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School of Electrical
Engineering

Mobile Communication Systems

Lecture III

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Outline

- **Legacy Networks:**
  - GSM
  - GPRS
  - UMTS
- **System Architecture Evolution**
  - Background & requirements
  - Motivation
  - Basic principles
  - Network elements and high level functions
  - Attach procedure
  - EPC Protocols
- **Architectural enhancements for E-UTRAN and interoperability with 3GPP and non-3GPP accesses**
  - Interoperability Mobility and handover management
  - Policy Control and Charging (PCC)
  - QoS Provisioning
  - Security (Authentication) & its evolution

Main References:

- 3GPP Technical Specifications 23.401
- 3GPP Technical Specifications 23.402
- TS 33.401 – LTE Security
- TS 33.102 – 3G Security

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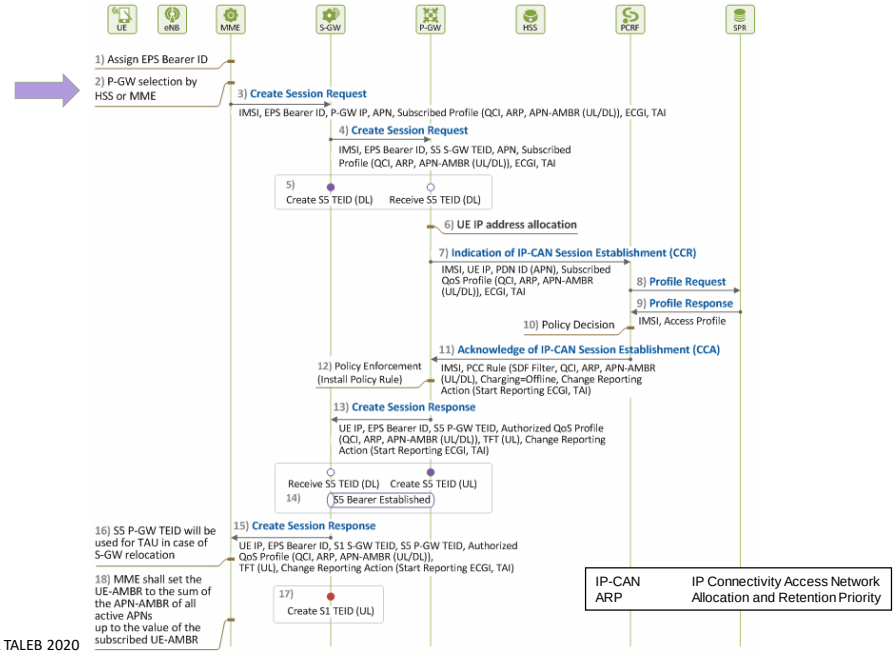
EPS Session Management



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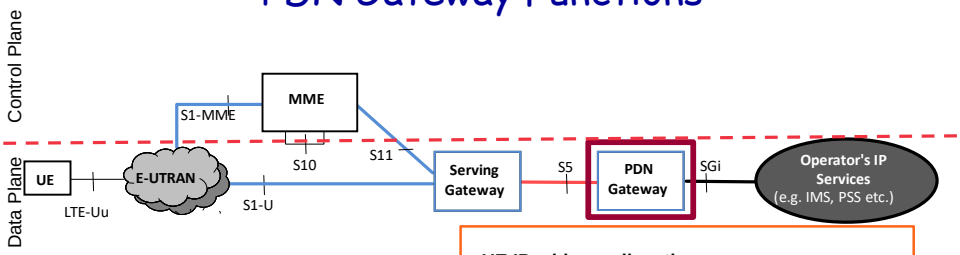
PDN Gateway Functions



- **UE IP address allocation**
- **UE data anchoring**
- **Per user packet filtering**
- **Lawful interception**
- **Transport level packet marking**
- **Service level charging**
- **Service level gating control**
- **Rate enforcement based on**
  - Aggregate Maximum Bit Rate for an APN
  - Accumulated Maximum Bit Rates of the aggregate of service data flows with the same guaranteed bit rate
- **DHCPv4 & DHCPv6 functions**

GTP-based S5

- **Up/Downlink bearer binding**
- **Uplink bearer binding verification**
- **IP neighborhood detection**

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Outline

- **5G Enabling Technologies**
  - Software Defined Networking (SDN)
  - Network Function Virtualization (NFV)
- **5G Requirements**
- **Network Softwarization and Slicing**
- **5G Architecture(s)**

Main References:

- 3GPP Technical Specifications 23.501
- ETSI ISG NFV https://www.etsi.org/technologies/nfv
- ONF https://www.opennetworking.org/

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Software Defined Networking

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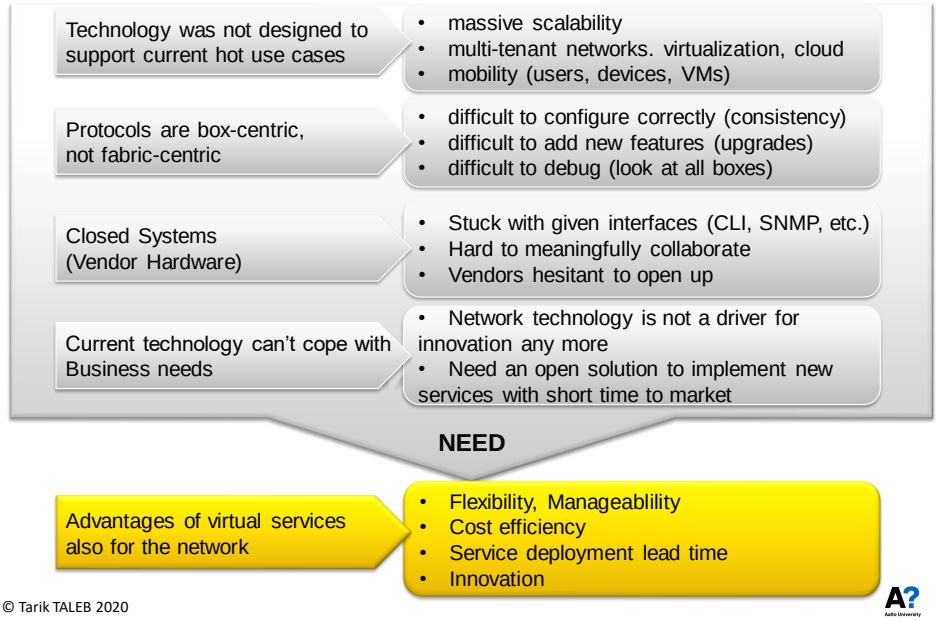
Conventional Network Technologies Are Not Agile!



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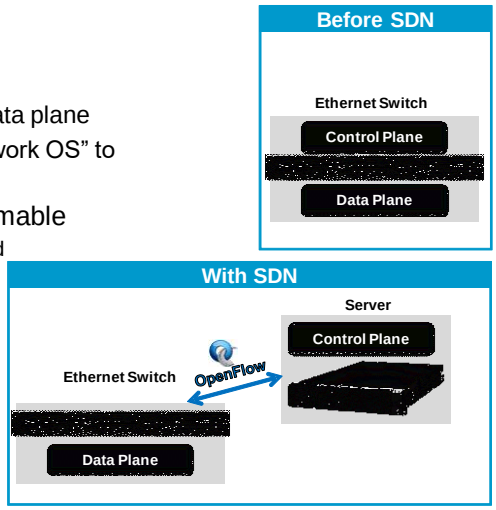
SDN – Software Defined Networking

Goal: Simplify networking and enable new applications

How?

- Decouple control plane from data plane
- Provide "Network API" or "Network OS" to application programmers
- Make the Network programmable
  - Increase network reliability and security
  - Automated management
  - Uniform policy enforcement
  - Fewer configuration errors



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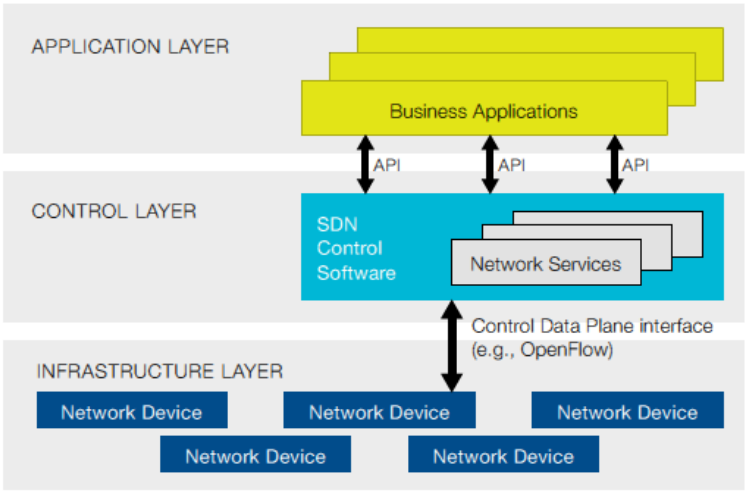
SDN – High Level Overview



ONF Software Defined Network Architecture
https://www.opennetworking.org/images/stories/downloads/white-papers/wp-sdn-newnorm.pdf

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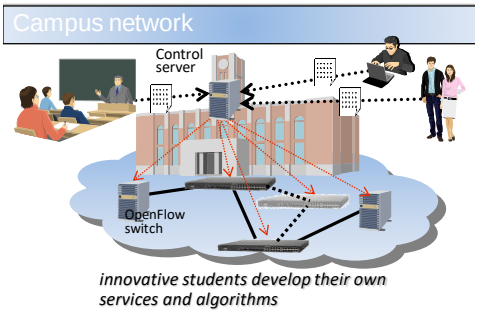
Example Scenarios for SDN



SDN-related SDO

OPEN NETWORKING FOUNDATION

The SDO for OpenFlow standardization
Perceived as leader for SDN standardization.

I E T F

ETSI

Leading Telco operators established ISG "**Network Function Virtualization (NFV)**"
Pre-standardization work for Carrier Networks.
Will probably use SDN to orchestrate NFV.

Competitor to ONF SDN
Focus on extending existing protocols for SDN without OpenFlow
Real work starts now! (I2RS)

ITU

Question 21, a group for Future Networks
It is an established SDN group

broadband forum
member company

Some SDN-related work appearing.

OIF OPTICAL INTERNETWORKING FORUM

Some SDN-related discussions appearing

3GPP A GLOBAL INITIATIVE
tmforum
GSMA

Commercial Switch Vendors

Model	Virtualize	Notes	
HP Procurve 5400zl or 6600	1 OF instance per VLAN	-LACP, VLAN and STP processing before OpenFlow -Wildcard rules or non-IP pkts processed in s/w -Header rewriting in s/w -CPU protects mgmt during loop	
NEC IP8800	1 OF instance per VLAN	-OpenFlow takes precedence -Most actions processed in hardware -MAC header rewriting in h/w	
Pronto 3240 or 3290 with Pica8 or Indigo firmware	1 OF instance per switch	-No legacy protocols (like VLAN and STP) -Most actions processed in hardware -MAC header rewriting in h/w	

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Controller Vendors

Vendor	Notes
Nicira's NOX	•Open-source GPL •C++ and Python •Researcher friendly
Nicira's ONIX	•Closed-source •Datacenter networks
SNAC	•Open-source GPL •Code based on NOX0.4 •Enterprise network •C++, Python and Javascript •Currently used by campuses

Vendor	Notes
Stanford's Beacon	•Open-source •Researcher friendly •Java-based
BigSwitch controller	•Closed source •Based on Beacon •Enterprise network
Maestro (from Rice Univ)	•Open-source •Based on Java
NEC's Helios	•Open-source •Written in C

OpenDayLight **ONOS**

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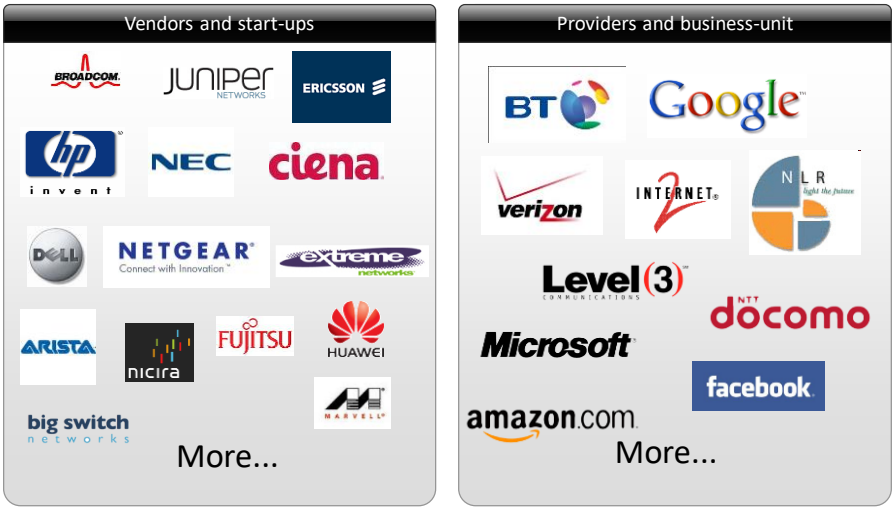
Growing Community



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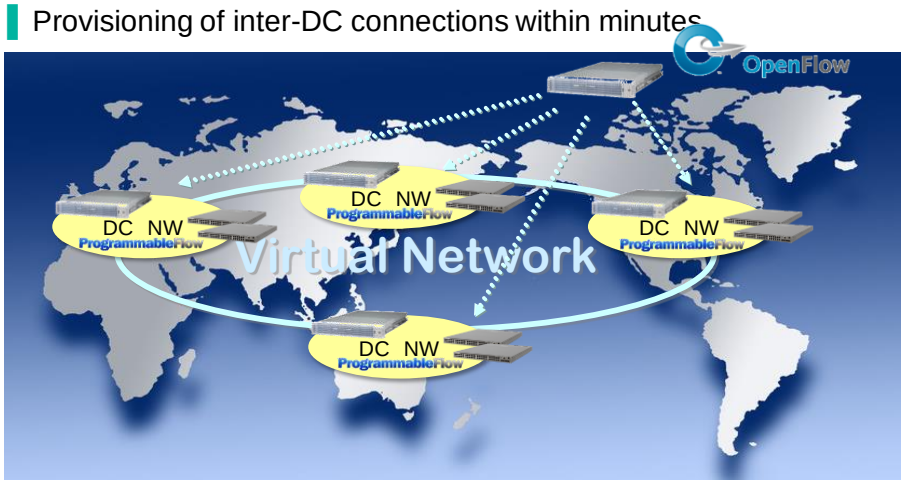
SDN Deployments: NTT Communications "BizHosting Enterprise Cloud"

- Uses ProgrammableFlow for Cloud Network Configuration
- Allows integrated management of globally distributed data centers
- Provisioning of inter-DC connections within minutes



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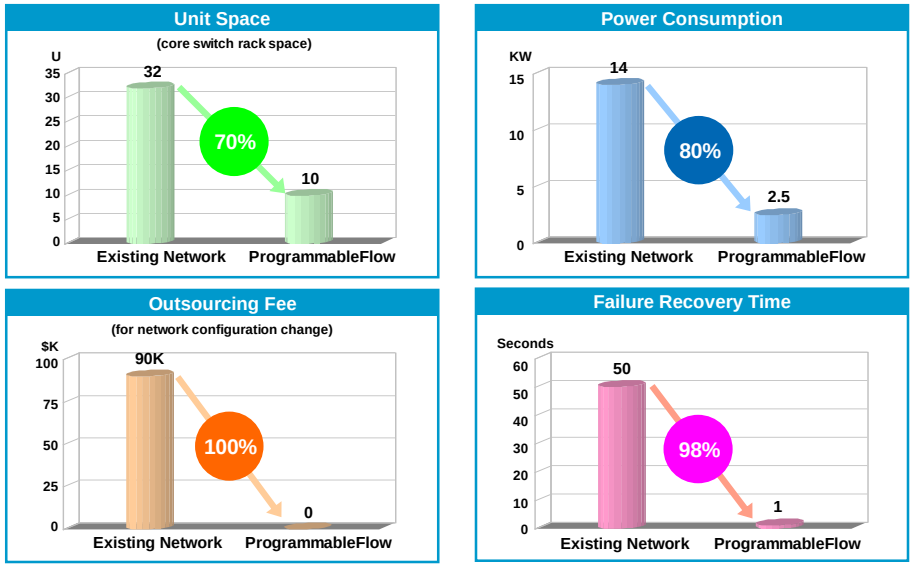
Nippon Express: Cost Saving Benefit



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What can SDN do?

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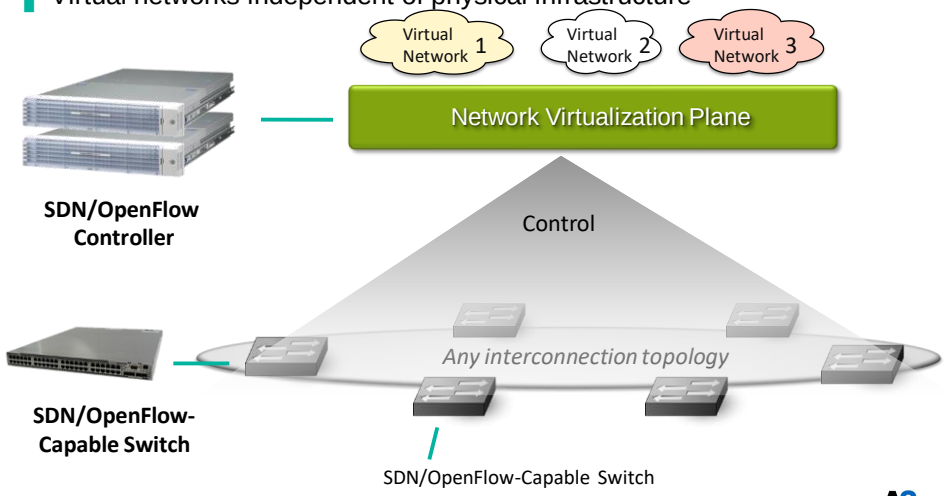
Virtualizing the Physical Network Fabric

On-demand create/edit/delete virtual networks
CLI / GUI / API based control
Virtual networks independent of physical infrastructure



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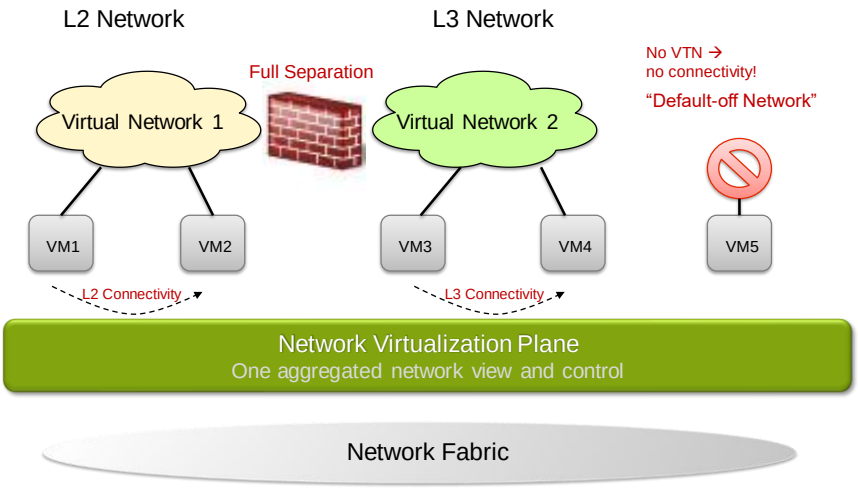
Network Isolation



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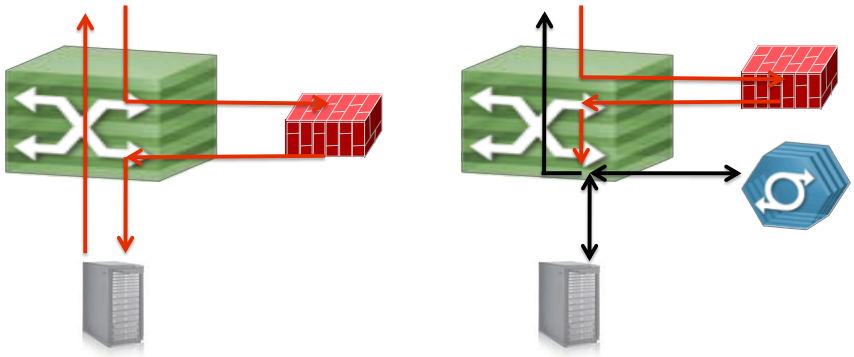
Policy-Based Appliance Inclusion

- Traffic can be explicitly routed to any appliance
- Selective forwarding possible (e.g., Web only)
- Any kind of appliance possible: FW, LB, IDS, DPI, …
- Multiple appliances can be composed



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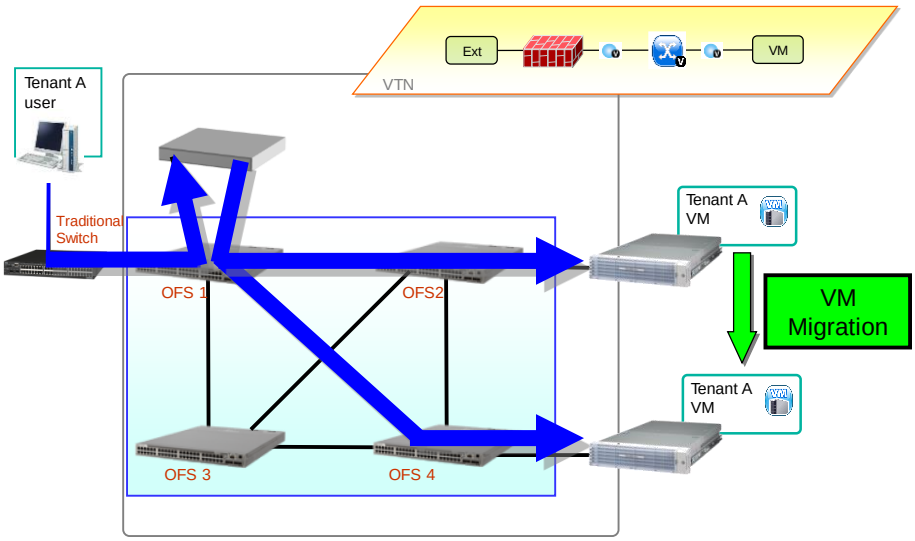
Virtual Machine Mobility



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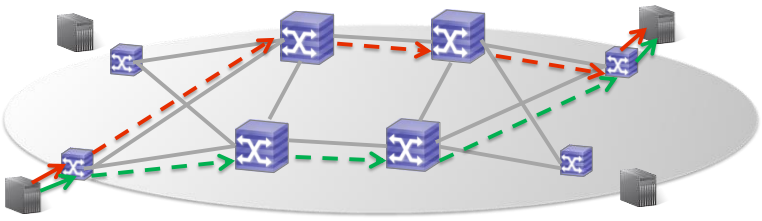
Improved Resource Usage

- Traffic load-balancing via multiple paths
- Supports any interconnect topology
- Compatible with loops in topology
- No distributed protocols necessary



Physical Network

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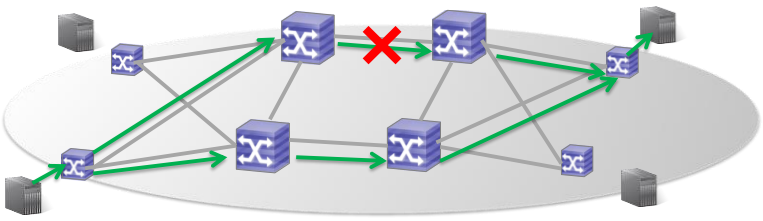
Path Fail-Over

- Multiple paths are used to protect each other
- No network downtime as with STP
- Fail-over happens immediately due to centralized control



Physical Network

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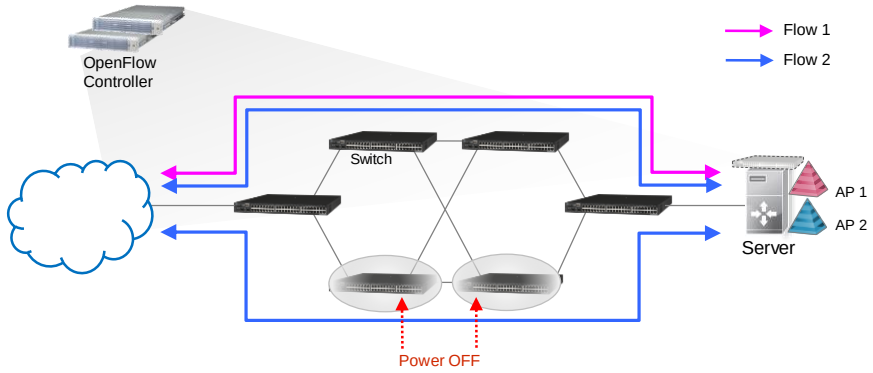
Energy Saving



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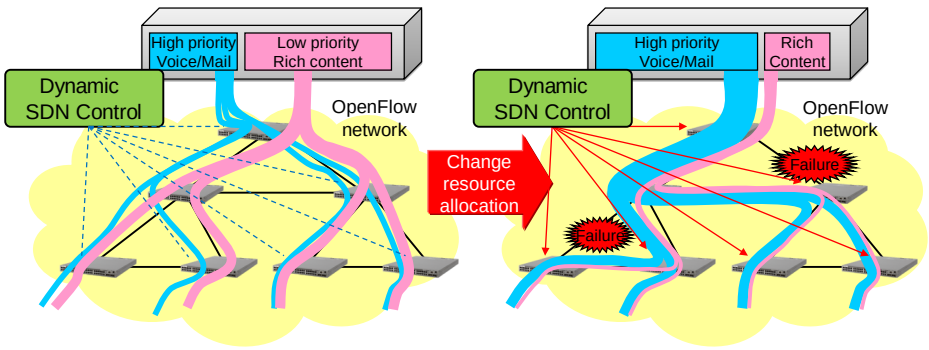
Dynamic Resource Allocation



According to network resource allocation policies and resource availability, network paths and resource assignment are dynamically adjusted.

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SDN Layered Architecture

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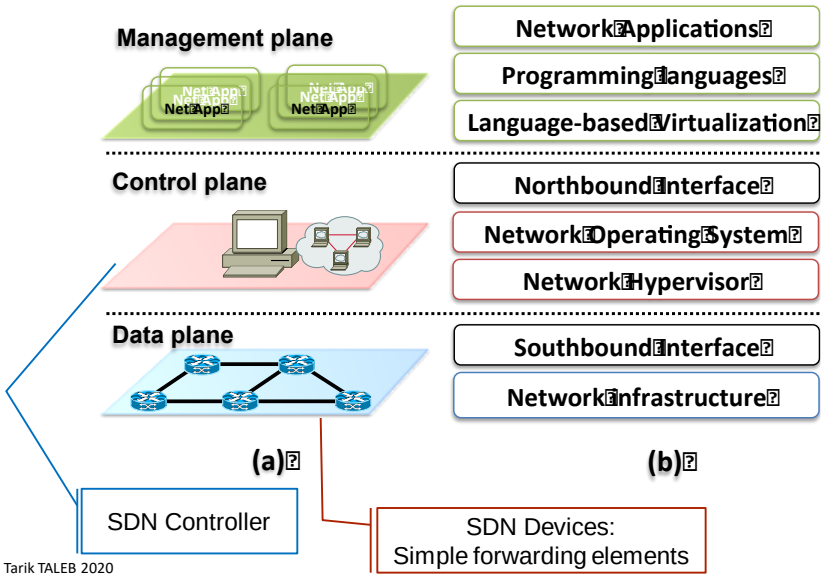
Layered SDN Architecture



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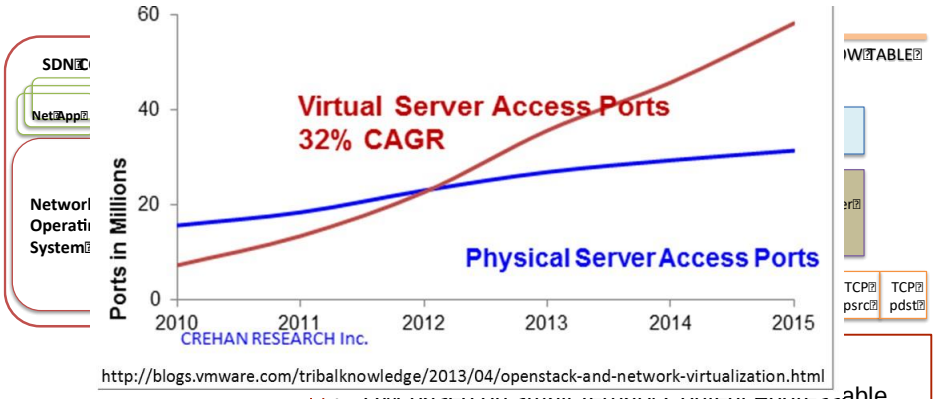
SDN Architecture: Two Main Components



http://blogs.vmware.com/tribalknowledge/2013/04/openstack-and-network-virtualization.html

Memory (TCAMs – limited # of rules in forwarding table)

- Software switches – Open vSwitch (i.e., in DC)

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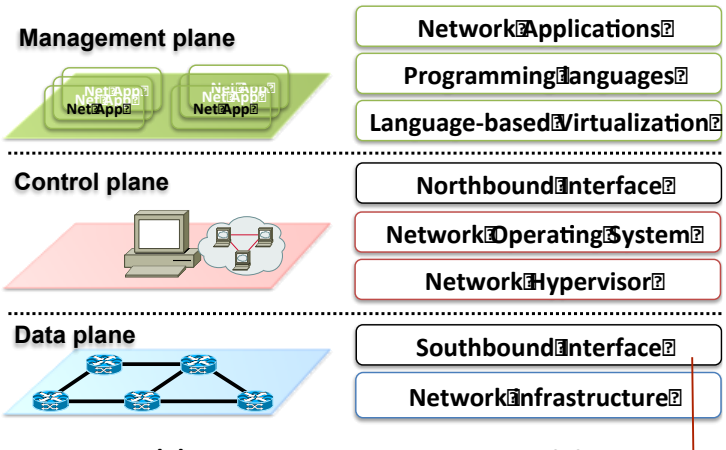
Layered SDN Architecture: Southbound Interface



- **OpenFlow** most widely accepted and deployed!
- Others: **NetConf**, ForCES, OVSDB, POF, OpFlex

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How does OpenFlow work?

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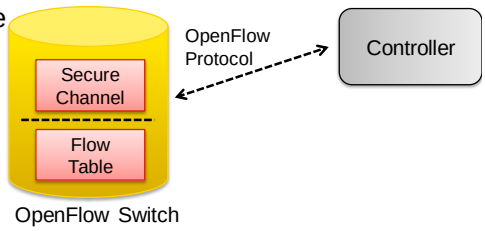
What is OpenFlow?

OpenFlow

- A brain child of **Stanford's Future Internet research programme**
- Defined by **Open Networking Foundation**
  - Major actors (Cisco, IBM, NEC, HP, Alcatel-Lucent, VMWare,…)
- **Separating control** and **data** plane
  - A **centralized** controller instance communicates with the network nodes using the **standardized OpenFlow** protocol
  - Allows to **program network behavior** directly by the network operator



- Switches/routers are modeled as forwarding elements with **forwarding tables**, containing "flow entries"
  - OpenFlow protocol affects the forwarding tables

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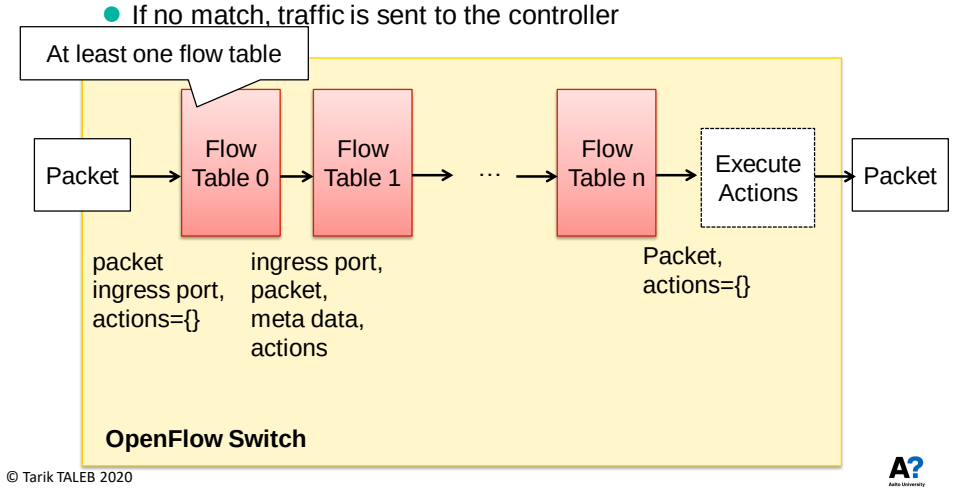
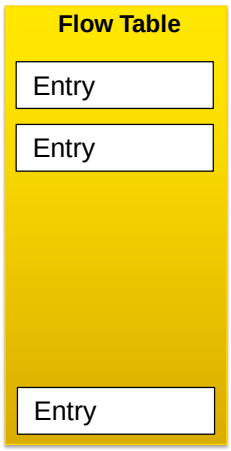
OpenFlow Forwarding Element

- Flow table: performs packet lookup
  - All packets compared to flow table for match
  - Actions depend on match being found
  - If no match, traffic is sent to the controller

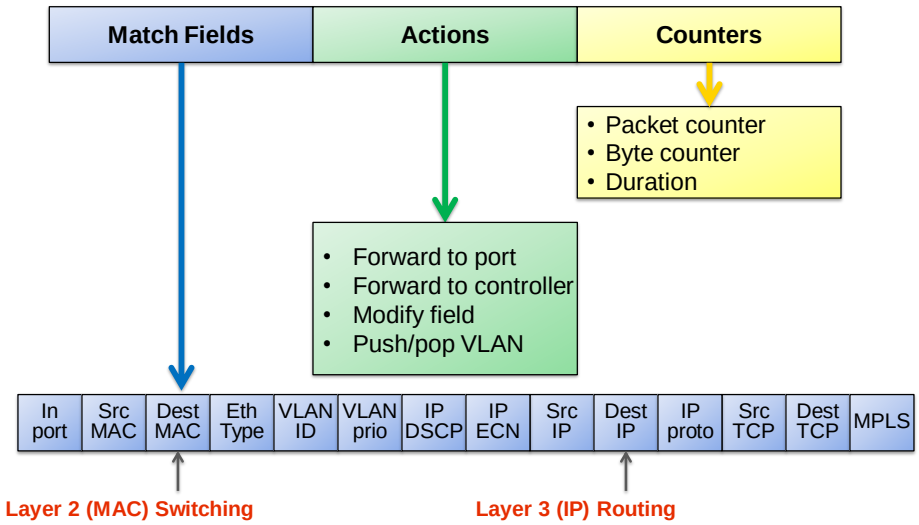


Flow Tables & Flow Entries

- **Flow tables** consist of a list of flow entries
- **Flow entry**:
  - Match field: defines matching packet
  - Priority: precedence of matching if multiple entries match
  - Counters: counts matches
  - Instructions
    - Modify action set and meta data
    - Forward to other tables (or stop)
  - Timeouts: removes entry after a certain (idle) time or hard timeout



Flow Table Entries



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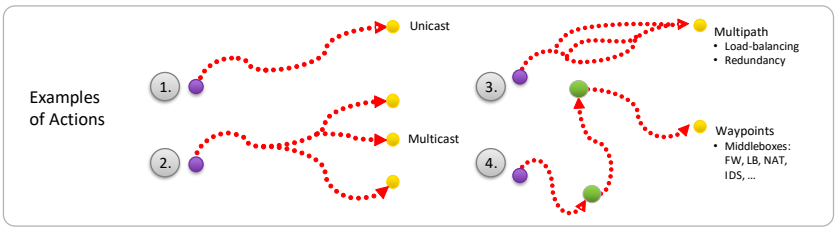
Flow-Based Actions



Any type of network path possible,
YOU program it!

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Flow Table Entry Examples 1

Switching

In port	Src MAC	Dest MAC	Eth Type	VLAN ID	Src IP	Dest IP	IP proto	Src TCP	Dest TCP	Actions
*	*	00:1f:…	*	*	*	*	*	*	*	Forward to port 5

In port	Src MAC	Dest MAC	Eth Type	VLAN ID	Src IP	Dest IP	IP proto	Src TCP	Dest TCP	Actions
3	00:2e:…	00:1f:…	0800	12	1.2.3.4	2.3.4.5	6	543	80	Forward to port 7

In port	Src MAC	Dest MAC	Eth Type	VLAN ID	Src IP	Dest IP	IP proto	Src TCP	Dest TCP	Actions
*	*	*	0800	*	*	*	6	*	22	Drop

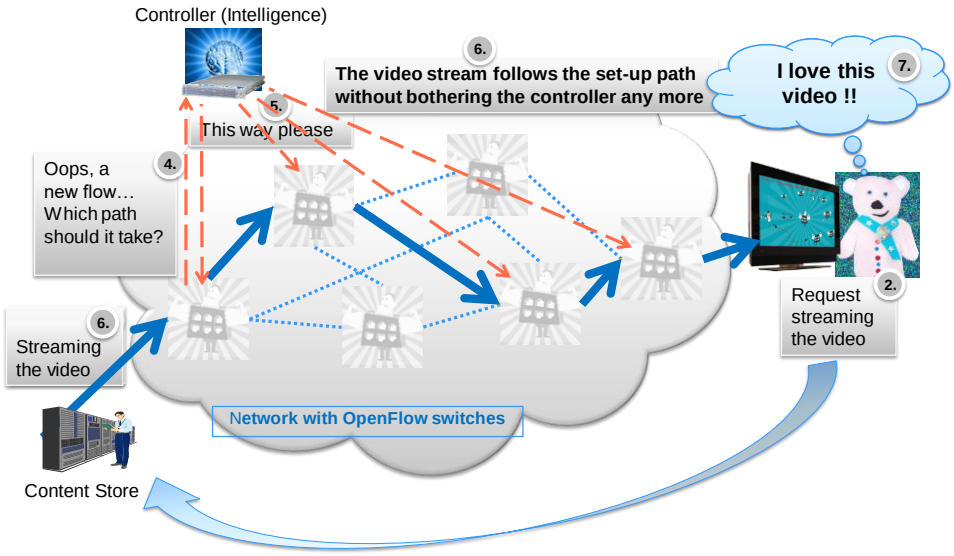
Flow Table Entry Examples 2

In port	Src MAC	Dest MAC	Eth Type	VLAN ID	Src IP	Dest IP	IP proto	Src TCP	Dest TCP	Actions
*	*	*	0800	*	*	2.3.4.5	*	*	*	Forward to port 44

In port	Src MAC	Dest MAC	Eth Type	VLAN ID	Src IP	Dest IP	IP proto	Src TCP	Dest TCP	Actions
*	*	00:1f:…	*	12	*	*	*	*	*	Forward to ports 2,3,6

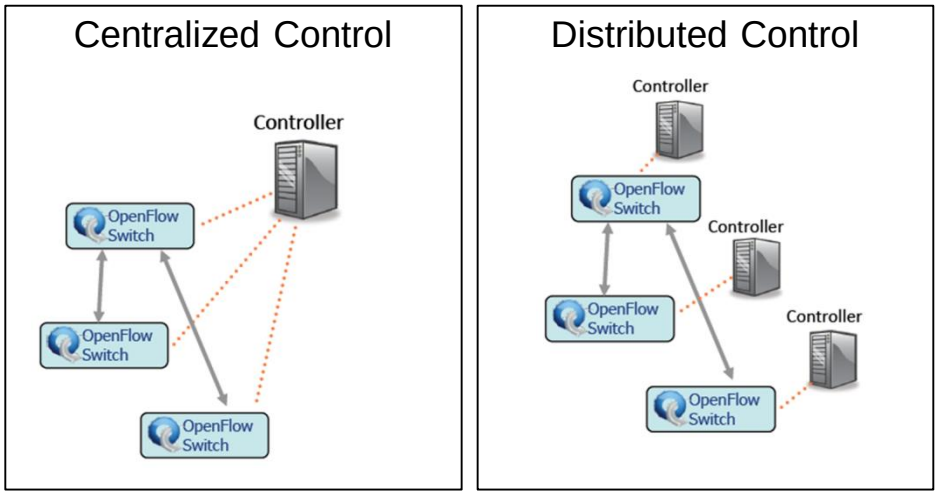
In port	Src MAC	Dest MAC	Eth Type	VLAN ID	Src IP	Dest IP	IP proto	Src TCP	Dest TCP	Actions
*	*	*	0800	*	1.2.3.4	*	6	5432	*	Rewrite src IP to 9.9.9.9 Rewrite src TCP to 2345 Forward to port 23

How Does it Work? An Example



SDN: Scalability – key challenge!

Controller Distribution



Flow Granularity

Individual Flows

- Flow entry covers small portion of header space
- Exact-match flow entries
- Good for fine-grained control, e.g. at network edge

Aggregated Flows

- Flow entry covers large portion of header space
- Wildcarded flow entries
- Good for large-scale flows, e.g. backbone

Aggregated Flows: Wildcard Matching

- Not all fields needs to be specified: Wildcard
  - Match any value
- For IP addresses, bitmasks can be specified
  - Example: Subnet mask of IPv4 192.168.1.1./24 (netmask 255.255.255.0)

In Port	Eth src	Eth Dest	Eth Type	VLAN ID	IP src	IP dst	IP proto	Src port	Dst port
*	*	*	0x8000	*	*	10.2.3.4	6 (TCP)	*	80
2	*	*	*	*	*	*	*	*	*
*	*	*	0x8000 (IPv4)	*	*	10.1.2.3	*	*	*

All traffic to a certain web server (port 80)

Traffic of a certain VLAN from a certain port

IPv4 traffic to a certain machine (e.g. result of a routing algorithm)

Flow Setup Policy

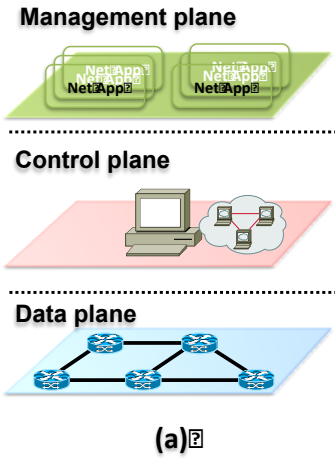
Reactive

- First packet of a flow triggers the controller to insert flow entries in the switch(es)
- Every flow incurs small additional flow setup time
- Flow table only as big as necessary

Proactive

- The controller pre-populates switch flow tables
- Zero additional flow setup time
- Some flow table entries might never be used

Layered SDN Architecture: NW Hypervisor



- Node Virtualization Techs
  - XEN, KVM, VMWare, Virtual Box
- Virtual Links
  - Ethernet GRE (EGRE) Tunneling
  - Virtual eXtended LAN (VXLAN)
  - Open vSwitch
  - **NICIRA NVP**
  - **FlowVisor**

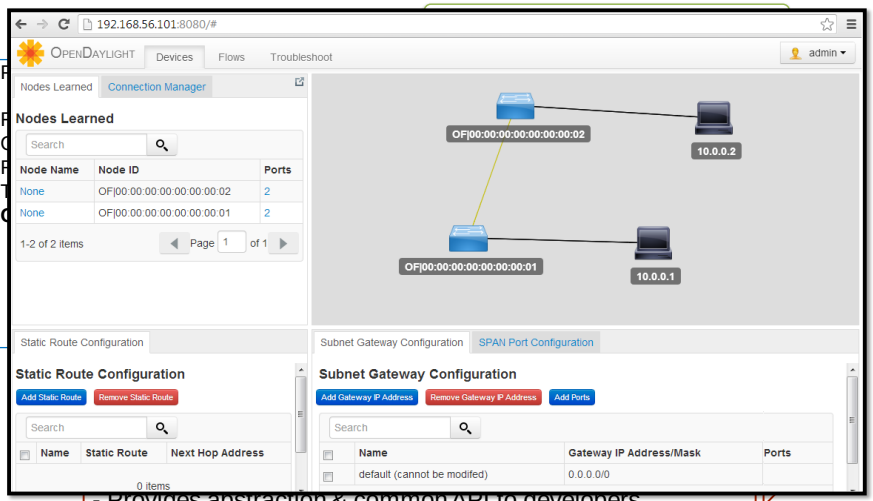
Network Hypervisor

Southbound Interface

Network Infrastructure

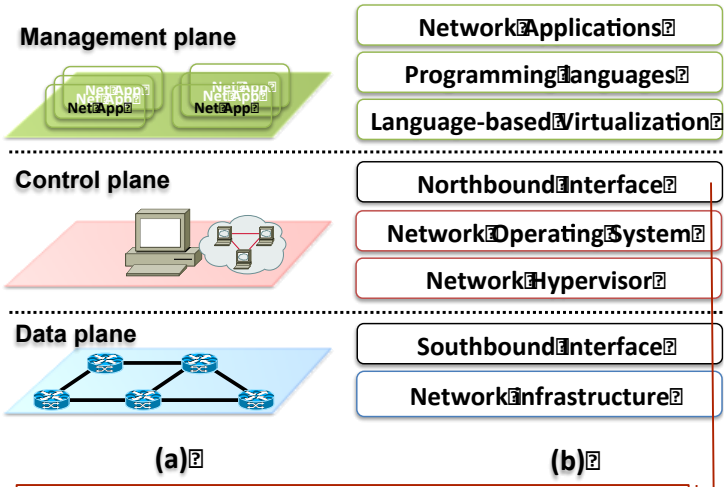
- Virtual NW: VMs, Storage, Links – logical connections
- Flexibility, Manageability, Scalability, Security & Isolation

Layered SDN Architecture: NOS



- Provides abstraction & common API to developers
- Generic functions & services: NW state, NW topology Information, device discovery, distribution of NW configuration

Layered SDN Architecture: NOS



- Allowing application & orchestration systems to program NW
- Northbound API is still an open issue (REST, JSON,)

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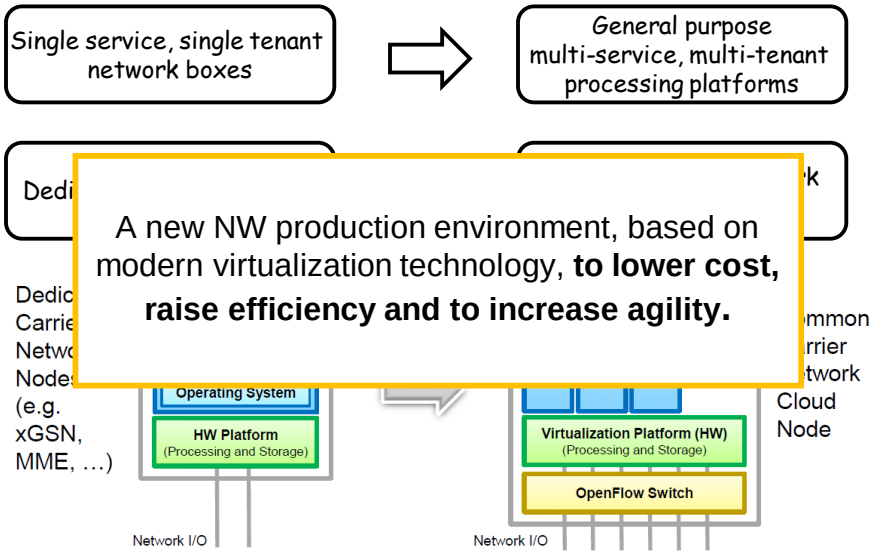
Network Function Virtualization

Mobile Network Function Virtualization



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Virtual Network Functions: Examples

- Switching: BNG, CG-NAT, routers.
- Mobile network nodes: HLR/HSS, MME, SGSN, GGSN/PDN-GW, RNC.
- Home routers and set top boxes.
- Tunneling gateway elements.
- Traffic analysis: DPI.
- Signaling: SBCs, IMS.
- Network-wide functions: AAA servers, policy control.
- Application-level optimisation: CDNs, Load Balancers.
- Security functions: Firewalls, intrusion detection systems.
- Etc

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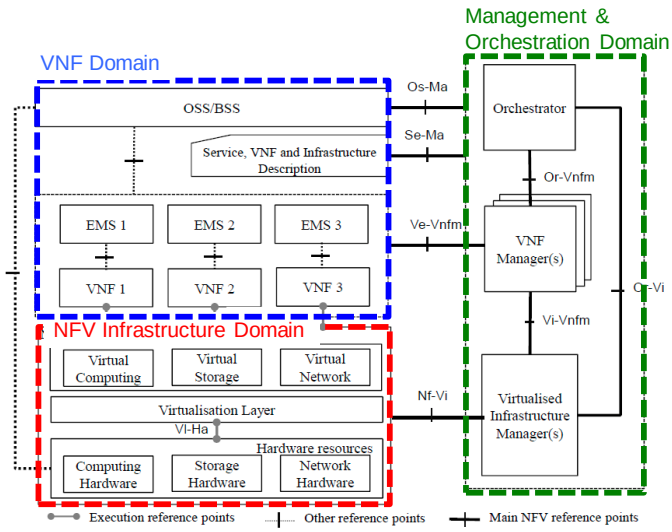
NFV vs SDN

- NFV and SDN are complementary
  - One does not depend upon the other.
- Both have similar goals but approaches are very different
- SDN needs new interfaces, control module applications.
- NFV requires moving network applications from dedicated hardware to virtual containers on commercial-off-the-shelf (COTS) hardware

NFV Components

- Network Function (NF): Functional building block with well defined interfaces and well defined functional behavior
- Virtualized Network Function (VNF): Software implementation of NF that can be deployed in a virtualized infrastructure
- VNF Forwarding Graph: Service chain when network connectivity order is important, e.g. firewall, NAT, load balancer
- NFV Infrastructure (NFVI): Hardware and software required to deploy, manage and execute VNFs including computation, networking and storage
- NFV Management & Orchestration: The orchestration of physical/software resources that support the infrastructure virtualisation, and the management of VNFs

ETSI NFV Architecture



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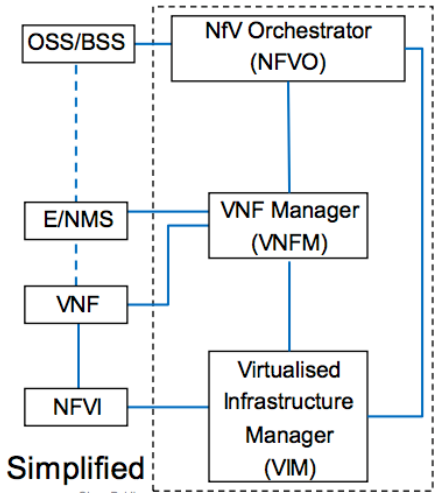
NFV MANO: NFV Orchestrator



- Responsible for the lifecycle management of Network Services:
  - In a single domain
  - Over multiple datacenters
- Applies policies for resource utilization
- Instantiates the VNF Managers
- Linkage to legacy systems through Operations/Business Support System (OSS/BSS)

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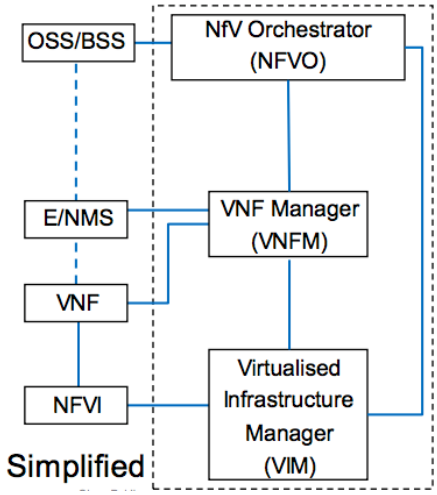
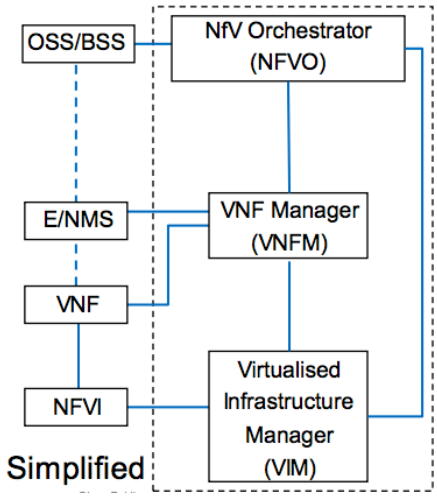
NFV MANO: VNF Manager



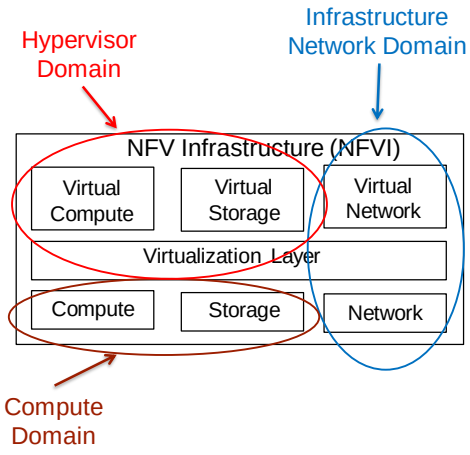
- Responsible for the lifecycle management of Virtual Network Functions instances
  - One per NF
  - One per multiple VNF instances even of different types
- It has to support the:
  - VNF instantiation
  - VNF configuration
  - VNF update
  - VNF scaling in / out
  - VNF instance termination
- Interfaces with E/NMS - Monitoring Systems

NFV MANO: Virtualized Infrastructure Manager



- Responsible for the lifecycle management of the compute, storage and network resources from the NFVI.
- It is basically a Cloud Management System which exposes an API for standard CRUD operations on those resources.
- OpenStack is the de facto standard implementation for this function block

NFV Infrastructure (NFVI)

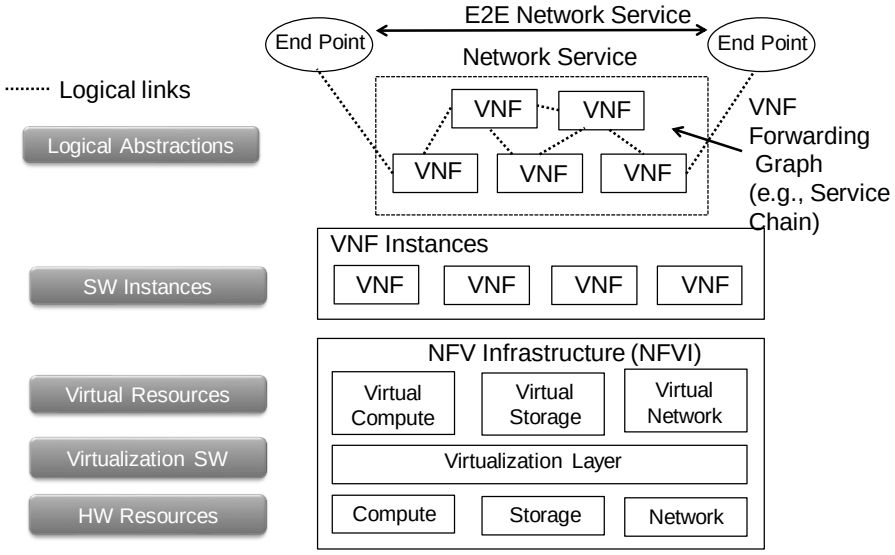


Compute domain
- Functional elements: Processors and accelerators, network interfaces and storage

Hypervisor domain
- Main focus on studying hypervisor technologies for supporting multitenant deployments

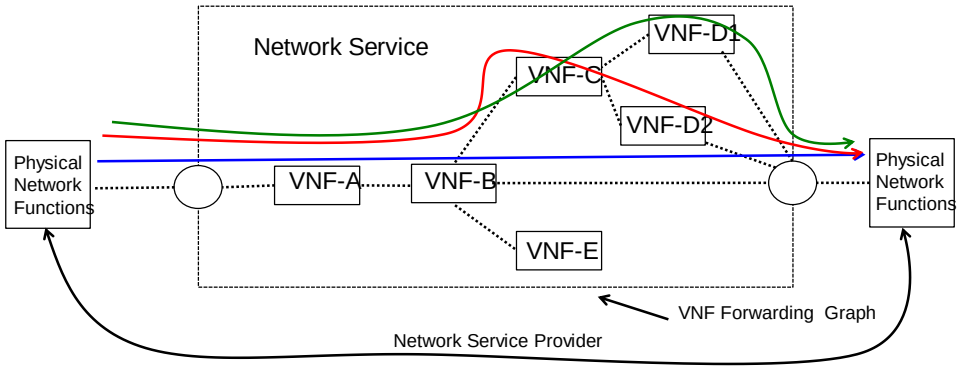
Infrastructure Network domain
- Functional elements: virtual networks, network resources Switches, Routers

NFV Components



Network Forwarding Graph

An end-to-end service may include nested forwarding graphs



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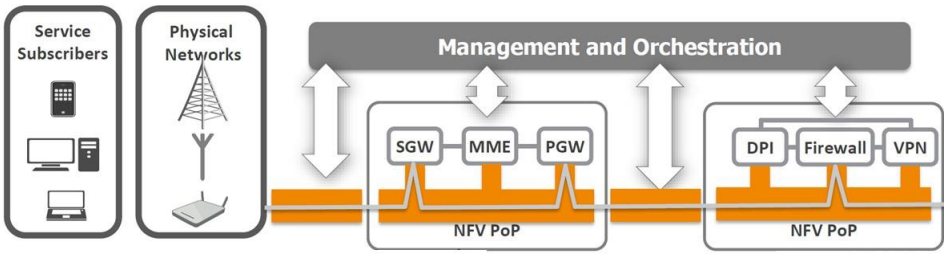
Network Forwarding Graph: Service Chaining



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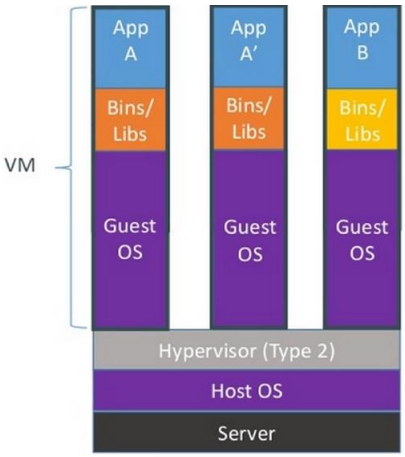
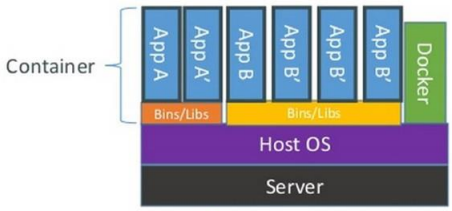
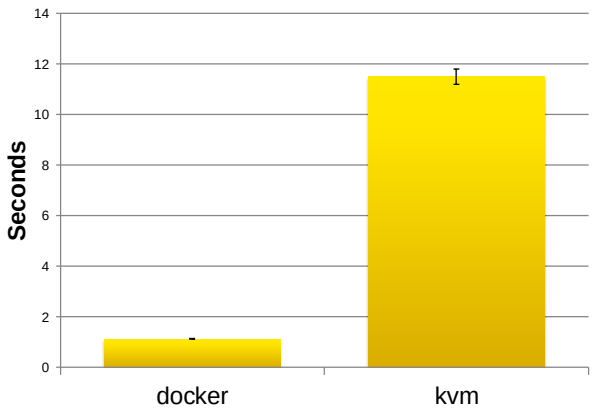
From Virtual Machines to Containers



Containers are isolated but share OS and, where appropriate, Bins and Libraries

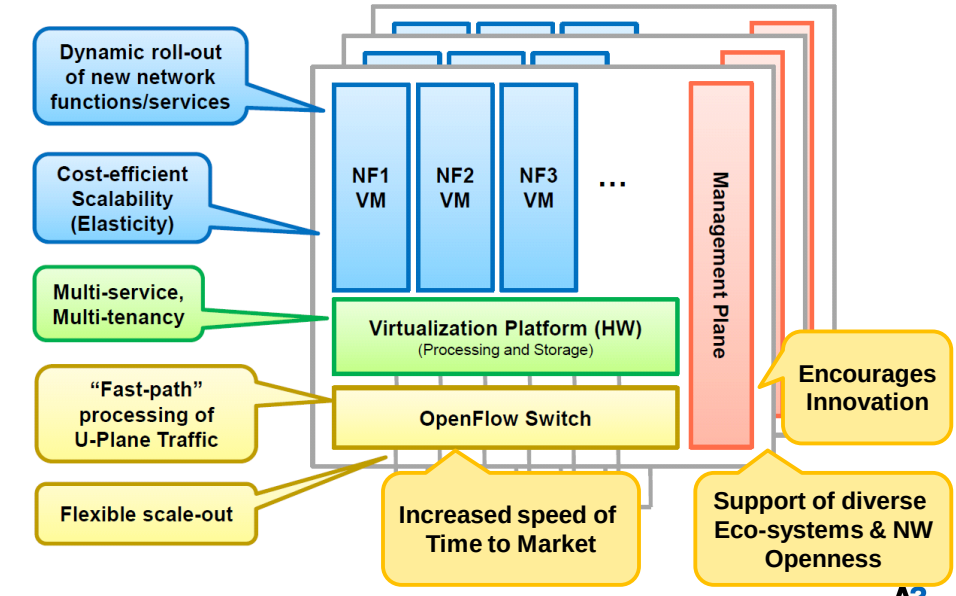


VNF Performance in Virtual Environments: NGINX HTTP Server – Startup Times



P. Frangoudis, L. Yala, A. Ksentini, and T. Taleb, "An architecture for on-demand service deployment over a telco CDN," in IEEE ICC'16, Kuala Lumpur, Malaysia, May 2016.

Mobile Network Function Virtualization



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5G Mobile Networks: Requirements & Features

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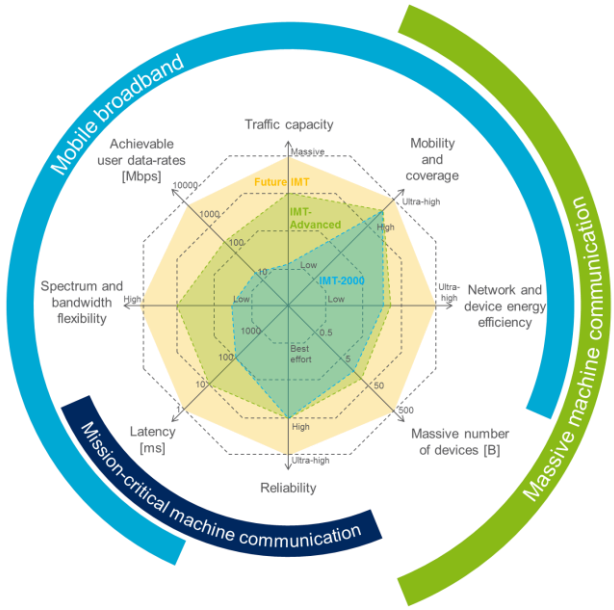
Requirements on 5G …



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Requirements on 5G …

High data rates everywhere

Very high traffic capacity

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ITU-R IMT-2020 Requirements – selected parameters

- The **minimum requirements** for eMBB peak data rate are as follows:
  - **Downlink** peak data rate is **20Gbps**
  - **Uplink** peak data rate is **10Gbps**

- The **minimum requirements** for eMBB peak spectral efficiencies are as follows:
  - **Downlink** peak spectral efficiency is **30 bit/s/Hz**
  - **Uplink** peak spectral efficiency is **15 bit/s/Hz**

- The target values for the user experienced data rate are as follows in the Dense Urban – eMBB test environment:
  - **Downlink** user experienced data rate is **100Mbps**
  - **Uplink** user experienced data rate is **50Mbps**

Requirements on 5G …

High data rates everywhere

Very high traffic capacity

Ultra-high reliability & security

Massive number of devices

ITU-R IMT-2020 Requirements – selected parameters

- The minimum requirement for mMTC connection density is 1,000,000 devices per km2

Requirements on 5G …

- **High data rates everywhere**
- **Very high traffic capacity**
- **Massive number of devices**
- **Ultra-high reliability & security**
- **Very low device cost**
- **Very low device energy consumption**
- **Very low latency**

Latency matters …

"Being fast really matters .. Half a second delay caused a 20% drop in traffic and it killed user satisfaction"
Marissa Mayer @ Web 2.0

"… a 400 millisecond delay resulted in a -0.59% change in servers/user … Google would lose 8 million searches per day … Google would serve up many millions fewer online adverts"
Jake Brutlag, Google Search

"… for Amazon every 100 ms increase in load times decreased sales with 1%"
Andy King, book author

"…when 50% of traffic was redirected to our edges preliminary results showed a 5.9% increase in click-thru rates"
Andy Lientz, BingEdge

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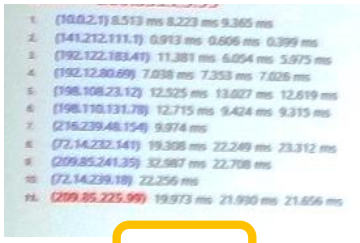
Is there a latency problem?

Traceroute to 209.85.225.99 (one of the Server IPs of www.google.com

Expt 1: Smartphone via WiFi
WiFi → 209.85.225.99



11 hops

Expt 2: Smartphone via cellular
3G → 209.85.225.99

25 hops

No control on how packets are routed!

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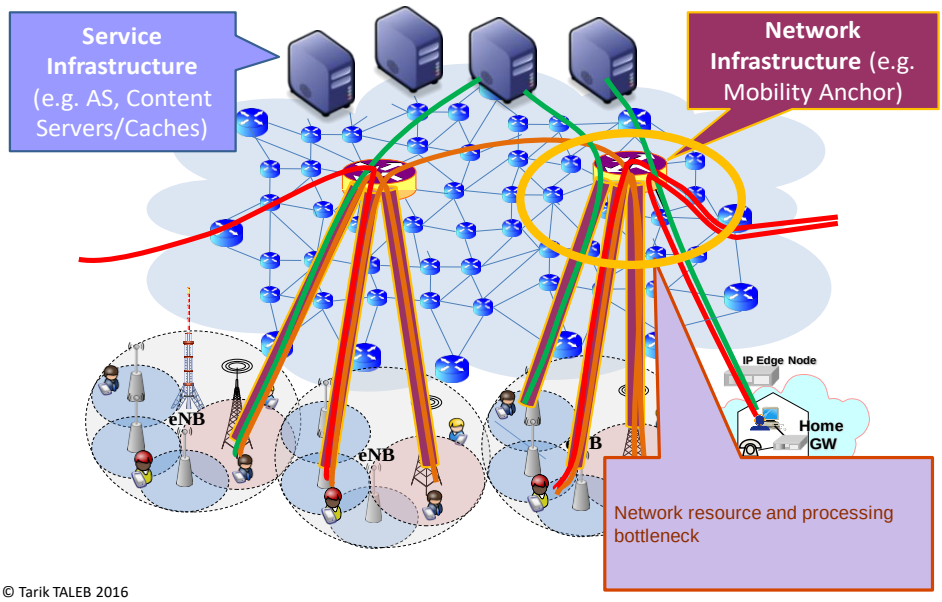
Current Mobile Operator NW Arch.



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5G Latency Requirements – Industry Targets

NGMN 5G Requirements

- 5G E2E Latency (eMBB) = **10ms** (i.e. RTT from UE-Application-UE)
- 5G E2E Latency (URLLC) = **1ms** (i.e. RTT from UE-Application-UE – or just UE-UE)

In both cases, the values are defined as capabilities that should be supported by the 5G System.

GSMA 5G Requirements

- 5G E2E Latency = **1ms** (again, defined as a capability target, not as a universal requirement)

ITU-R IMT-2020 Requirements

- eMBB User Plane Latency (one-way) = **4ms** [radio network contribution]
- URLLC User Plane Latency (one-way) = **1ms** [radio network contribution]
- Control Plane Latency = **20ms (10ms target)** [UE transition from Idle to Active via network]

Low Latency Use Case Requirements (various sources)

- Virtual Reality & Augmented Reality: **7-12ms**
- Tactile Internet (e.g. Remote Surgery, Remote Diagnosis, Remote Sales): < **10ms**
- Vehicle-to-Vehicle (Co-operative Driving, Platooning, Collision Avoidance): < **10ms**
- Manufacturing & Robotic Control / Safety Systems: **1-10ms**

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From Ericsson

Requirements on 5G …

More than just bigger and better mobile broadband

A platform on which any wireless application can be implemented

Requirements on 5G

- **Support Vertical Markets:** Automotive, energy, food and agriculture, healthcare, etc.

- **Accelerate the Service delivery** to all involved stakeholders

5G: Key Challenges

- **x1000** data **volume** / geographical area
- **x10** lower **energy** consumption
- Very **short service creation time** cycle (i.e. in minutes)
- **Very short latency**
- Very **dense deployments of wireless** links
- **Scalable & Cognitive** management framework for fast deployment
- **OPEX reduction** with more than 20% of today
- Multi domain virtualised networks and services
- **Complete network convergence** (fixed, backhaul, satellite)

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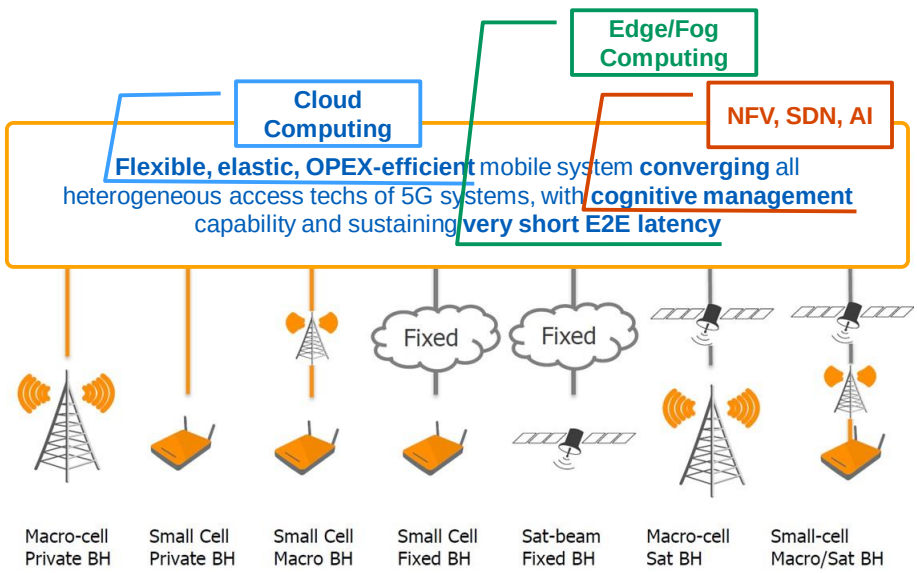
Towards an Innovative 5G Mobile System



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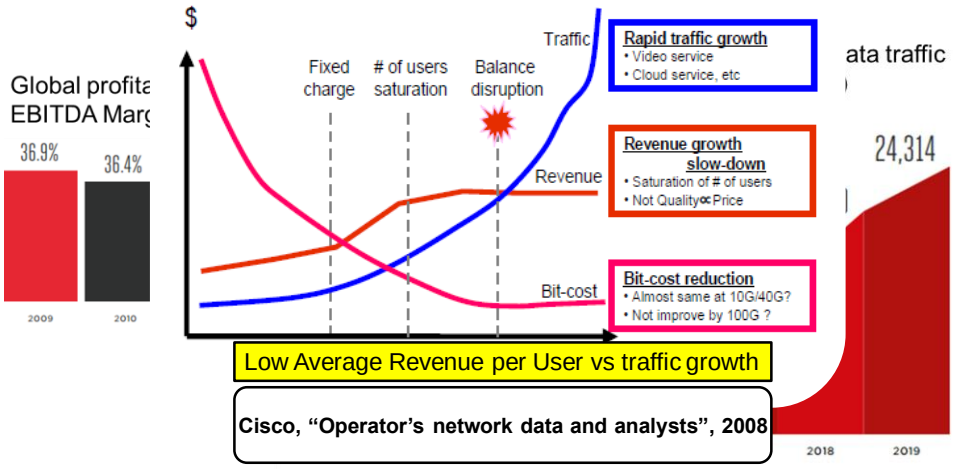
Cost efficiency: why?



"The Mobile Economy 2017", GSMA

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5G Features

- Cost Efficiency
- Agility
- Elasticity
- Flexibility
- Rapidity
- …

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Network Softwarization

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Network Softwarization?

International Telecommunication Union

NW softwarization is an overall transformation trend for designing, implementing, deploying, managing & maintaining NW equipment and NW components by SW programming, exploiting characteristics of SW such as flexibility & rapidity of design, development and deployment throughout the lifecycle of NW equipment and components,

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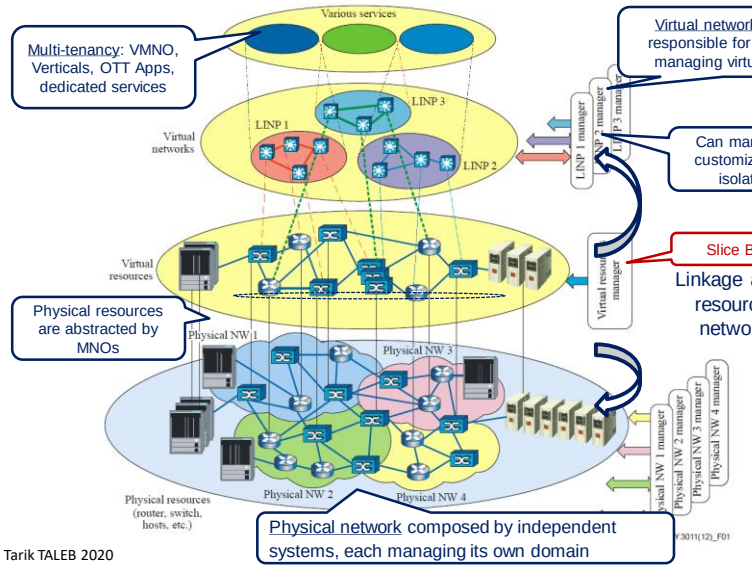
Network Softwarization in 3GPP?

Work Task ID	Work Task(s)	Work Task Description
NS_WT_#1	Network Slice Instance Selection and Association	1) Initial network slice instance selection to support UE's service establishment and re-selection to support UE mobility and other scenarios that are TBD, Note: M 2) N 3) a
NS_WT_#2	Network Slicing Isolation	1 2) 3) Note:
NS_WT_#3	Network Slicing Architecture	1) I n 2) I n I s
NS_WT_#4	Network Slicing Roaming support	1) D r
NS_WT_#5	Network Slicing terminology & definitions	1) If new

- How to **achieve isolation and separation** between network slices?
- How and what type of resource **and NF sharing can be used between NW slices**?
- How to enable **UEs to obtain services simultaneously from multiple slices**?

Network Softwarization in ITU-T

ITU-T Y.3011 – Virtual Resource Manager Framework



Multi-tenancy: VMNO, Verticals, OTT Apps, dedicated services

Virtual network controllers responsible for creating and managing virtual networks

Can manage a single customized service or isolated tenant

Slice Broker

Linkage among physical resource and virtual network controllers

Physical resources are abstracted by MNOs

Physical network composed by independent systems, each managing its own domain

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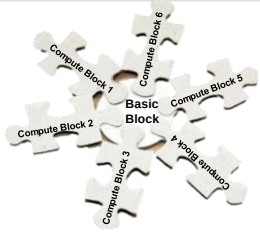
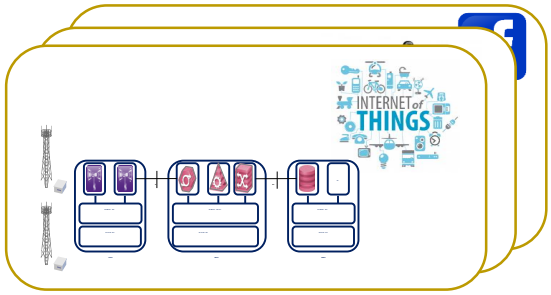
NW Softwarization: Objectives in Nutshells!

- Transform mobile networks into virtualized software components



- Enable the creation & lifecycle management of diverse network slices for different verticals



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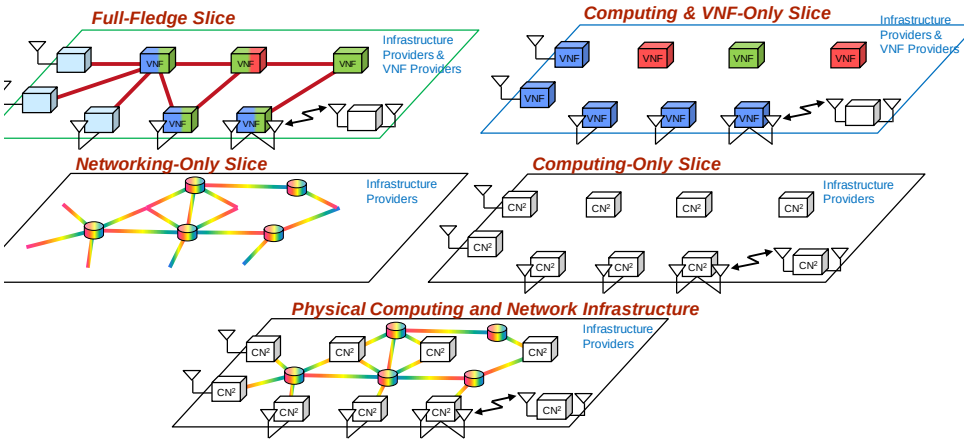
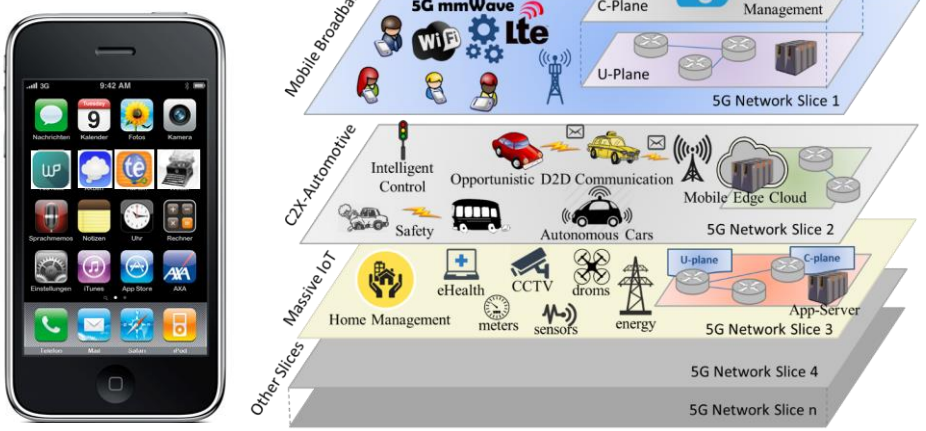
What does a slice mean?



Slicing: UE Perspectives?



Slicing: UE Perspectives?

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Mobile Network Virtualization

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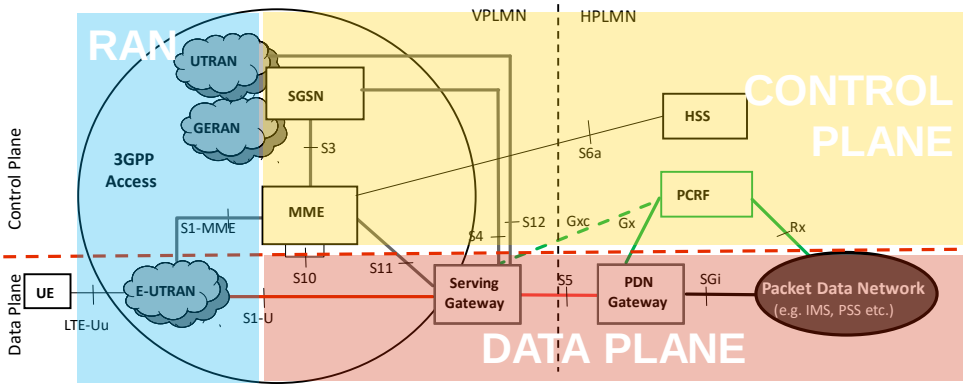
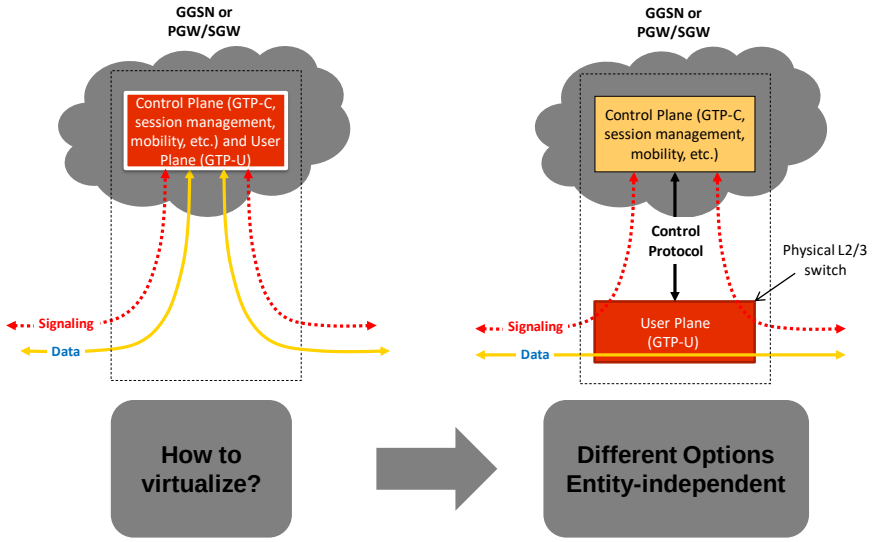
Virtualising the mobile network - how far?

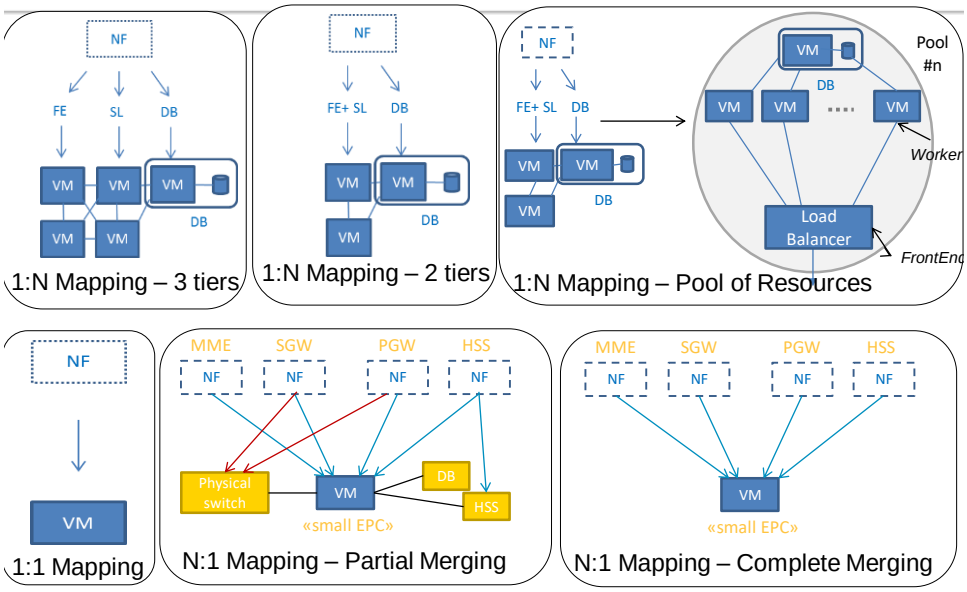


T. Taleb, "Towards Carrier Cloud: Potential, Challenges, & Solutions," in IEEE Wireless Communications Magazine, Vol. 21, No. 3, Jun. 2014. pp. 80-91.

What to Virtualize: Full vs Partial Virtualization



How to Virtualize?



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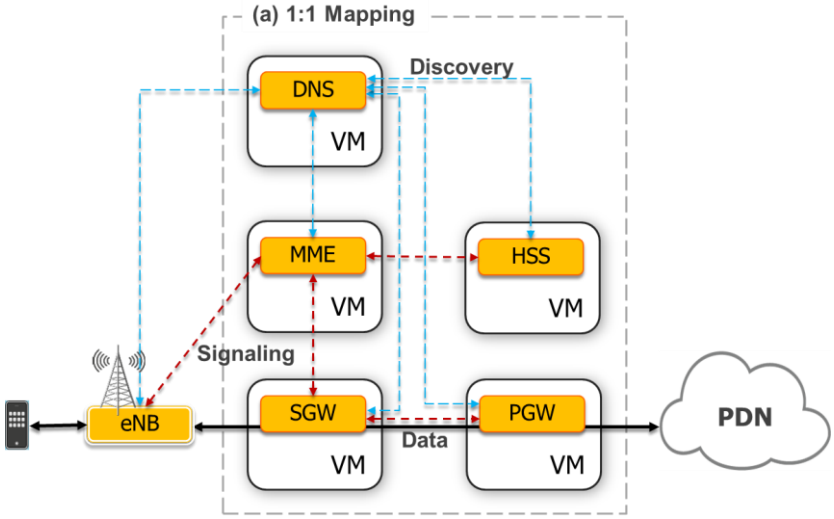
EPCaaS Architecture Options

1:1 Mapping



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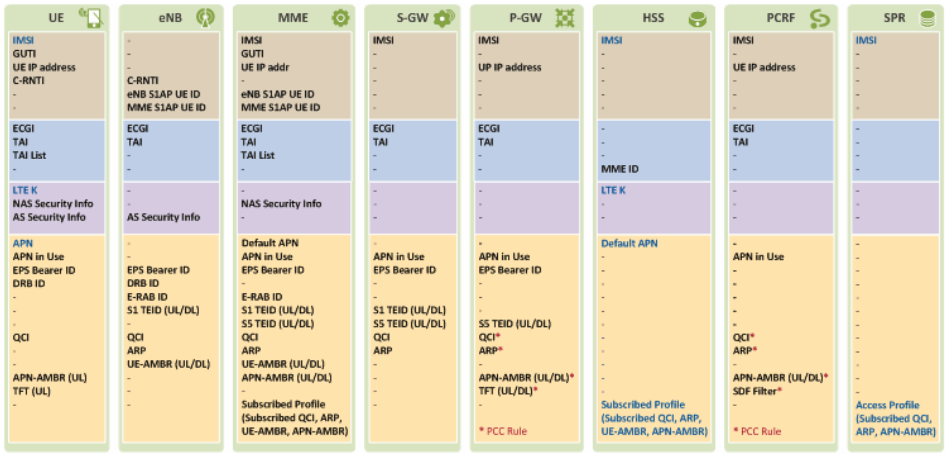
Information Elements: After Attach

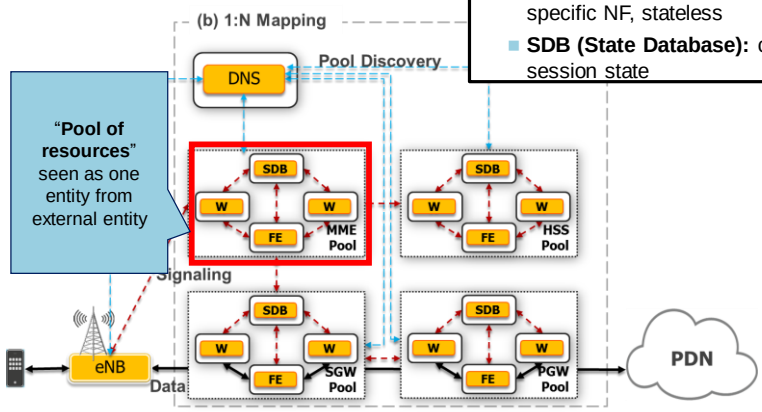


http://www.netmanias.com/en/post/techdocs/6098/emm-initial-attach-lte/emm-procedure-1-initial-attach-part-1-cases-of-initial-attach

EPCaaS Architecture Options

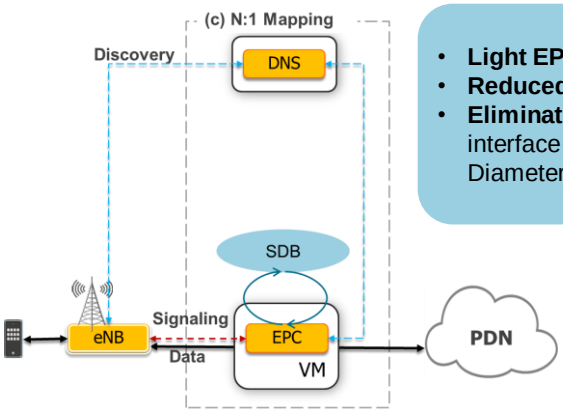
1:N Mapping

- **FE (Front End)**: load Balancer/Scheduler service
- **W (Worker):** implements the logic of that specific NF, stateless
- **SDB (State Database):** contains live session state



EPCaaS Architecture Options

N:1 Mapping

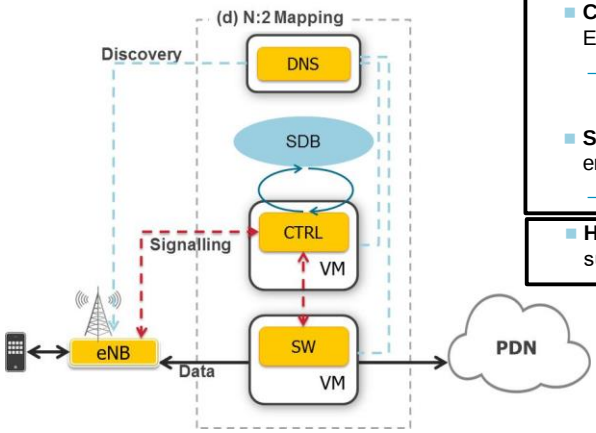


- **Light EPC** (i.e., less functionalities)
- **Reduced** internal **interfaces**
- **Eliminating** encoding, decoding, interface synchronization (e.g, over Diameter, GTP)

Full Virtualization of the E2E Mobile Connection

EPCaaS Architecture Options

N:2 Mapping



- **SDB:** Session DB
- **CTRL**: Control plane functions of EPC
  - MME, PCRF, HSS-FE, SGW-C, PGW-C
- **SW**: User data processing & policy enforcement.
  - SGW-U, PGW-U
- **HSS-BE**: HSS Back End, contains subscribers' profile.

Aalto's virtual EPC – deployment scenarios

1:N Scenario – Standalone VM with all VNFs, on any virtualization environment

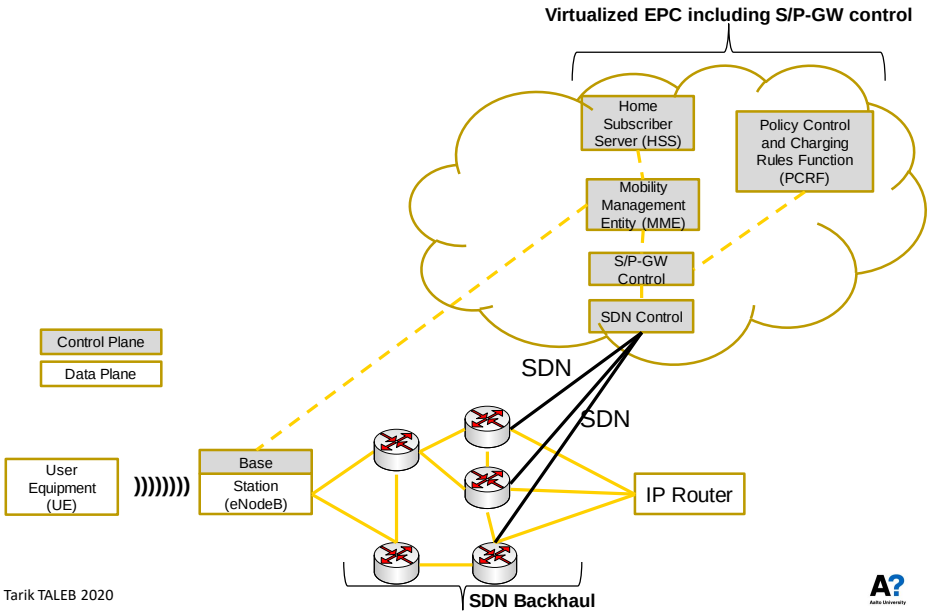
Hardware requirements
- 2GB RAM
- 10GB Hard Drive
- 2 cores 64 bits
- Minimum 1xNIC, recommended 2xNIC
- Linux OS, Debian-based e.g. Ubuntu

Network requirements
- Connectivity to Internet (also possible via NAT)
- Connectivity to eNB network via flat IP-networks, i.e. without NAT

1:1 Scenario – Cluster of VMs for distributed VNFs, with Heat on OpenStack

- **Minimum HW per VNF**
  - 512MB RAM
  - 8GB Hard Drive
  - 1 core 64 bits
  - 1xNIC
  - Debian-based Linux OS, e.g. Ubuntu
- **Network requirements**
  - Connectivity to Internet (also possible via NAT)
  - Connectivity to eNB network via flat IP-networks, i.e. without NAT
- **OpenStack requirements**
  - OpenStack Liberty release
  - OpenStack Heat, Neutron, Nova
  - Connectivity to public OpenStack API network from the VMs

EPCaaS Architecture Options
N:2 Mapping + SDN-based mobile backhaul



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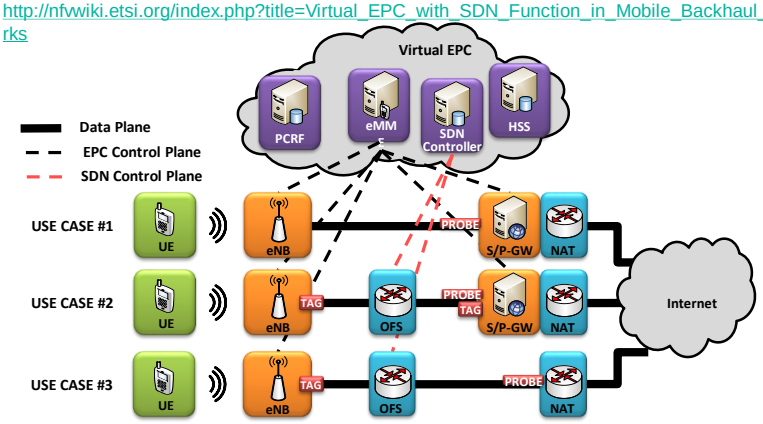
Aalto Contribution to Standardisation

- ETSI PoC based on SIGMONA testbed submitted in cooperation with Nokia, Coriant, EXFO and Telecom Italia.
- Objectives:
  - Integration of SDN and NFV functions in mobile backhaul
  - Show with off the shelf devices (Nokia eNBs, Coriant MPLS switches, EXFO Monitoring) the mobility and network adaptation during congestion or link breaks
  - http://nfvwiki.etsi.org/index.php?title=Virtual_EPC_with_SDN_Function_in_Mobile_Backhaul_Networks



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5G Control & User Plane

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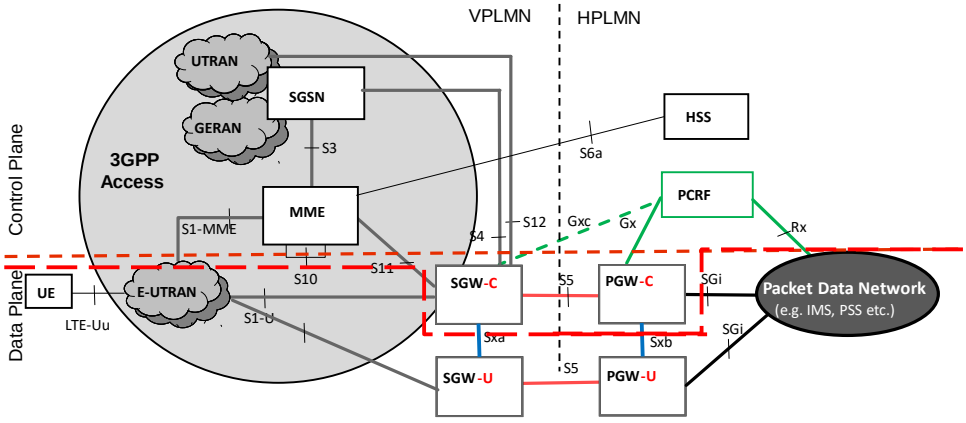
EPC after CUPS



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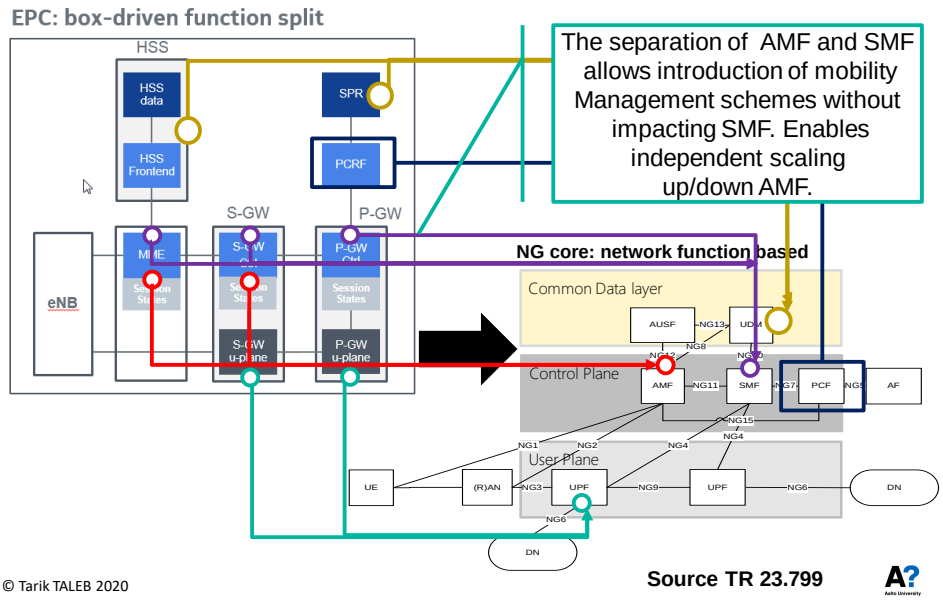
5G System Architecture: Key Design Principles

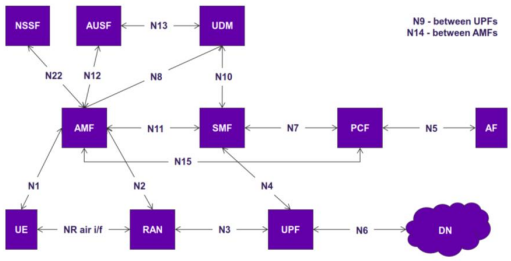
- Clear separation of the user and control plane functionality.
- Core network control functions are **cloud native**.
- **Access and Mobility management Function separated from Session Management Functions**:
  - Common Access mobility management function (AMF) that is independent from any access type that can be 3GPP or non-3GPP (e.g WiFi).
  - Session Management Function
- User plane changes:
  - **No bearer concept beyond radio, but PDU sessions instead**. Needed for new QoS model.
  - New user plane functions to implement **multi-homing and traffic redirection**:
    - Uplink classifier for IPv4 traffic.
    - Branching point for IPv6 traffic.

Regrouping LTE functionality to match cloud nativeness – Network Functions instead of Box



Source TR 23.799

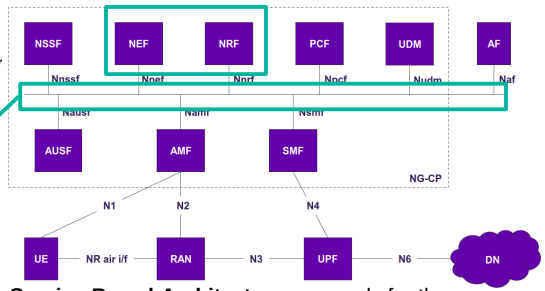
5G System Architecture: Two variants



Note: Focus on mobile however Access Network (AN) could be fixed

Traditional **reference point approach** for 5G (Rel 15)

Message bus type connectivity rather than P2P



Source: TS 23.501

Service Based Architecture approach for the control plane functions. (Some in Rel15 and more in Rel 16)

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Functional blocks within 5G network architecture

- AUSF = Authentication Server Function
- UDM = Unified Data Management
- NSSF = Network Slice Selection Function
- NEF = Network Exposure Function
- NRF = Network Repository Function
- AMF = Core Access and Mobility Management Function
- SMF = Session Management Function
- PCF = Policy Control Function
- AF = Application Function
- UE = User Equipment
- RAN = Radio Access Network
- CU = Centralised Unit
- DU = Distributed Unit
- UPF = User Plane Function
- DN = Data Network, e.g. operator services, Internet or 3rd party services

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5G interfaces (reference points)

- N1: Reference point between the UE and the Access and Mobility Management function (AMF).
- N2: Reference point between the (R)AN and the Access and Mobility Management function.
- N3: Reference point between the (R)AN and the User plane function (UPF).
- N4: Reference point between the Session Management function (SMF) and the User plane function (UPF).
- N5: Reference point between the Policy Function (PCF) and an Application Function (AF).
- N6: Reference point between the UP function (UPF) and a Data Network (DN).
- N7: Reference point between the Session Management function (SMF) and the Policy Control function PCF).
- N7r: Reference point between the vPCF and the hPCF.
- N8: Reference point between Unified Data Management and AMF.
- N9: Reference point between two Core User plane functions (UPFs).
- N10: Reference point between UDM and SMF.
- N11: Reference point between Access and Mobility Management function (AMF) and Session Management function (SMF).
- N12: Reference point between Access and Mobility Management function (AMF) and Authentication Server function (AUSF).
- N13: Reference point between UDM and Authentication Server function (AUSF).
- N14: Reference point between 2 Access and Mobility Management function (AMF).
- N15: Reference point between the PCF and the AMF in case of non-roaming scenario, V-PCF and AMF in case of roaming scenario.
- N16: Reference point between two SMFs, (in roaming case between V-SMF and the H-SMF).
- N22: Reference point between AMF and Network Slice Selection Function (NSSF).

Reference point representation vs. Service-based representation

Reference point representation

- All network functions have fixed roles and peers.
- Fixed reference points between the functions.
- Network function are still expected to be virtualized.
- Follows the way how earlier 3GPP generations have been specified.
- Static architecture and role division.

Service Based Architecture

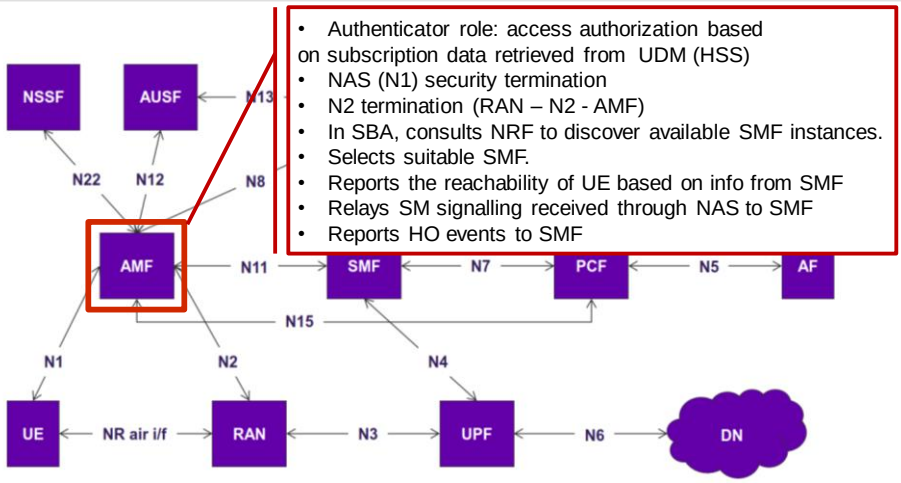
- Builds on consumer-provider relationships following IT principles.
- Network Functions discovers each other dynamically. Therefore the service registration and discovery function is very essential for SBA. This is implemented through Network Function Repository Function.

5GC Service Based Architecture

- A system architecture is composed of a set of Network Functions (NF) providing services to other authorized NFs.
- NFs can be in the role of service consumer or service provider within a transaction.
- An NF service consumer consists of:
  - service business logic,
  - service producer discovery and,
  - service producer instance selection.
- An NF producer consists of:
  - service business logic,
  - service registration and,
  - optional load balancing.
- Assumes a message bus type connectivity rather than ptp between NFs.

3GPP TS 29.500 Rel. 15

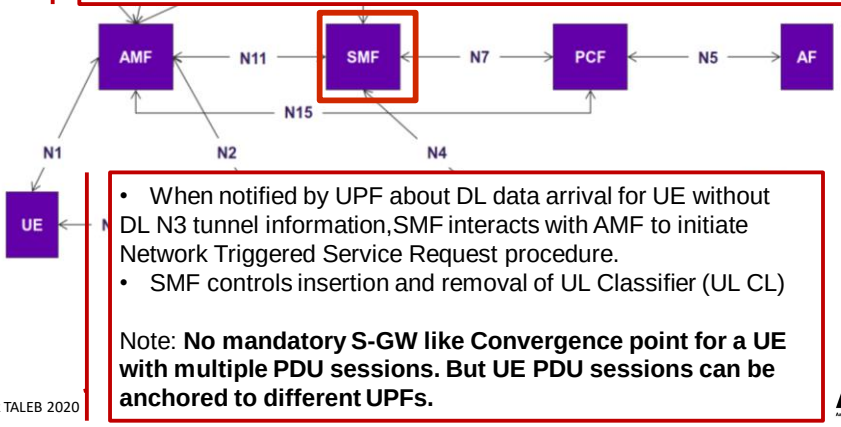
3GPP 5G Architecture



Note: Focus on mobile however Access Network (AN) could be fixed

3GPP 5G Architecture

- Provides PDU Connectivity Service for different PDU types, including IP, Ethernet and non-IP PDU types for a UE
- Handles Session Management signalling for PDU Sessions from AMF
- Selects UPF
- Sets up multiple PDU Sessions to the same or different DNs over 3GPP and non-3GPP accesses
- Sets up multiple PDU Sessions to the same DN via different UPFs
- Indicates to AMF when a PDU Session has been released



- When notified by UPF about DL data arrival for UE without DL N3 tunnel information,SMF interacts with AMF to initiate Network Triggered Service Request procedure.
- SMF controls insertion and removal of UL Classifier (UL CL)

Note: **No mandatory S-GW like Convergence point for a UE with multiple PDU sessions. But UE PDU sessions can be anchored to different UPFs.**

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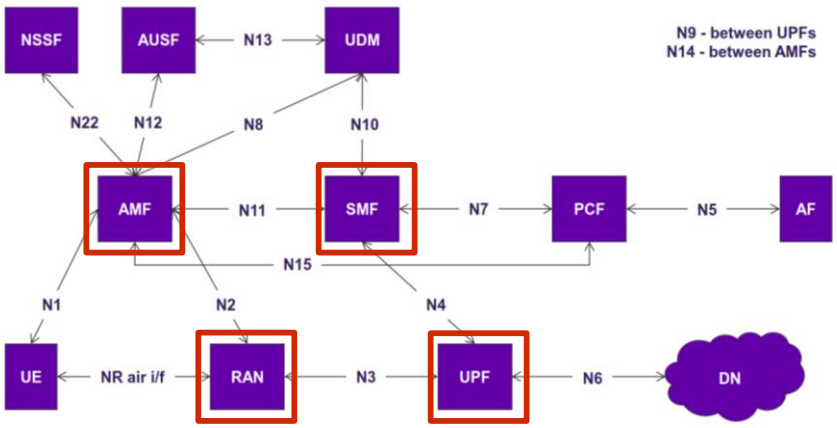
3GPP 5G Architecture



Note: Focus on mobile however Access Network (AN) could be fixed

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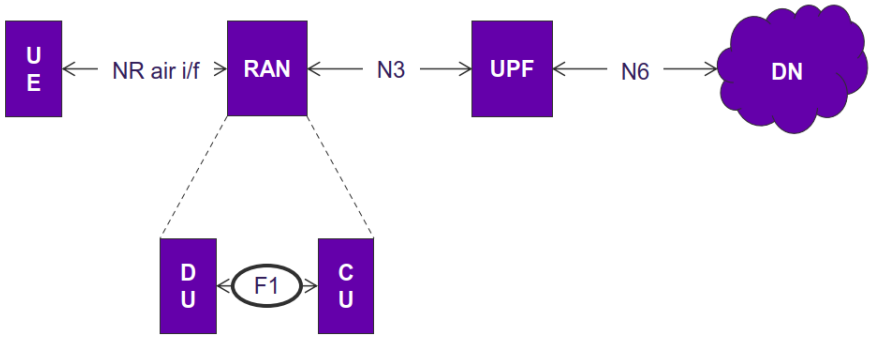
Functional Decomposition of the 5G RAN



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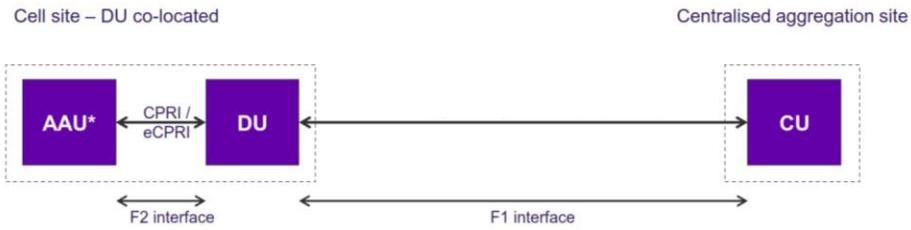
5G RAN Architecture – DU collocated with RF



*AAU illustrated, actual implementation could be AAU or passive antenna with RRU

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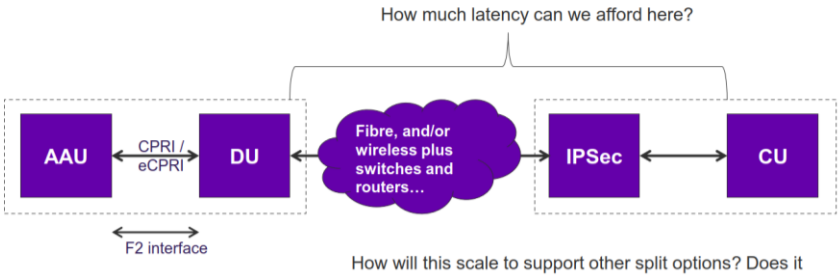
Latency Requirements



How will this scale to support other split options? Does it need to?
Alternative splits in uplink/downlink?
Alternative splits as subs move from cell centre to cell edge?
…

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5G Latency Requirements – Industry Targets

NGMN 5G Requirements

- 5G E2E Latency (eMBB) = **10ms** (i.e. RTT from UE-Application-UE)
- 5G E2E Latency (URLLC) = **1ms** (i.e. RTT from UE-Application-UE – or just UE-UE)

In both cases, the values are defined as capabilities that should be supported by the 5G System.

GSMA 5G Requirements

- 5G E2E Latency = **1ms** (again, defined as a capability target, not as a universal requirement)

ITU-R IMT-2020 Requirements

- eMBB User Plane Latency (one-way) = **4ms** [radio network contribution]
- URLLC User Plane Latency (one-way) = **1ms** [radio network contribution]
- Control Plane Latency = **20ms (10ms target)** [UE transition from Idle to Active via network]

Low Latency Use Case Requirements (various sources)

- Virtual Reality & Augmented Reality: **7-12ms**
- Tactile Internet (e.g. Remote Surgery, Remote Diagnosis, Remote Sales): < **10ms**
- Vehicle-to-Vehicle (Co-operative Driving, Platooning, Collision Avoidance): < **10ms**
- Manufacturing & Robotic Control / Safety Systems: **1-10ms**

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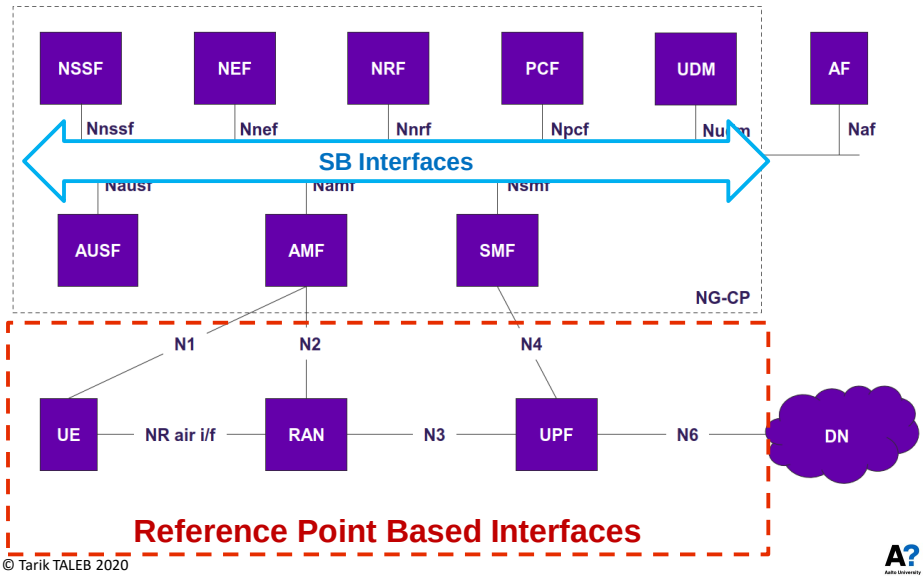
Scope of Service Based Interfaces (Rel 15)



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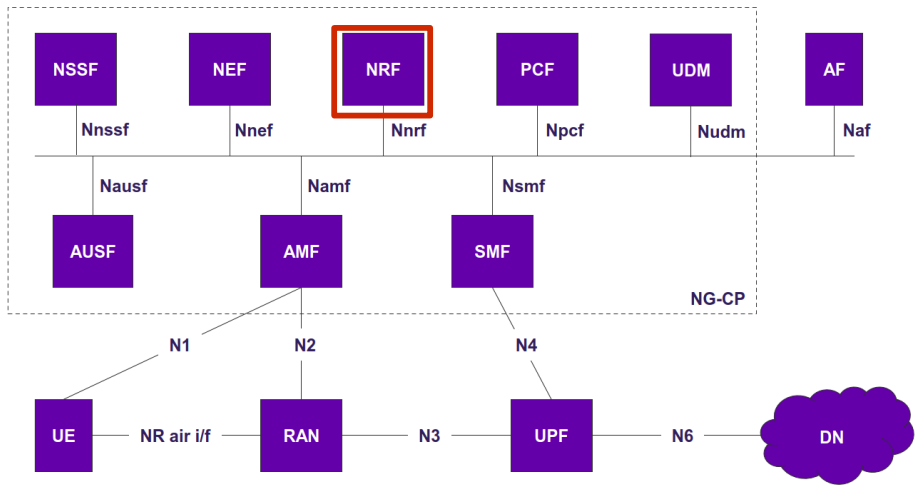
3GPP 5G Service-Based Architecture



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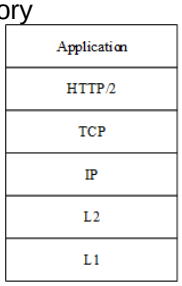
5GC Service Based Architecture

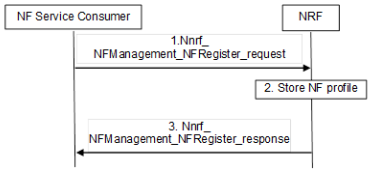
- Key role of Network Repository Function (NRF)
  - The NF Service Framework is based on Network Repository Function (NRF) that provides registration, discovery and authorization services to other NFs.
- All SBA Network Functions implement Service Based Interfaces:
  - Serialization protocol: JSON (IETF RFC 7159).
  - REST based OpenAPI Specification for SBI.
  - HTTP2 over TCP.
  - Subscribe-Notify service operations supported with two TCP connections, one per direction.
- NF Service Based Interface naming convention example:
  - Namf = SBI of Access Mobility Management Function
  - Nsmf = SBI of Session Management Function



3GPP TS 29.500 Rel. 15

Network Function Repository Function

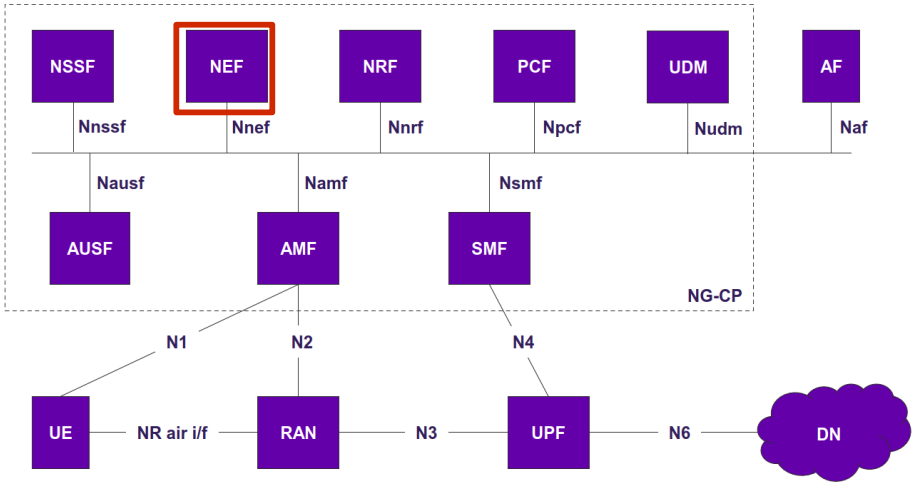
- NRF supports service discovery function.
  - Receives NF Discovery Requests from NF instances, and provides the information of the discovered NF instances to the NF instance.
  - Makes first level NF selection based on the request attributes.
- NRF monitors NF availability
  - NFs send regularly status update messages to NRF
- NRF maintains the NF profile of available NF instances and their supported services.



Nnrf_NF Registration procedure, TR23.502

Network Function Repository Services defined in 3GPP TS 29.510

3GPP 5G Service-Based Architecture

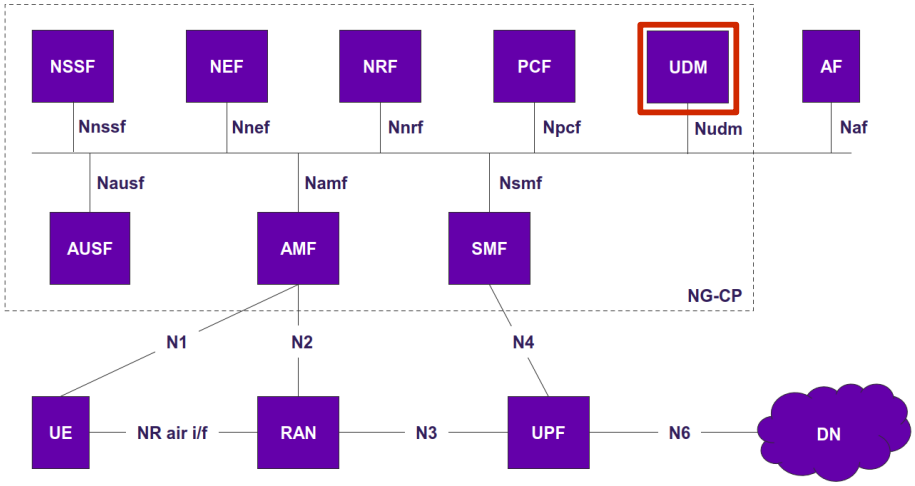


Network Exposure Function

- NEF offers to Application Functions (AF) RESTful APIs that allows them to access the services and capabilities provided by the 5G:
  - Monitoring
  - Device Triggering
  - Resource management of Background Data Transfer
  - Communication Pattern Parameters Provisioning
  - Packet Flow Description Management
  - Traffic Influence (Traffic rerouting)
- Trusted applications may bypass NEF.

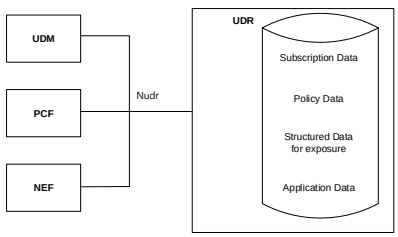
Network Function Repository Services defined in 3GPP TS 29.510

3GPP 5G Service-Based Architecture



Unified Data Repository (UDR)

- Unified Data Repository (UDR) stores and provides the following data:
  - Subscription data,
  - Policy data,
  - Structured data (e.g. data from 3GPP NFs) ,
  - Application data such as Packet Flow Descriptions (PFDs) for application detection.
- Provides notifications of subscribed data changes to its consumers.
- Offers Nudr_DataRepository Service interface to its consumers:
  - Unified Data Managament (UDM)
  - Policy Control Function (PCF)
  - Network Exposure Function (NEF)



Network Function Repository Services defined in 3GPP TS 29.510

Source TS 29.504

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5G NW Planning

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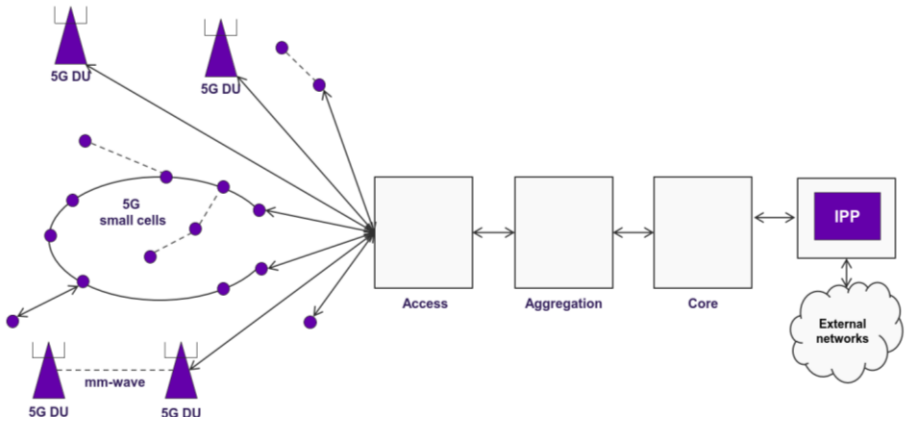
Developing a 5G NW



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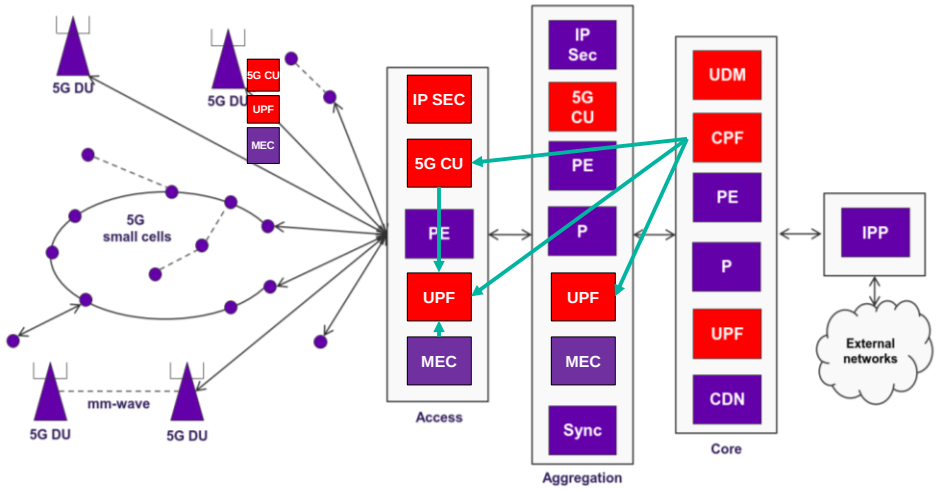
Conceptual 5G NW Architecture



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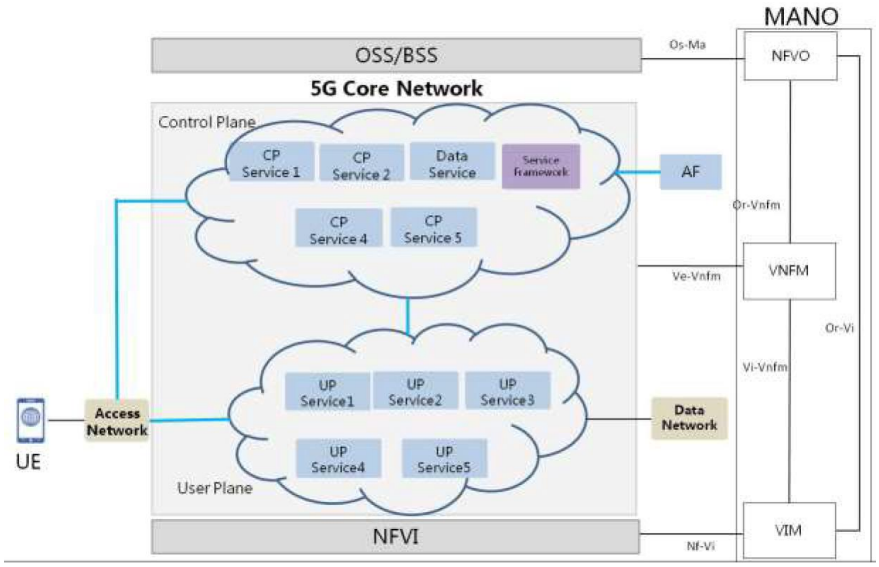
Mapping SBA on ETSI NFV



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E2E Slicing

A journey to a very innovative world …

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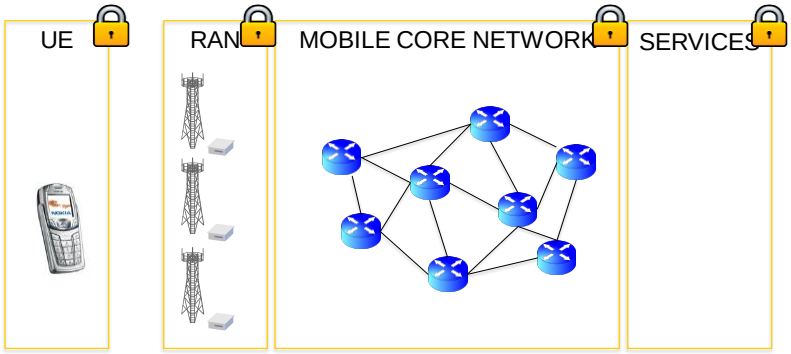
Pre-Apple Era



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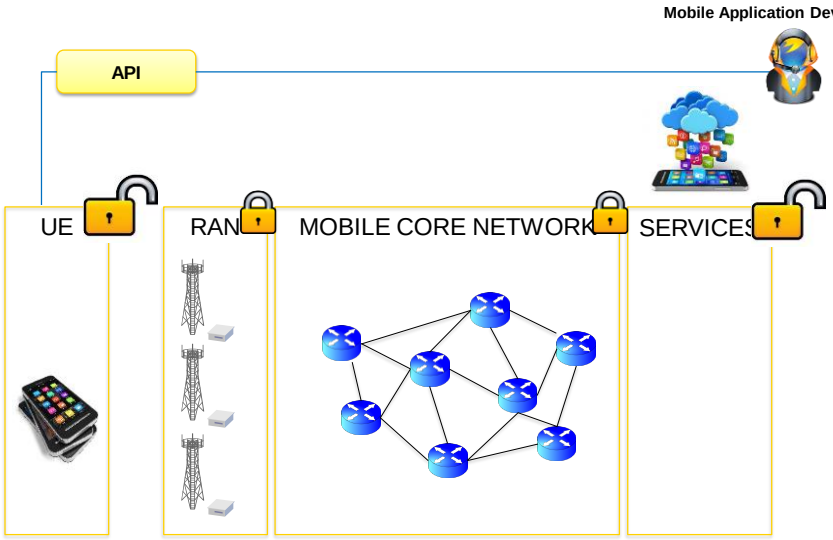
On-going Apple Era



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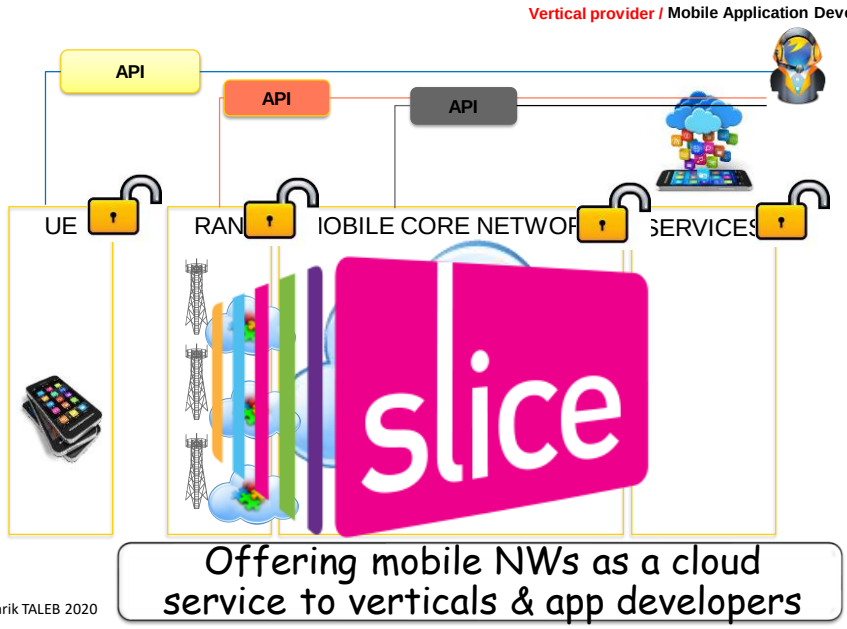
… the journey …



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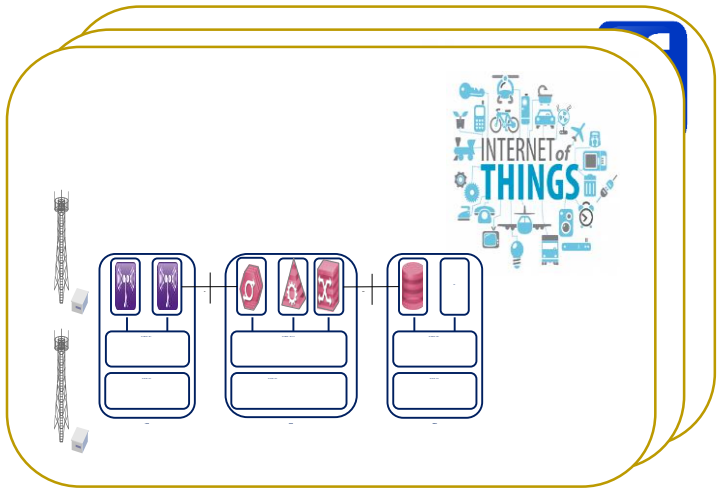
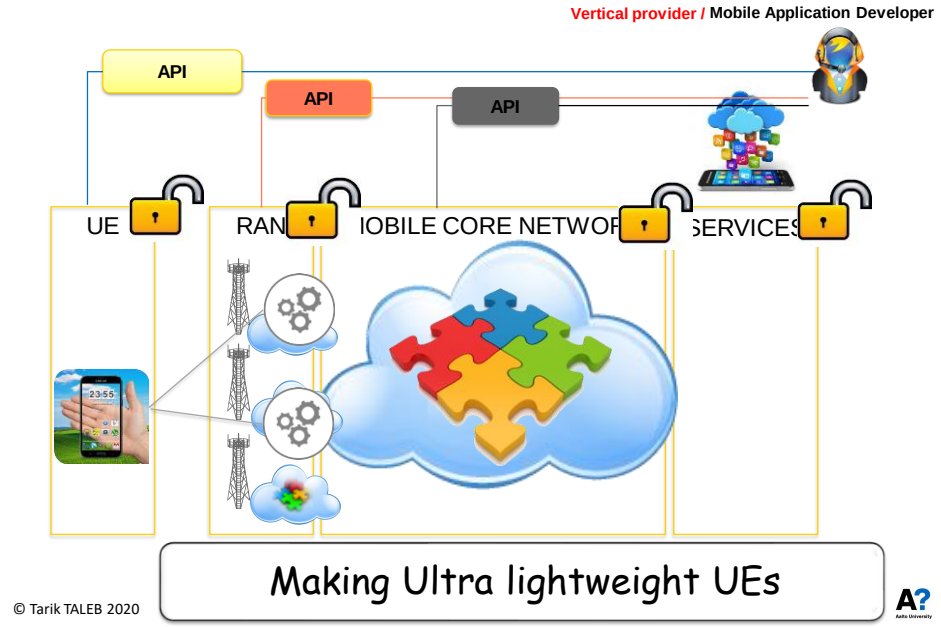
NW Softwarization: A NW slice for every mobile service



172

… the journey …



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Network Softwarization (continued)

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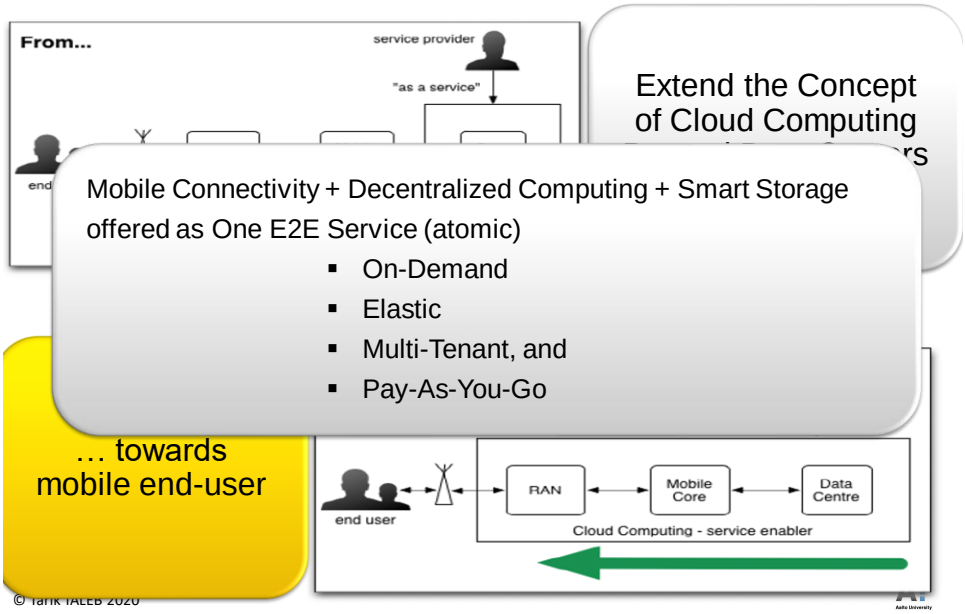
NW Softwarization: Core Idea



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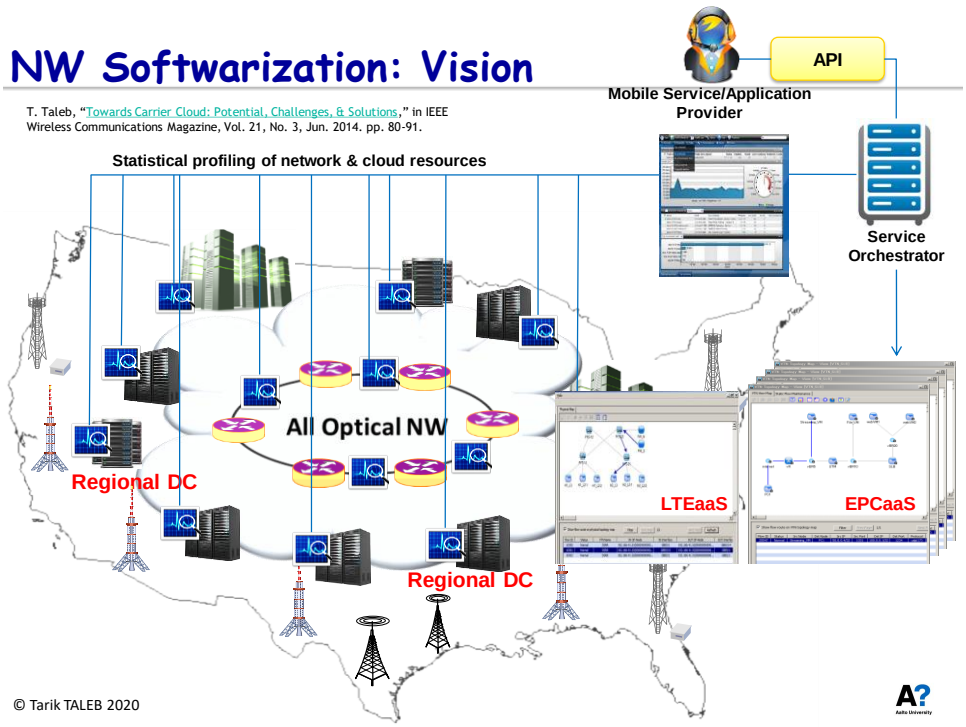
NW Softwarization: Vision



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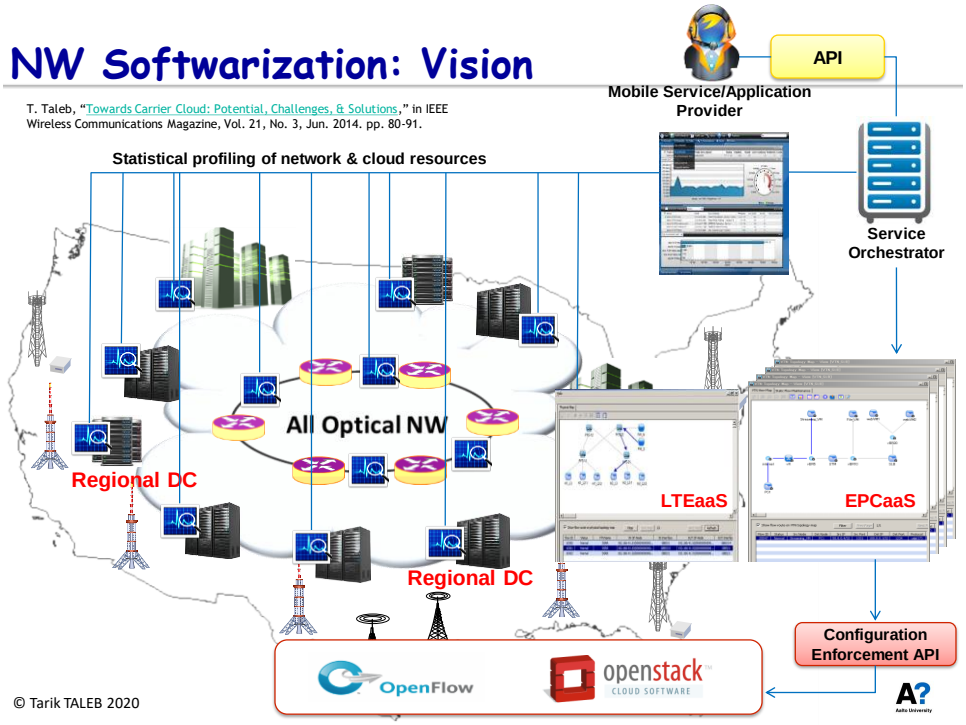
NW Softwarization: Vision

T. Taleb, "Towards Carrier Cloud: Potential, Challenges, & Solutions," in IEEE Wireless Communications Magazine, Vol. 21, No. 3, Jun. 2014. pp. 80-91.



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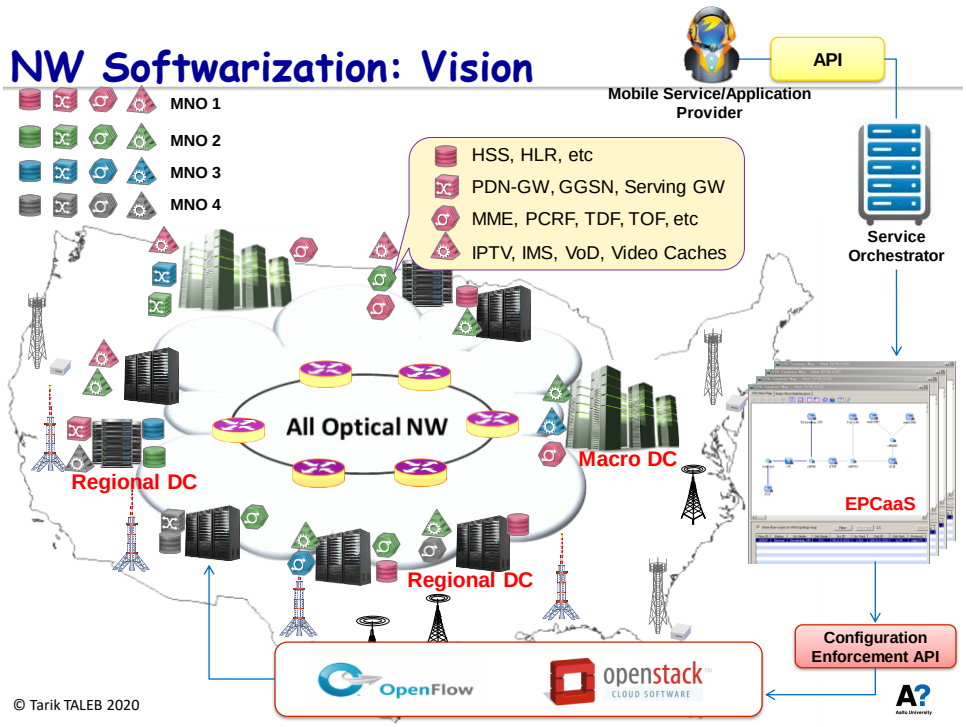
NW Softwarization: Vision



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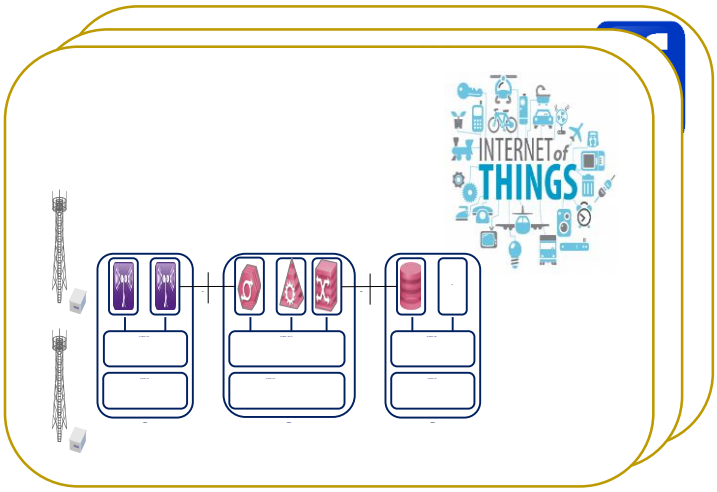
NW Softwarization: A NW slice for every mobile service



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Turning Mobile Networking into Software Engineering

Can we do it?

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Joining efforts and expertise …

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Enabling Technologies

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Conclusion

- 5G
  - Requirements: Elasticity, flexibility, agility, short latency!
  - New vision for mobile core
  - Cloud potential
- Network Softwarization
  - Many advantages to offer
  - Key enabling technologies
    - NFV
    - SDN
- 5G architectures: two approaches
  - Reference point based
  - Service based
- Use cases

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