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Network functions computation and programmability

Some Results and Research

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# Network Computing and Programmability – Key Terms

Programmability refers to executable code activated on the execution environments of network elements to create the new functionality at run time with security characteristics. The primary approach is to enable trusted third parties (end-users, operators, and service providers) to inject application-specific services (in the form of code) into any or all network segments (wireless/wire access, core, metro, edge, space). Network services may utilize this network support in terms of optimized network resources and, as such, they are becoming network-aware. Network resources' behaviors can then be changed through programming interface for forwarding, control, management, and servicing functionality.

In-Network Computing and Programmability (I-NCP) enables the functionality of some of their network elements to be dynamically changed. These networks aim to provide an easy introduction of new network services by adding dynamic programmability to network devices such as routers, switches, devices 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 network infrastructure segments.

I-NCP facilitates the decomposition of current monolithic network entities into network functions or virtual network functions; enabling functions to be composed in an "on-demand", "on-the-fly" basis deployability on a Continuum Central Cloud-to-edge cloud-to-mobile edge computing-to device compute.

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Future Networking Context & Characteristics

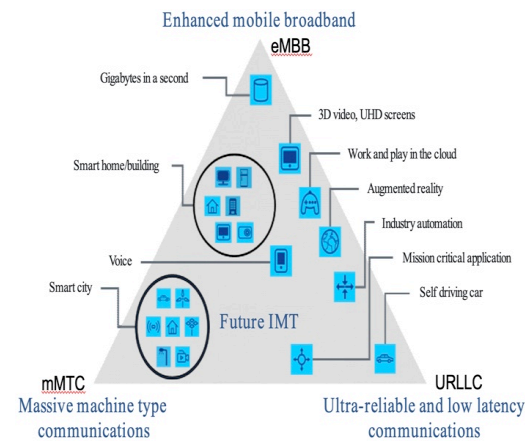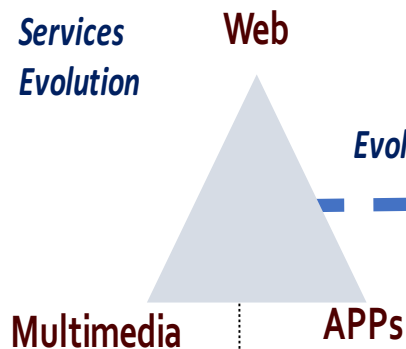**1. Networking -** an integrated, highly automated and intelligent infrastructure (In-Network communication, compute, storage and network services/applications paradigm), which contain a number of operational domains in all network segments (wire/wireless access, core, metro, edge, space or mixture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

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

3. Cross systems new requirements /characteristics /design choices: 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).
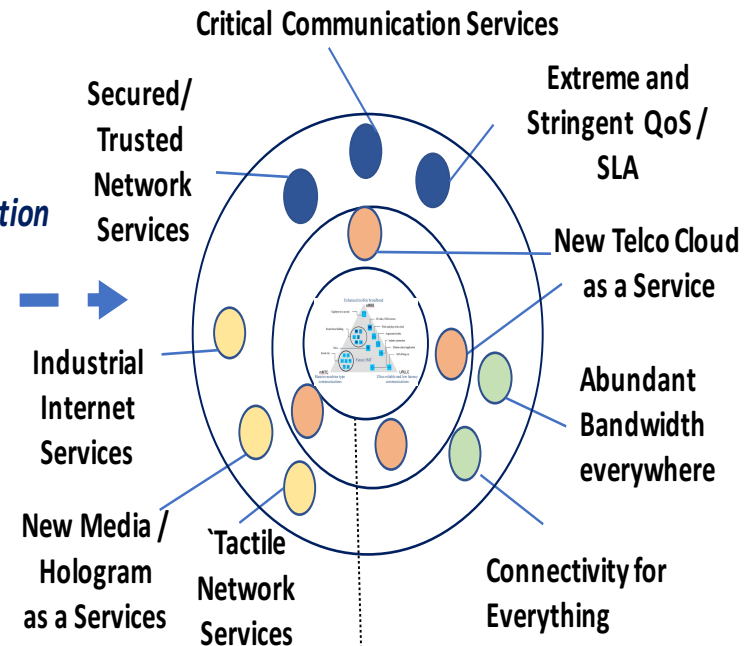
4. Softwarization
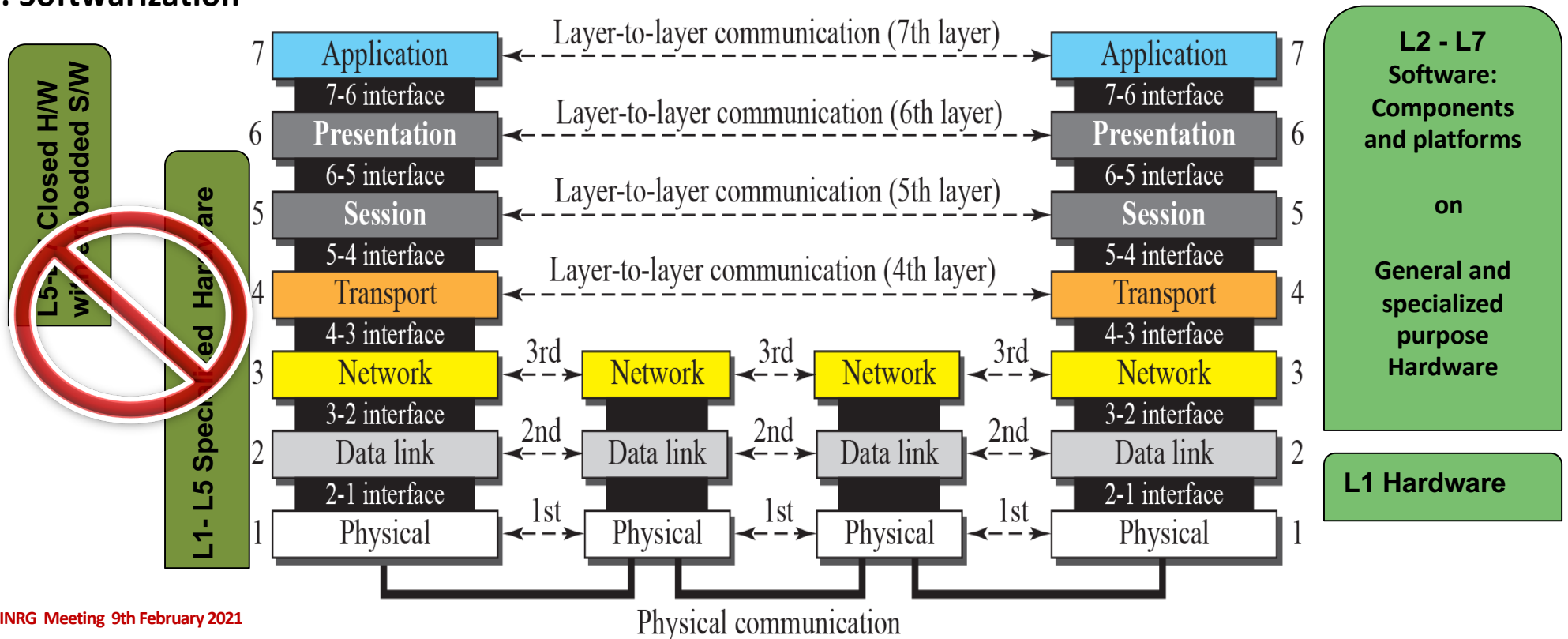
Networking - Context & Trends (Network Services Evolution)

- Delivery of stringent KPIs / SLAs per service (i.e. Gbps →Tbps, less than 20 ms for round trip latency)
- Guarantees and monitor mission critical 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
- Increased Autonomicity
- New Telco Precision Service Cloud, Industrial Internet Services, Hologram as a Service, New Secure Network Services
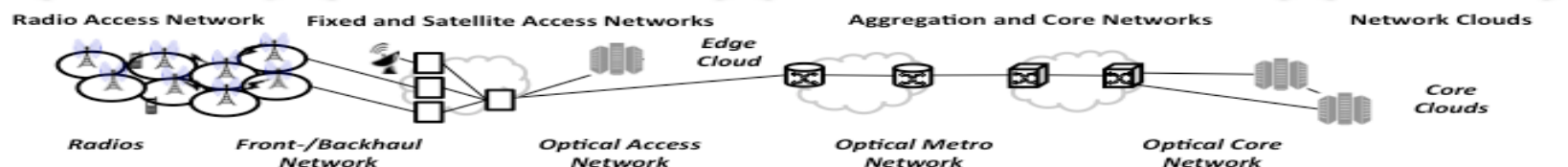
Network Slice – A Network Slice is a **managed group of subsets of resources, network functions / network virtual functions at the data, control, management/orchestration, and service planes at any given time.** The behavior of the network slice is realized via network slice instances (i.e. activated network slices, dynamically and non-disruptively re-provisioned). A network slice is programmable and it has the ability to expose its capabilities.

Network Slice Types Vs. Management Responsibilities

Network Slice Types

Management Responsibilities

Network Slice Types	Management Responsibilities
External Tenant Managed Slices	Tenant Manages Slices and Services
External Provider Managed Slices	Provider Manages Slices and Tenant Manages Services
Provider Slice As A Service	Provider Manages Slices as a Service
Provider Internal Slices	Provider Manages Slices and Services

Infrastructure

Radio Access Network   Fixed and Satellite Access Networks   Aggregation and Core Networks   Network Clouds

Edge Cloud

Core Clouds

Radios   Front-/Backhaul Network   Optical Access Network   Optical Metro Network   Optical Core Network

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Network Computing & Programmability – Evolution Space

USERS

Interface	
V Interface	Applications invoking methods on objects below
U Interface	Policy-Based Differentiated Services Scheduling / Customized Routing / Routing Algorithms / RSVP or Other per-flow protocol
L Interface	
Service-specific building blocks	
Resource building blocks	
Base building blocks	
CCM Interface	Controller / Hardware and other resources / Routing table / Data

Low ... *High* — *Degree of Abstraction*

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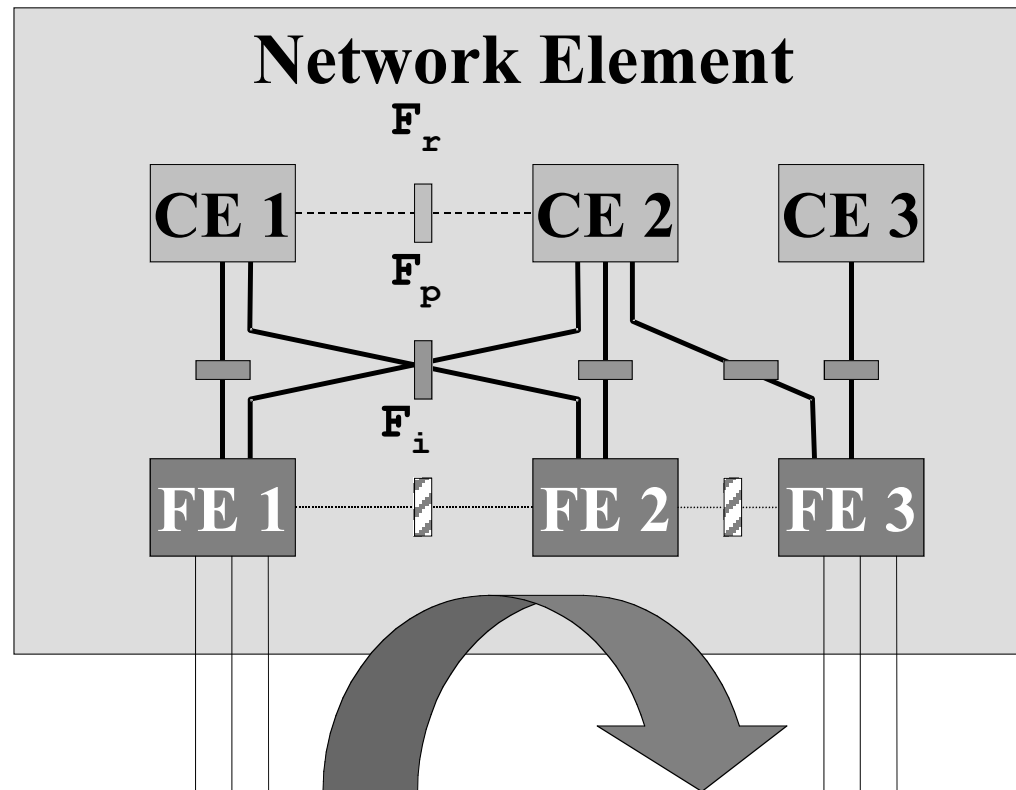
IETF ForCES, draft-ietf-forces-framework-04.txt, December 2002. http://www.ietf.org/Internet-drafts/draft-ietf-forces-framework-04.txt

Active Node Architecture

Network API

Applications

EE1 EE2 EEn

Execution Environments

Node API

Node OS

Router
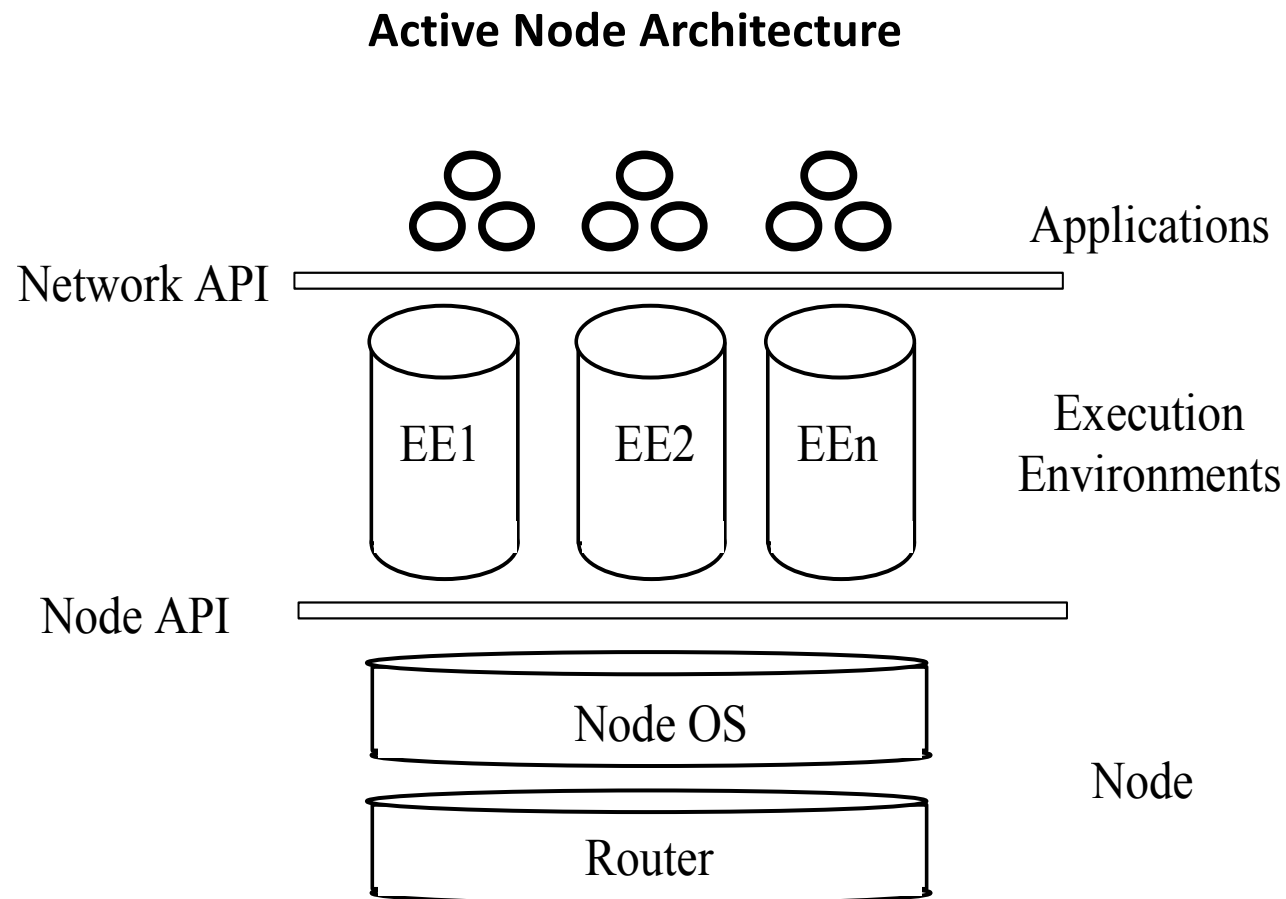
Node

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.

SDNs Revisited Architecture
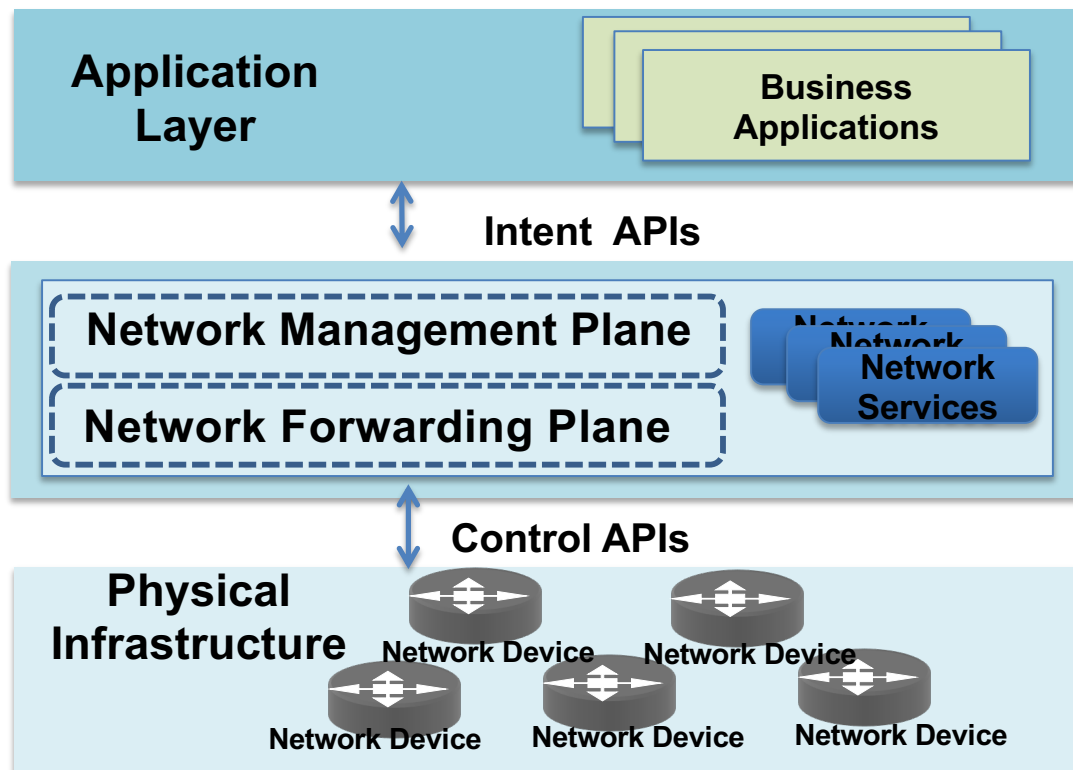
Application Layer

Business Applications

↕ **Intent APIs**

Network Management Plane

Network
Network
Network Services

Network Forwarding Plane

↕ **Control APIs**

Physical Infrastructure

Network Device

Network Device

Network Device

Network Device

Network Device

Add-ons to Linux, NetBSD and MS Windows

- Pronto
- Bowman
- SILK
- PromethOS
- Crossbow/ANN
- Lara++
- eBPF

Proprietary NodeOS

- Scout
- Nemesis
- Exokernel
- Moab/Janos

Execution Environments

- ANTS
- ALIEN
- PLAN
- SNAP
- CANES
- ASP
- Tamanoir
- SwitchWare
- FAIN EE
- AKA
- P4

Data Plane Devices

1. CONTROL LAYER
Pyretic , Maple, Kinetic , NetEgg
2. SOFTWARE SWITCHES
OVS, BESS, VPP, ESwitch, PISCES, NetBricks , Andromeda
3. DATA FLOW GRAPH
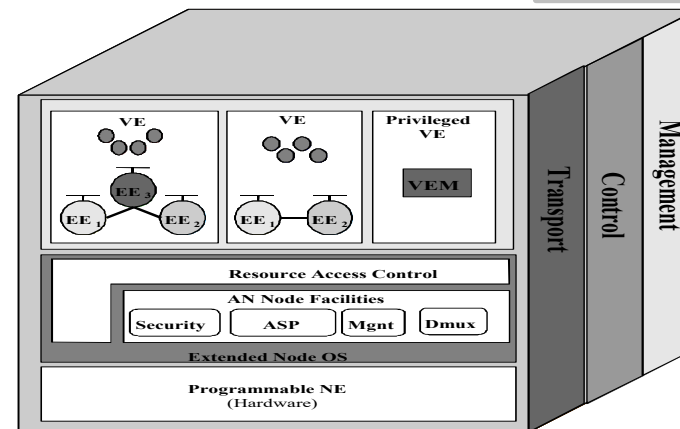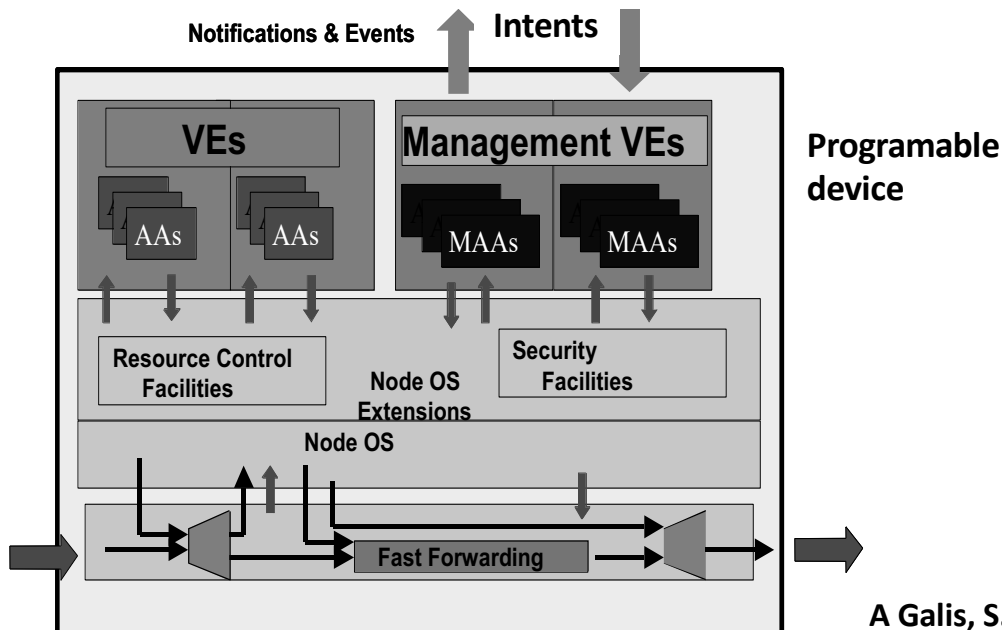Click, VPP, BESS, NetBricks
4. MATCH-ACTION PIPELINE
OpenFlow, P4, FAST, OpenState, Domino
5. STATE-Based
FAST, OpenState, NetBricks , Domino
6. FFLOWS programmability - SDN

Programable device

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 functions computation and programmability - Selected New Challenges across all network segments

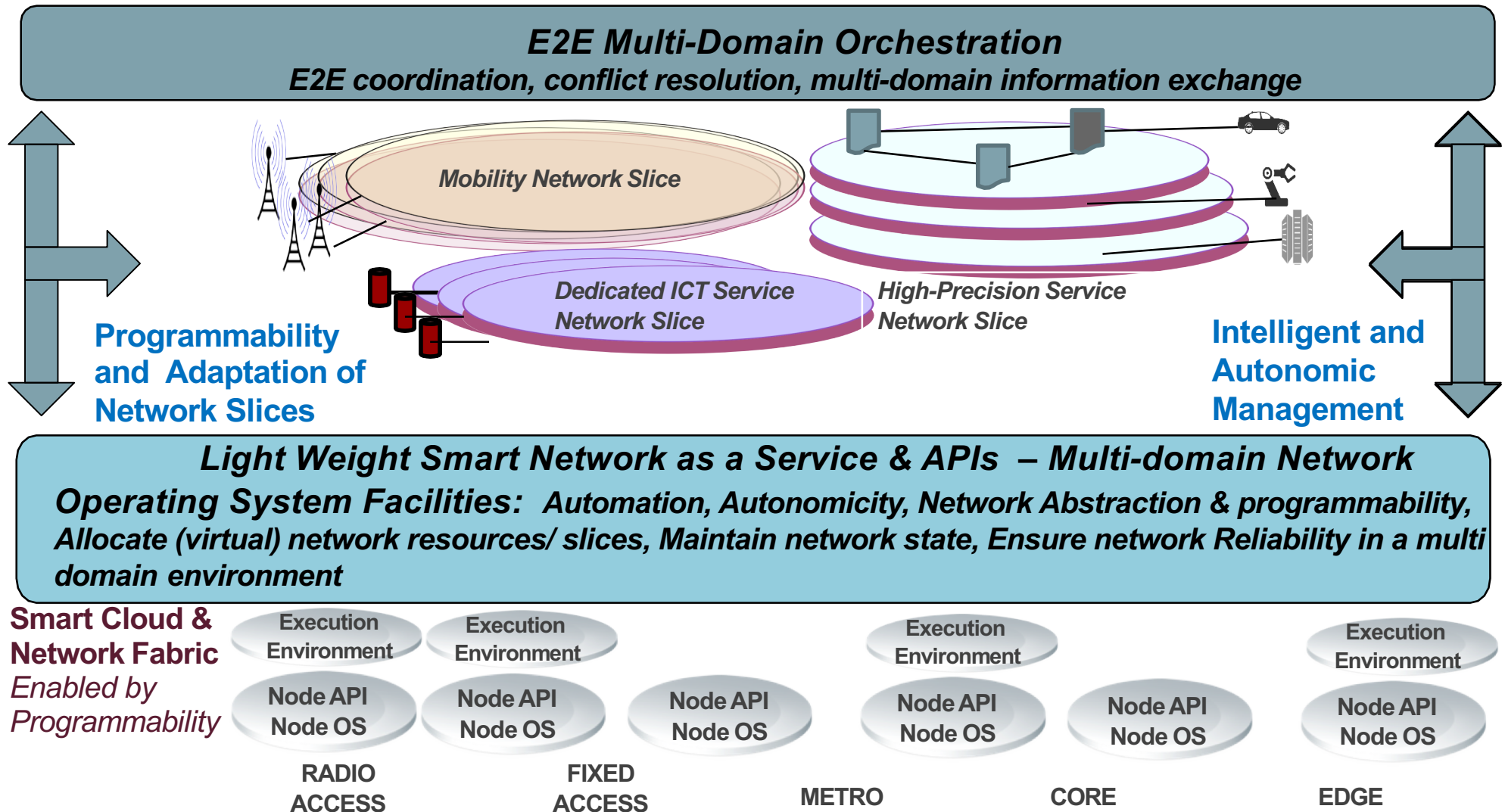*Data/ Forwarding Plane Programmability (part of IP layer re-engineering):*

• **Intent-based data plane APIs -** Expose data plane functionality to the operator offering programming freedom while masking the underlying complexities efficiently.

• **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).

• **Replacement of best effort with 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.

Management & Orchestration Plane Programmability:

• **Need for an architectural and platform level progress on how to address the new network programmability requirements and how to address (inter)network new characteristics and challenges**

• **Triggering network programmability methods & platforms**

• **Efficient network function programmability:** efficient activation of network (virtual) functions with KPIs guarantees in IP environments ans also across network segments; **increased autonomicity**

• **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 forwarding Planes; high reliability and KPIs control loops.

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

• **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.

Multi-domain In-Network Computing and Programmability

- Transition from network devices to (virtual) light-weight network functions with inbound self management
- Dynamically adapting the network services with guaranteed KPIs demands
- Creating programmable, dynamic, configurable, resilient and safer networks
- Programmable network operating facilities with simple interface to the smart network fabric
- Increased Network Autonomicity & Inteligence-enabled Management

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

Mobility Network Slice

Dedicated ICT Service Network Slice

High-Precision Service Network Slice

Programmability and Adaptation of Network Slices

Intelligent and Autonomic Management

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

Execution Environment	Execution Environment		Execution Environment		Execution Environment
Node API Node OS	Node API Node OS	Node API Node OS	Node API Node OS	Node API Node OS	Node API Node OS
RADIO ACCESS	FIXED ACCESS	METRO	CORE		EDGE

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Concluding Remarks

In-Network computation and programmability (I-NCP) refers to executable code that is injected or activated into the execution environments of network elements to create the new (network, network service) functionality or new configuration at run time with the required security characteristics and guarantees in each and all networking segments (wire/wireless access, core, edge, space). I-NCP is both an old and new approach to networking, and it is also a network design choice. It enables:

- unprecedented levels of abstraction, disaggregation, operation, integration, and control of network infrastructures and services.
- soft network re-architecting avoiding ossification, accelerate service deployment and facilitate infrastructure management.
- even greater flexibility, reliability, adaptability, scalability and potential for automation and autonomicity.

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.

(I-NCP) techniques are moving from software-defined infrastructures towards the open edge and access networks, from continuous deployment towards full automation, from service function, chaining towards network slicing, from optimization techniques towards intelligent-based decisions, all of them leading towards further *convergence between internetworking and IP layer re-engineering, Network 2030, 5G and Beyond, and industry verticals*.

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Thank you