Network Function Virtualization

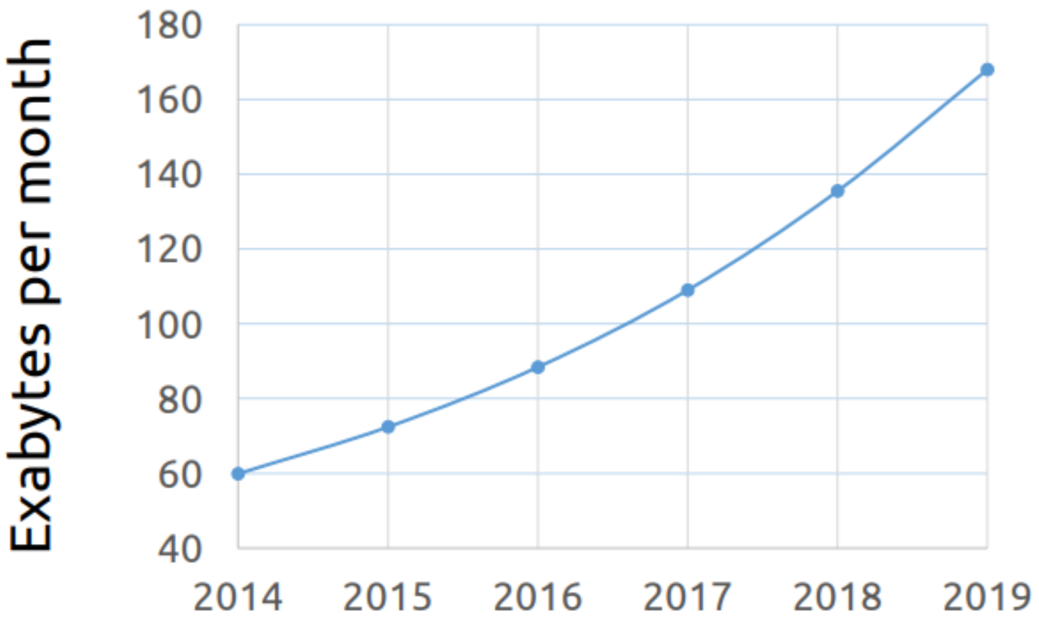
MOBILE CYBERPHYSICAL SYSTEMS

Goals

1. NFV: main concepts
2. Key benefits of NFV
3. Overview of the NFV architecture
4. Deployment of a network service

Global Traffic trend

Continuously increasing user requirements: more data, rapidly changing services: Increased CAPEX



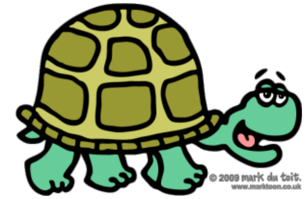
1 exabyte = 1 000 000 000 gigabytes

Data Source: Cisco VNI Global IP Traffic Forecast, 2014–2019. May 2015

Problem : OVER/UNDER PROVISING of HW resources

Context

- days to move HW configuration



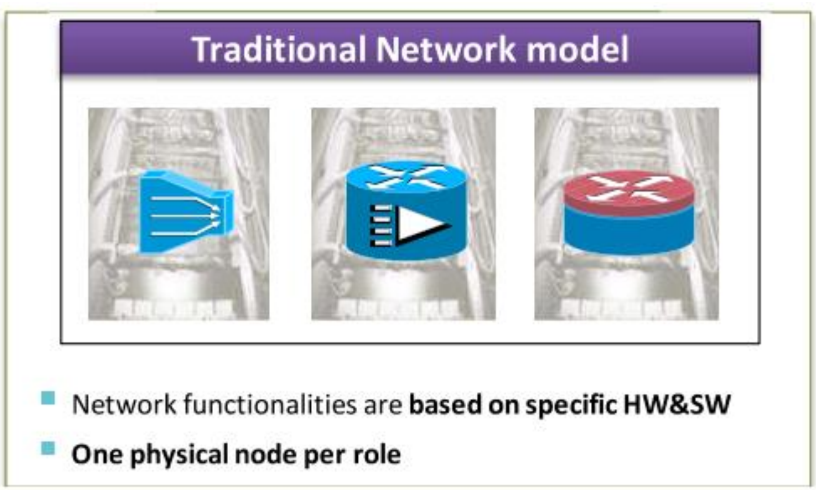
Traditional telecommunications industry

FW before a load balancer

- Based on deploying physical proprietary equipment for each function that is part of a given service
- Service components have strict chaining/ordering that must be reflected in the network topology
- Requirements for high quality, stability and protocol adherence

This has led to

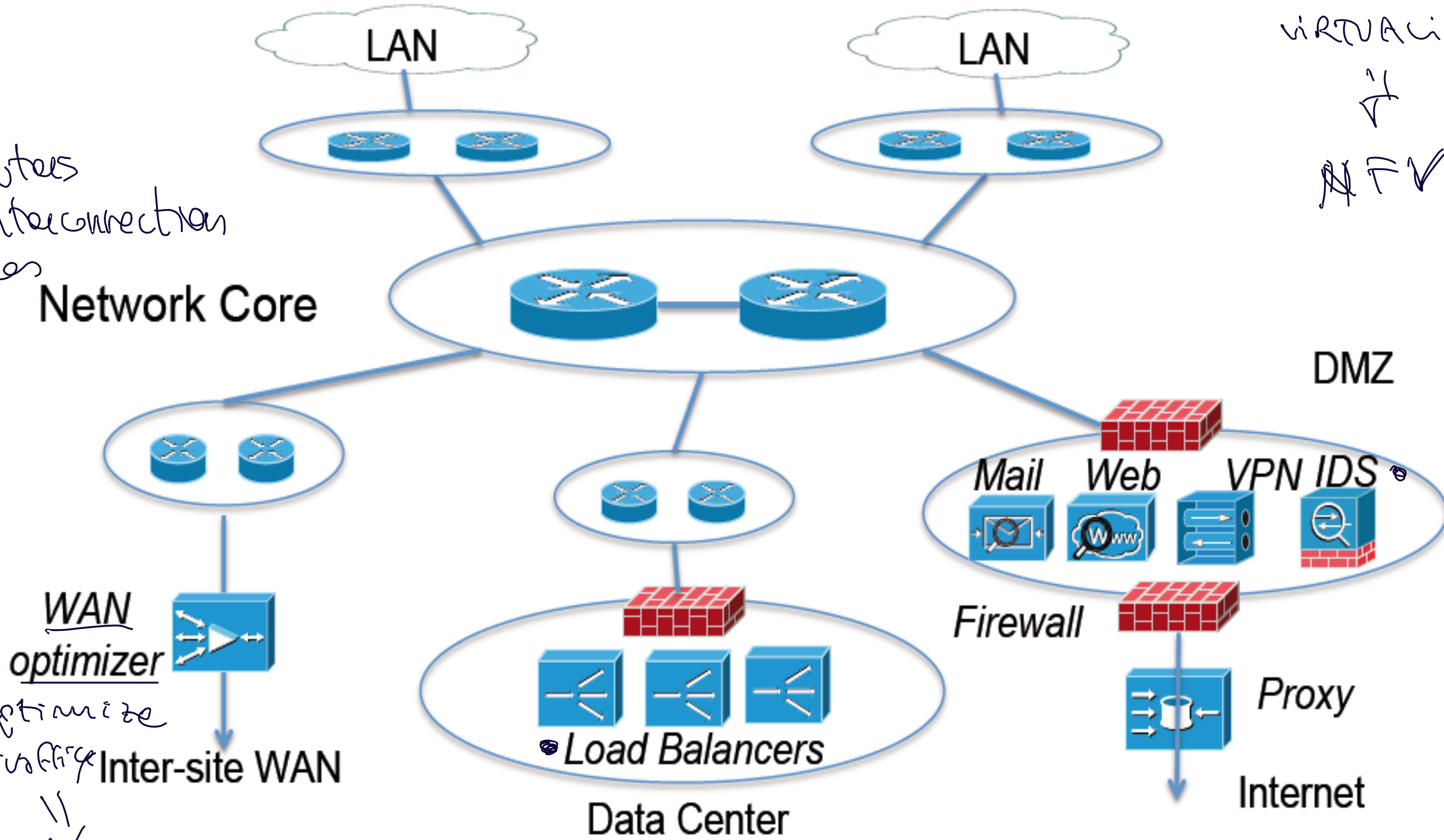
- long product cycles,
- very low service agility and
- heavy dependence on specialized hardware



Typical enterprise network

Firwall, lod balancers, WAN optimizer, IDS ...
were hw resources
⇓
now can be VIRTUALIZED
⇓
NFV

Z2: routers as interconnection devices



: optimize traffic
⇓
LIKE DATA COMPRESSION

(from: Vyas Sekar, Sylvia Ratnasamy, Michael K. Reiter, Norbert Egi, and Guangyu Shi. 2011. The middlebox manifesto: enabling innovation in middlebox deployment. In *Proceedings of the 10th ACM Workshop on Hot Topics in Networks* (HotNets-X). ACM, New York, NY, USA, Article 21, 6 pages. DOI: https://doi.org/10.1145/2070562.2070583)

A world of middleboxes

Data from a large enterprise:
>80K users across tens of sites

Type of appliance	*Number*
Firewalls	166
NIDS	127
Media gateways	110
Load balancers	67
Proxies	66
VPN gateways	45
WAN Optimizers	44
Voice gateways	11
Total Middleboxes	***636***
Total routers	***~900***

(from: Vyas Sekar, Sylvia Ratnasamy, Michael K. Reiter, Norbert Egi, and Guangyu Shi. 2011. The middlebox manifesto: enabling innovation in middlebox deployment. In *Proceedings of the 10th ACM Workshop on Hot Topics in Networks* (HotNets-X). ACM, New York, NY, USA, Article 21, 6 pages. DOI: https://doi.org/10.1145/2070562.2070583)

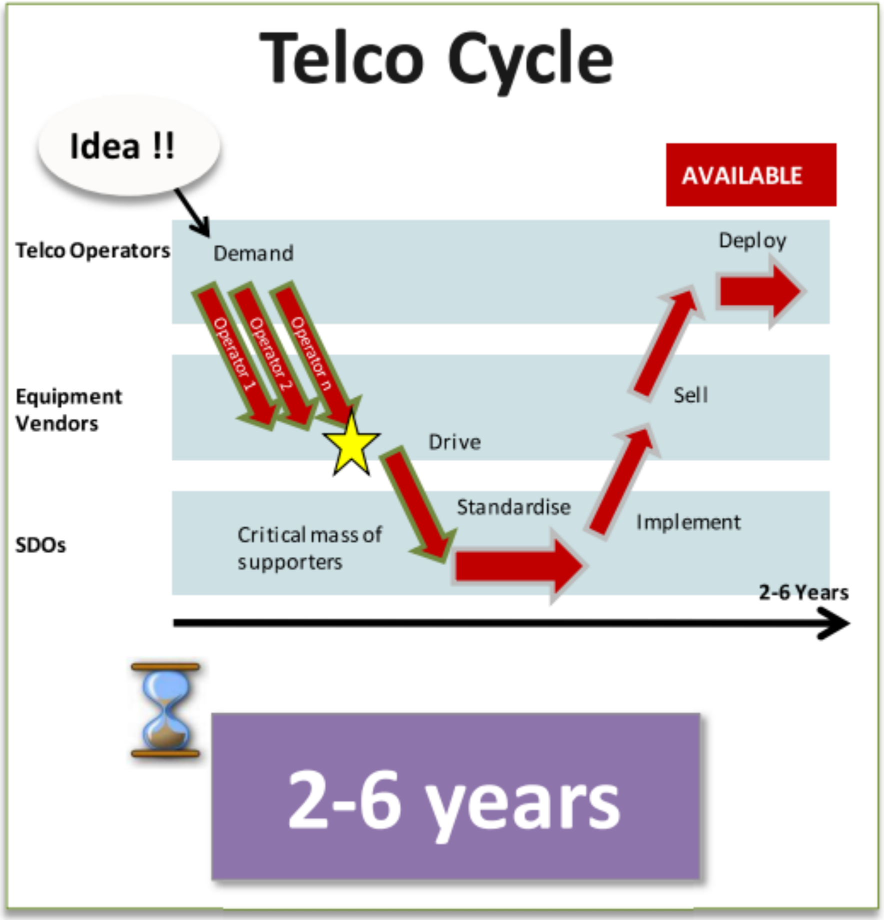
Problem statement

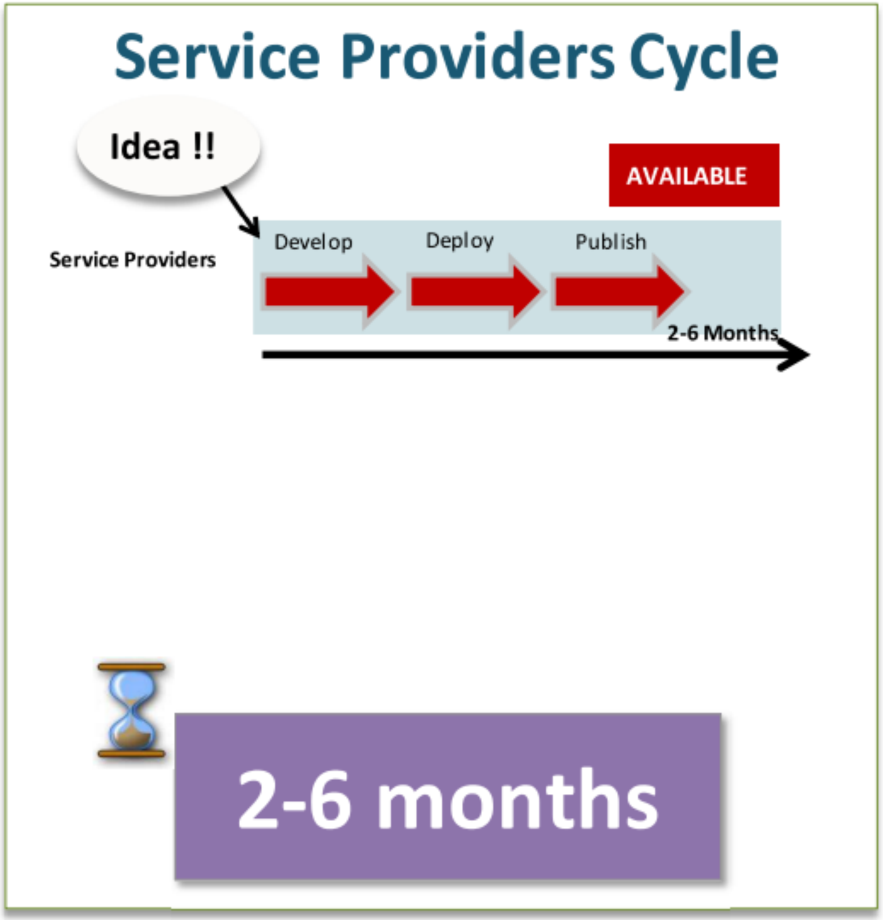
Users increasingly demand more diverse and short-lived services with high data rates

- Need for purchase, store and operate new physical equipment
- New and rapidly changing skills to operate and manage the equipment
- Dense deployment of network equipment
- It leads to higher CAPEX and OPEX but…

- cannot be translated in higher subscription costs

Telco vs Service Provider

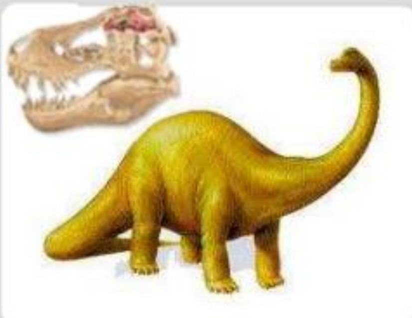




Source: Adapted from D. Lopez Telefonica I+D, NFV

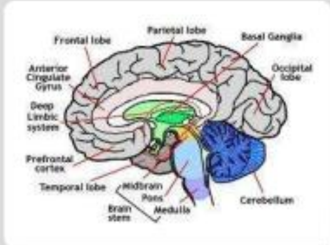
Telco vs Service Provider

Traditional telcos



- Very **intensive in hardware**
- Software not at the core

Internet players



- Very **intensive in software**
- Hardware is a necessary base

HARDWARE **SOFTWARE**

AT&T, Telefonica, Telebras

Google, Facebook

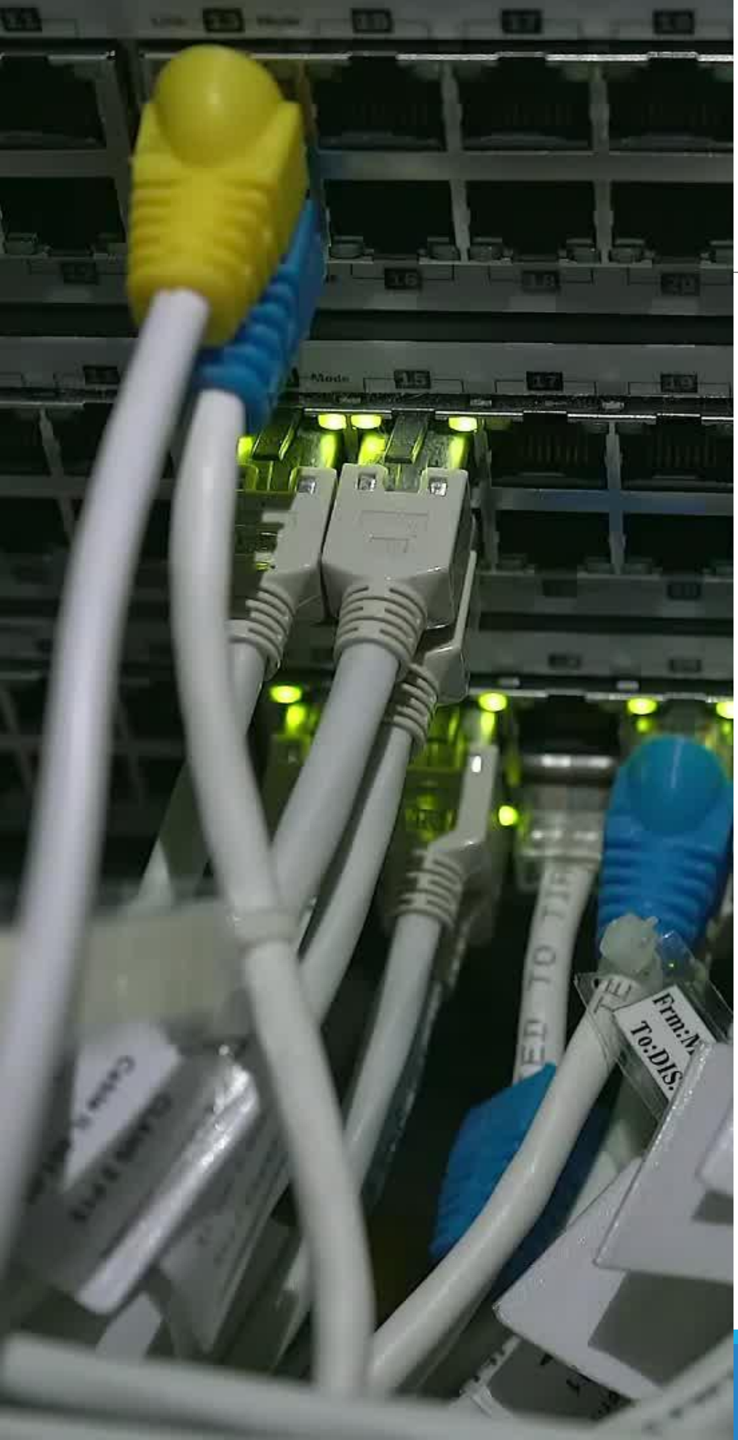
Adapt to survive: telco focus shifting from hardware to software

Source: Cesar Marcondes (UFSCar) 2014

2012 - Call for Action

Providers forced to find **new ways of building more dynamic and service-aware networks, with shorter product cycles, cheaper and more agile**

Some of the operators selected the **European Telecommunications Standards Institute** (ETSI) to be the home of the Industry Specification Group for **Network Function Virtualization (NFV)**



NFV – main idea

NFV is one (the?) way to address these challenges by leveraging virtualization technologies

=> Dec. HW from SW: - generic HW
- implement via SW the network functions

- Main idea: **decoupling of physical network equipment from the functions that run on them**
- Network functions provided as plain software

using virtualization

A Network service can be decomposed into a set of Virtual Network Functions (VNFs)

NVN layer to decouple HW/SW

VNFs may then be relocated and instantiated at different network locations without requiring to buy and install new hardware

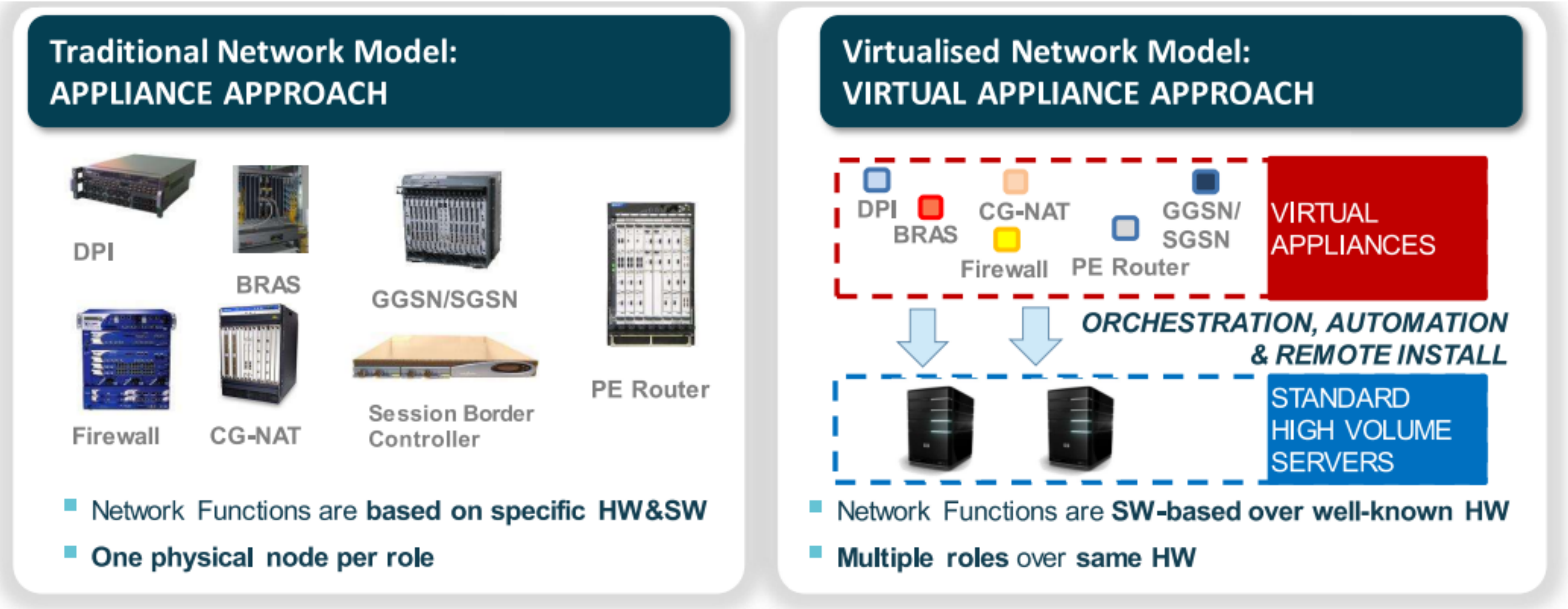
- Capacity vs functionality
- Opportunity for new players

• migrate Net Function if traffic change (NFV)

NFV

virtualization of network functions by implementing these functions in software and running them on VMs hosted by general purpose HW

a significant departure from traditional approaches to the design deployment, and management of networking services



Use cases

carrier-grade NAT

transcoder

DDoS protection

firewall

NFV is applicable to several data plane packet processing and control plane functions in mobile and fixed networks

→ Broadband Network Gateway: ap point for subscriber (telecom operator)
→ carrier pro

Some examples:

- Switching elements: BNG, CG-NAT, routers
  4G/5G
- Mobile network nodes: HLR/HSS, MME, SGSN, GGSN/PDN-GW, RNC, Node B, eNodeB
- Functions contained in home routers and set top boxes to create virtualized home environments (NAT, Firewall)
- Tunneling gateway elements: IPsec/SSL VPN gateways
- Traffic analysis: DPI, QoE measurement
- Service Assurance, SLA monitoring, Test and Diagnostics
- NGN signaling: IMS
- Converged and network-wide functions: AAA servers, policy control and charging platforms
- Application-level optimization: CDNs, Cache Servers, Load Balancers, Application Accelerators
- Security functions: Firewalls, virus scanners, intrusion detection systems, spam protection

• USING NFV FOR MOBILE NETWORK

One example of use case: vEPS

Both the core (EPC) and the RAN can be mostly virtualized

Evolved packet core

Radio Access Network

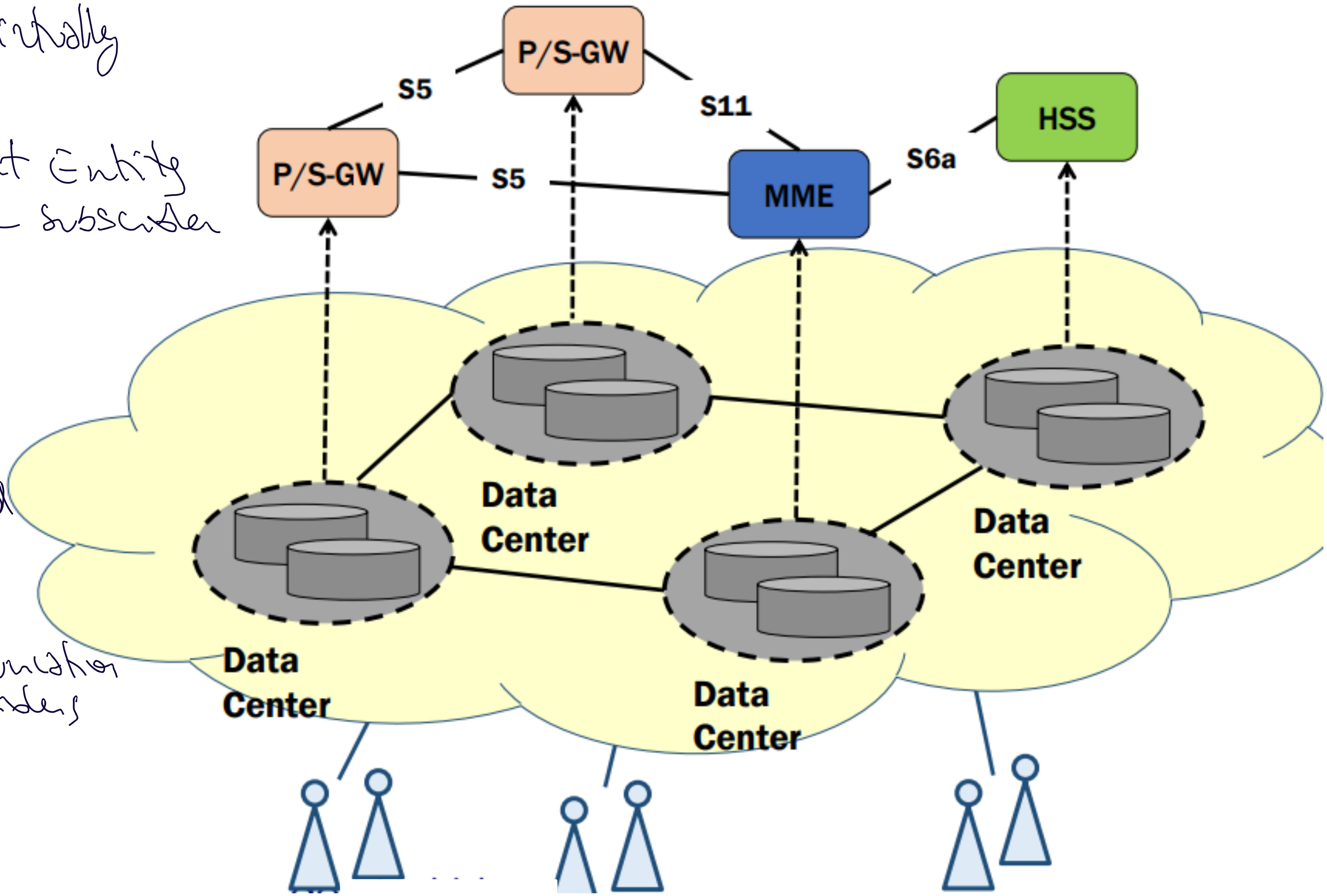
- Improved network usage efficiency
  - Due to flexible allocation of different NFs on the HW pool
- Higher service availability and resiliency
  - Provided by dynamic network reconfiguration
- Elasticity
  - Capacity dedicated to each NF can be dynamically modified according to actual load on the network, thus increasing scalability
- Topology reconfiguration
  - Network topology can be dynamically reconfigured to optimize performance

One example of use case: vEPS

- Can deploy virtually
- P/S - gtway
- Mobility mgmt Entity
- Home Service Subscriber

ON TOP OF DC

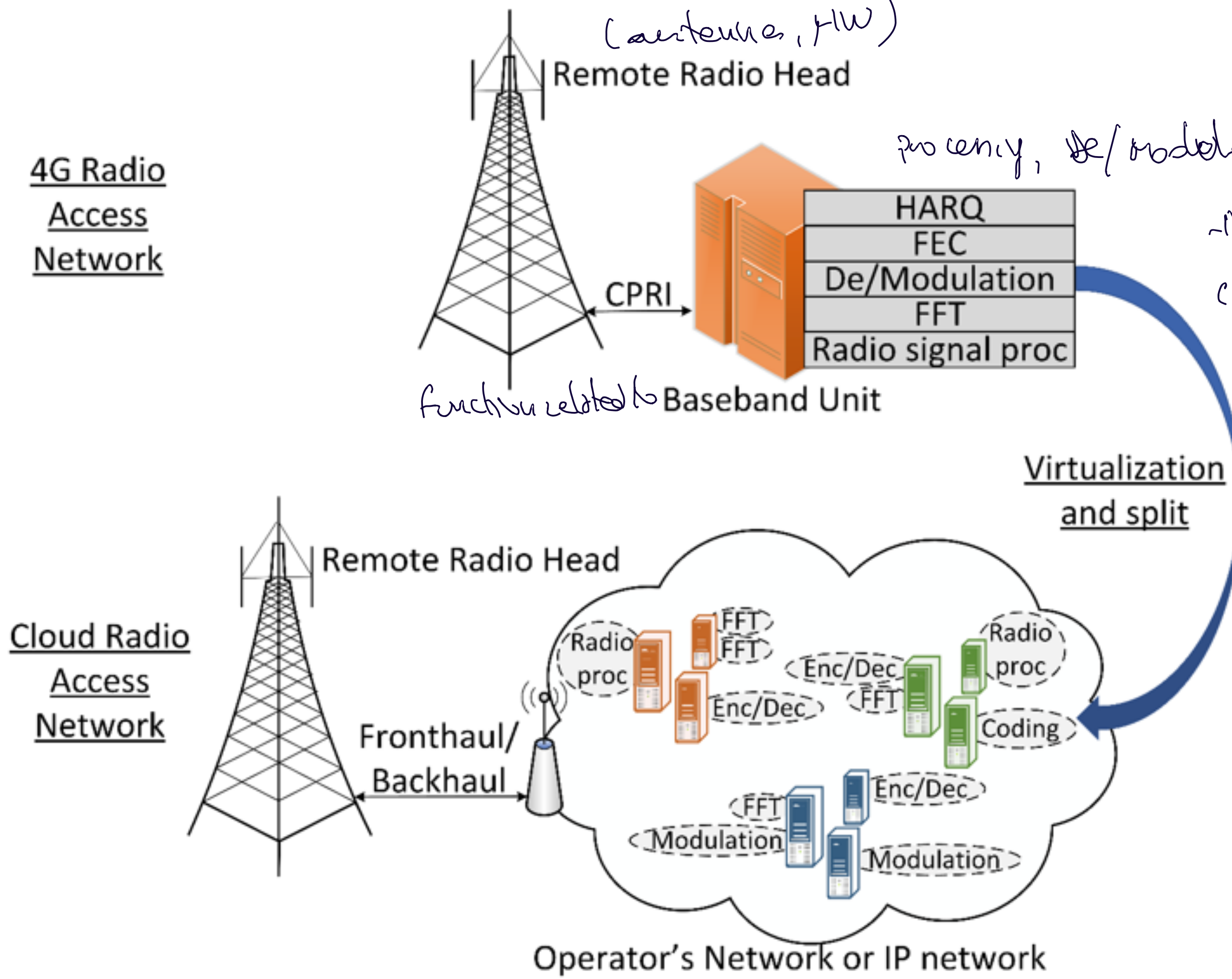
DC can deployed in all point of presence of telecommunication providers



Virtualization of RAN

(antennae, HW)

processing, de/modulation



functions related to Baseband Unit

-instead have it near to RRH
can split and virtualized
⇓
deploy f(x)s to your closest DC

NFV - benefits

1) Implement network functions as SW
2) Deploy them on general purpose HW
3) locate/relocate accordingly to needs
4) can better use the resources

In traditional networks, all devices are deployed on proprietary/closed platforms. All network elements are enclosed boxes, and hardware cannot be shared. Each device requires additional hardware for increased capacity, but this hardware is idle when the system is running below capacity.

With NFV, however, network elements are independent applications that are flexibly deployed on a unified platform comprising standard servers, storage devices, and switches.

In this way, **software and hardware are decoupled**, and capacity for each application is increased or decreased by adding or reducing virtual resources

(+)

- Flexibility (change/adapting topology of the network)
- Faster innovation
- Services can be rapidly scaled up/down as required

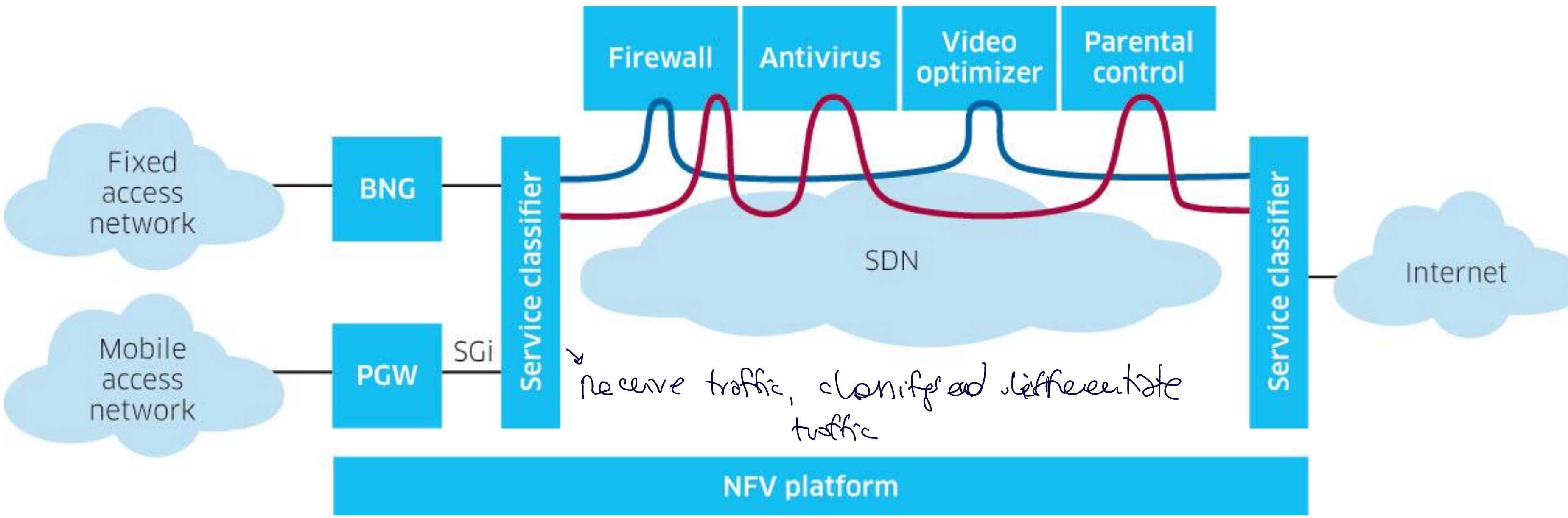
(−)

- PROBLEMS: OVERHEAD, performance (no specific HW)

Network service

Network service example

• Composition of network function to manage traffic flow



Receive traffic, classify and differentiate traffic

Network Service in NFV

An **end-to-end network service** can be defined as a **forwarding graph of network functions and end points/terminals**

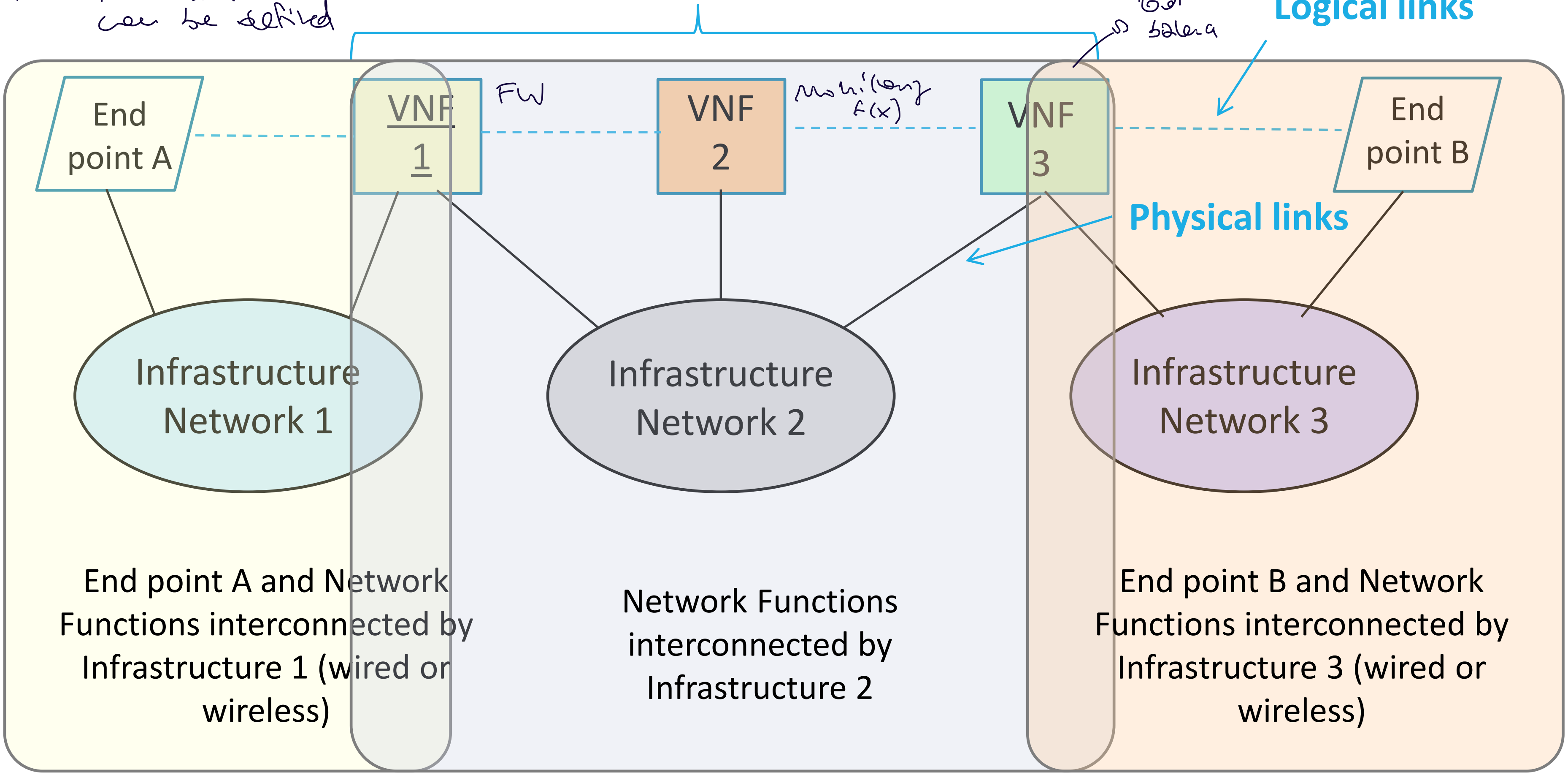
"What" an operator provides to customers.

A network service can be viewed architecturally as a forwarding graph of Network Functions (NFs) interconnected by supporting network infrastructure.

- These network functions can be implemented in a single operator network or interwork between different operator networks.
- The underlying network function behaviour contributes to the behaviour of the higher-level service.

How NTWK service can be defined

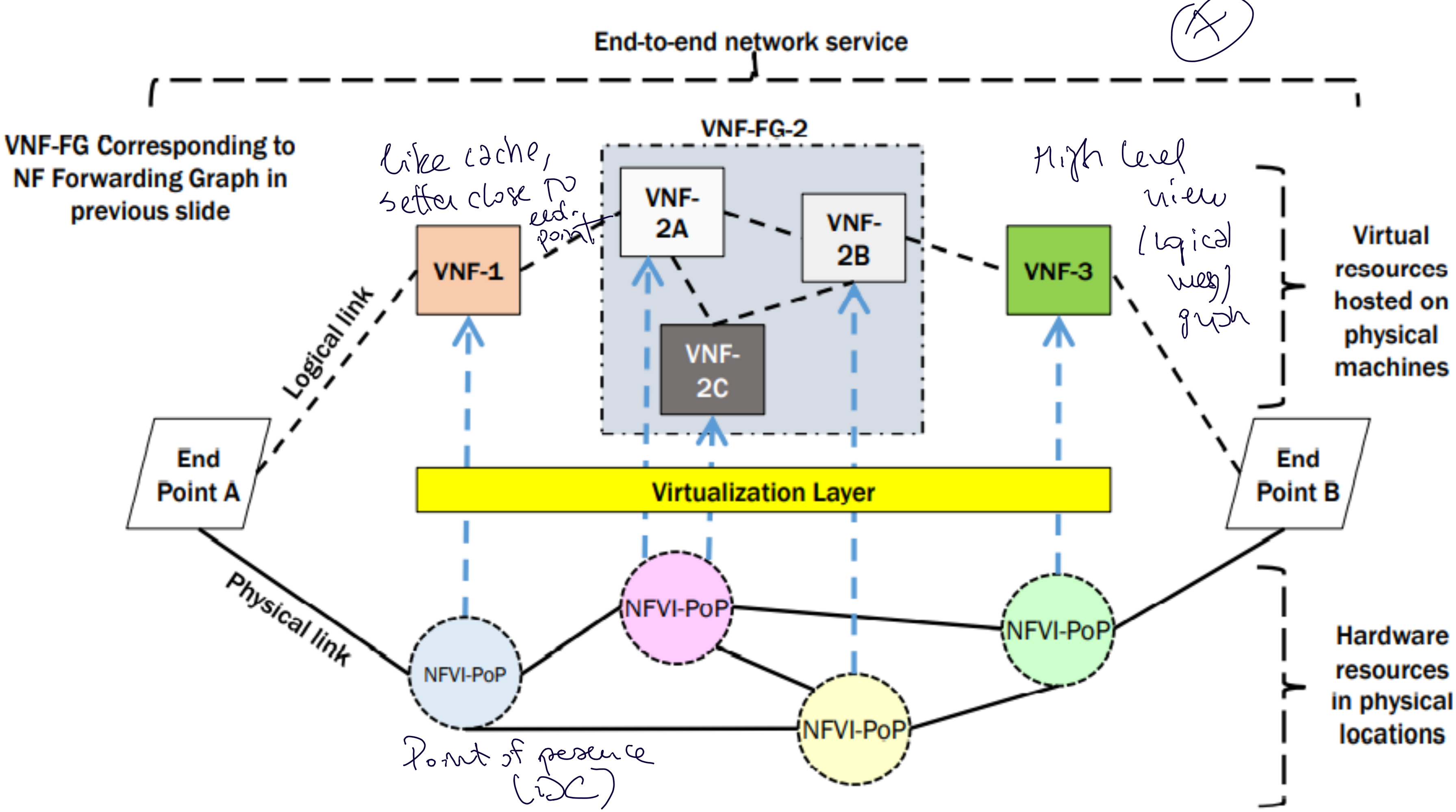
Network Function Forwarding Graph



Example: chain of network functions

The interconnections among the NFs and endpoints are depicted by dashed lines, representing logical links.

These logical links are supported by physical paths through infrastructure networks (wired or wireless).



All of these VNFs run as VMs on physical machines, called points of presence (PoPs).

VNF forwarding graph (VNF-FG)

- Example of nested VNF-FG (i.e. VNF-FG-2) constructed from other Virtualised Network Functions (i.e. VNF-2A, VNF-2B and VNF-2C).

- Need entities to manage NFV (life cycle of NTWK services):
  - a customer requires new network service
  - operator takes in account the description of the network service (document that specify the service)
  - operator choose which point of presence has to be used to deploy the network function and activate set of ORCHESTRATION and mgmt functions that automatically take the description of the service and allocate a VM on a PoP and install the network function on that VM
  - also set-up / organize links so that function can communicate

NFV architectural framework

= Entities to manage life cycle of network service & components of nwk service

NFV Architectural Framework

- functions
- logical links

The NFV Archictectural Framework addresses the following:

1) - The resources required to setup a Network service NFVI
  (HW, infrastructure, NFV Infrastructure

2) - The functionality that is required due to the decoupling network functions into software and hardware => SW that implements the network functions VNF

3) - The functionality that is required for NFV-specific management and orchestration : ENTITIES that orchestrate / allocate resources MANO

Management & Orchestration

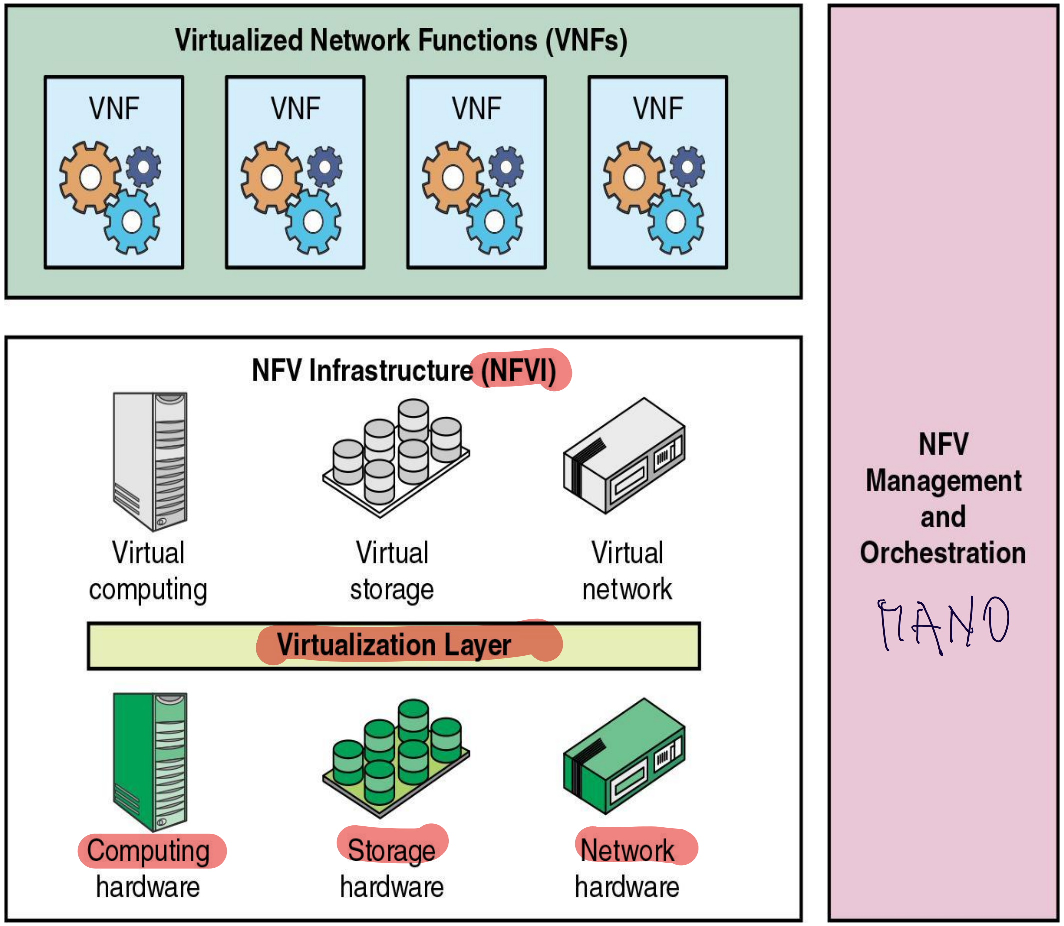
- Let's look more closely to the NFV Architecture

High-level view of the NFV framework

e) **NFV infrastructure (NFVI)**: Comprises the hardware and software resources that create the environment in which VNFs are deployed. executed on this NFVI

VNF: The collection of VNFs implemented in software to run on virtual computing, storage, and networking resources.

NFV management and orchestration (NFV-MANO): Framework for the management and orchestration of all resources in the NFV environment.



NFV Infrastructure

the totality of all hardware and software components which build up the environment in which VNFs are deployed, managed and executed.

- NFVI virtualizes physical computing, storage, and networking and places them into resource pools

physical hardware resources include computing, storage and network that provide processing, storage and connectivity to VNFs through the virtualisation layer (e.g. hypervisor).

- Computing hardware is assumed to be general-purpose
- Storage resources can be differentiated between shared network attached storage (NAS) and storage that resides on the server itself
- Network resources are comprised of switching functions and wired or wireless links

NFV Infrastructure

Compute domain:

- Provides commercial off-the-shelf (COTS) high-volume servers and storage.

Hypervisor domain:

- Mediates the resources of the compute domain to the VMs of the software appliances, providing an abstraction of the hardware.
- e.g. VMs but now VNFs are also executed in containers -> Cloud Native Functions (CNF)

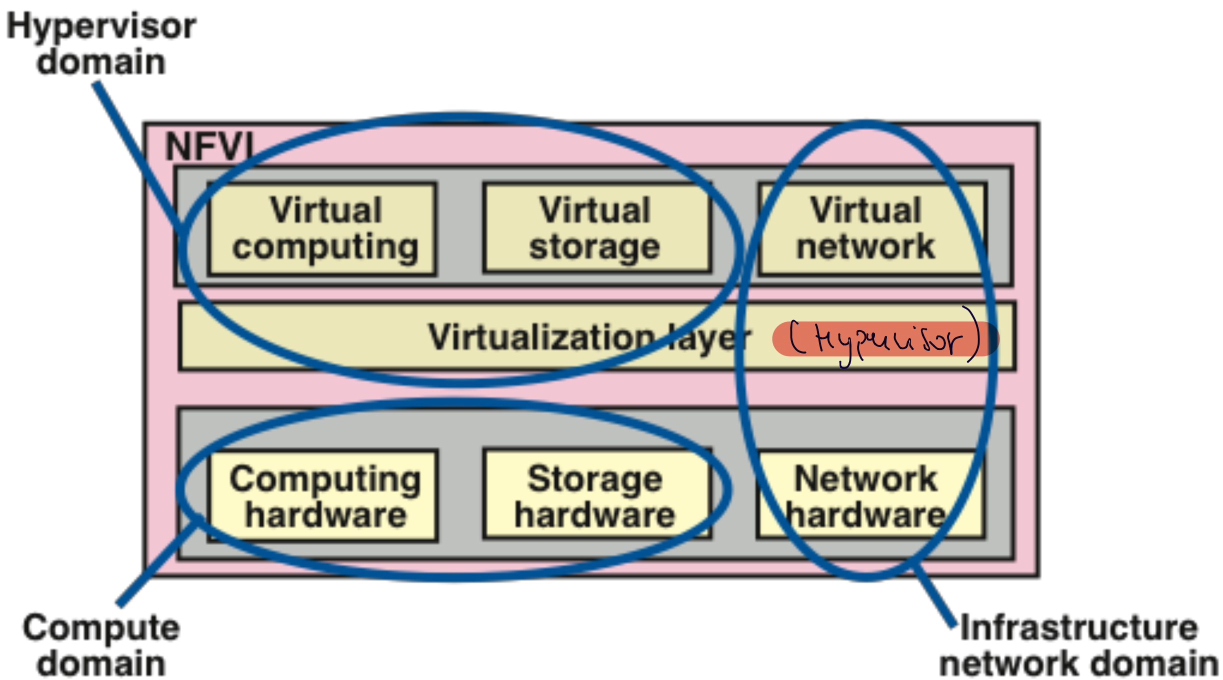


Figure 8.1 NFV Domains

Infrastructure network domain

Comprises all the generic high volume switches interconnected into a network that can be configured to supply network services.

NFV Infrastructure

The NFVI can span across several locations

Two main types of networks:

- **NFVI-PoP network**: interconnects the computing and storage resources contained in an NFVI-PoP. It also includes specific switching and routing devices to allow external connectivity.
- **Transport network**: interconnects NFVI-PoPs, NFVI-PoPs to other networks owned by the same or different network operator, and NFVI-PoPs to other network appliances or terminals not contained within the NFVI-PoPs.

Infrastructure Network domain

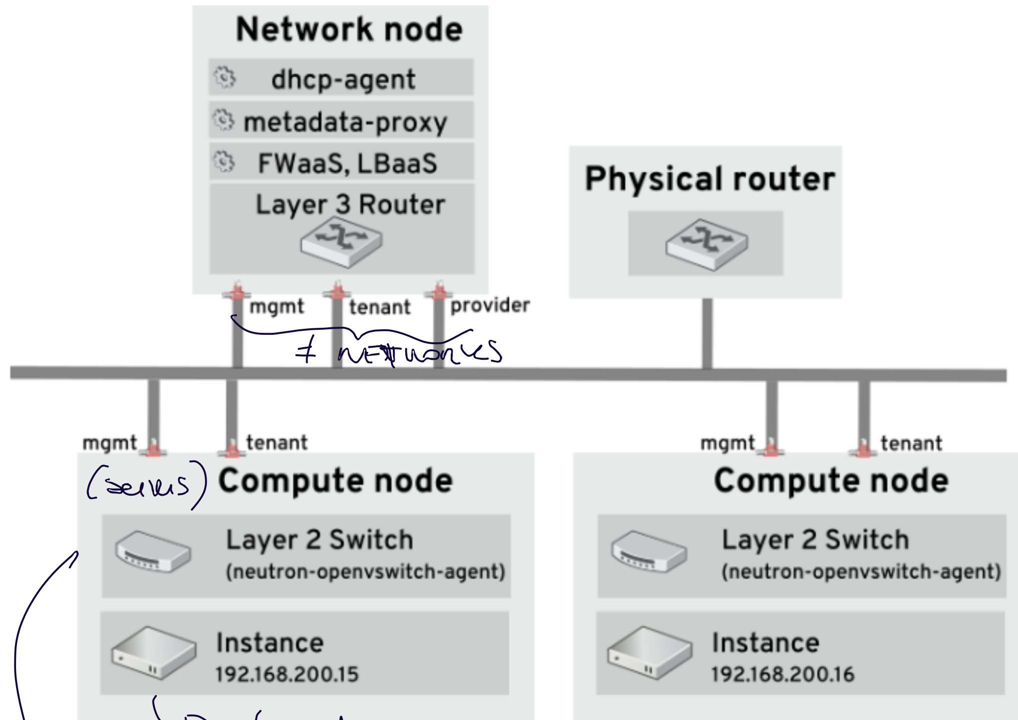
Possible deployment of a network in OpenStack

platform for managing physical resources

Node dedicated to network f(x)s

Example: OpenStack Networking deployment

- A dedicated OpenStack Networking node performing L3 routing and DHCP, and running the advanced services *FWaaS* and *LBaaS*.
- Two Compute nodes run the Open vSwitch (*openvswitch-agent*) and have two physical network cards each, one for tenant traffic, and another for management connectivity.
- The OpenStack Networking node has a third network card specifically for provider traffic



≠ instances of VMs on compute nodes

switch realized via SW, interconnect VMs instances

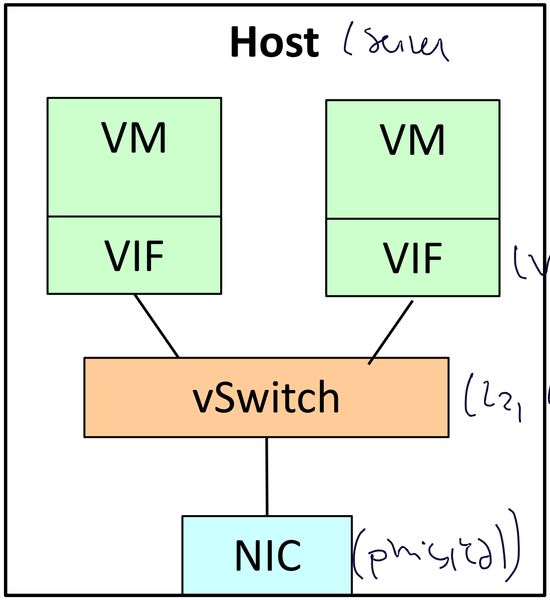
vSwitch

VMs are often connected to virtual interfaces (VIFs).

Virtual switches provide connectivity between these VIFs and the physical interfaces (PIFs), and also handle traffic between VIFs colocated on the same physical host.

Virtual switches reside in the host and are typically written entirely in software

Example: Open vSwitch, https://www.openvswitch.org/



(virtual interface assigned to each VM

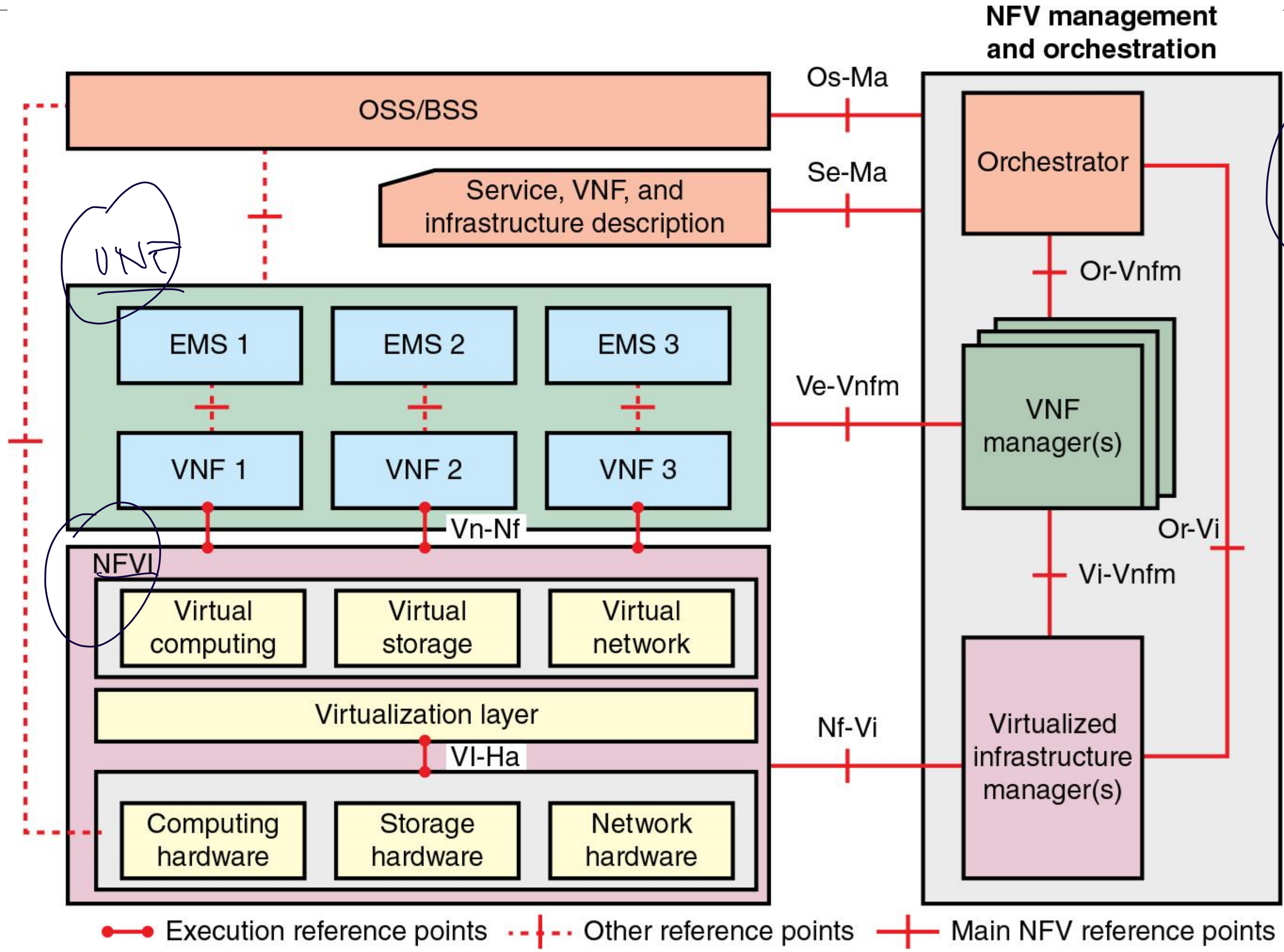
(L2, L3 interconnection)

(Mininet uses containers

Pfaff B, Pettit J, Amidon K, Casado M, Koponen T, Shenker S. Extending networking into the virtualization layer. InHotnets 2009 Oct 22.

Management and Orchestration => MANO

NFV Reference Architectural Framework

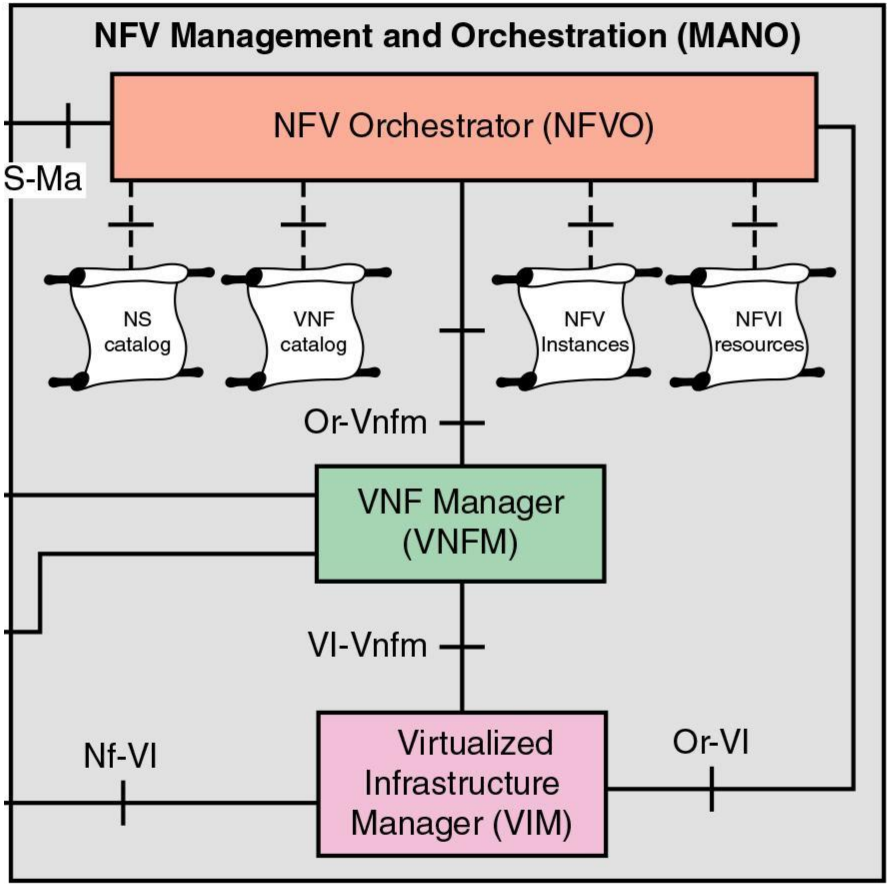


MANO

- receive request for network service deployment
- interact with the infrastructure resources.
- to create network service

NFV MANO

- Provides the functionality required for the provisioning of the VNFs, and related operations
  - the configuration of the VNFs, and
  - the configuration of the infrastructure the VNFs run on
- Includes orchestration and lifetime management of physical and/or software resources supporting the infrastructure virtualization and the lifecycle management of VNFs
- Includes databases used to store information and data models defining deployment and lifecycle properties of functions, services and resources
- Defines interfaces used for communications between components of the MANO, as well as coordination with traditional network management, such as OSS/BS



Virtualized Infrastructure Management (VIM)

• VIRTUALIZED INFRASTRUCTURE MNGMNT: platform that manages the Cloud (DC), like OpenStack
=> IaaS paradigm

VIM comprises the functions that are used to control and manage the interaction of a VNF with computing, storage, and network resources under its authority, as well as their virtualization

- A single instance of a VIM is responsible for controlling and managing the NFVI compute, storage, and network resources, usually within one operator's infrastructure domain.
- **Infrastructure as a Service cloud computing platforms**, such as OpenStack
- To deal with the overall networking environment, multiple VIMs within a single MANO may be needed.

VNF MANAGER: in charge to instanciate a single network service: may be composed by ≠ VNFs

Virtual Network Function Manager (VNFM)

Oversees lifecycle management (e.g. instantiation, update, query, scaling, termination) of VNF instances, e.g.:

VIM to allocate resources to that network service

- VNF instantiation, including VNF configuration if required by the VNF deployment template
- VNF instance scaling out/in and up/down
- VNF instance-related collection of NFVI performance measurement results and faults/events information, and correlation to VNF instance-related events/faults
- VNF instance assisted or automated healing
- VNF instance termination

ORCHESTRATION: - receive whole service request,
- and is in charge of creating the NTWRK service, interacting with

NFV Orchestrator (NFVO)

Responsible for installing and configuring new network services (NS) and virtual network function (VNF) packages, NS lifecycle management and global resource management

Network services orchestration

- manages/coordinates the creation of an end-to-end service that involves VNFs
  - It creates end-to-end service between different VNFs
  - It can instantiate VNFMs, where applicable

Resource orchestration

- Manages and coordinates the resources under the management of different VIMs

- Open source Orchestrators
  - OSM MANO https://osm.etsi.org/
  - ONAP https://www.onap.org/

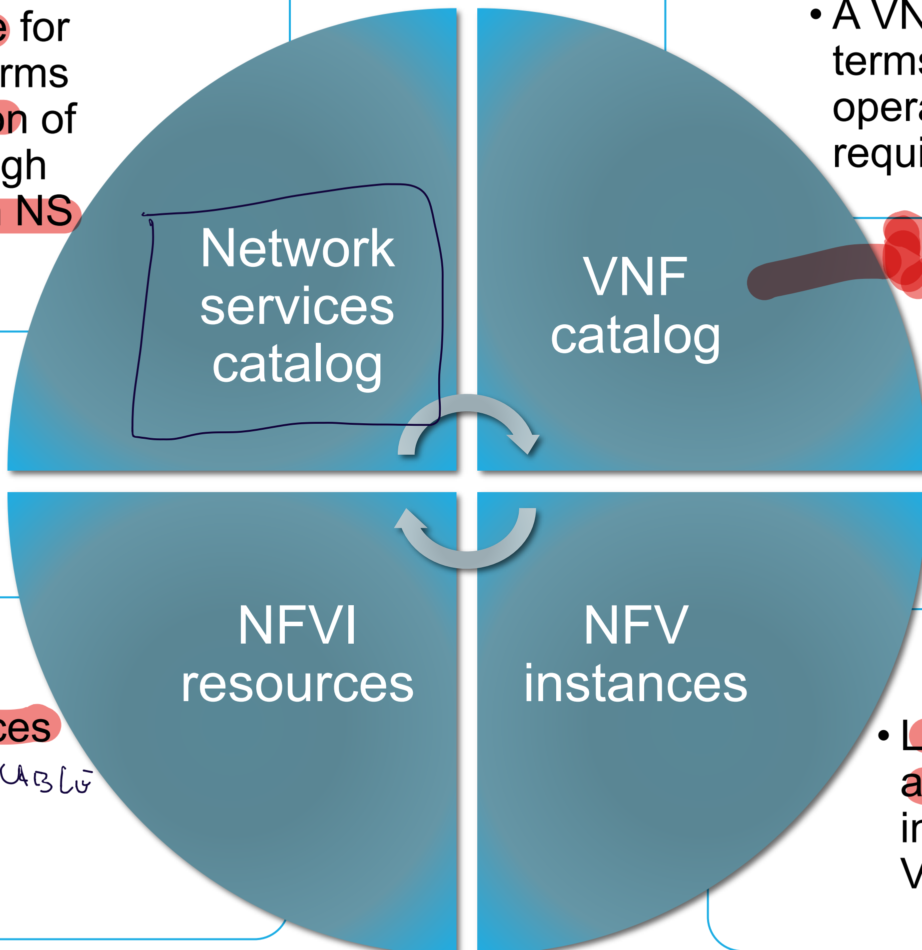
informations

Repositories (DB)

FINAL: - which linux image
- resources required
- how to deploy that FUNCTION

- List of the usable network services
- A deployment template for a network service in terms of VNFs and description of their connectivity through virtual links is stored in NS catalog for future use

- Database of all VNF descriptors (VNFD) for a FN
- A VNFD describes a VNF in terms of its deployment and operational behavior requirements



describe how a virtual network function can be deployed

• ORCHESTRATOR instanciate the network service, but have access to manage its entire lifetime

here / you can have cycles / rules to how scaling the data base

- List of NFVI resources ~~utilized for the~~ AVAILABLE purpose of establishing NFV services

- List containing details about network services instances and related VNF instances (deployed and related VNF instance

NSD _ example

```
{
    "name":"iperf-NSD",
    "vendor":"fokus",
    "version":"0.1-ALPHA",
    "vnfd":[  ...  ],
    "vld":[
        {
            "name":"private"
        }
    ],
    "vnf_dependency":[
        {
            "source" : {
                "name": "iperf-server"
            },
            "target":{
                "name": "iperf-client"
            },
            "parameters":[
                "private"
            ]
        }
    ]
}
```

see next slide

name	The name of the Network Service
vendor	The vendor or provider of the Network Service
version	The version of the Network Service (can be any string)
vnfd	The list of Virtual Network Functions composing the Network Service
vld	The list of Virtual Links that are referenced by the VNF Descriptors in order to define network connectivity
vnf_dep.	Dependency between VNFs: the source VNF shall provide some information (e.g. its IP address) to the target VNF

NSD _ example

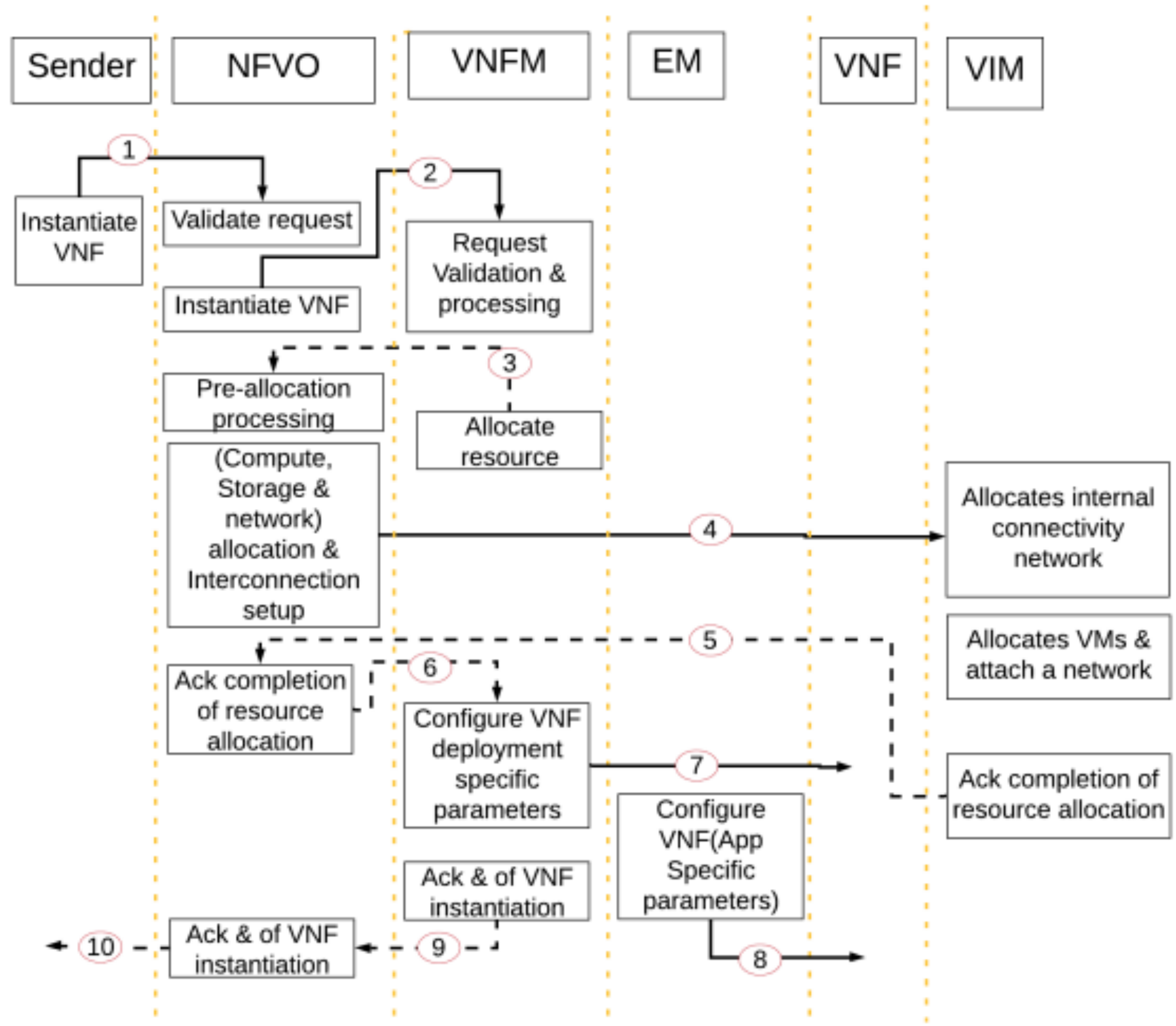
```
…
"vnfd":[
      {
         "vendor":"tbr",
         "version":"0.1",
         "name":"iperf-server",
         "type":"server",
         "endpoint":"generic",
         "configurations":{
            "name":"config_name",
            "configurationParameters":[]
         },
         "vdu":[
            {
               "vm_image":[
                  "ubuntu-14.04-server-
                  cloudimg-amd64-disk1"
               ],
         …
```

```
…
"virtual_link":[
            {
               "name":"private"
            }
         ],
"lifecycle_event":[
            {
               "event":"INSTANTIATE",
               "lifecycle_events":[
                  "install.sh",
                   "start-srv.sh"
               ]
            }
         ],
"deployment_flavour":[
            {
               "flavour_key":"m1.small"
            }
         ],

"vnfPackageLocation":"https://github.com
/openbaton/vnf-scripts.git"

      },
```

From: https://openbaton-docs.readthedocs.io/en/stable/ns-descriptor/

Network service deployment

Example of a simple network service deployment (one VNF)



From: Yilma GM, Yousaf ZF, Sciancalepore V, Costa-Perez X. Benchmarking open source NFV MANO systems: OSM and ONAP. Computer communications. 2020 Sep 1;161:86-98.

References

- Foundations of Modern Networking: SDN, NFV, QoE, IoT, and Cloud, W. Stallings et al. – chapter 8, Addison-Wesley Professional, 1st edition, 2015
- ETSI NFV ISG documents
  - http://www.etsi.org/technologies-clusters/technologies/nfv
  - http://www.etsi.org/deliver/etsi_gs/
  - https://docbox.etsi.org/ISG/NFV/Open/Drafts/

Questions

1. List the main elements of the NFV Architectural Framework

2. Provide a definition of Network Function Virtualization

3. What is a network service catalog?

Appendix

OPTIONAL CONTENT

Element Management (EM)

Is responsible for fault, configuration, accounting, performance, and security management functionality for a VNF

EM functions include:

- Configuration for the network functions provided by the VNF
- Fault management for the network functions provided by the VNF
- Accounting for the usage of VNF functions
- Collecting performance measurement results or the functions provided by the VNF
- Security management for the VNF functions

OSS/BSS

Combination of the operator’s other operations and business support functions that are not otherwise explicitly captured in the present architectural framework, but are expected to have information exchanges with functional blocks in the NFV-MANO architectural framework

May provide management and orchestration of legacy systems and may have full end-to-end visibility of services provided by legacy network functions in an operator’s network

Network Function Taxonomy 1/3

Non-exhaustive taxonomy

see: Middleboxes: Taxonomy and Issues, https://tools.ietf.org/html/rfc3234#section-2.1

Network Address Translator (NAT). A function, often built into a router, that dynamically assigns a globally unique address to a host that doesn't have one, without that host's knowledge.

NAT with Protocol Translator (NAT-PT). A function, normally built into a router, that performs NAT between an IPv6 host and an IPv4 network, additionally translating the entire IP header between IPv6 and IPv4 formats.

IP firewall: The simplest form of firewall is a router that screens and rejects packets based purely on fields in the IP and Transport headers (e.g., disallow incoming traffic to certain port numbers, disallow any traffic to certain subnets, etc.)

Network Function Taxonomy 2/3

Load balancers: variety of techniques that divert packets from their intended IP destination, or make that destination ambiguous. The motivation is typically to balance load across servers.

Transcoders: boxes performing some type of on-the-fly conversion of application level data. Examples include the transcoding of existing web pages for display on hand-held wireless devices, and transcoding between various audio formats for interconnecting digital mobile phones with voice-over-IP services

SOCKS [RFC 1928]: A *SOCKS* server is a general purpose proxy server that establishes a TCP connection to another server on behalf of a client, then routes all the traffic back and forth between the client and the server.

Network Function Taxonomy 3/3

Proxy: An intermediary program which acts as both a server and a client for the purpose of making requests on behalf of other clients. Requests are serviced internally or by passing them on, with possible translation, to other servers

Anonymisers: Anonymiser boxes can be implemented in various ways that hide the IP address of the data sender or receiver (in practice very similar to a NAT)

WAN optimization: techniques for increasing data transfer efficiencies across wide-area networks (WANs), e.g. compression, caching, traffic shaping

And many more…. DPI, IDS, cache

NFV terms 1/2

Term	Definition
Compute domain	Domain within the NFVI that includes servers and storage
Infrastructure network domain	Domain within the NFVI that includes all networking that interconnects compute/storage infrastructure
Network Function (NF)	Functional block within a network infrastructure that has well-defined external interfaces and well-defined functional behavior. Typically, a network node or physical appliance
Network Functions Virtualization (NFV)	Principle of separating network functions from the hardware they run on by using virtual hardware abstraction
Network Functions Virtualization Infrastructure (NFVI):	The totality of all hardware and software components that build up the environment in which VNFs are deployed. The NFV-Infrastructure can span across several locations. The network providing connectivity between these locations is regarded to be part of the NFVI
NFVI-Node	Physical device[s] deployed and managed as a single entity, providing the NFVI Functions required to support the execution environment for VNFs
NFVI-PoP	N-PoP where a Network Function is or could be deployed as Virtual Network Function (VNF)
Network forwarding path	Ordered list of connection points forming a chain of NFs, along with policies associated to the list
Network Point of Presence (N-PoP)	Location where a Network Function is implemented as either a Physical Network Function (PNF) or a Virtual Network Function (VNF)

NFV terms 2/2

Term	Definition
Network service	Composition of Network Functions and defined by its functional and behavioral specification
Physical Network Function (PNF)	An implementation of a NF via a tightly coupled software and hardware system. This is typically a proprietary system
Virtual Machine (VM)	A virtualized computation environment that behaves very much like a physical computer/server
Virtual network	A topological component used to affect routing of specific characteristic information. The virtual network is bounded by its set of permissible network interfaces. In the NFV architecture, a virtual network routes information among the network interfaces of VM instances and physical network interfaces, providing the necessary connectivity
Virtualized Network Function (VNF)	An implementation of an NF that can be deployed on a NFVI
VNF Forwarding Graph (VNF FG)	Graph of logical links connecting VNF nodes for the purpose of describing traffic flow between these network functions
VNF Set	Collection of VNFs with unspecified connectivity between them

History of NFV: ETSI NFV ISG


etwork Functions Virtualisation – Introductory White Paper

Network Functions Virtualisatio

n Introduction, Benefits, Enablers, Challenges & Call for

BJECTIVES

his is a non-proprietary white paper authored by network operators.

he key objective for this white paper is to outline the benefits, enablers and challe
unctions Virtualisation (as distinct from Cloud/SDN) and the rationale for encoura
ternational collaboration to accelerate development and deployment of interope
ased on high volume industry standard servers.

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his white paper is available at the following link: http://portal.etsi.org/NFV/NFV_V

October 2012

Collaboration around NFV started in Oct. 2012

- Leading operators and service providers authored the NFV Whitepaper
- 7 of these operators selected the ETSI to be the home of the Industry
- Specification Group (ISG) for NFV: ETSI ISG NFV

Now, much more people working on NFV

- 75 members + 52 participants in ETSI NFV (May 2022)
- ISGs are not meant to develop standards
- Their recommendations are expected to be enforced by other SDOs such as 3GPP

NFV Architectural Framework

- NFV infrastructure (NFVI)
  - HW and SW resources that create the environment in which VNFs are deployed
  - NFVI virtualizes physical computing, storage, and networking and places them into resource pools
- VNF/EM
  - Collection of VNFs implemented in SW to run on virtual computing, storage, and networking resources, and
  - Collection of element management systems (EMS) that manage the VNFs
- NFV management and orchestration (NFV-MANO)
  - Framework for the management and orchestration of all resources in the NFV environment (computing, networking, storage, and VM resources)
- OSS/BSS
  - Operational and business support systems implemented by the VNF service provide

NFV Architectural Framework

- The NFV Management and Orchestration (MANO) includes the following functional blocks:
- NFV orchestrator (NFVO)
  - Responsible for installing and configuring new network services (NS) and virtual network function (VNF) packages, NS lifecycle management, global resource management, and validation and authorization of NFVI resource requests
- VNF manager (VNFM)
  - Oversees lifecycle management (e.g. instantiation, update, query, scaling, termination) of VNF instances
- Virtualized infrastructure manager (VIM)
  - Controls and manages the interaction of a VNF with computing, storage, and network resources under its authority, in addition to their virtualization