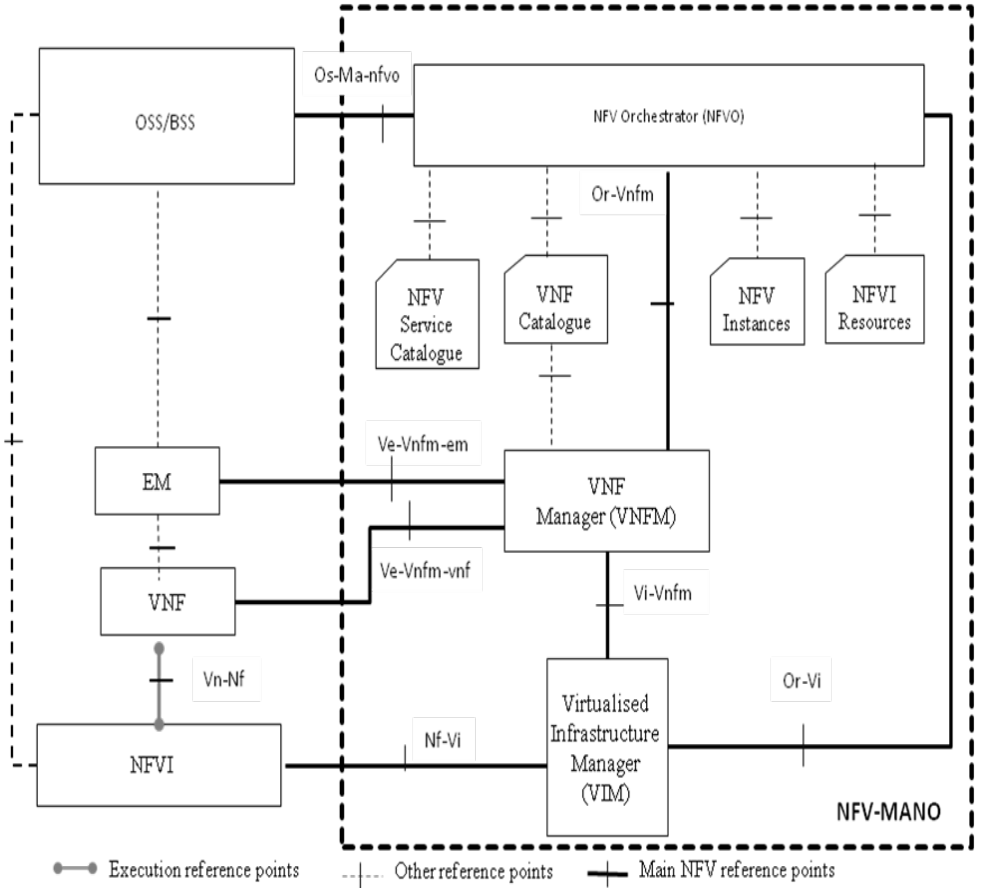
# Network Programmability Evolution – SDN & NFV Environments (2010+)

## *SDNs Architecture*
## ONF – Open Networking Foundation




ONF https://www.opennetworking.org

## *ETSI NVF Architecture*




ETSI NFV https://www.etsi.org/technologies/nfv

# Network 2030: In-Network Computing and Programmability Selected Use Cases

***Data Plane Programmability:***

• **User-defined networking**: programming the packet header, the variable–length IP addresses and the time-varying topology as driven and triggered by network services/applications characteristics and intents.

• **Deterministic forwarding**: programming customized functions to be performed on data packets as driven and triggered by intents of network services/applications (in-time and on-time determinism).

***Management & Orchestration Plane Programmability:***

• **Intrinsic anonymity programmability*:*** programming the network to provide communications channels where one endpoint is not made aware of any identity of the other side of the communication (i.e. for anonymity of deployed network services and higher protection) enabling critical national infrastructure as far as national and global security and economy is concerned.

• **Intrinsic slicing programmability**: programming life-cycle management of network slicing (Deploy, Change, Delete): Optimization resources (Auto-scaling/migration), Auto-healing; Efficient Interplay between Management and Data Planes; high reliability and KPIs control loops.

• **Intrinsic network function programmability:** Programming and activation of network (virtual) functions with KIPs guarantees in NFV or IP environments.

• **Intrinsic security programmability:** Programming, triggering, management, control of security characteristics.

***Service Plane Programmability:***

•High-precision network services deployment for robust and/or critical connectivity services, extreme QoS, autonomous driving, smart grids, unmanned vehicle management, tele-healthcare, automatic factory/industrial internet, entertainment, hologram, instantaneous teleporting, real-time gaming, tactile internet.

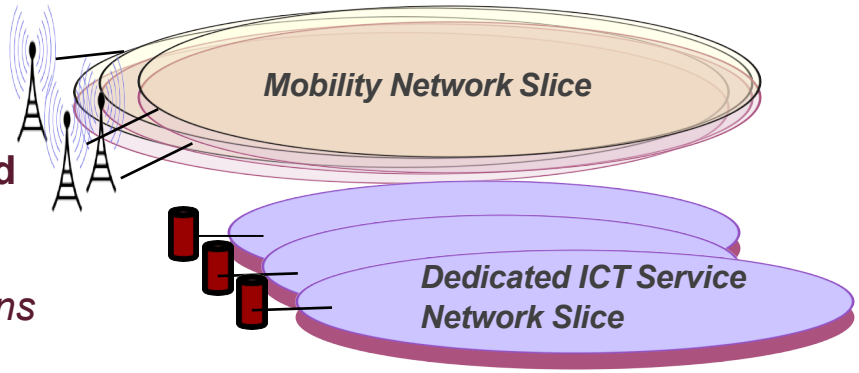
# Multi-domain In-Network Computing and Programmability

- Transition from network devices to (virtual) light-weight network functions with inbound management
- Dynamically adapting the network services with guaranteed bandwidth & latency & QoS demands
- Creating dynamic, configurable, programmable, resilient and safe networks
- Programmable network operating facilities with simple interface to the smart network fabric
- Increased intelligence-enabled application & network infrastructure

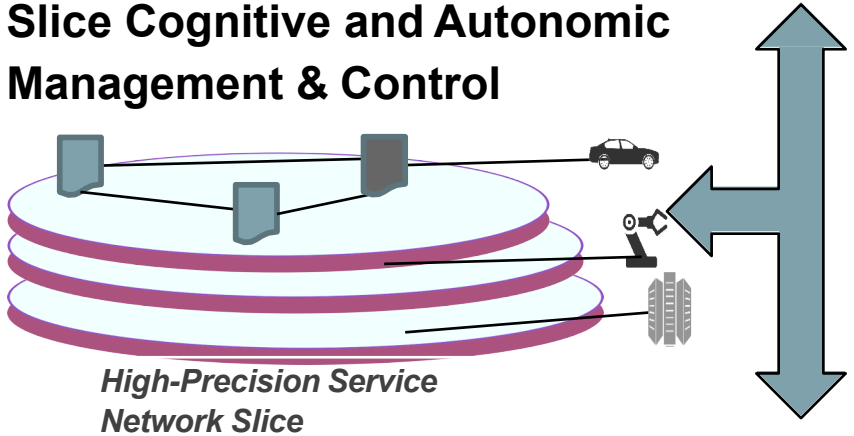
***E2E Multi-Domain Orchestration***

***E2E coordination, conflict resolution, multi-domain information exchange***

**Service Adapted Network Slices**
*Enabled by Network Functions Including NFV*

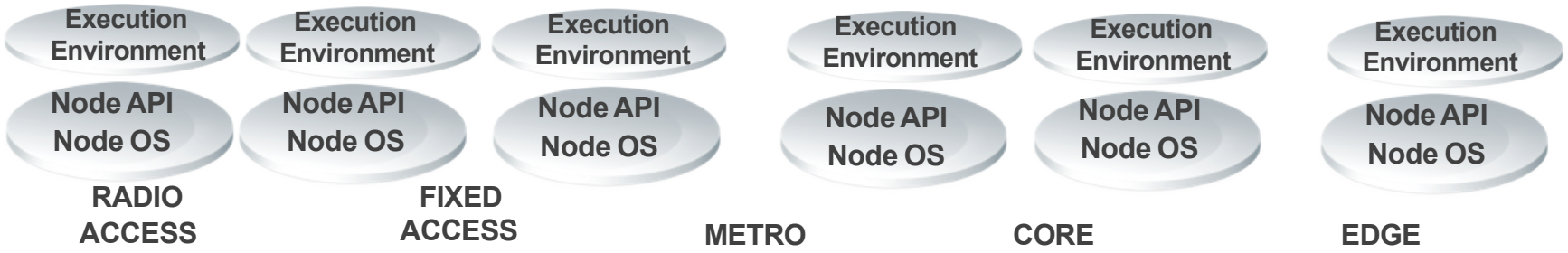



**Slice Cognitive and Autonomic Management & Control**




***Light Weight Smart Network as a Service & APIs – Multi-domain Network Operating System Facilities:*** ***Automation, Autonomicity, Network Abstraction & programmability, Allocate (virtual) network resources/ slices, Maintain network state, Ensure network Reliability in a multi domain environment***

**Smart Cloud & Network Fabric**
*Enabled by Programmability*



# Concluding Remarks

- **In-Network Computation and Programmability is both an old and new approach to networking and it is also a network design choice (an architectural principle).**

- **It enables soft network re-architecting avoiding ossification.**

- **In-Networks computation and programmability refers to executable code that is injected or activated into the execution environments of network elements in order to create the new functionality or new configuration at run time with the required security characteristics and guarantees.**

- **The basic approach is to enable trusted third parties (tenants, operators, and service providers) to activate application-specific services (in the form of code) into safe execution environment in the network. Network services may utilize this approach in terms of optimized network resources and, as such, they are becoming network aware. The behavior of network (computation, connectivity and storage) resources can then be customized and changed through a standardized programming interface for network control, management and servicing functionality.**

- **The significant value is in terms of practical solutions applicable to parts of the network 2030 and as well as of dynamic and non-disruptive control, operation, deployment and scaling of network and network service functions at the edge, core and access.**

# Thank you