Software Defined Networking and applications in next generation mobile networks

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Outline

- **The need of Virtualization in future networks:**
  - What is Network Virtualization?
  - How to virtualize the network
  - How to enable rapid innovation in networking with Network Virtualization

- **Enabling technologies for next generation networking:**
  - **Software Defined Networking:**
    - SDN: Key Idea and Architecture
    - Standardization of SDN solutions: OpenFlow
  - **Network Function Virtualization**:
    - NFV architecture
    - NFV use cases

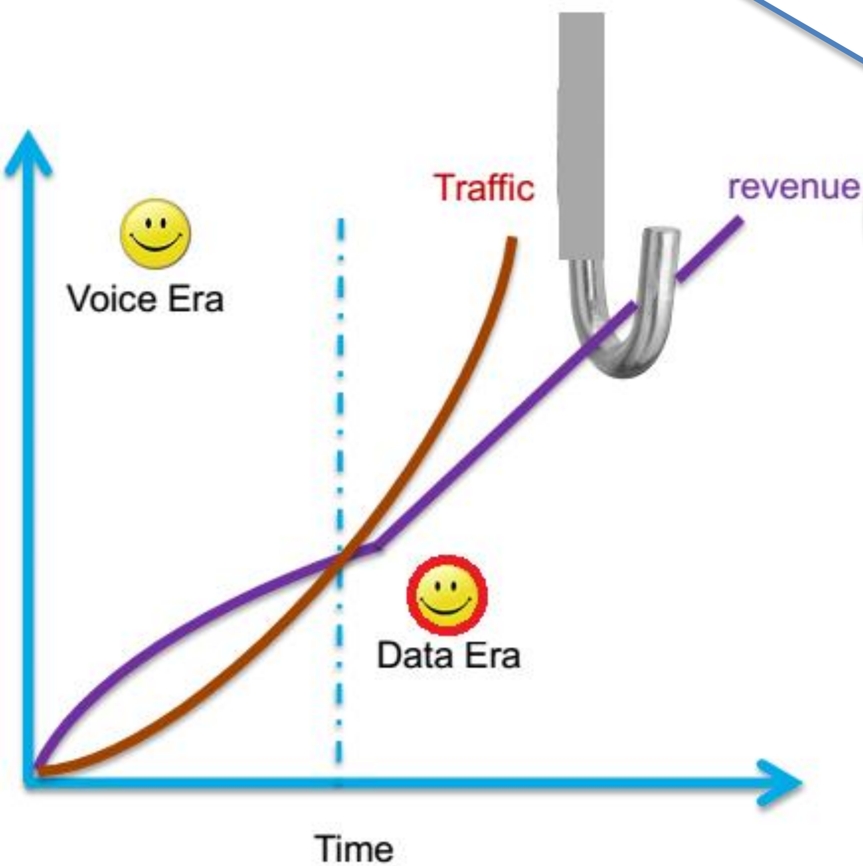
- **SDN and NFV in evolving mobile networks:**
  - RAN Virtualization: benefits, challenges and solutions
  - Core Network Virtualization

Challenges in future networks

- Explosion of devices and traffic: huge capital investment
- Network operators face an increasing disparity between costs and revenues
- Complexity: large and increasing variety of proprietary network hardware appliances
- Lack of flexibility and agility: launching new services is difficult and takes too long

The need of elastic networks

Enablers?



- Network Virtualization
  - Software Defined Networking
  - Network Function Virtualization
- Cloud orchestration

Network Virtualization

What is Virtualization?

vir·tu·al *adjective* \ˈvər-chə-wəl, -chəl; ˈvərch-wəl\

: very close to being something without actually being it

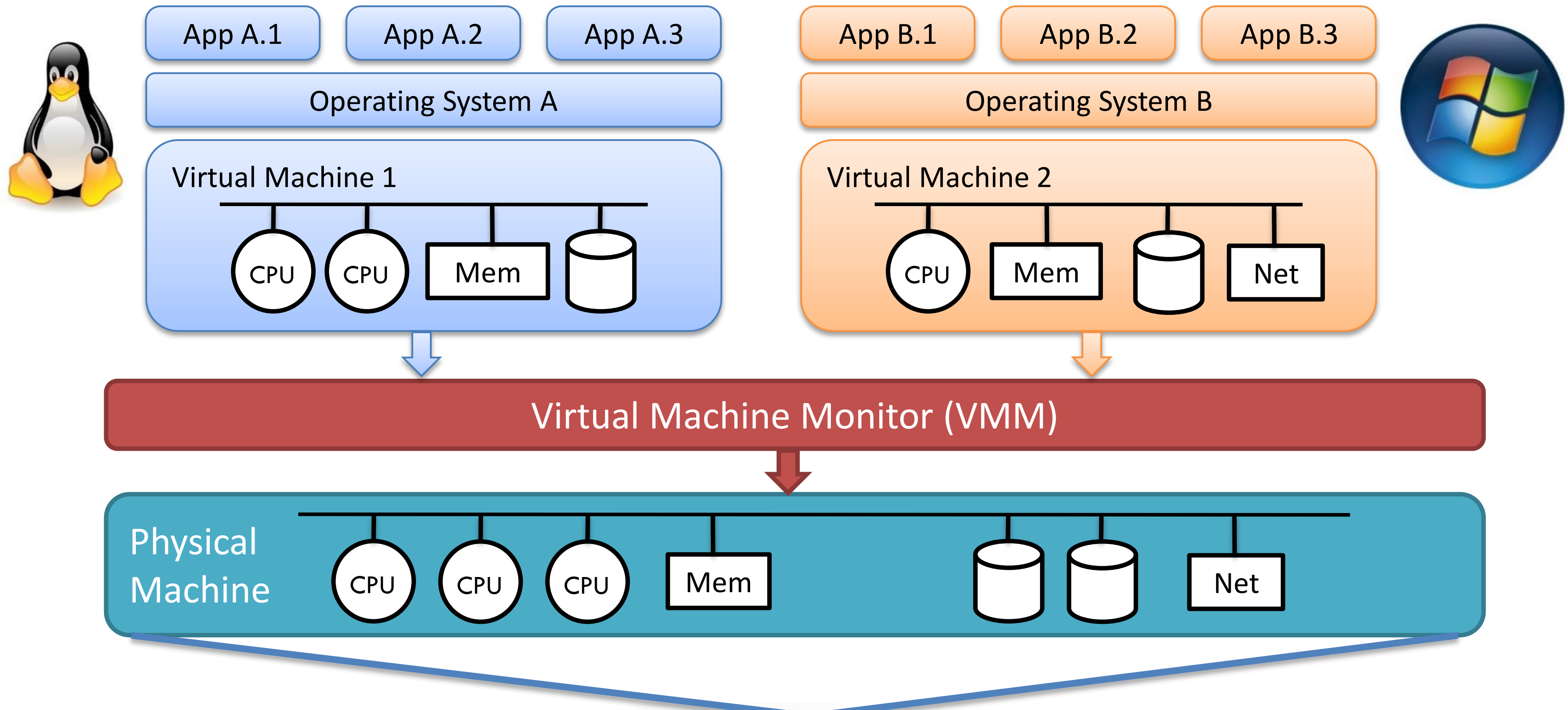
: existing or occurring on computers or on the Internet

"Virtualization is the process of creating virtual versions of physical resources that emulate the same physical characteristics"

Trend of Virtualized everything:

- Virtual machines: VMware, Xen
- Data-center virtualization
- Network Virtualization

Example: Virtualization in computers: Virtual Machine



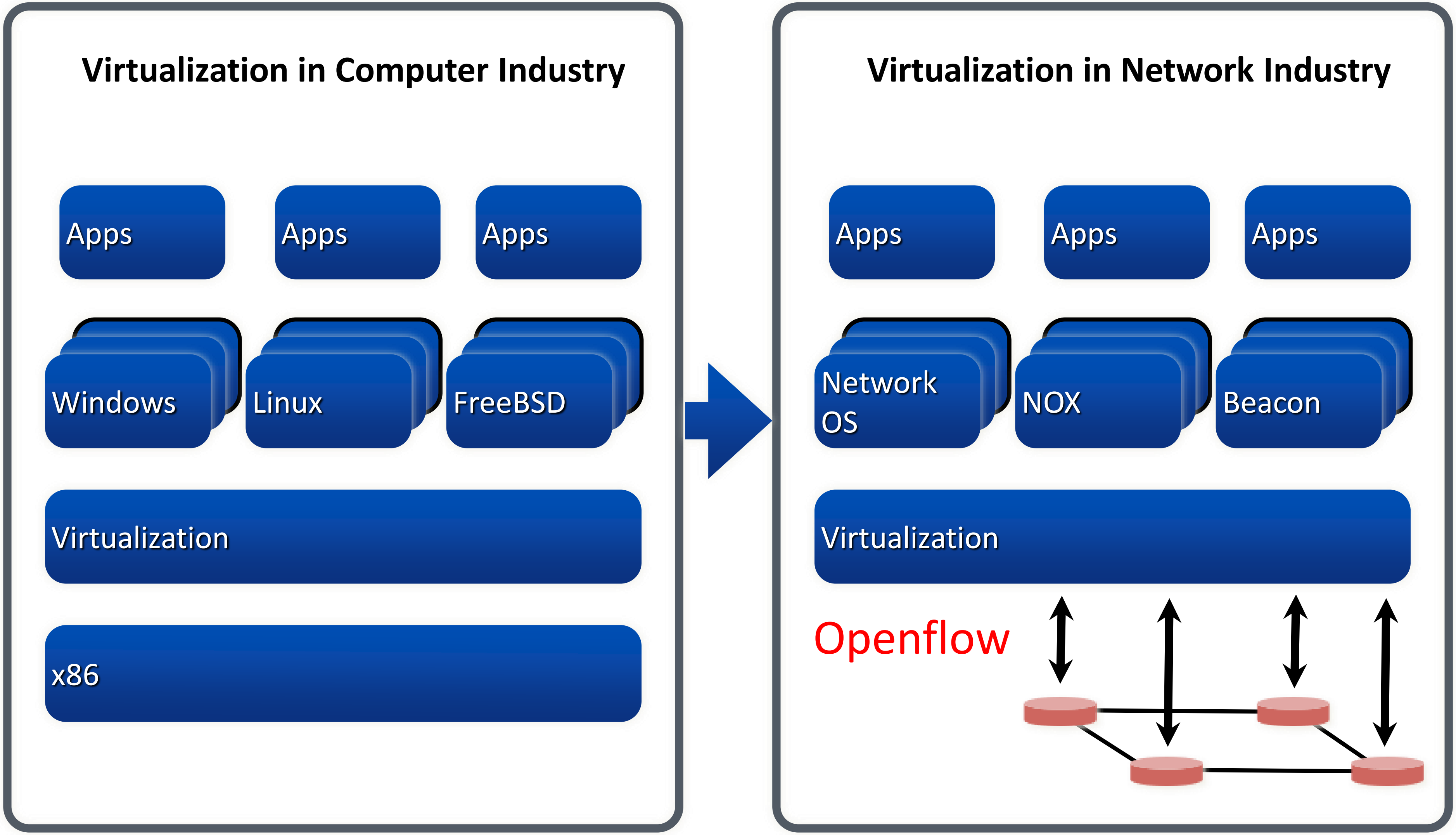
Computers Inside Computers!

Why Virtualize?

- Virtualization adds flexibility, allows heterogeneity, and improves manageability of the computing infrastructure

- Virtualization allows resource sharing :
  - Reduced number of equipment devices
  - Higher availability
  - Reduced time needed for deployments using virtualized infrastructure
  - Lower cost of ownership
  - More resilient and simpler to manage

Computer and Network virtualization

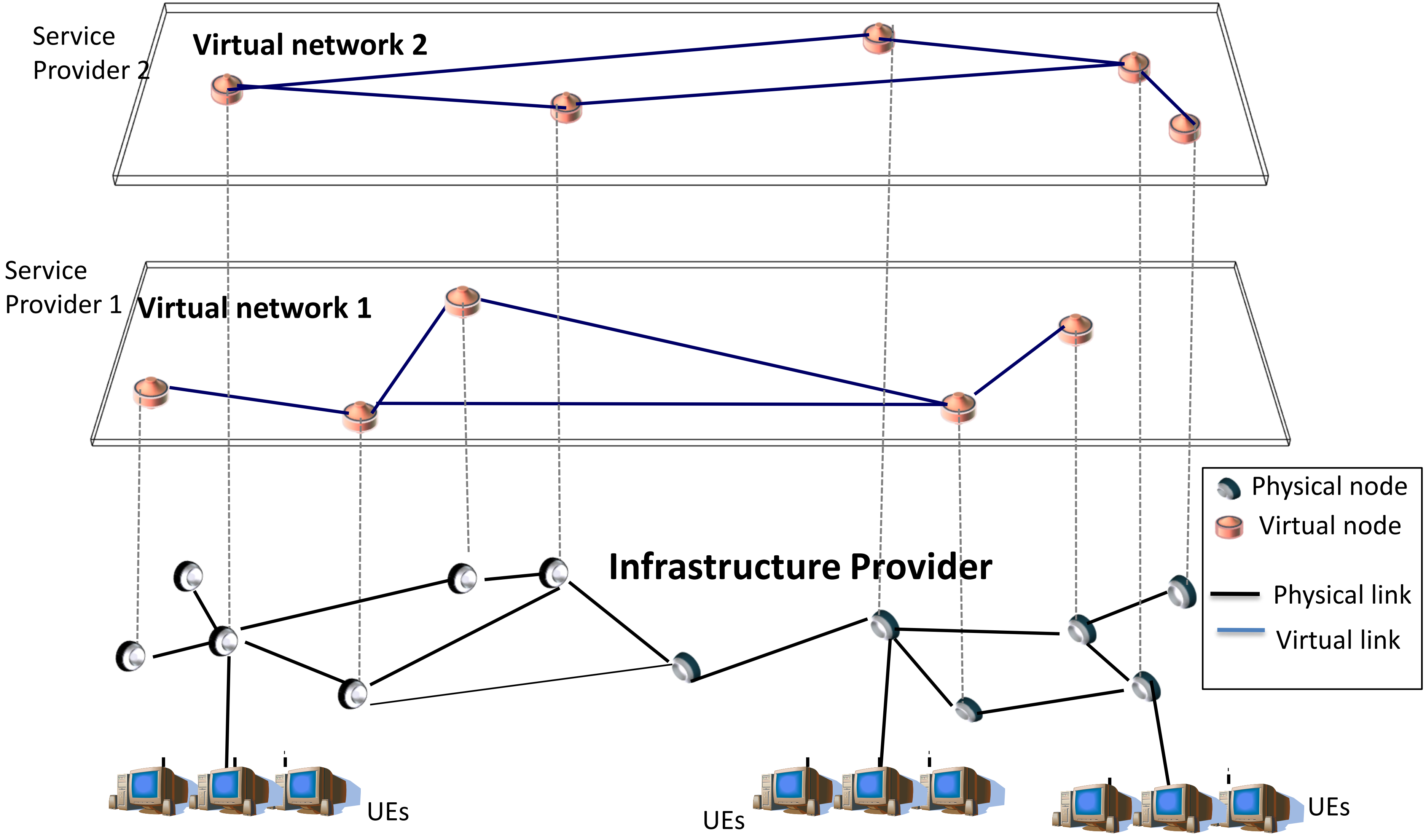


Virtual Networks: applications

- Overlay Networks
  - An overlay network is a computer network which is built on the top of another network.
  - Nodes in the overlay can be thought of as being connected by virtual or logical links, each of which corresponds to a path, perhaps through many physical links, in the underlying network

Networks Inside Networks!

Network Virtualization Scenario



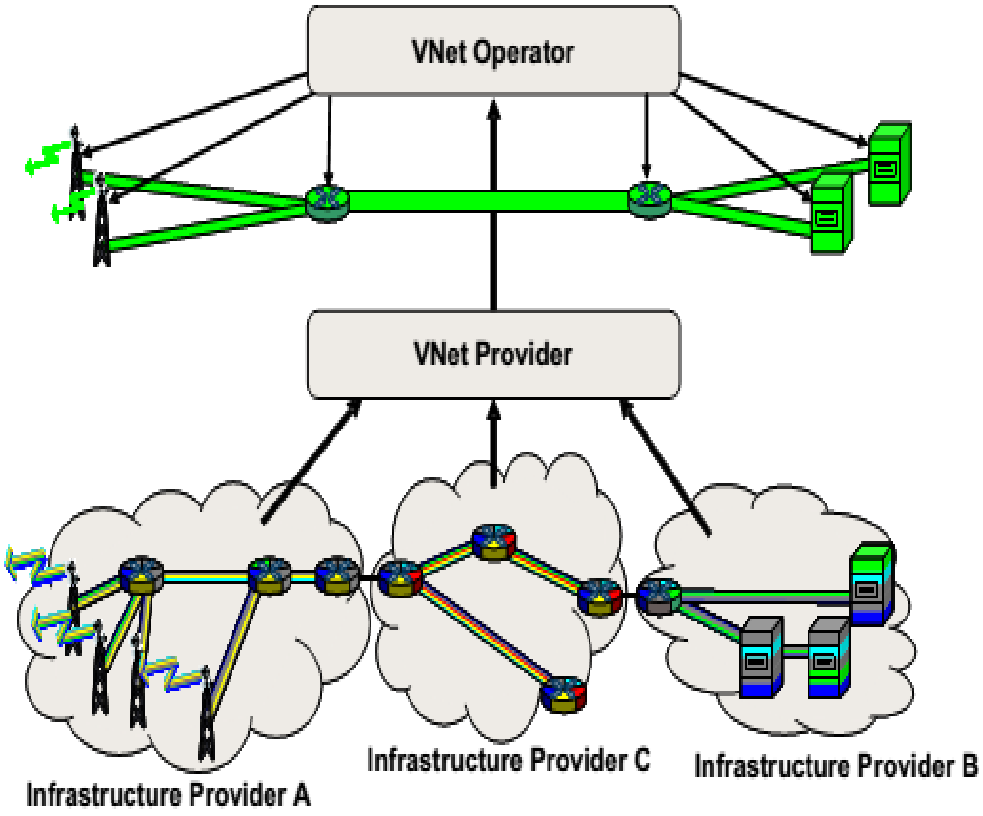
Network Virtualization: Business roles

- Network virtualization refers to the creation of a set of overlay architectures built on top of one or more existing physical infrastructures.

Virtual Network Operators :
who run the Virtual Network and
provide their services to the end-users.

Virtual Network Providers :
who combine the virtual resources
in order to form Virtual Networks

Infrastructure providers:
They own and manage the
physical network devices
and virtualize the physical resources



Network Virtualization for Mobile networks?

Motivations

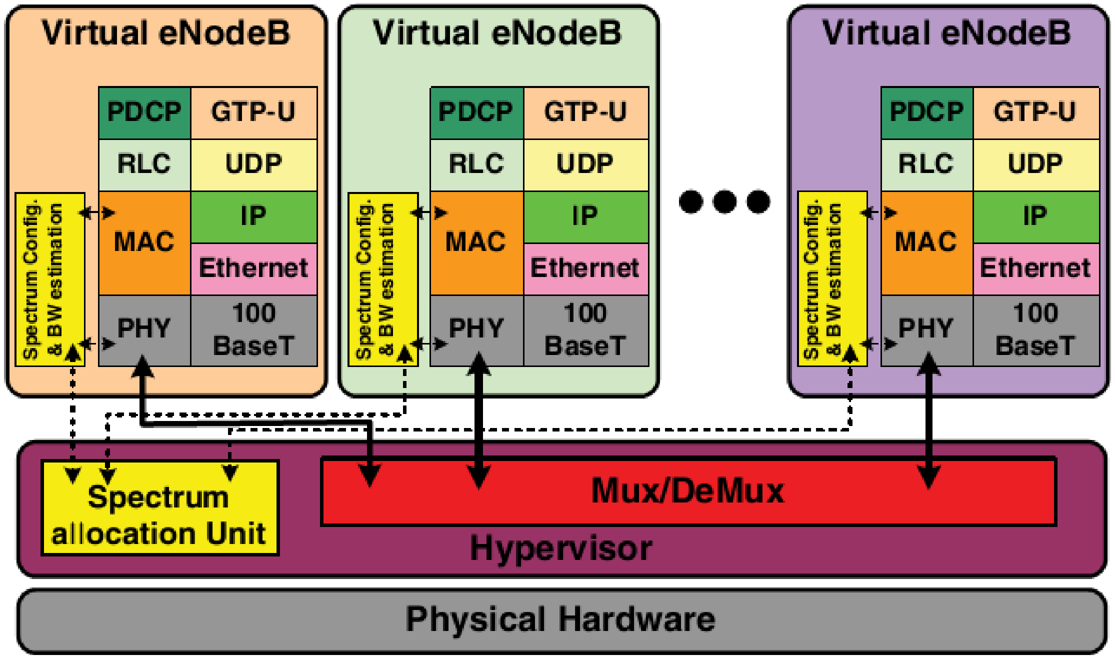
- The wireless resources of mobile networks are expensive and scarce. Network Virtualization will bring a more efficient utilization of the scarce wireless resources.

- Network Virtualization is a good solution for:
  - reducing the number of base stations (reduce energy usage)
  - reducing the overall investment capital required by mobile operators to setup their own infrastructure.
  - allowing smaller players to come into the market and provide new services to their customers using a virtual network without the need of built a network infrastructure

Use Case for LTE:
Virtualization of base stations

Two layers of scheduling:

- one layer for splitting the spectrum between the different virtual operators
- and one layer for splitting the allocated spectrum among the users belonging to the same operator



The scheduling can be based on different criteria such as: bandwidth, data rate, power, interference, pre-defined contract, channel condition, traffic load or a combination of these

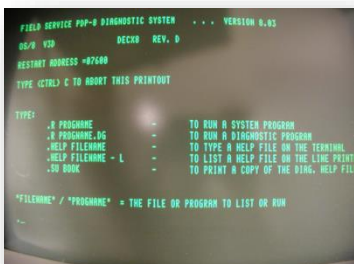
*As appears in Yasir Zaki,Liang Zhao,Carmelita Goerg ,Andreas Timm-Giel,“LTE mobile network virtualization Exploiting multiplexing and multi-user diversity gain”, in Vehicular Technology Conference (VTC Spring), 2012 IEEE 75th

Enable rapid innovation in networking with Network Virtualization

Everything is evolving: machines, O.S., games.

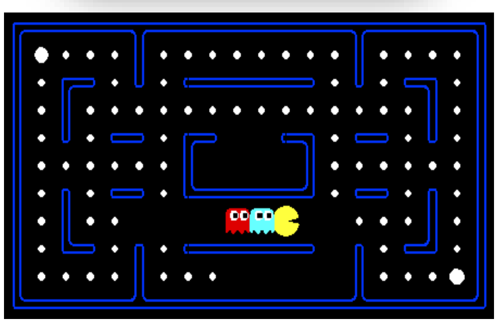
Fist laptop IBM 5100 (1973)

iPad



OS-8 (1971)

Macosx

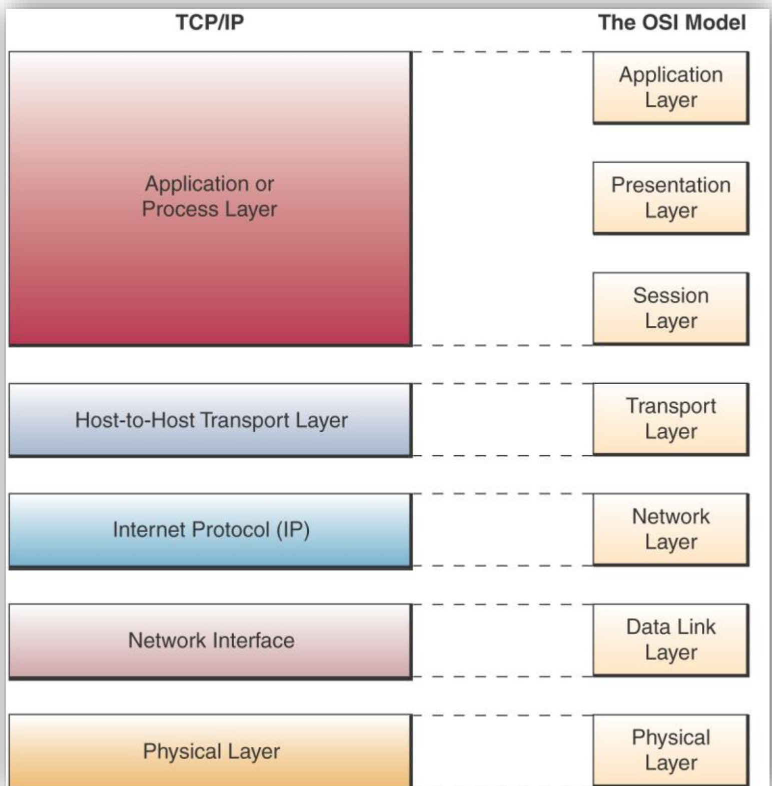


Pacman (1980)

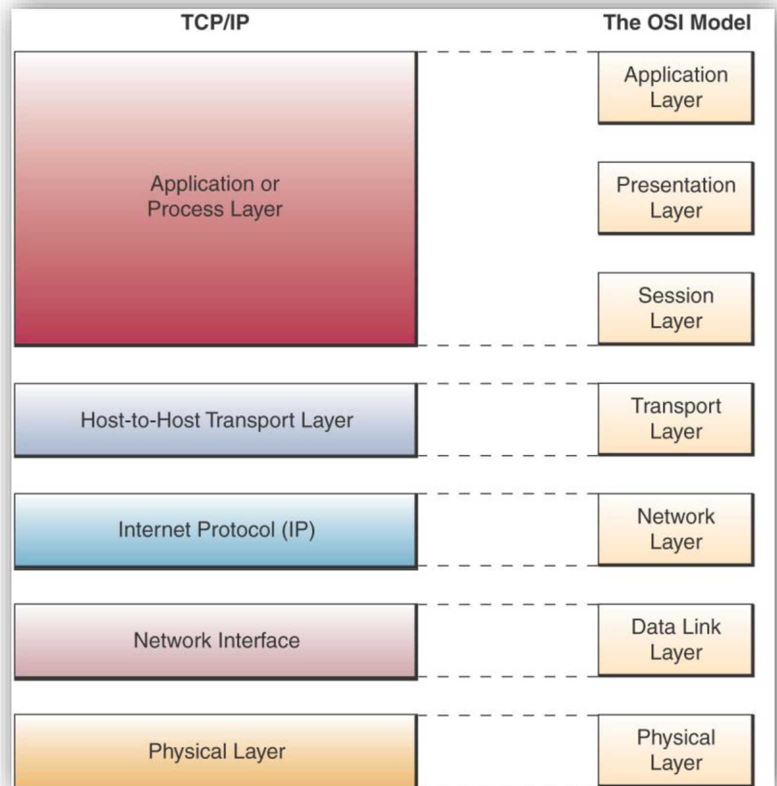
Nintendo wii

Everything is evolving except the Network…

TCP/IP (70's)



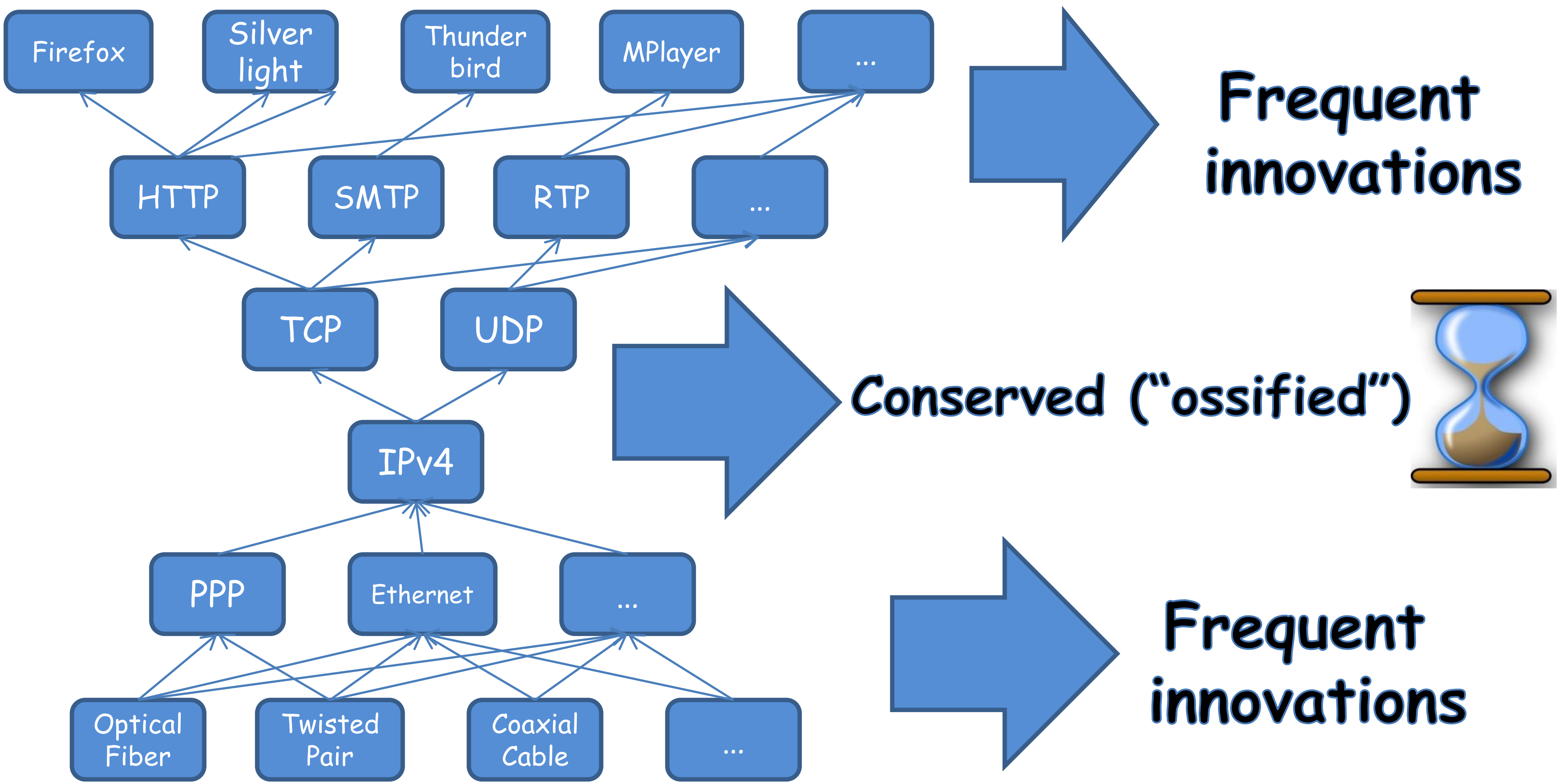
Today? Still .. TCP/IP



We are still using the same network architecture of 1970!

Why networks don't evolve?

Internet Hourglass problem…



Ossification of IP Networks

- Traditional IP networks are complex and hard to manage:
  - To express the desired high-level network policies, network operators need to configure each individual network device separately using low-level and often vendor-specific commands
  - To make it even more complicated, current networks are also vertically integrated: Control and Data plane are bundled inside the networking devices, reducing flexibility and hindering innovation

Hardware based networks, not easy to evolve

We need a software based approach…

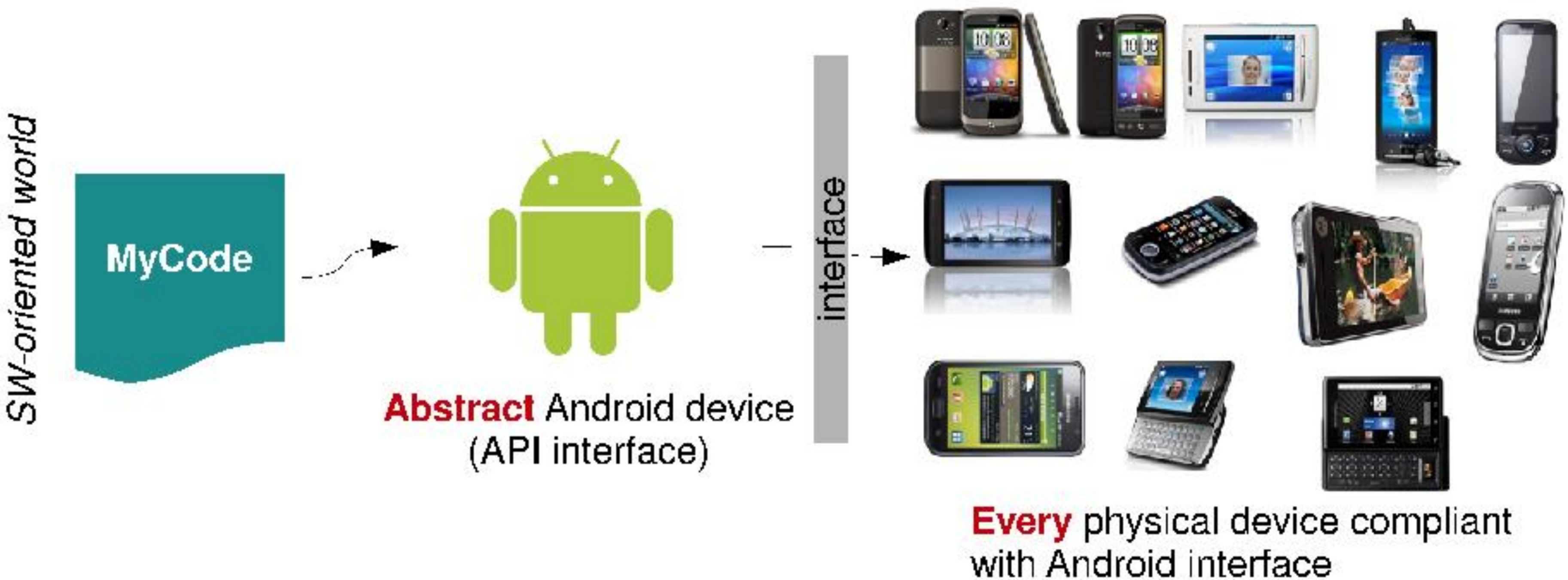
Benefits of a Software-oriented paradigm

- Abstract models hide technical, complicated, useless details
- Applications on abstract models can run on many different devices
- Applications can be replaced in any time without the need to change the hardware

Are there benefits of applying a software paradigm in a network architecture?

Why a modern smartphone is better than Nokia 3310?

Because of a software oriented paradigm!



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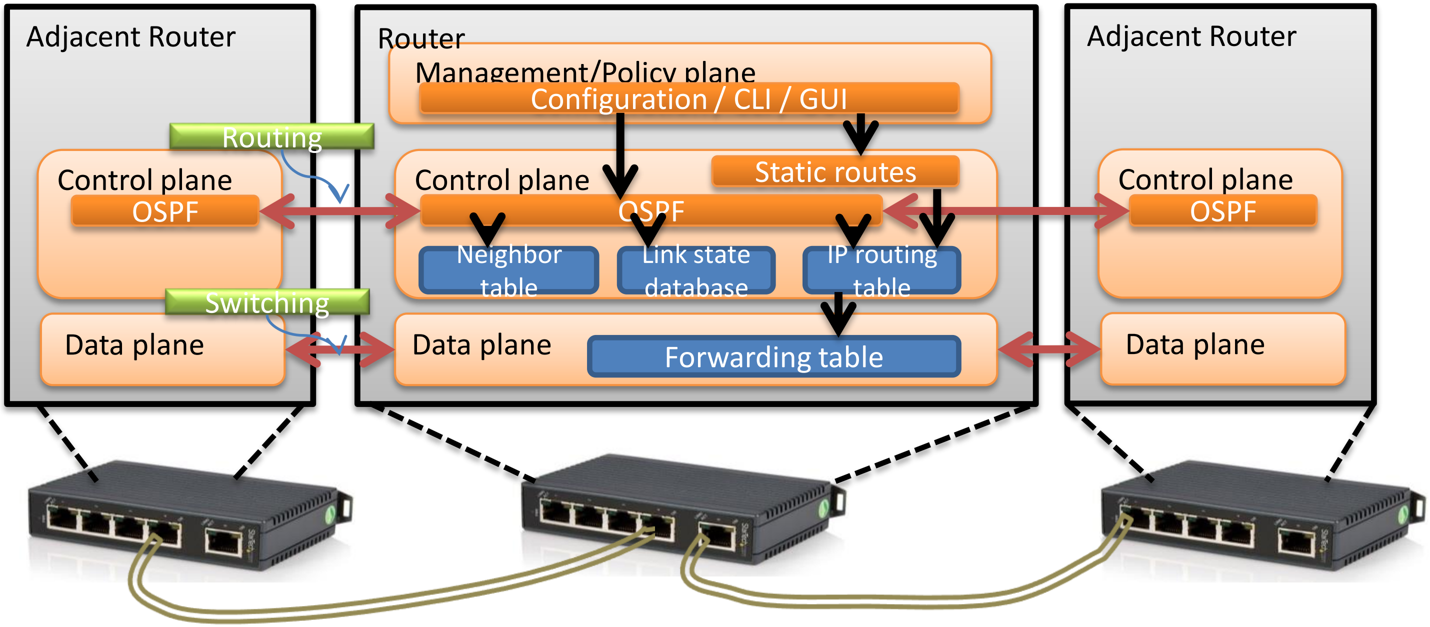
The planes in networking



Management Plane: software services used to remotely monitor and configure the control functionality.

Control Plane: protocols used to populate the forwarding tables of the data plane elements

Data Plane: networking devices, which are responsible for forwarding data

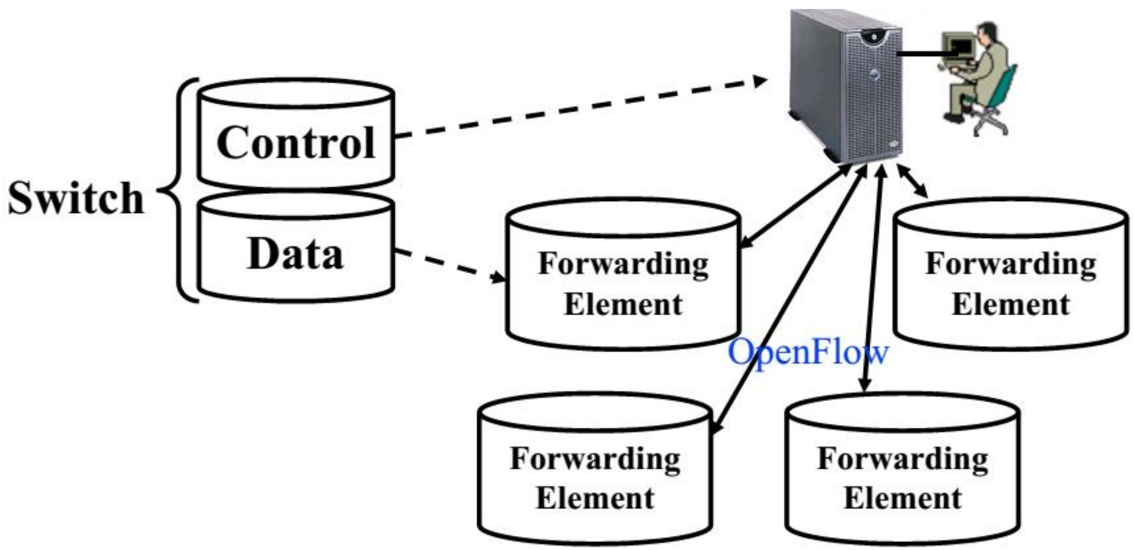
INTERNET After 30+ years!

Almost the same protocols, same philosophy

- static and monolithic network apparatus
- Black box policy: no one can modify them, except the manufacturer

Software Defined Network

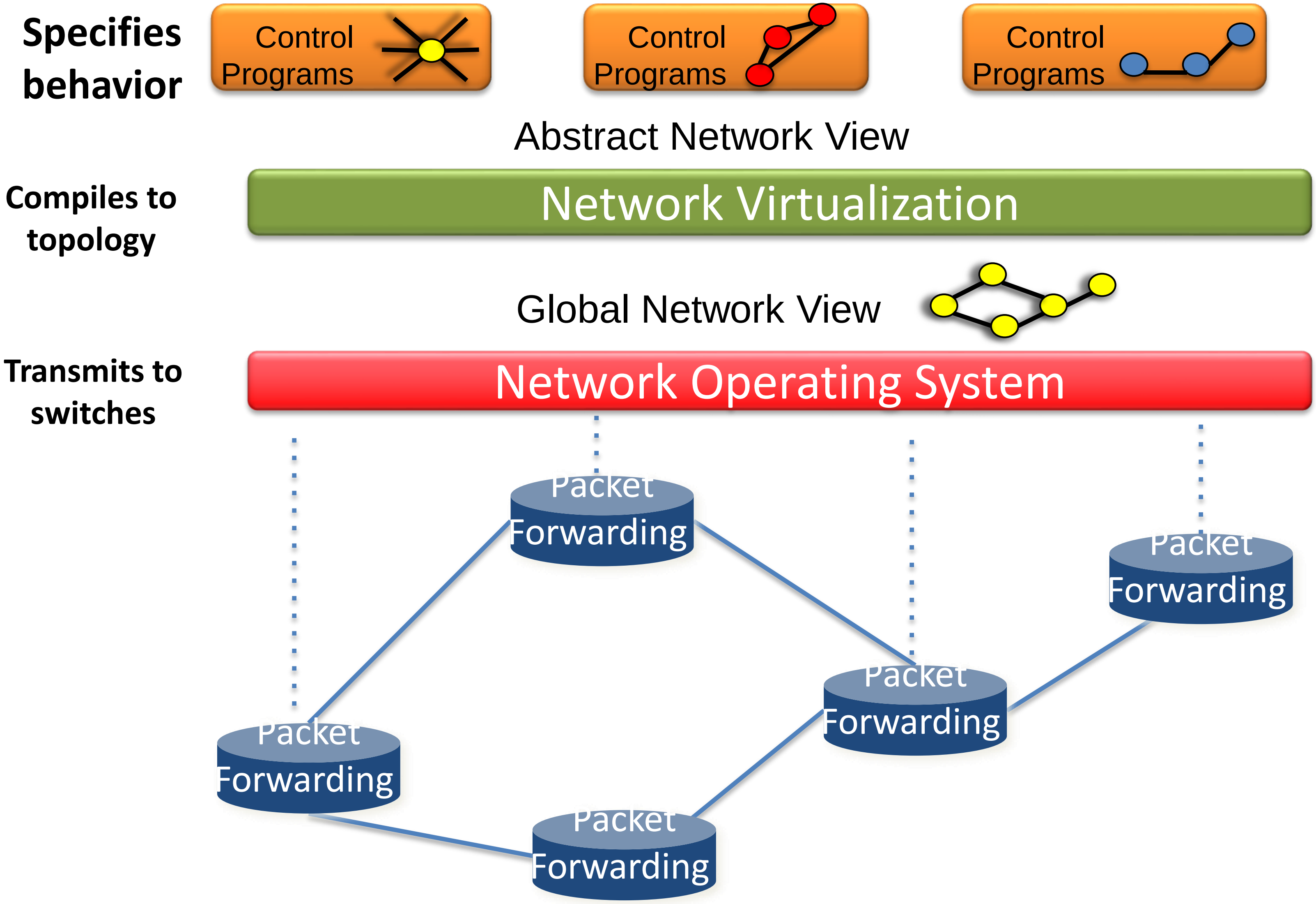
- Paradigm that introduces the possibility to program the network
- Control logic is moved to a logic central controller
  - Switches only have forwarding elements
  - One expensive controller with a lot of cheap switches
    - Logical centralization doesn't implied a physically centralized controller



By programming the controller, we can quickly change the entire network behavior

Network Management is not more platform dependent!

SDN architecture



SDN Pillars

1. Control plane abstractions:
   - Replace control plane protocols with well-defined APIs to network applications

2. Packet forwarding abstraction:
   - SDN switch treats an incoming packet as a simple sequence of bytes.
   - SDN switch neither knows nor cares to which network layer the bytes it examines belong

3. Flow-based forwarding decisions:
   - Packets are handled solely based on the flow to which they belong
   - Flows are thus just like Forwarding Equivalence Classes

4. Centralized routing engine:
   - Eliminate distributed protocols
   - The forwarding algorithm is not performed at the network node
   - SDN switches are stupid and flows are configured by an SDN controller
   - The decision algorithms is performed in a central location by an entity with full knowledge: CONTROLLER

Is SDN better than routing ?

OK, SDN switches may be cheaper…

but is that the only advantage of SDN ?

Distributed routing protocols are limited to

- finding simple connectivity
- minimizing number of hops

but can not perform more sophisticated operations, such as

- optimizing paths under constraints (e.g., security)
- setting up non-overlapping backup paths
- integrating networking functionalities (e.g., NAT, firewall) into paths

An SDN controller is omniscient (“God box”)

- can perform arbitrary optimization calculations on the network graph
- directly configures the forwarding actions of the SDN switches

But this advantage comes at a price

- the controller is a single point of failure
- additional (overhead) bandwidth is required
- additional set-up delay may be incurred

Standardization of SDN solutions

SDN Standard Developing Organizations

OPEN NETWORKING FOUNDATION

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

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

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

Joint Coordination Activity on Software-Defined Networking

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

broadband forum
member company

Some SDN-related work started

OIF OPTICAL INTERNETWORKING FORUM

Some SDN-related discussions started

Open Networking Foundation (ONF)

- A non-profit industry consortium
  - Founded: March 2011, >130 member organizations
  - Telecom operators, network providers, service providers
  - Equipment vendors, networking and virtualization software suppliers, and chip technology providers
- Vision: Make Software-Defined Networking the new norm for networks
  - ONF wants to transform networking industry to software industry through open SDN standards
- Mission: commercialize and promote SDN and its underlying technologies for their user benefits
- ONF attempts to create the most relevant SDN standards
- Aims at the dissemination and practical implementation of SDN through open standard development such as OpenFlow

ONF structure

Management Structure

- Board of Directors (no vendors allowed)
- Executive Director (presently Dan Pitt, employee, reports to board)
- Technical Advisory Group (makes recommendations not decisions, reports to board)
- Working Groups (chartered by board, chair appointed by board)
- Council of Chairs (chaired by executive director, forwards draft standards to board)

ONF Board members

- **Dan Pitt** Executive Director
- **Nick McKeown** Stanford University
- **Scott Shenker** UC Berkeley and ICSI
- Deutsche Telecom AG
- Facebook
- Goldman Sachs
- Google
- Microsoft
- NTT Communications
- Verizon
- Yahoo

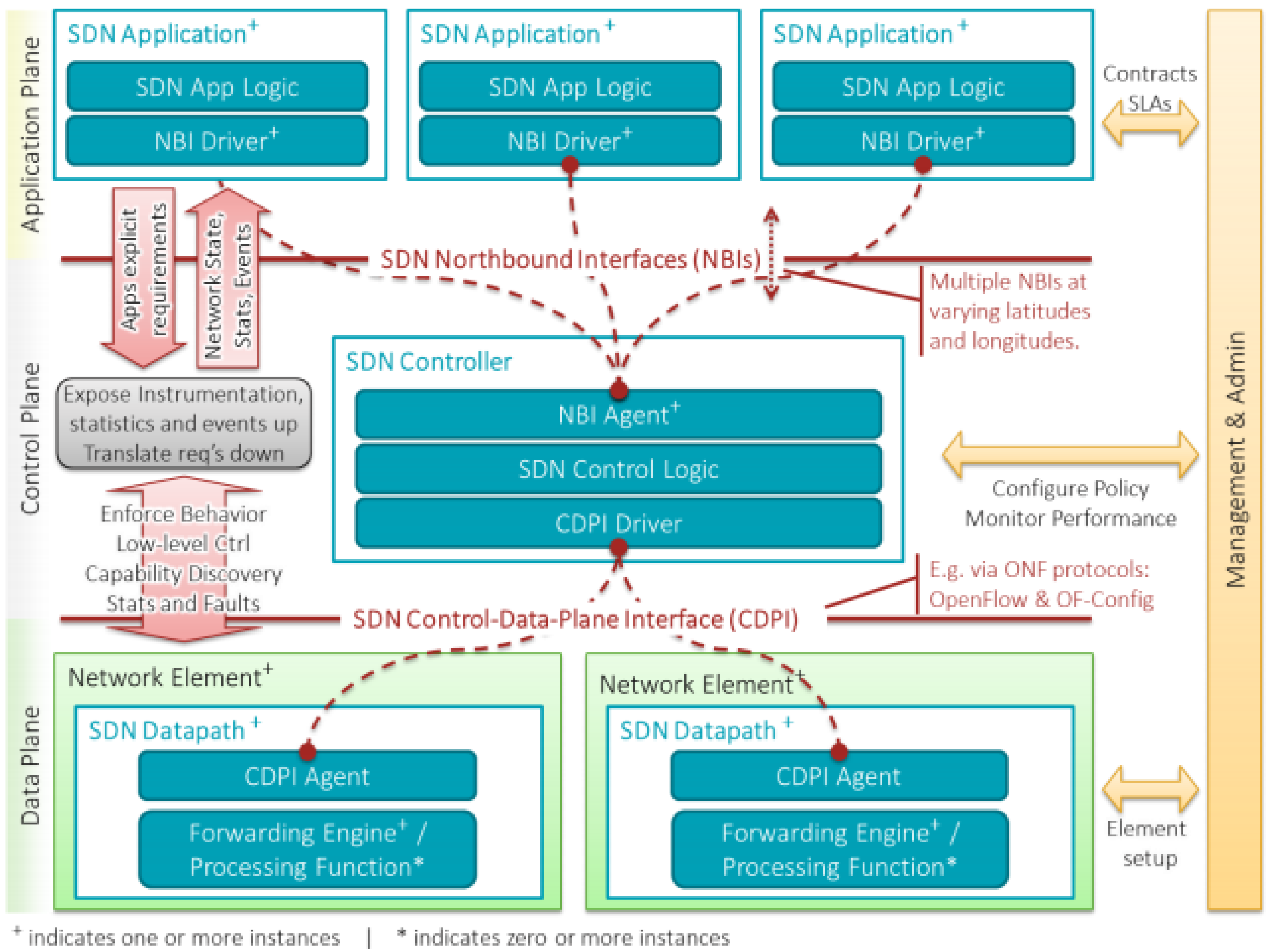
Working Groups

- Architecture and Framework
- Forwarding Abstraction
- Northbound Interface (new)
- Optical Transport (new)
- Wireless and Mobile (new)
- Configuration and Management
- Testing and Interoperability
- Extensibility
- Migration
- Market Education
- Hybrid - closed

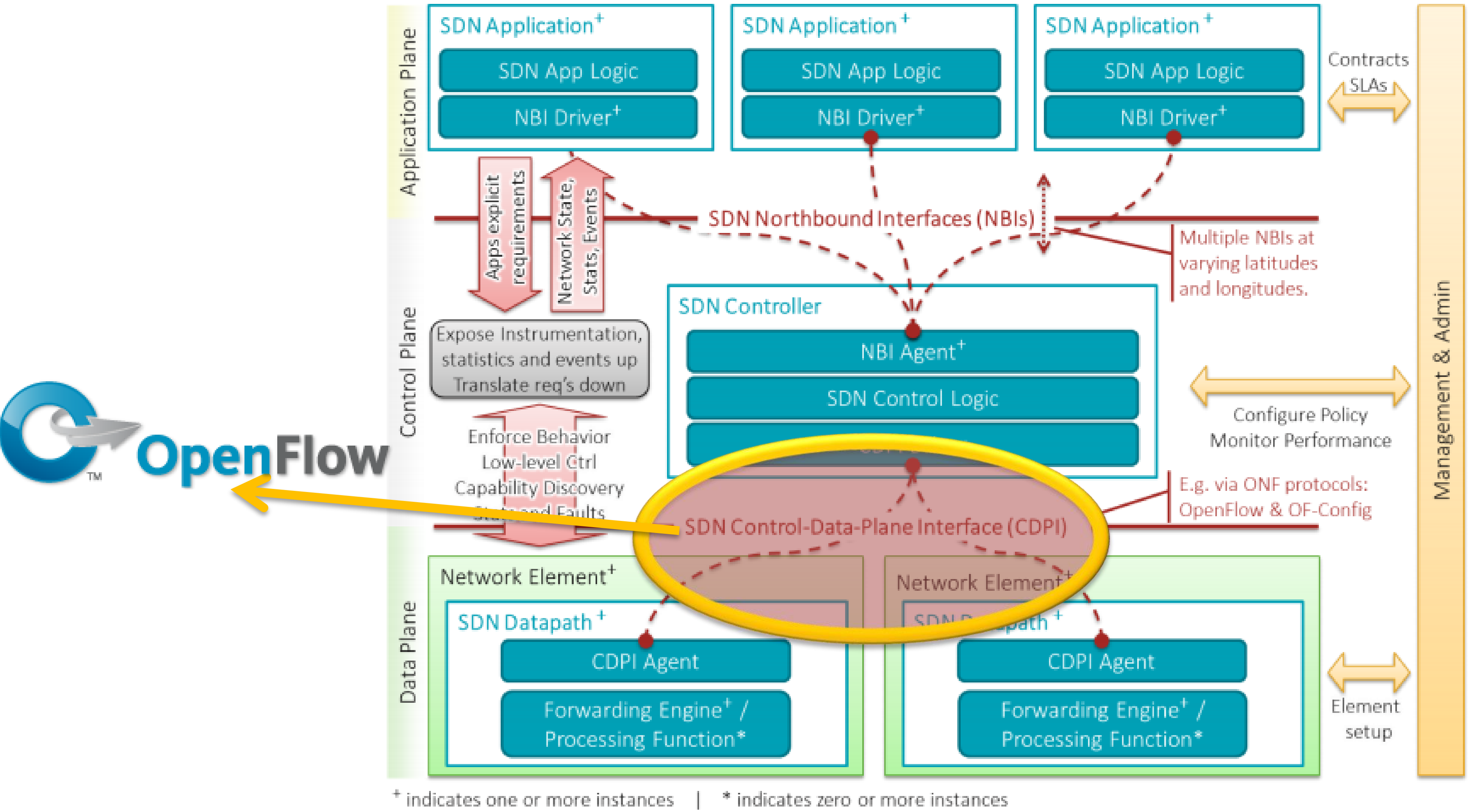
ONF SDN Architecture Overview

Key features

- Applications can be network aware
- Control plane is logically centralized
- Control plane is decoupled from the data plane
- SDN Controller has complete control of the SDN Datapaths



ONF SDN Architecture Overview



OpenFlow™

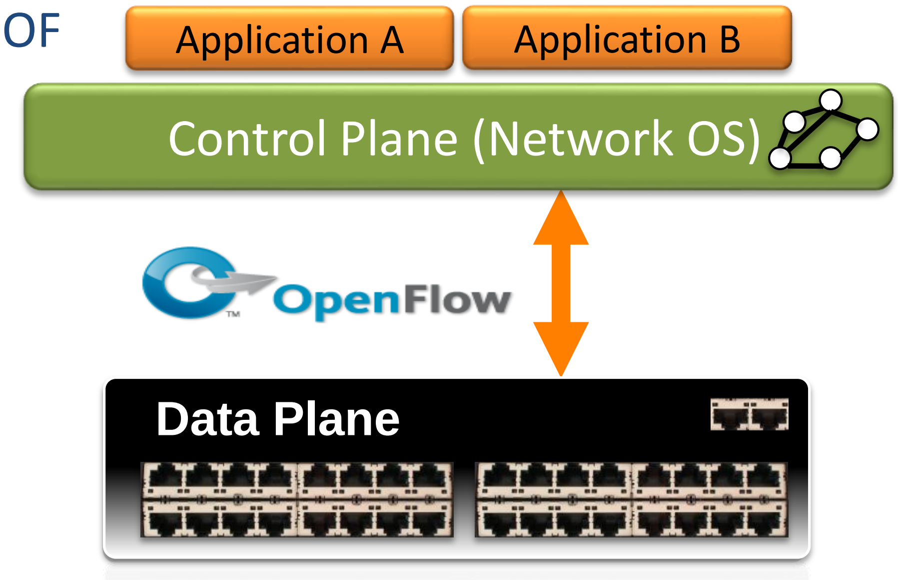
Define mechanisms for configuration of OpenFlow capable network devices to realize the vision of Software Defined Networking

The OpenFlow specifications describe

- the southbound protocol between OF controller and OF switches
- the operation of the OF switch

The OpenFlow specifications do not define

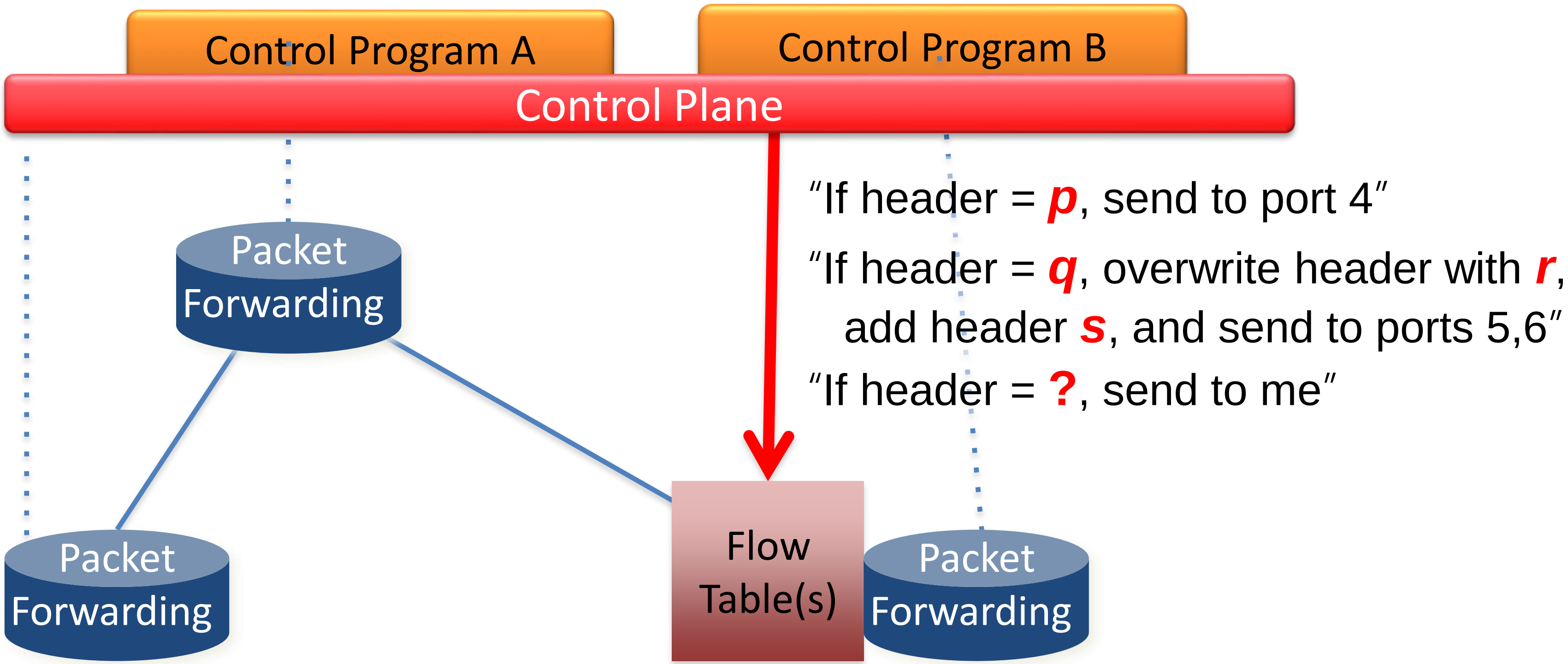
- the northbound interface from OF controller to applications
- how to boot the network



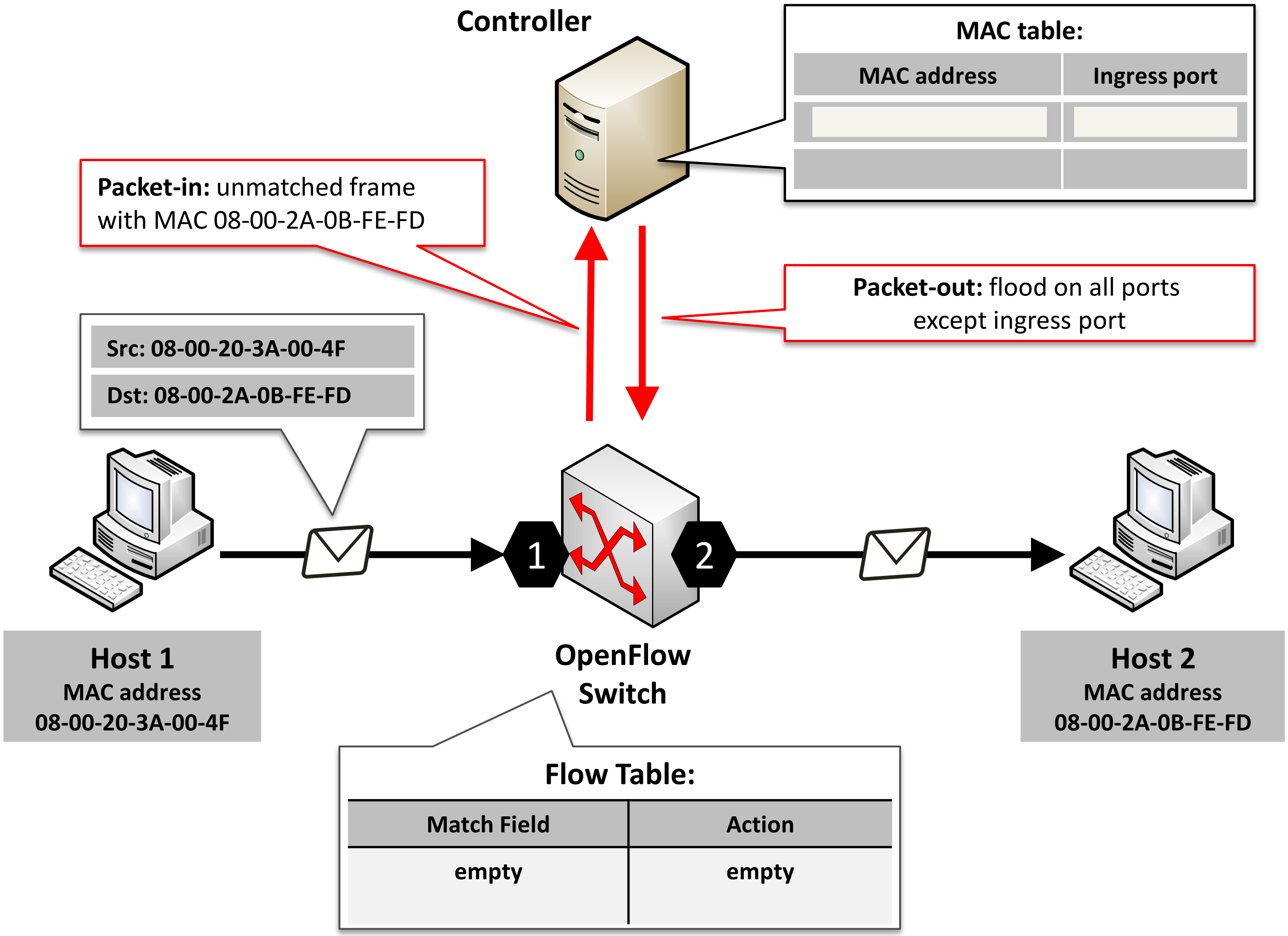
OpenFlow Forwarding Abstraction

Controller manages the traffic (network flows) by manipulating the flow table at switches.

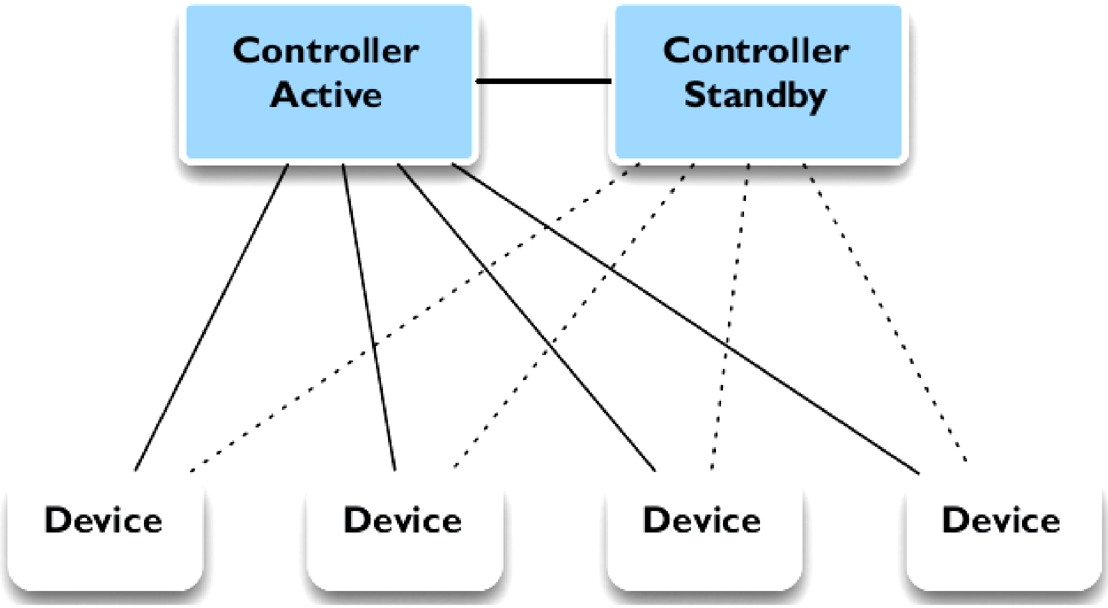
1. *Instructions are stored in flow tables.*
2. *When packet arrives at switch, match the header fields with flow entries in a flow table.*
3. *If any entry matches, performs indicated actions and update the counters.*
4. *If Does not match, Switch asks controller by sending a message with the packet header.*



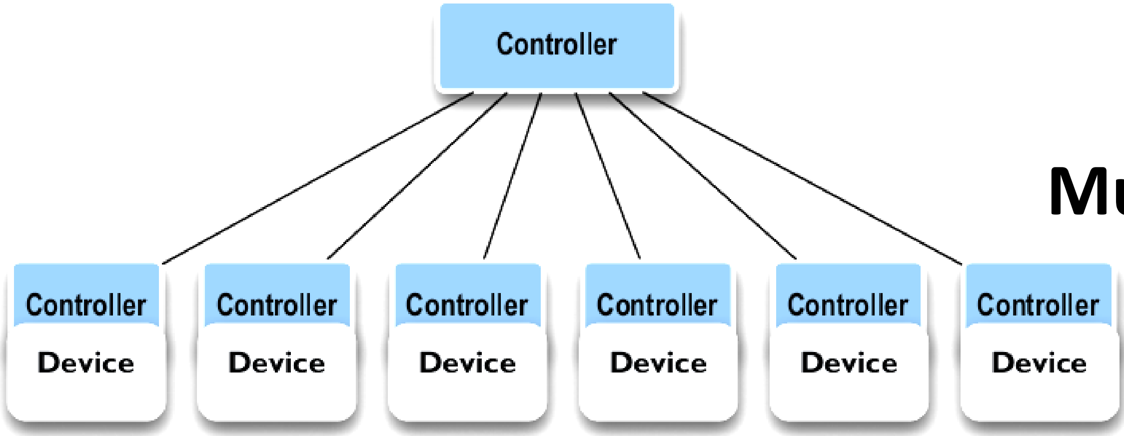
OpenFlow: How does it work?



CONTROLLER ARCHITECTURES

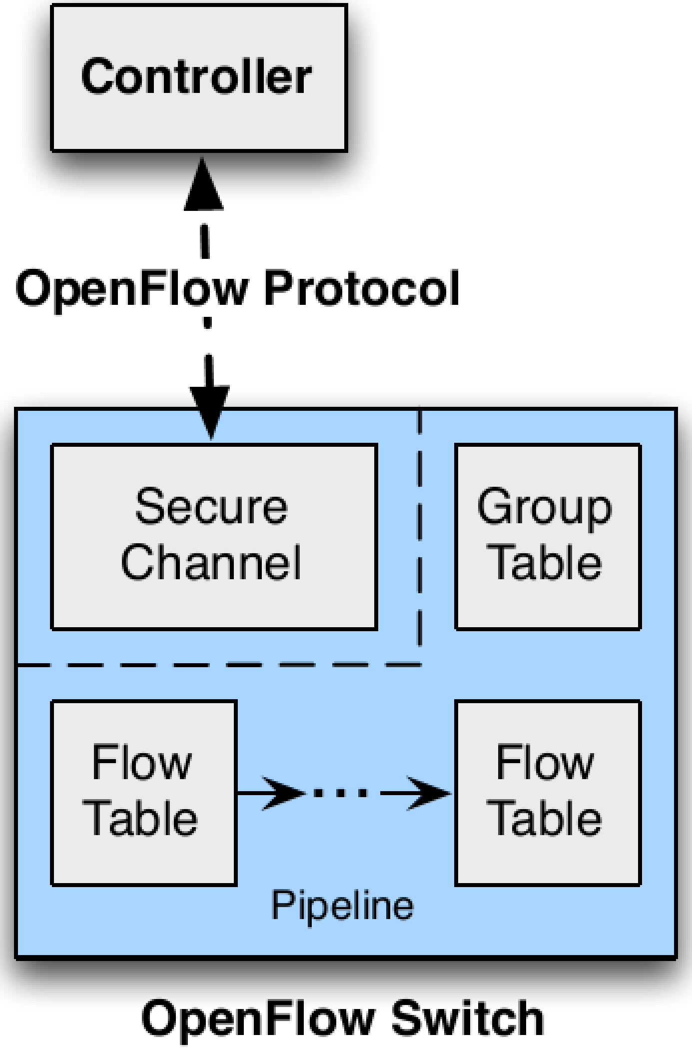


Centralized Or Distributed



Multilayer

OpenFlow Switch



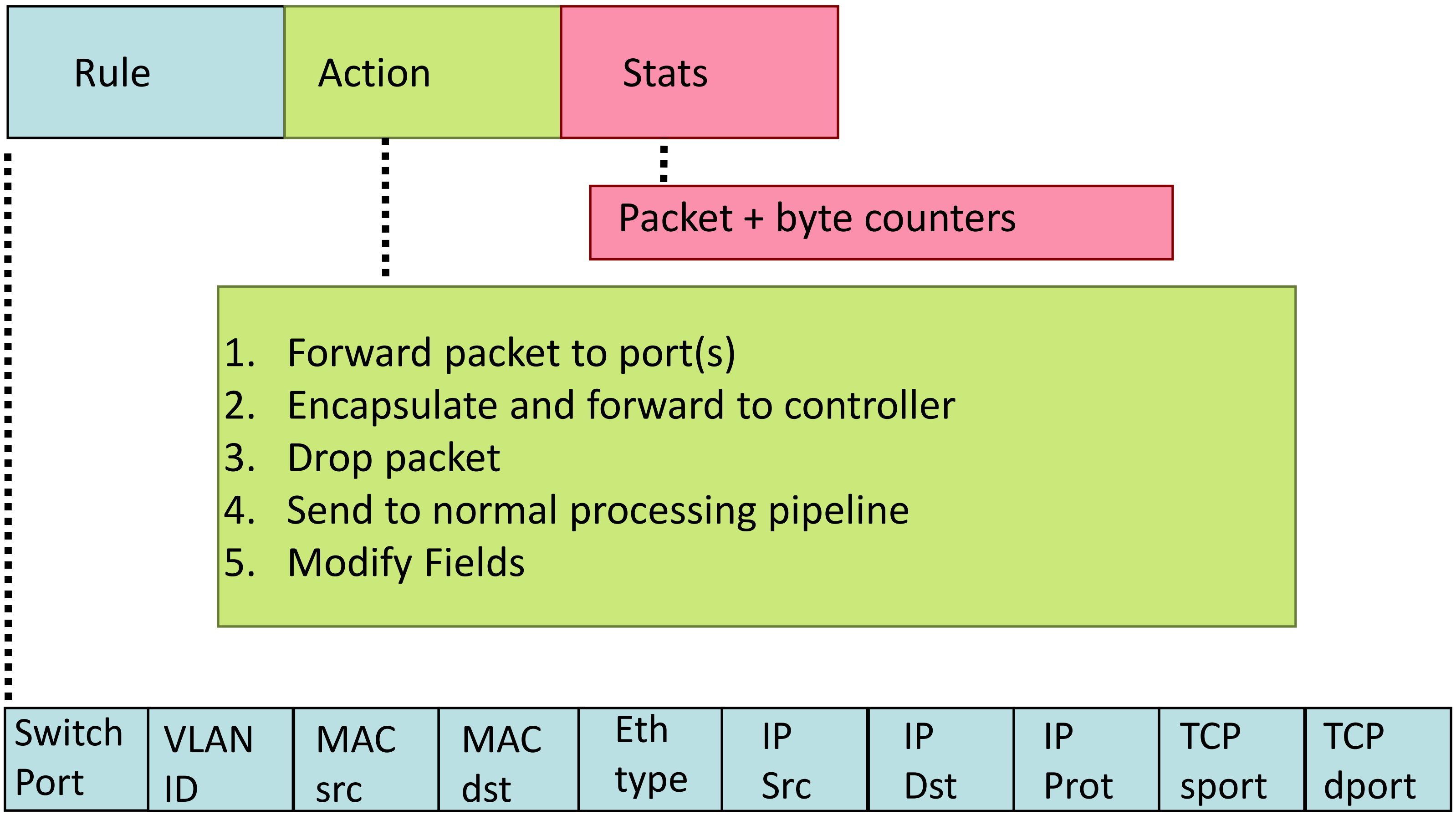
An OpenFlow Switch consists of :

- one or more flow tables and a group table, which perform packet lookups and forwarding
- an OpenFlow channel to an external controller

The controller manages the switch via the OpenFlow protocol. Using this protocol, the controller can add, update, and delete flow entries, both reactively (in response to packets) and proactively.

OpenFlow Basics

Flow Table Entries



+ mask what fields to match

Examples

Switching

Switch Port	MAC src	MAC dst	Eth type	VLAN ID	IP Src	IP Dst	IP Prot	TCP sport	TCP dport	Action
*	*	00:1f:..	*	*	*	*	*	*	*	port6

Flow Switching

Switch Port	MAC src	MAC dst	Eth type	VLAN ID	IP Src	IP Dst	IP Prot	TCP sport	TCP dport	Action
port3	00:20..	00:1f..	0800	vlan1	1.2.3.4	5.6.7.8	4	17264	80	port6

Firewall

Switch Port	MAC src	MAC dst	Eth type	VLAN ID	IP Src	IP Dst	IP Prot	TCP sport	TCP dport	Forward
*	*	*	*	*	*	*	*	*	22	drop

Examples

Routing

Switch Port	MAC src	MAC dst	Eth type	VLAN ID	IP Src	IP Dst	IP Prot	TCP sport	TCP dport	Action
*	*	*	*	*	*	5.6.7.8	*	*	*	port6

VLAN Switching

Switch Port	MAC src	MAC dst	Eth type	VLAN ID	IP Src	IP Dst	IP Prot	TCP sport	TCP dport	Action
*	*	00:1f..	*	vlan1	*	*	*	*	*	port6, port7, port9

OF 1.1+ flow table operation

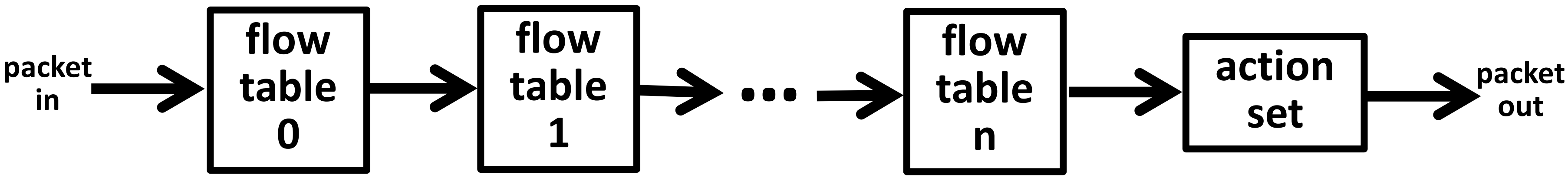
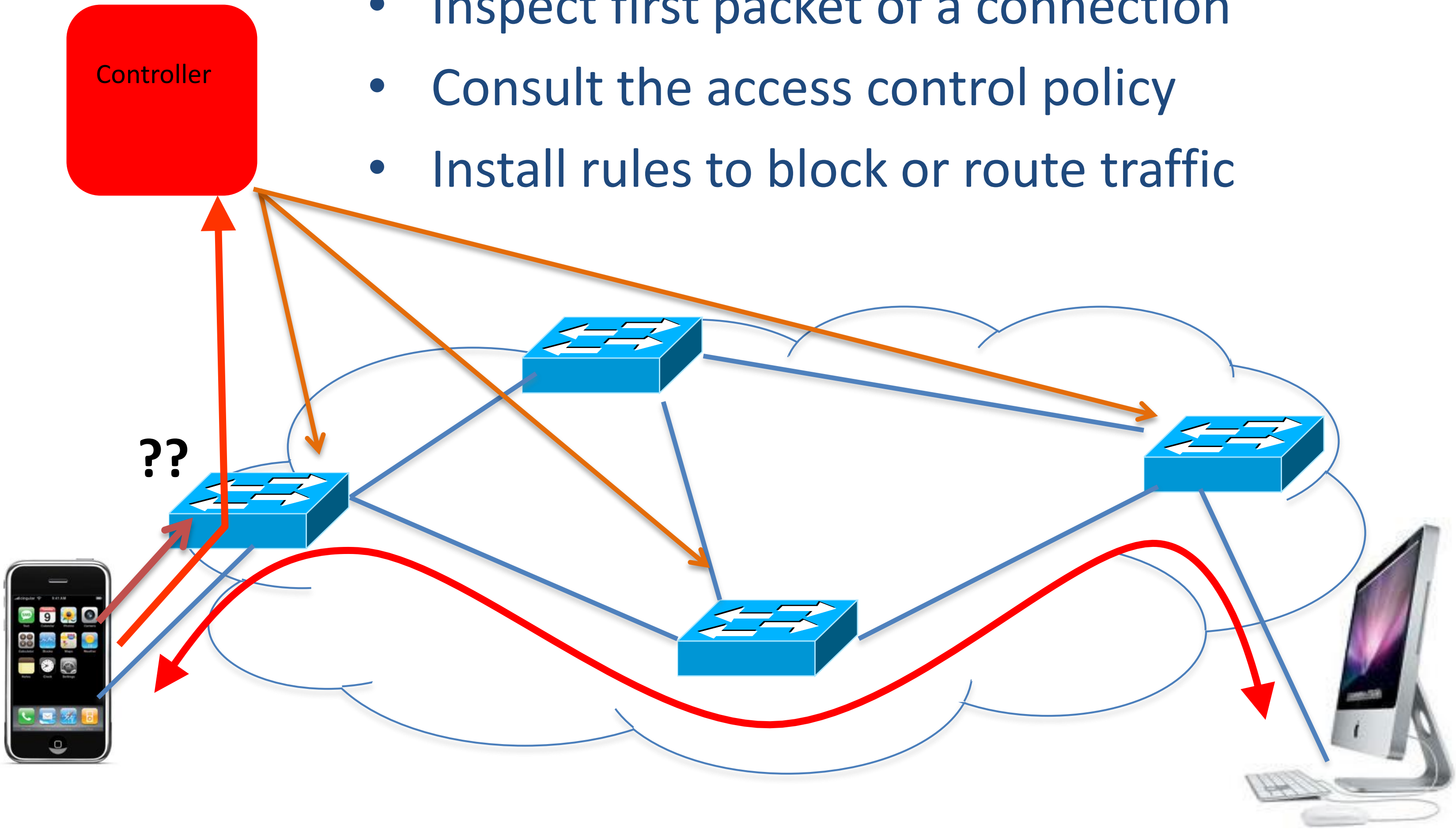


Table matching

- each flow table is ordered by priority
- highest priority match is used (match can be made "negative" using drop action)
- matching is exact match with certain fields allowing bit masking
- table may specify ANY to wildcard the field
- fields matched may have been modified in a previous step

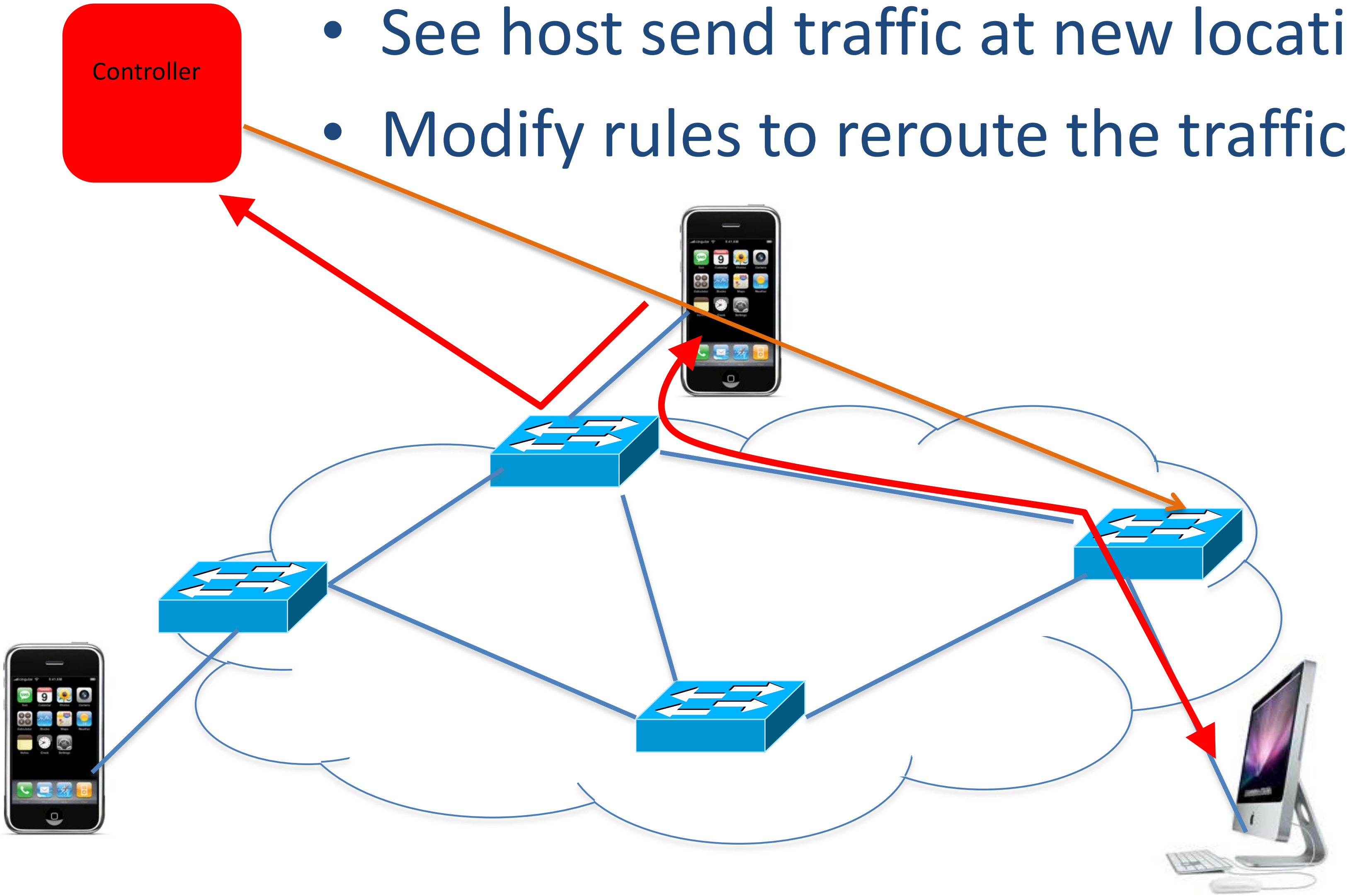
OpenFlow Applications:
Dynamic Access Control

- Inspect first packet of a connection
- Consult the access control policy
- Install rules to block or route traffic



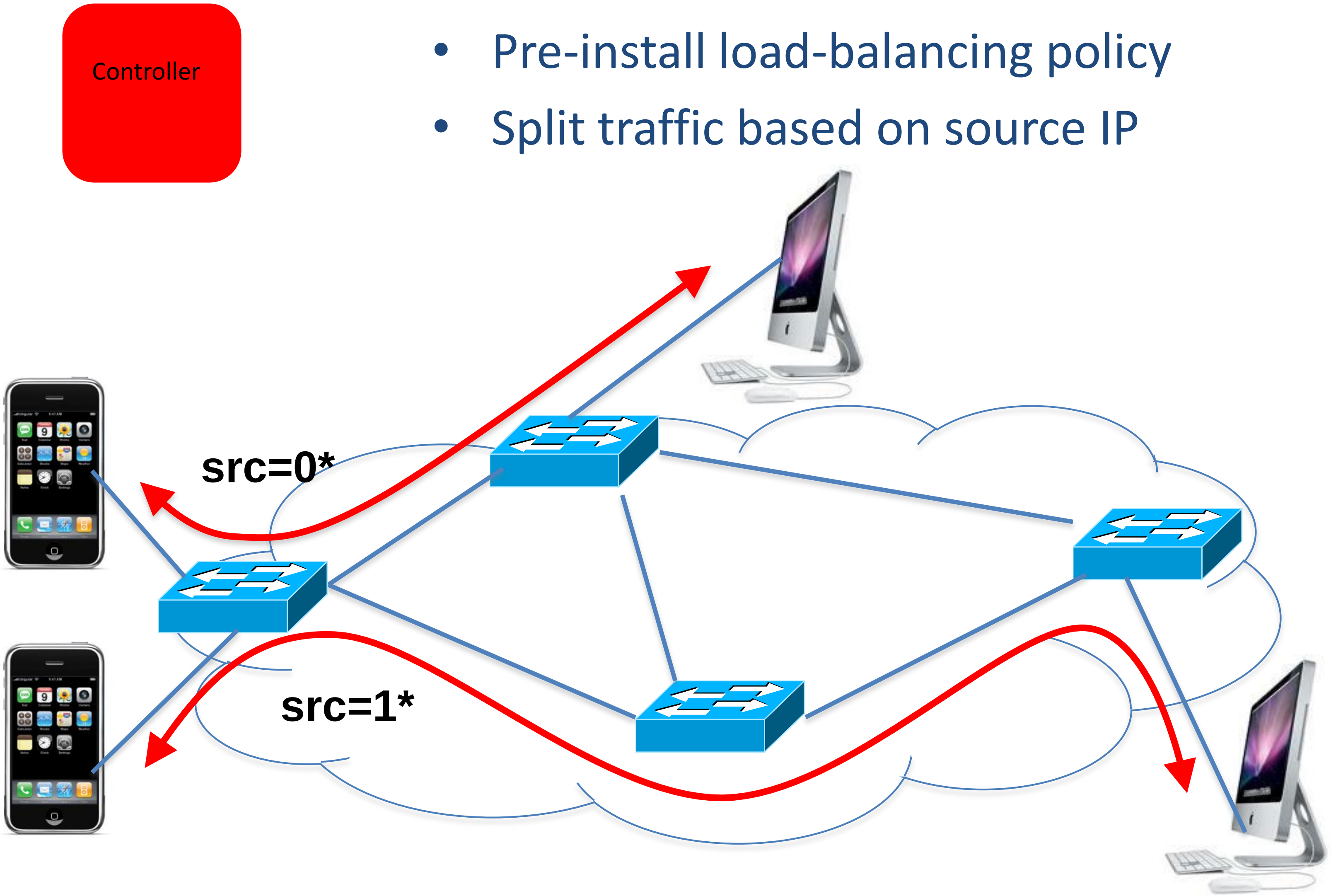
Seamless Mobility/Migration

- See host send traffic at new location
- Modify rules to reroute the traffic



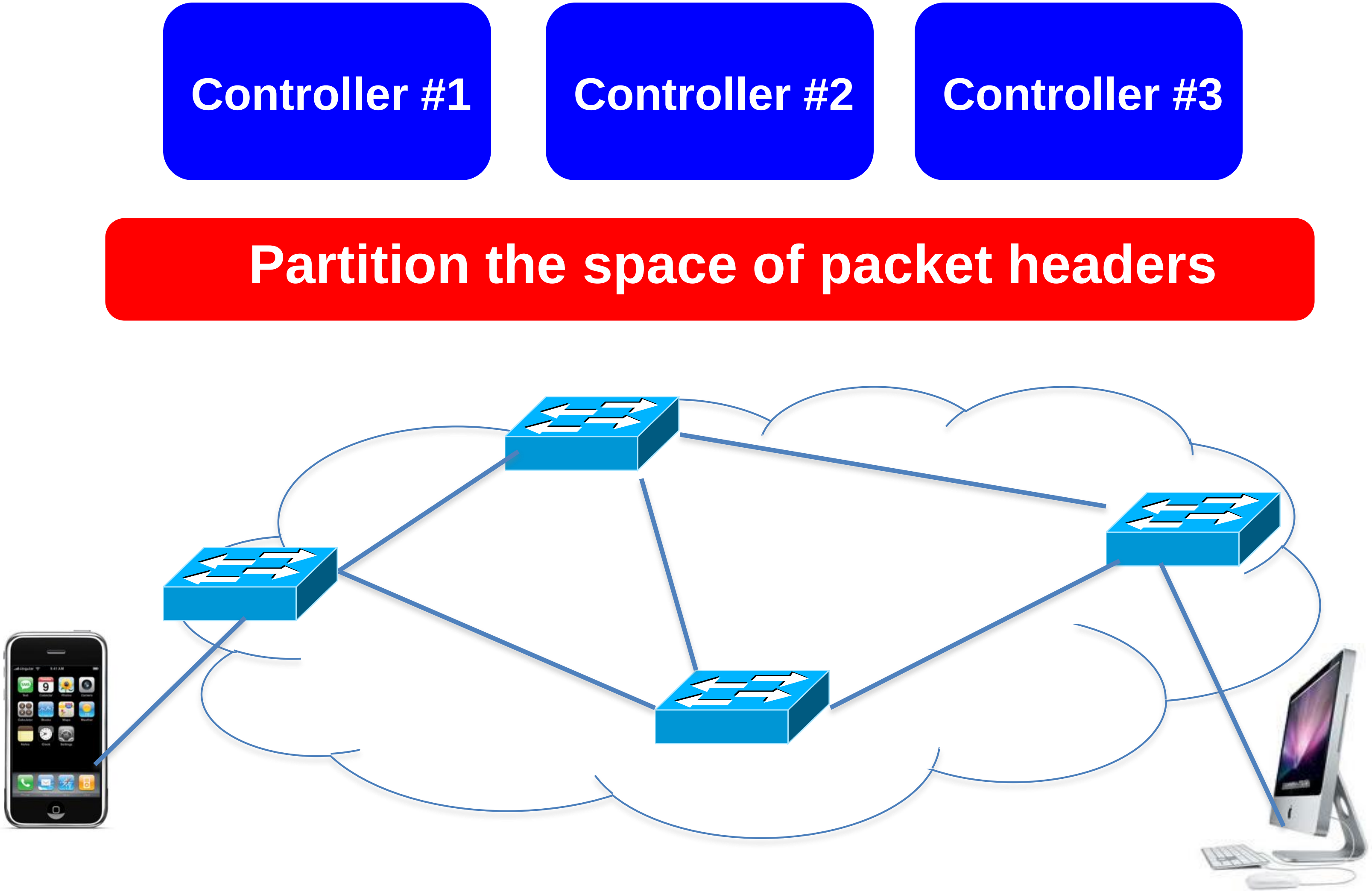
Server Load Balancing

- Pre-install load-balancing policy
- Split traffic based on source IP

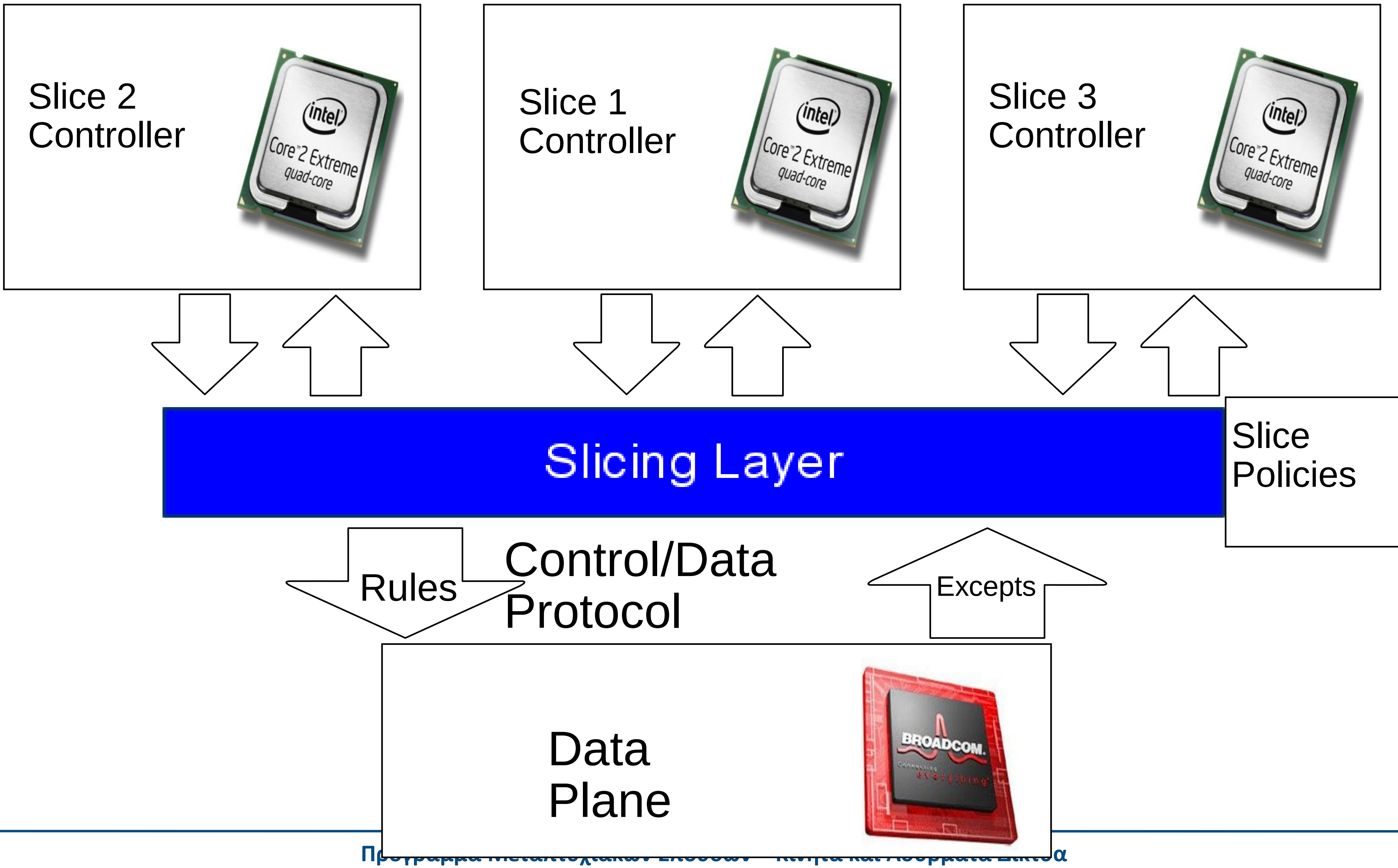


Network Slicing

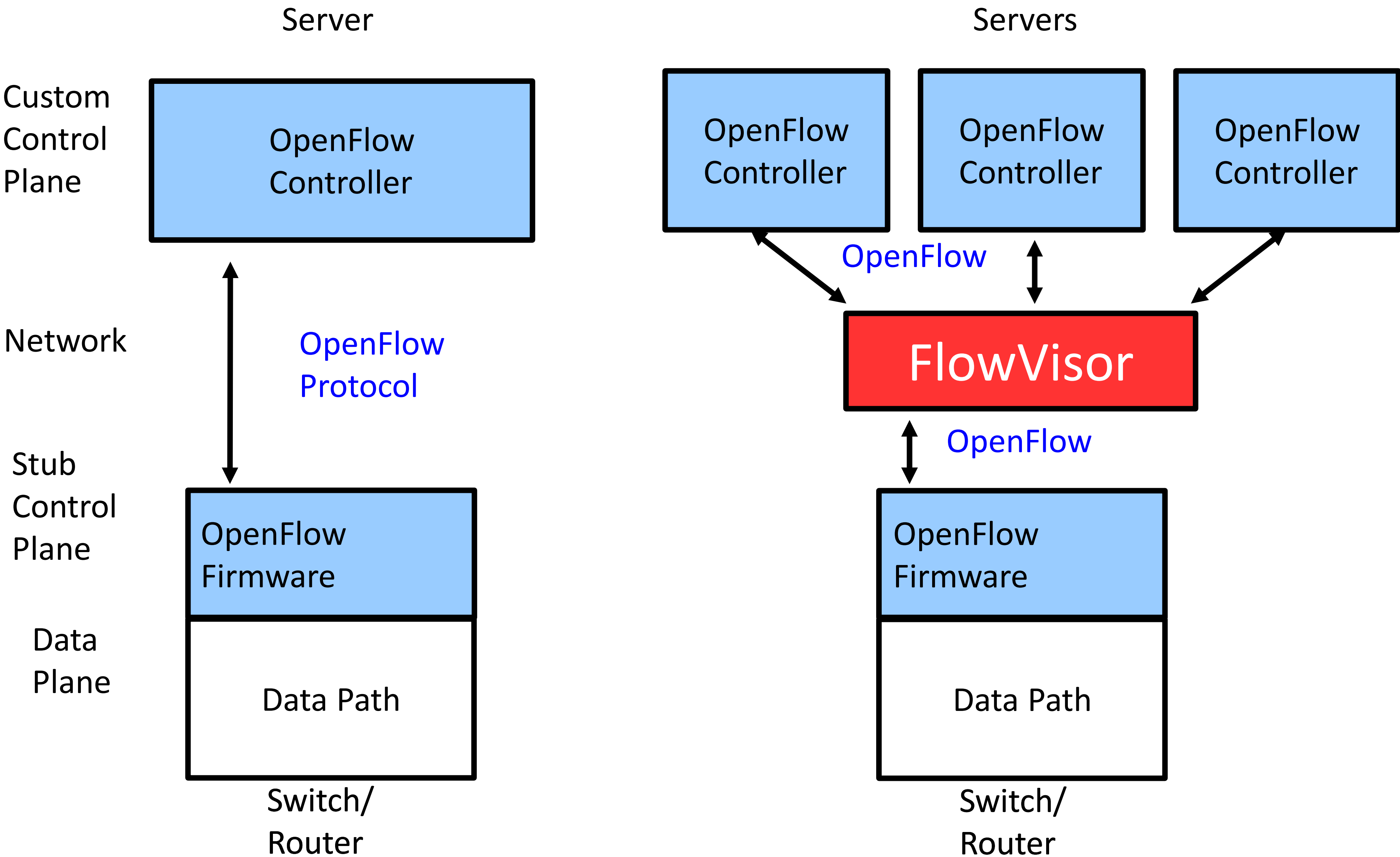
A network slice is a collection of sliced switches/routers



Add a Slicing Layer Between Planes

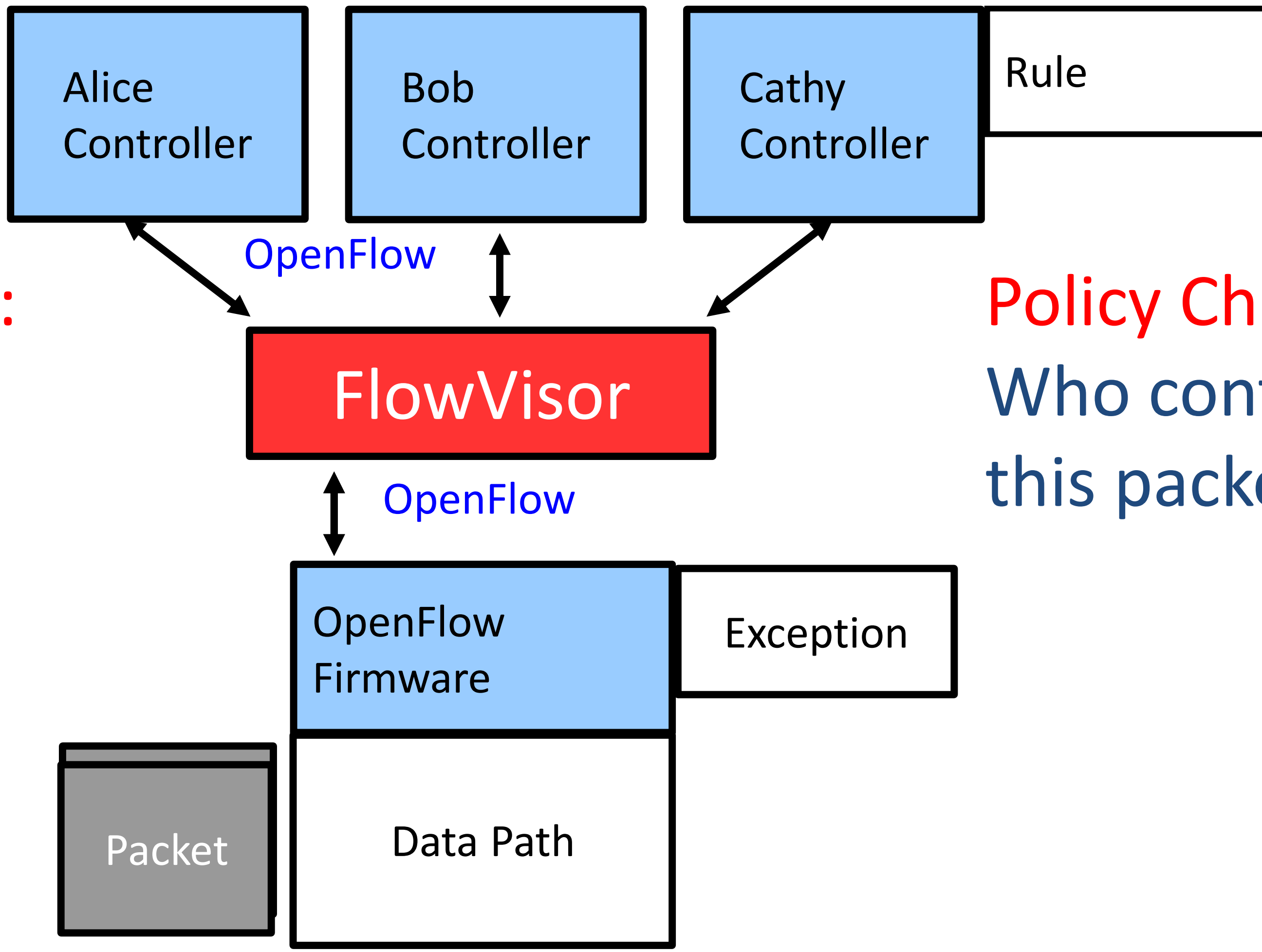


FlowVisor : A Slicer on OpenFlow



FlowVisor: A Slicer for OpenFlow

Policy Check:
Is this rule allowed?

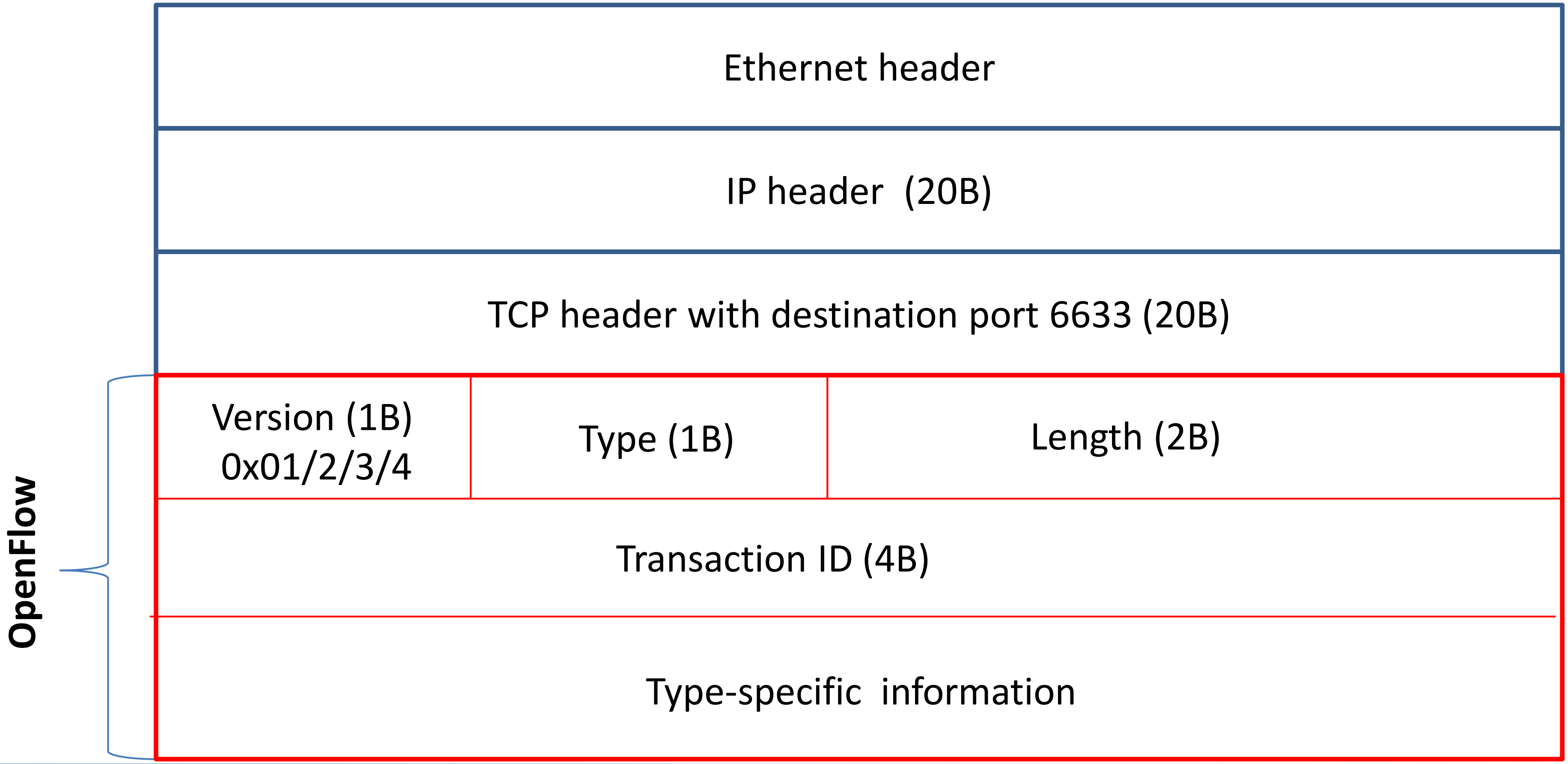


Policy Check:
Who controls this packet?

OpenFlow protocol packet format

OF runs over TCP (optionally SSL for secure operation) using port 6633 and is specified by C structs

OF is a very low-level specification (assembly-language-like)



OpenFlow messages

The OF protocol was built to be *minimal* and *powerful* (like x86 instruction set ☺) and indeed it is low-level assembly language-like

There are 3 types of OpenFlow messages :

OF controller to switch

- populates flow tables which SDN switch uses to forward
- request statistics

OF switch to controller (asynchronous messages)

- packet/byte counters for defined flows
- sends packets not matching a defined flow

Symmetric messages

- hellos (startup)
- echoes (heartbeats, measure control path latency)
- experimental messages for extensions

OpenFlow message types

Symmetric messages

0 HELLO
1 ERROR
2 ECHO_REQUEST
3 ECHO_REPLY
4 EXPERIMENTER

Switch configuration

5 FEATURES_REQUEST
6 FEATURES_REPLY
7 GET_CONFIG_REQUEST
8 GET_CONFIG_REPLY
9 SET_CONFIG

Asynchronous messages

10 PACKET_IN = 10
11 FLOW_REMOVED = 11
12 PORT_STATUS = 12

Controller command messages

13 PACKET_OUT
14 FLOW_MOD
15 GROUP_MOD
16 PORT_MOD
17 TABLE_MOD

Multipart messages

18 MULTIPART_REQUEST
19 MULTIPART_REPLY

Barrier messages

20 BARRIER_REQUEST
21 BARRIER_REPLY

Queue Configuration messages

22 QUEUE_GET_CONFIG_REQUEST
23 QUEUE_GET_CONFIG_REPLY

Controller role change request messages

24 ROLE_REQUEST
25 ROLE_REPLY

Asynchronous message configuration

26 GET_ASYNC_REQUEST
27 GET_ASYNC_REPLY
28 SET_ASYNC

Meters and rate limiters configuration

29 METER_MOD

Can OpenFlow architecture scale to large networks ?

- **Switch flows**
  - Existing OF switch table can handle 1000s of flows
  - With multiple tables, or use of switch fabric and memory for basic matching, this grows to 100s of thousands of flows per switch

- **Controller based on commercial server can handle**
  - a single server processor can handle 100Gbps = 150 Mpps

    (enough to control many 1000s of switches)

- **A single server can handle 1000s to 10,000s of TCP connections**:
  - limitation of about 10K switches per controller
    - solution is slicing to use multiple controllers, (still an open issue)

SDN success story- Google

Google operates two large backbone networks:

- Internet-facing backbone (user traffic): **I-scale**
- Datacenter backbone (internal traffic): **G-scale**

Managing large backbones is hard

- OpenFlow has helped Google to improve backbone performance and reduce backbone complexity and cost

Since early 2012 G-scale is managed using OpenFlow

Since no suitable OF device was available Google built its own switches from merchant silicon and open source stacks

Why did Google re-engineer G-scale ?

The new network has centralized traffic engineering that leads to network utilization is close to 95% !

Network can respond quickly and be easily upgraded

OK, so we can virtualize a basic switch…

What else may be useful ?

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  - RAN Virtualization: benefits, challenges and solutions
  - Core Network Virtualization

Network Functions Virtualization (NFV)

NFV

- The NFV concept was presented by a group of seven leading telecoms network operators at the SDN and OpenFlow World Congress in October 2012. (AT&T, BT, Deutsche Telekom, Orange, Telecom Italia, Telefonica, and Verizon)

- Approximately three years after its creation, it has already brought together around 230 members in an Industry Specification Group (ISG) within the European Telecommunication Standards Institute (ETSI).

The goal of NFV

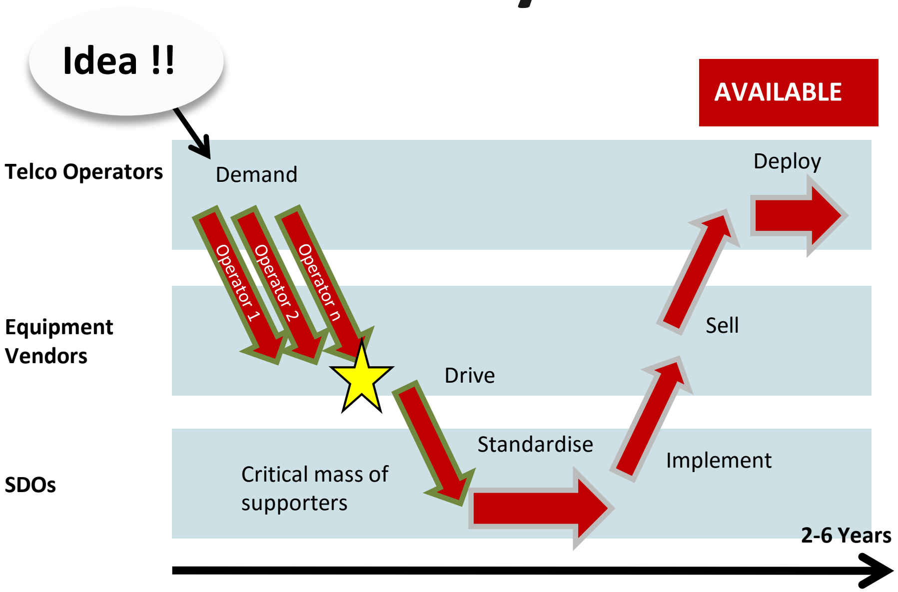
1. Decoupling software from hardware:

- Decoupling of physical network equipment from the functions that run on them
- The network element is no longer a composition of integrated hardware and software entities
- The evolution of both are independent of each other.

This allows separate development timelines and maintenance for software and hardware.

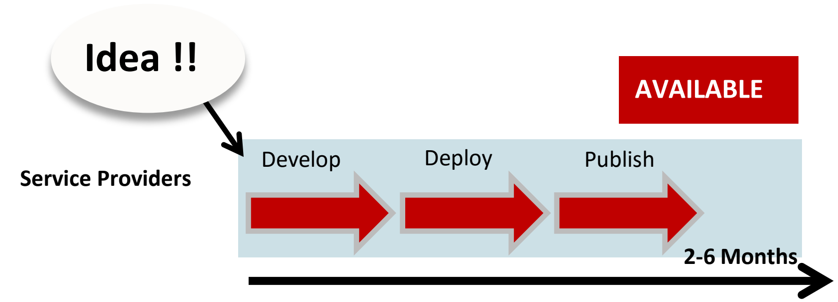
Reduce cycle of innovation

Telco Cycle



2-6 years

Service Providers Cycle



2-6 months

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

The goal of NFV

2. **Flexible network function deployment**

The detachment of software from hardware helps reassign and share the infrastructure resources:

- hardware and software can perform different functions at various times
- components can be instantiated at any NFV-enabled device in the network and their connections can be set up in a flexible way

The goal of NFV

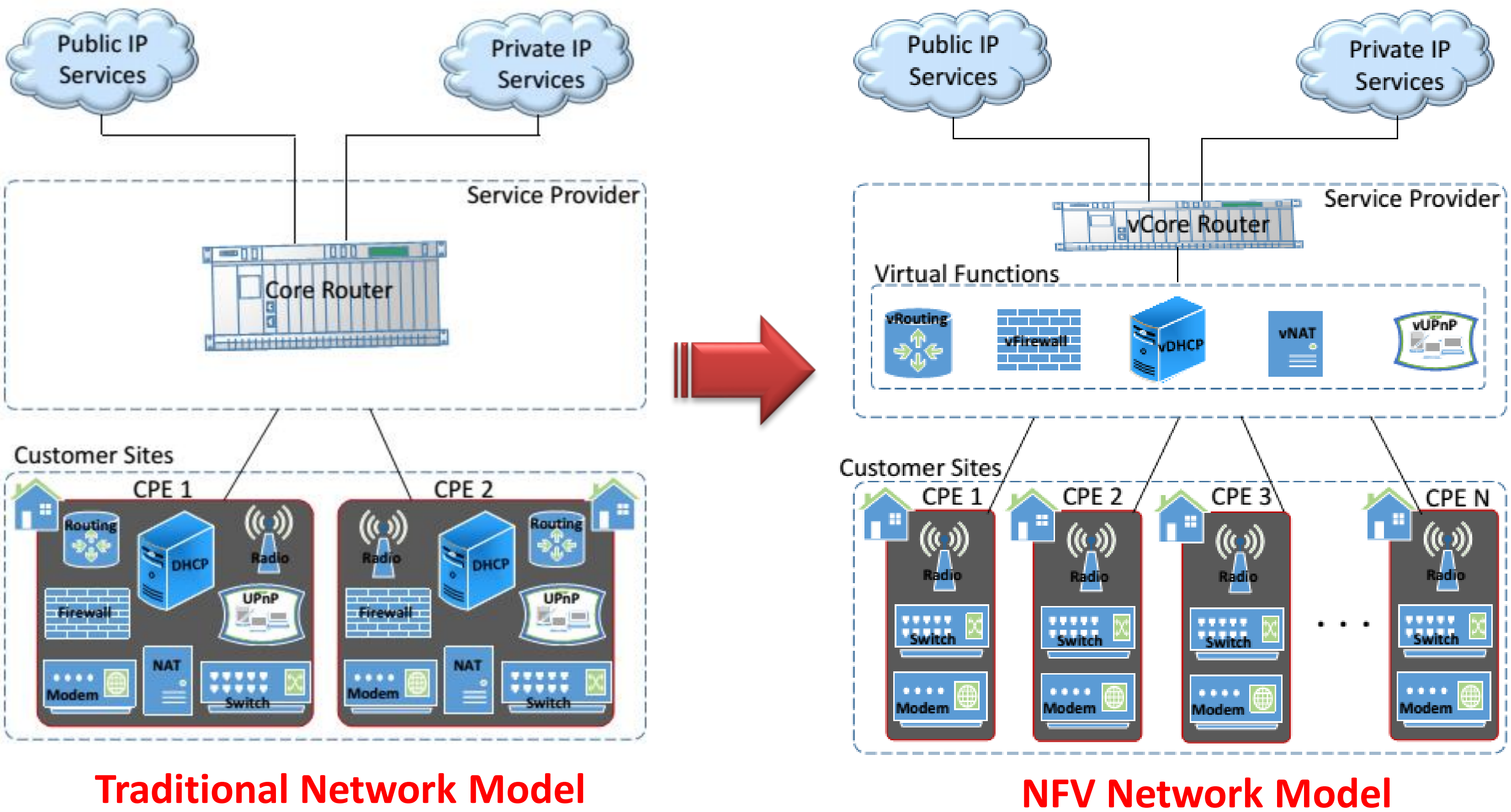
2. **Dynamic scaling**

Greater flexibility to scale the actual VNF performance in a more dynamic way and with finer granularity

e.g. according to the actual traffic for which the network operator needs to provision capacity

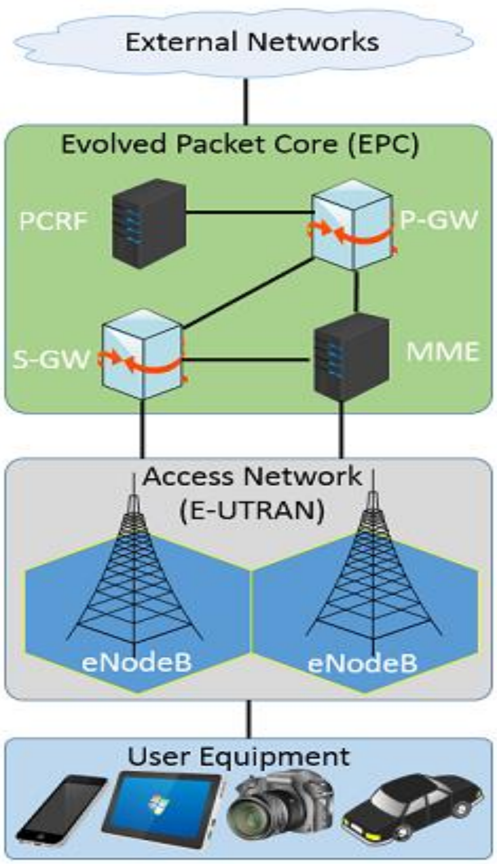
NFV Use Case (1)

NFV Applied at the Customer Premises Equipment

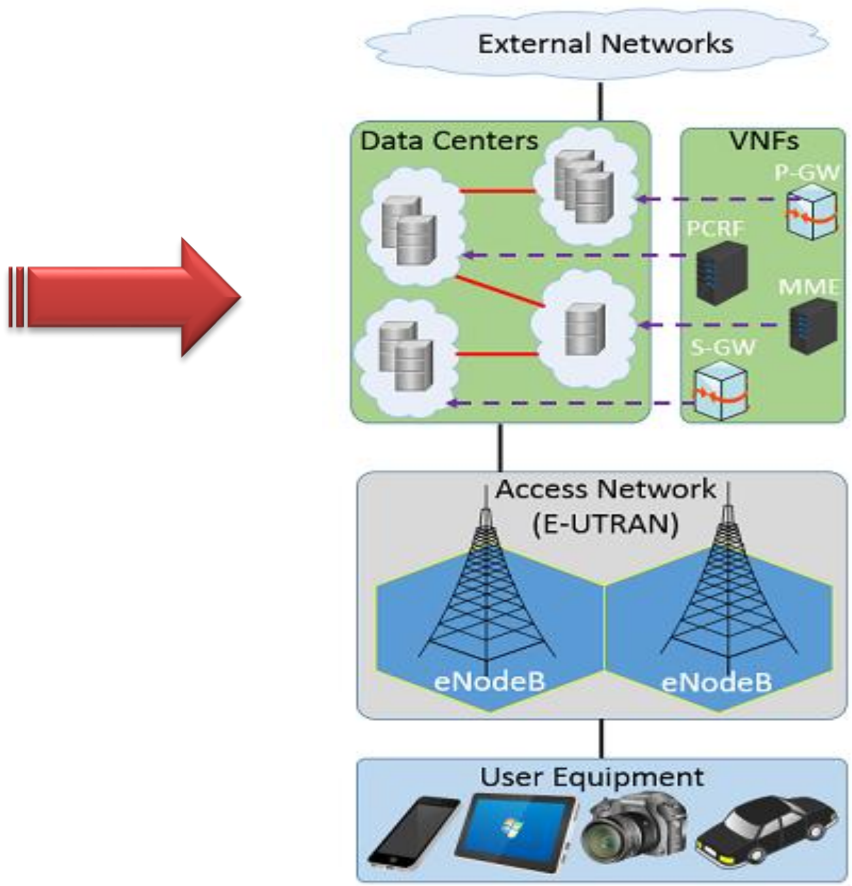


NFV Use Case (2)

NFV Applied at the Evolved Packet Core (EPC)

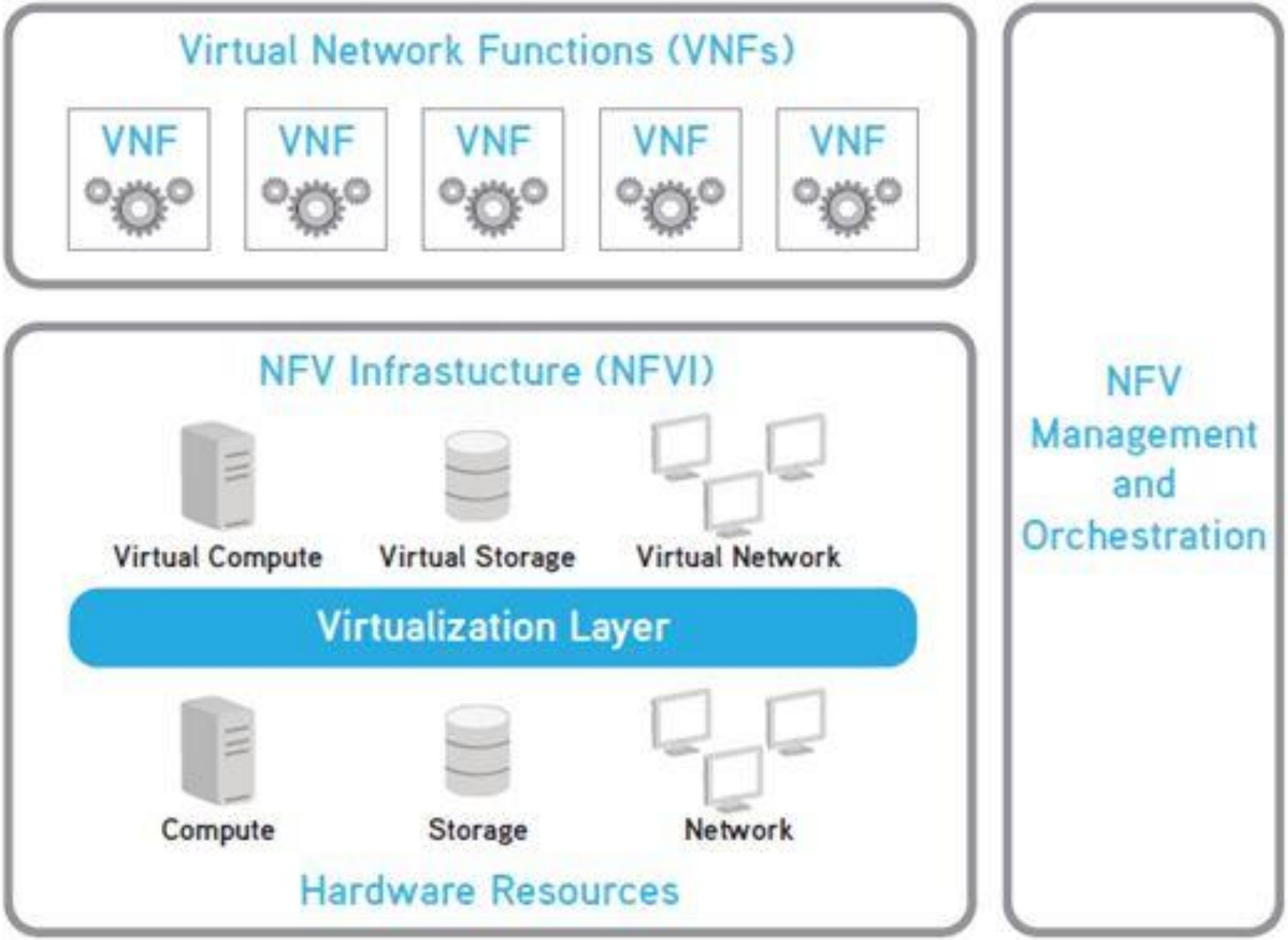


Traditional EPC



NFV applied at the EPC

High level NFV Architecture



*ETSI GS NFV 002 V1.2.1 (2014-12)

Building blocks of NFV architecture

1. **NFV Infrastructure** (NFVI)

- Computing and storage resources may be represented in terms of one or more Virtual Machines (VMs)
- A virtual node is a software component with either hosting or routing functionality, for example an operating system encapsulated in a VM
- A virtual link is a logical interconnection of two virtual nodes, appearing to them as a direct physical link

Building blocks of NFV architecture (2)

2. Virtual Network Functions (*VNFs*)

- An implementation of network functions deployed on virtual resources (e.g. virtual machines)

A service is an offering provided by a Service Provider that is composed of one or more network functions

→

In NFV, the NFs that make up the service are virtualized and deployed on virtual resources

Building blocks of NFV architecture (3)

3. NFV Management and Orchestration (NFV MANO)

- Provides the functionality required for the provisioning of VNFs
- Orchestration and lifecycle management of physical and/or software resources that support the infrastructure virtualization, and the lifecycle management of VNFs
- Defines interfaces that can be used for communications between the different components of the NFV MANO
- Coordination with traditional network management systems such as OSS and BSS

A business model for NFV

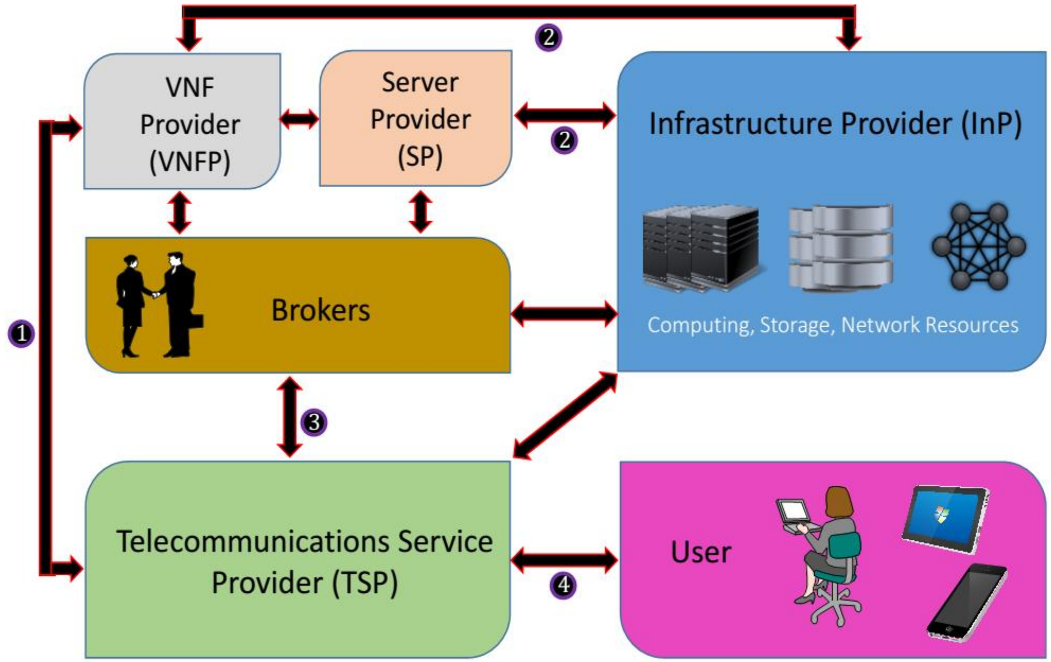
-1- InP: deploys and manages physical resources

-2- TSP: leases resources from one or more InPs, which they use for running VNFs.

-3- VNFP: provides software implementations for NFs:

- #1 directly to TSPs
- #2 indirectly via the InPs

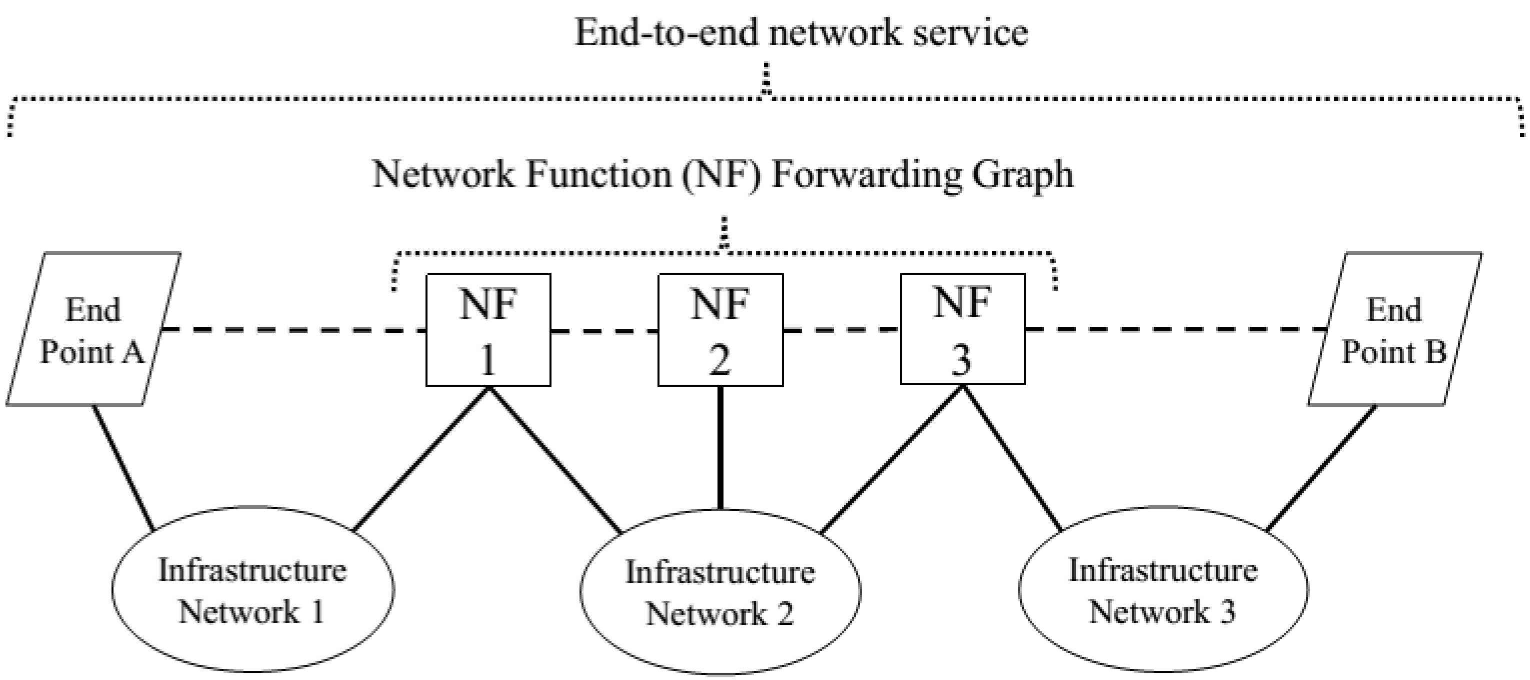
-4- SP: SPs provide industry standard servers on which VNFs can be deployed



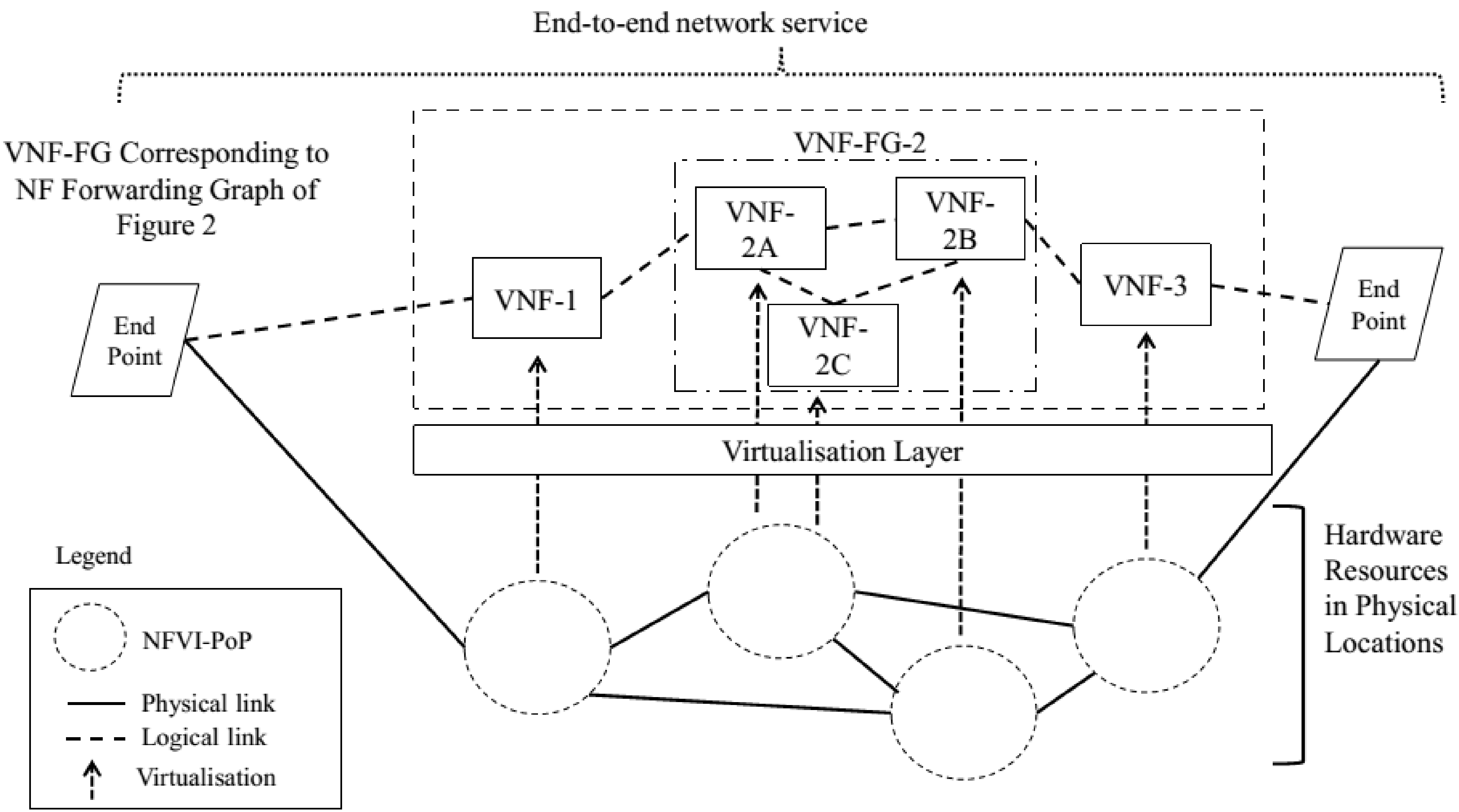
-**5- Brokers:** receive resource and/or functions requirements from TSPs and then discover, negotiate and aggregate resources and functions from multiple InPs, VNFPs and SPs.

Network Services in NFV

An end-to-end network service (e.g. mobile voice/data, Internet access, a virtual private network) can be described by an NF Forwarding Graph of interconnected Network Functions (NFs) and end points.



End to End Network Service



Example with VNFs and nested forwarding graphs

NFV Challenges

- **Achieving high performance virtualised network appliances**
  - portable between different HW vendors, and with different hypervisors
- **Management and orchestration of virtual network appliances**
  - ensuring security from attack and misconfiguration
  - appropriate level of resilience to HW and SW failure
- **Integrating multiple virtual appliances from different vendors**
  - Network operators need to be able to “mix & match” HW,
  - hypervisors and virtual appliances from different vendors,
  - without incurring significant integration costs and avoiding lock-in.

NFV vs SDN

- **NFV: re-definition of network equipment architecture**
  - NFV was born to meet Service Provider (SP) needs:
    - Lower CAPEX by reducing/eliminating proprietary hardware
    - Consolidate multiple network functions onto industry standard platforms
- **SDN: re-definition of network architecture**
  - SDN comes from the IT world:
    - Separate the data and control layers, while centralizing the control
    - Deliver the ability to program network behavior using well-defined interfaces
- **Both have similar goals but approaches are very different**
    - SDN needs new interfaces, control modules, applications.
    - NFV requires moving network applications from dedicated hardware to virtual containers
    - NFV and SDN are highly complementary
    - Both topics are mutually beneficial but not dependent on each other

Outline

- **The need of Virtualization in future networks:**
  - What is Network Virtualization?
  - How to virtualize the network
  - How to enable rapid innovation in networking with Network Virtualization

- **Enabling technologies for next generation networking:**
  - **Software Defined Networking:**
    - SDN: Key Idea and Architecture
    - Standardization of SDN solutions: OpenFlow
  - **Network Function Virtualization**:
    - NFV architecture
    - NFV use cases

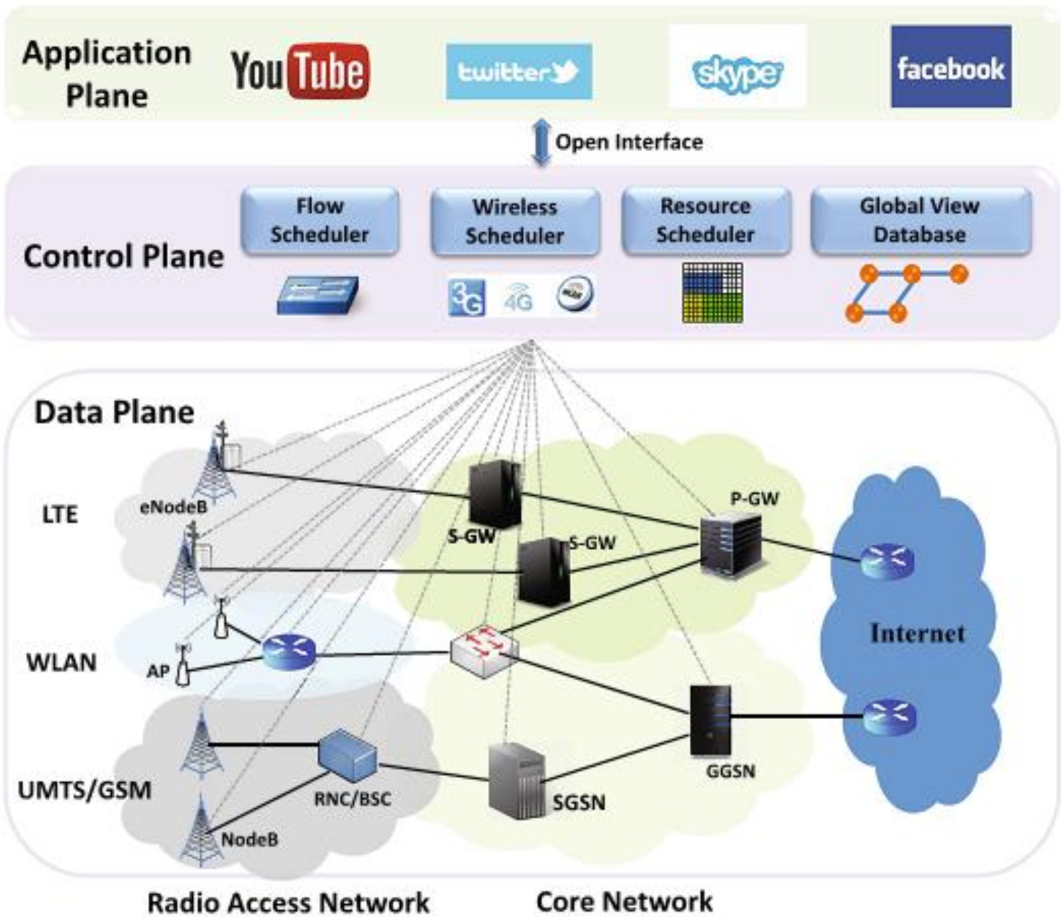
- **SDN and NFV in evolving mobile networks:**
  - RAN Virtualization: benefits, challenges and solutions
  - Core Network Virtualization

Applications of SDN/NFV in Mobile and Wireless Networks

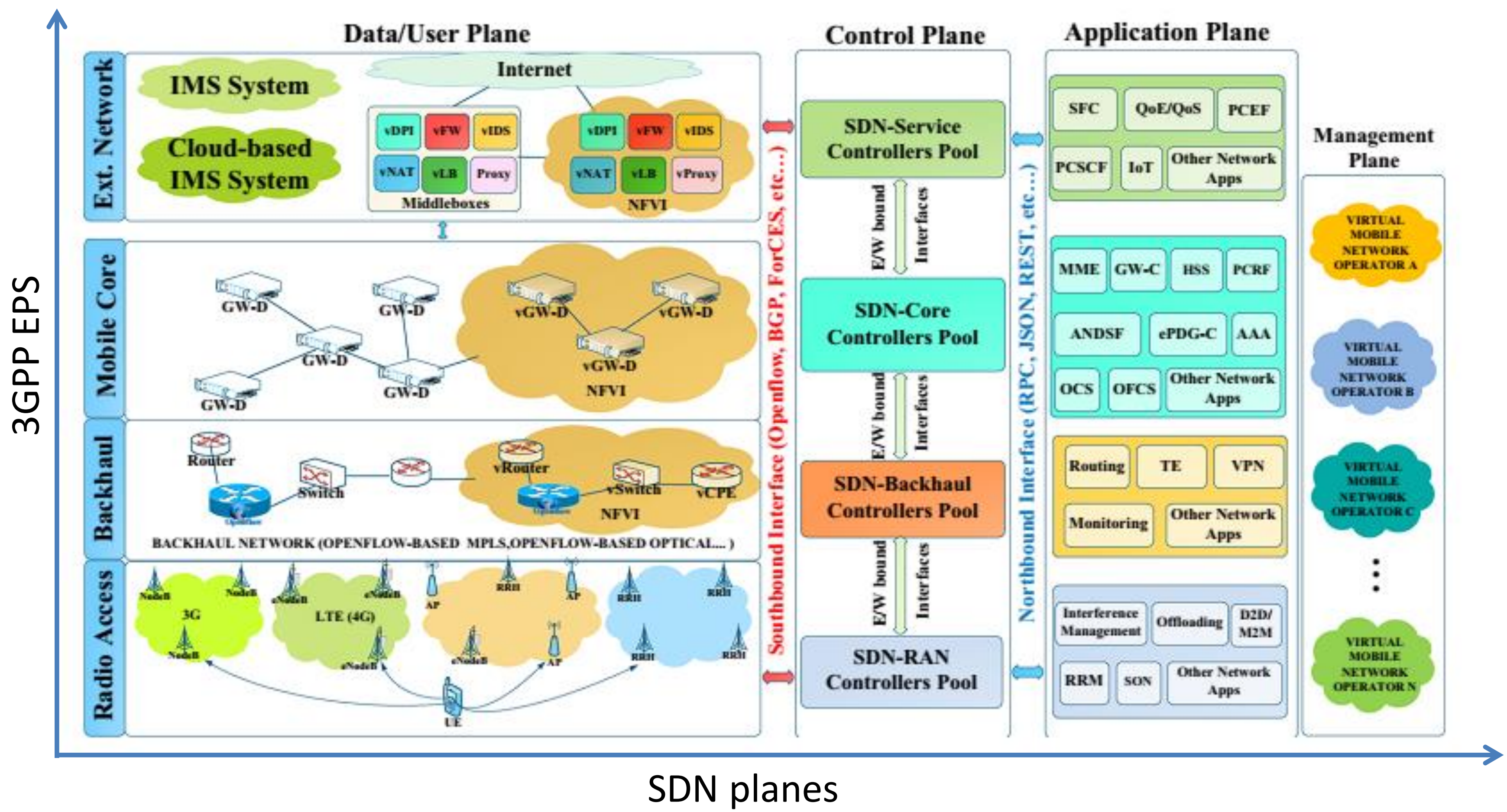
Opportunities offered by SDN/NVF:

- Network devices dynamically report the runtime network status of heterogeneous network
- SDN Controller easily possesses the global network views and, consequently, schedules the forwarding rules and data processing strategies
- Data/Control plane separation enables the interconnections among heterogeneous network
- The control plane may dynamically optimize multiple heterogeneous Networks
  - Resource allocation based on the real-time network requirements
  - Capacity offloading,
  - Efficient network cooperative strategies

SDN-based mobile architecture



SDN planes vs 3GPP EPS



*Yang M, Li Y, Jin D, Zeng L, Wu X, Vasilakos AV (2014). Software-Defined and virtualized future mobile and wireless networks: a survey. Mobile Networks and Applications, 1–15

SDN-based RAN

- The physical RAN resources (i.e. eNodeB) can be abstracted and sliced into virtual RAN resources and shared by multiple operators
- RRM task is simplified by using a centralized controller for the RAN.

SDN-based Backhaul

- Backhaul network equipment can be enhanced with programmability with the support of NFV and SDN
- Slicing the mobile backhaul infrastructure provides the ability to share the network resource between different mobile operators:
  - Traffic offload from one operator to another in cases of congestion or heavy traffic conditions

SDN-based Core Network

- Virtualization of core network functions:
  - Reduce CAPEX and OPEX
  - Supports multi-tenancy
  - Scales core network resources according to the demands of mobile operators
  - Simplifies management by using centralized control

Cloud RAN virtualization

C-RAN is a new cellular network architecture introduced by China Mobile Research Institute in April 2010 in Beijing, China

MOTIVATIONS

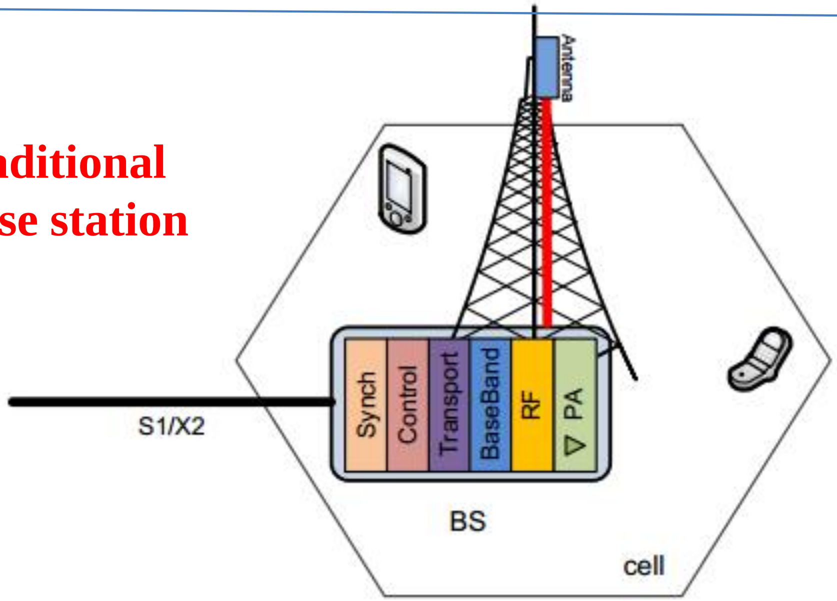
- A RAN node utilization is usually lower than its MAX capacity because the system is designed to cover the peak load
- BS cell site is the major source of power consumption, ≈72% of total power!

SOLUTION

- Centralizing the RAN resources in the cloud can leverage more efficient resource utilization among different physical BSs
- Radio function unit remote radio head (RRH) is separated from the digital function unit, the baseband unit (BBU) by fiber
  - The RRH can be installed on the top of tower
  - The fibre link between RRH and BBU allows much more flexibility in network planning and deployment as they can be placed a few hundreds meters or a few kilometres away now.

C-RAN features

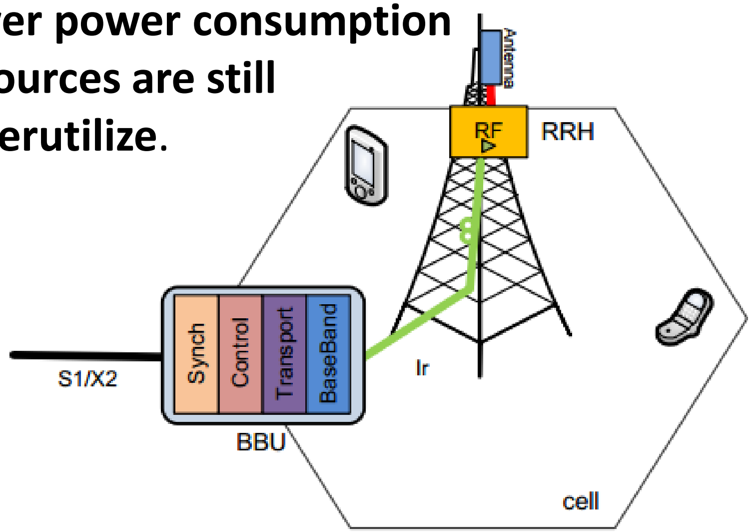
Traditional base station



High power consumption
Resources are underutilized

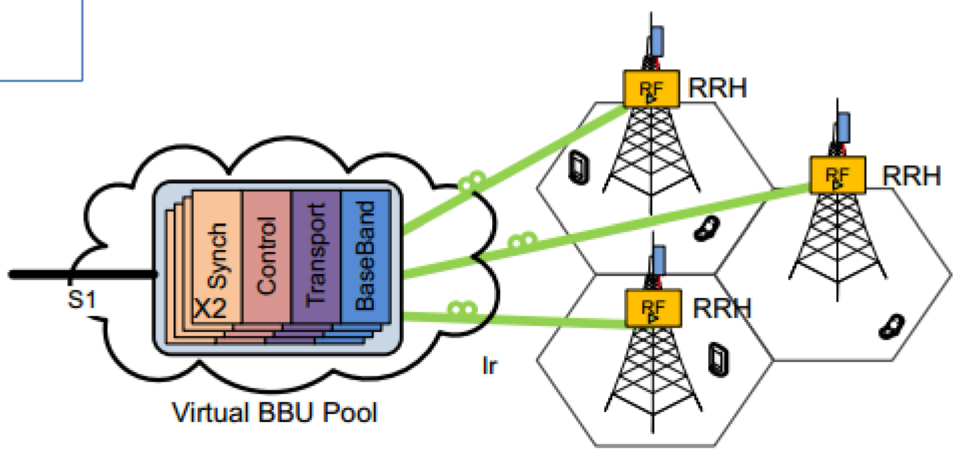
Base station with RRH

Lower power consumption
Resources are still underutilize.



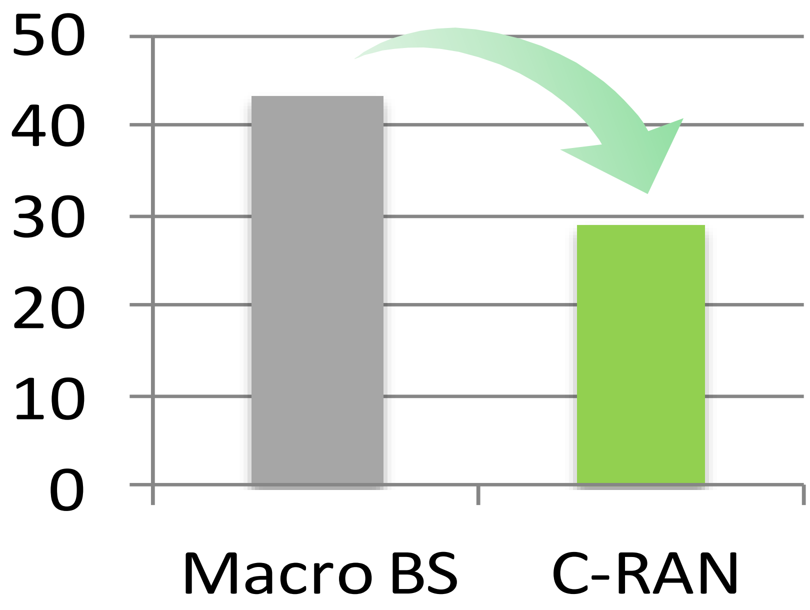
C-RAN

Centralized Baseband Pool

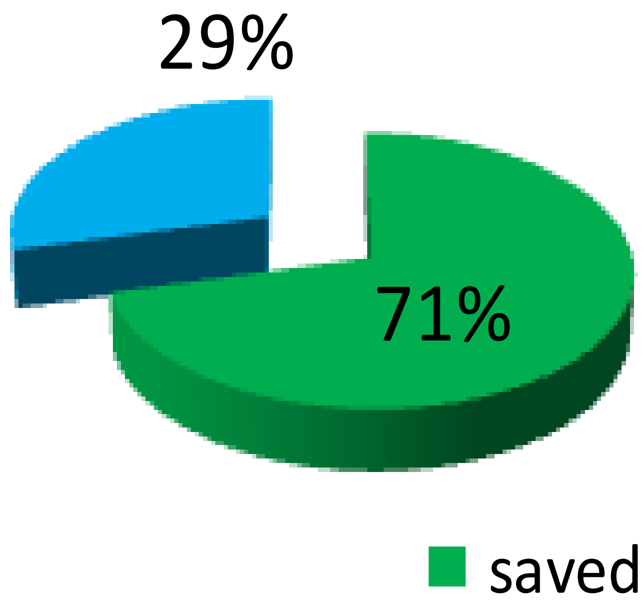


C-RAN Clean System Target

Construction cost per site reduced by 1/3



Power consumption reduced by at most 71%

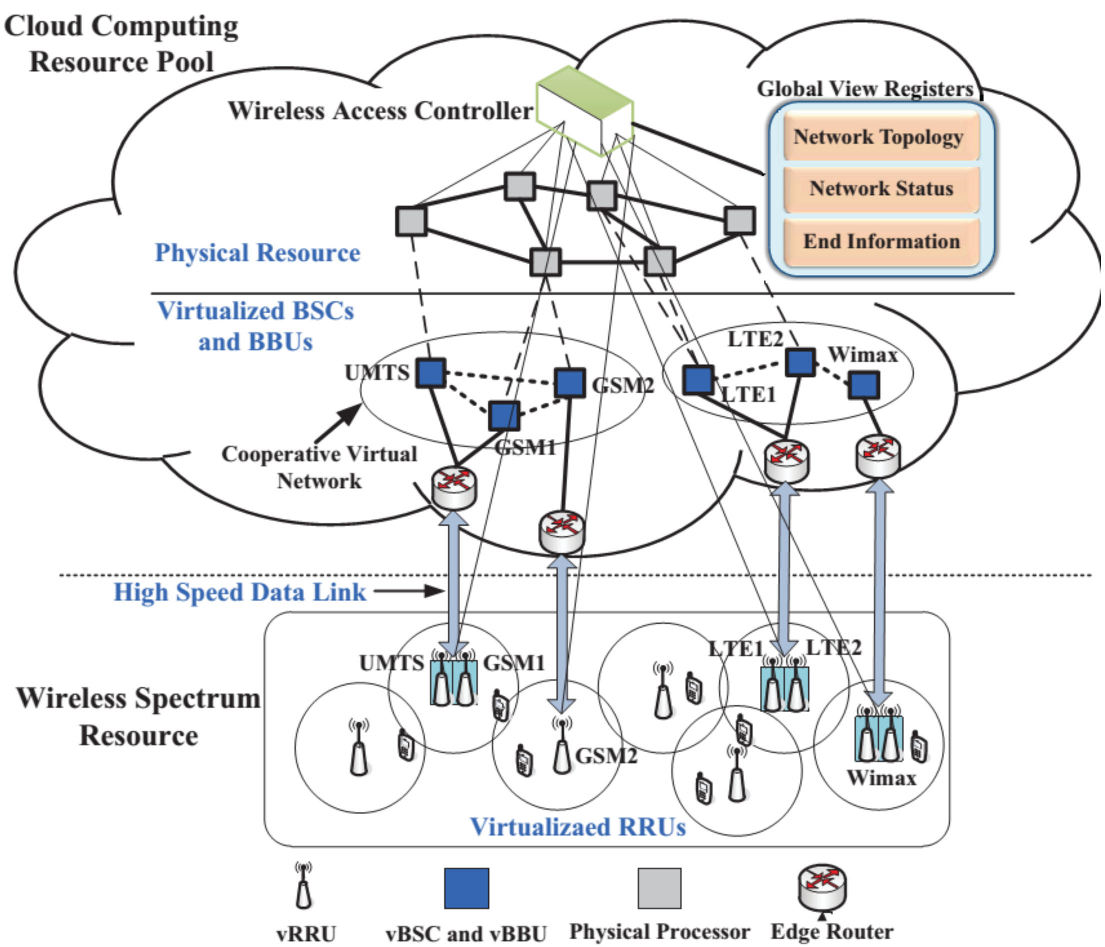


*Source: Base on China Mobile field trial surveys

OpenRAN: C-RAN+SDN

Key Elements:

- wireless spectrum resource pool
- cloud computing resource pool
- SDN controller to establish:
  - the virtual base station in the wireless spectrum resource pool
  - corresponding virtual baseband processing unit in the cloud computing pool by installing appropriate PHY and MAC layer protocols

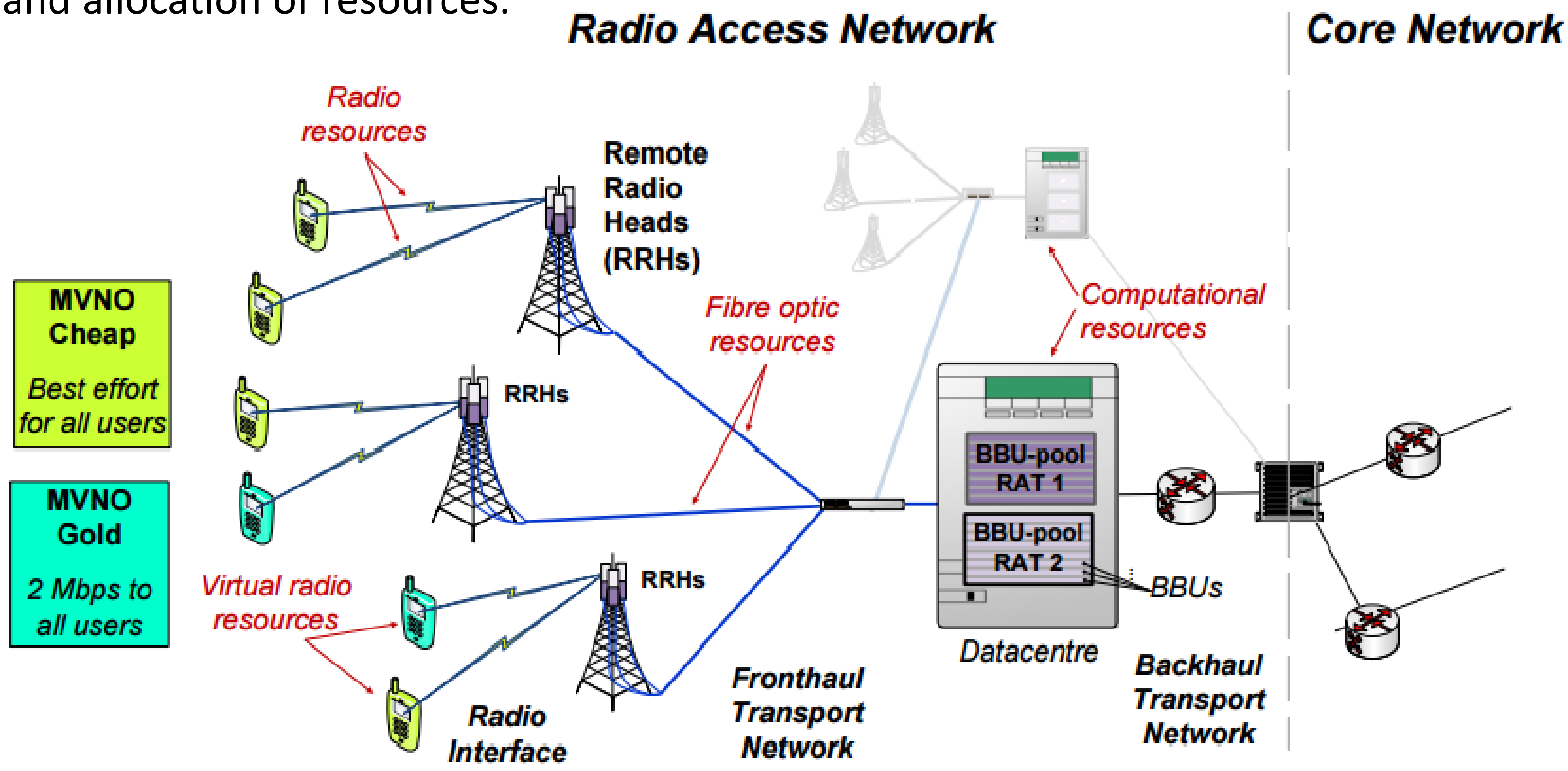


Yang M, Li Y, Jin D, Su L, Ma S, Zeng L (2013) Openran: a software-defined ran architecture via virtualization. SIGCOMM Comput Commun Rev 43(4):549–550

RAN+Backhaul Virtualization

On demand RANaaS:

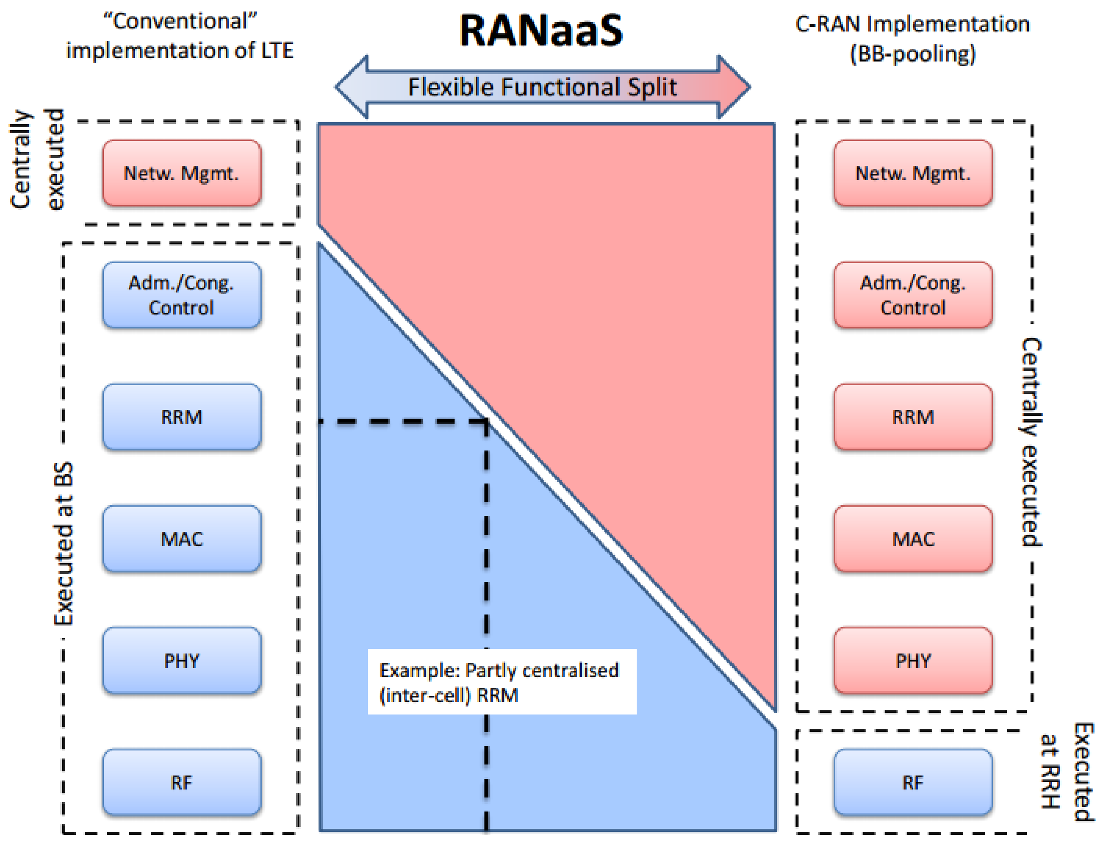
Offer SLA-guaranteed connectivity to multiple tenants (MVNOs) through an elastic on-demand allocation of resources.



*Studer Ferreira, et. al. "An architecture to offer cloud-based radio access network as a service," in *EuCNC 2014*

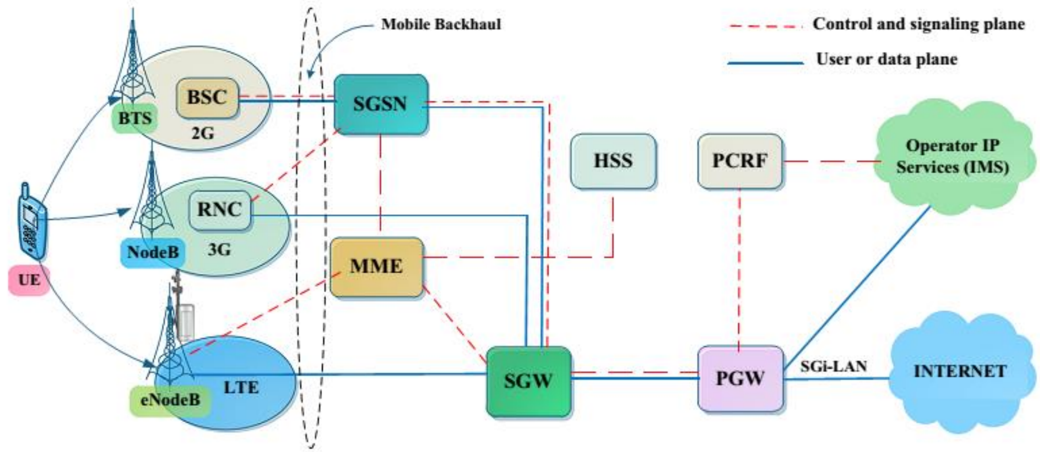
SDN in the RAN+Backhaul Network

RAN as a service concept

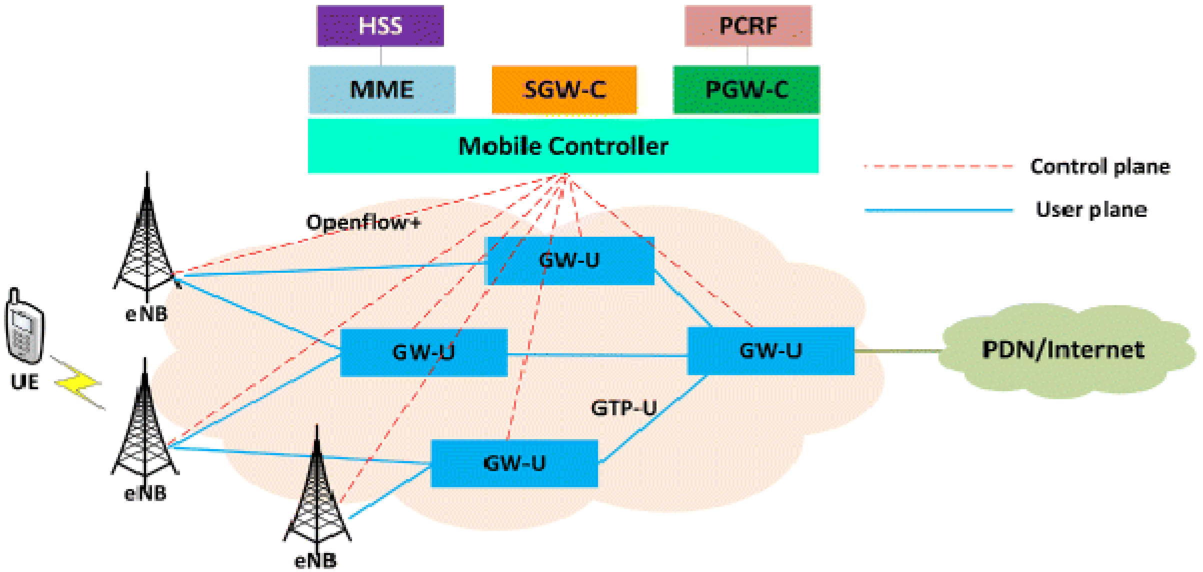


*I-Join project: Cloud Technologies for Flexible 5G Radio Access Networks

SDN in the EPC



3GPP legacy LTE architecture

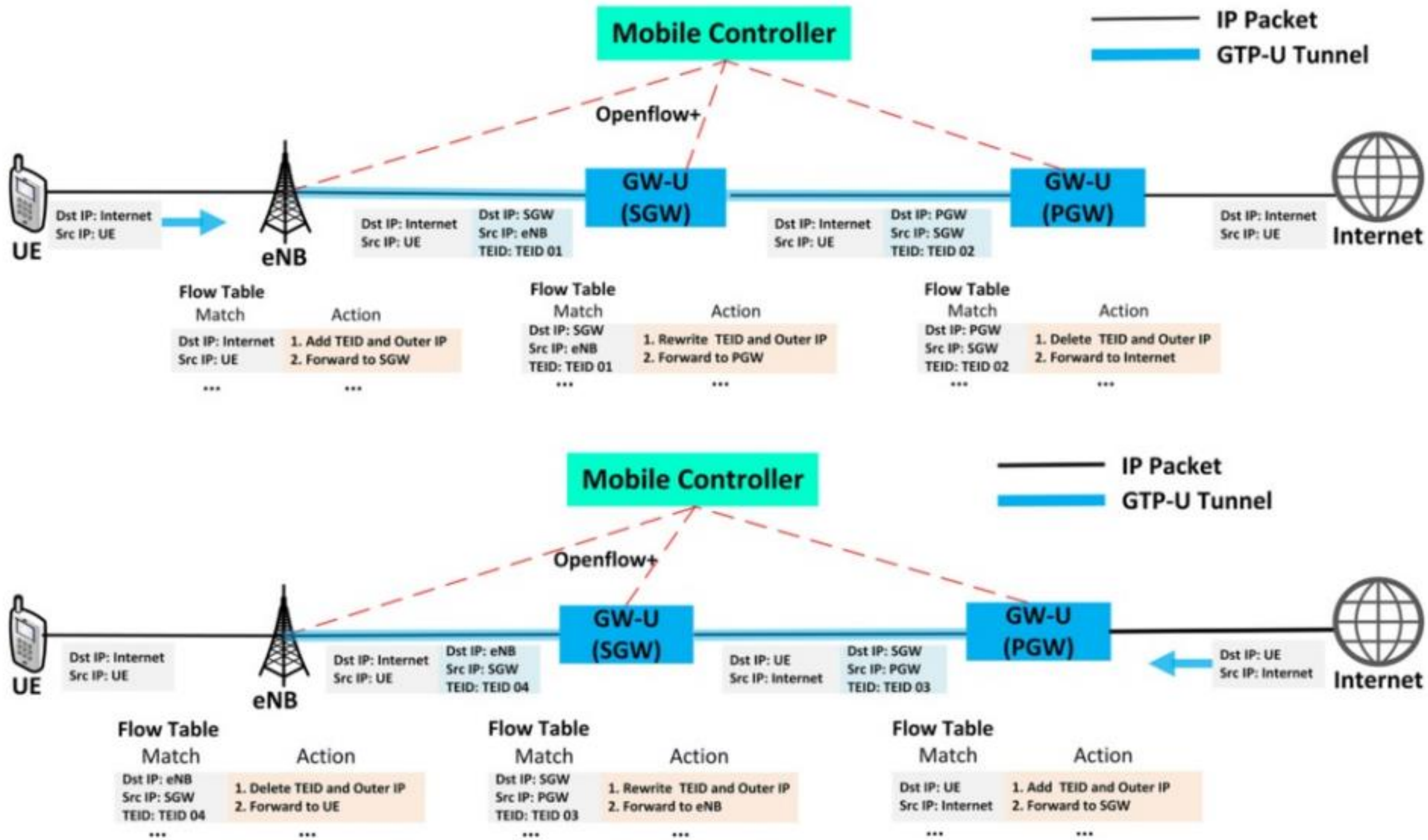


SDN-based LTE/EPC architecture

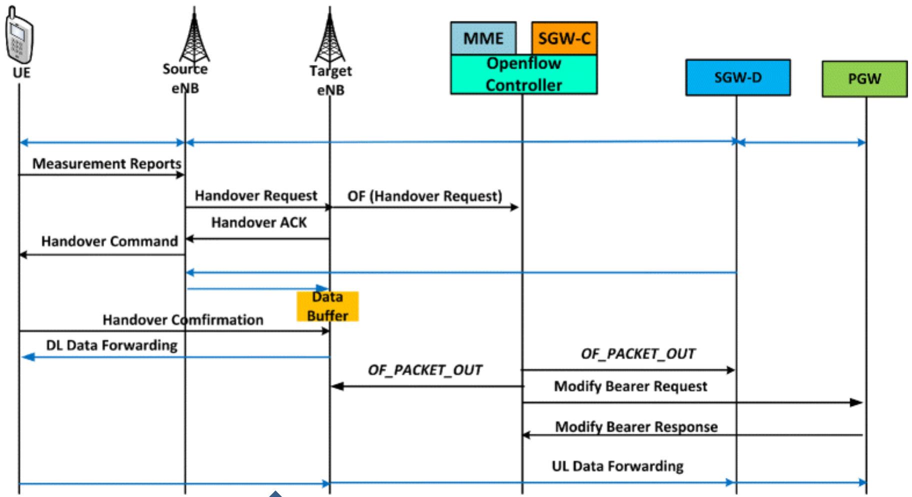
VG Nguyen, Y Kim, "Proposal and evaluation of SDN-based mobile packet core networks", EURASIP J. Wirel. Commun. Networking. 2015

SDN in EPC

OpenFlow-based procedures

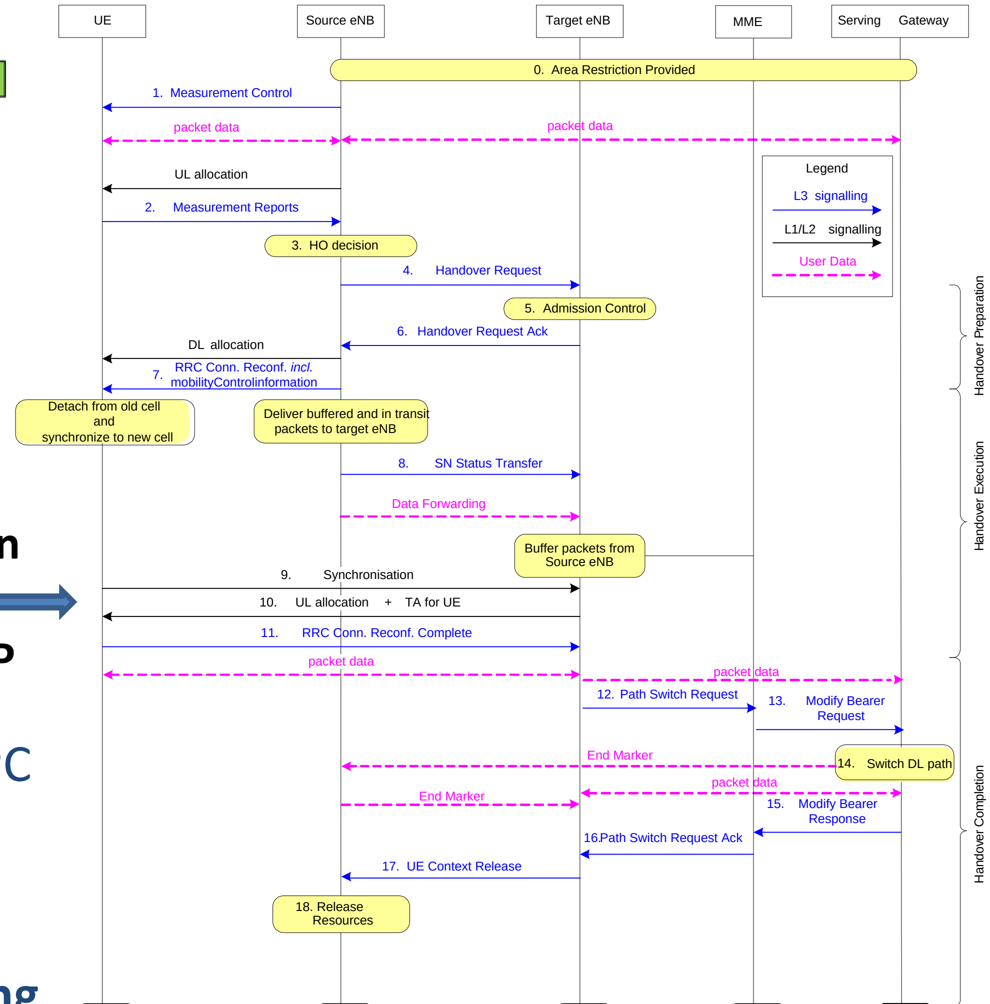


SDN-EPC evaluation



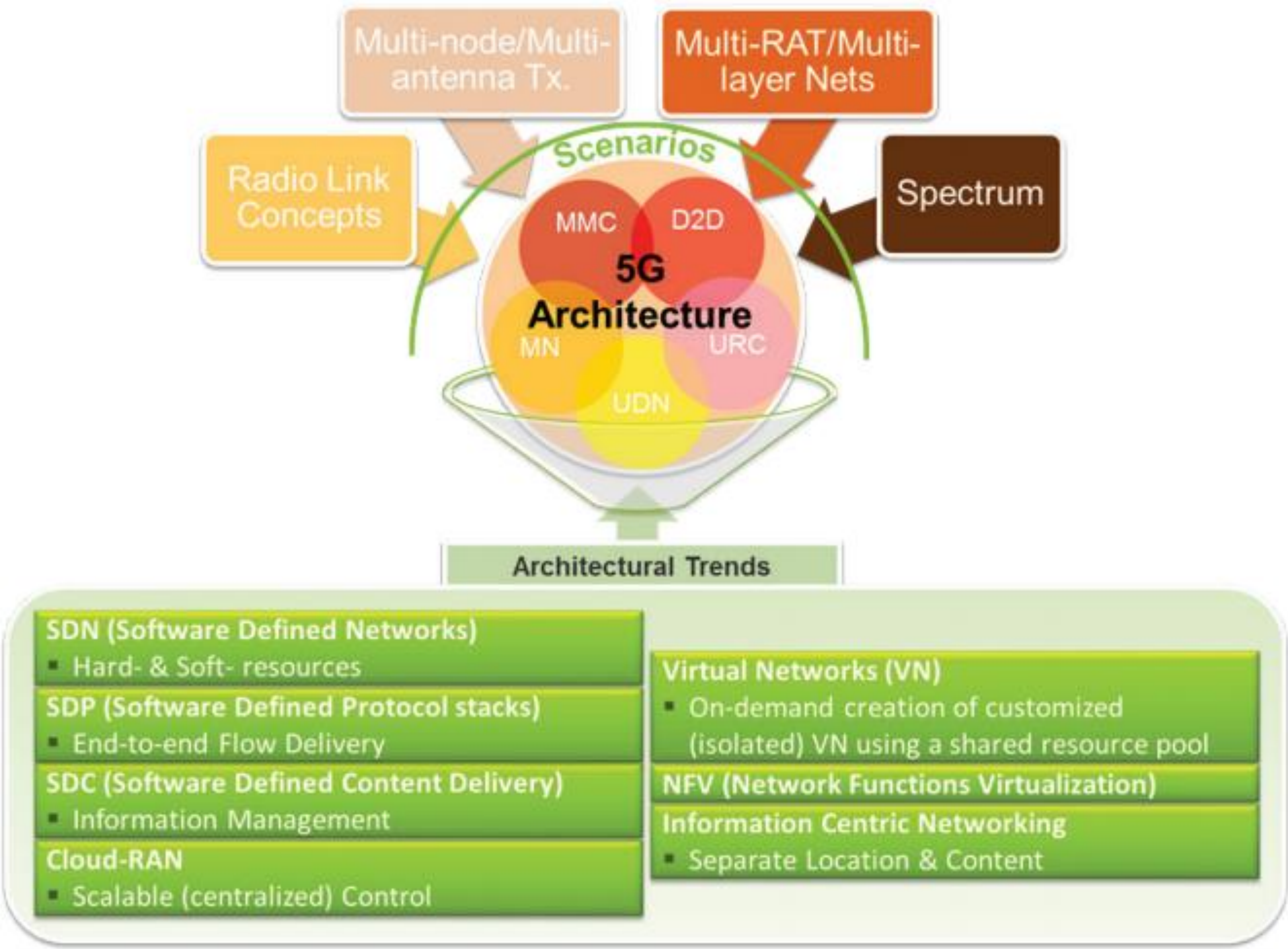
HO with SDN-EPC

HO in 3GPP

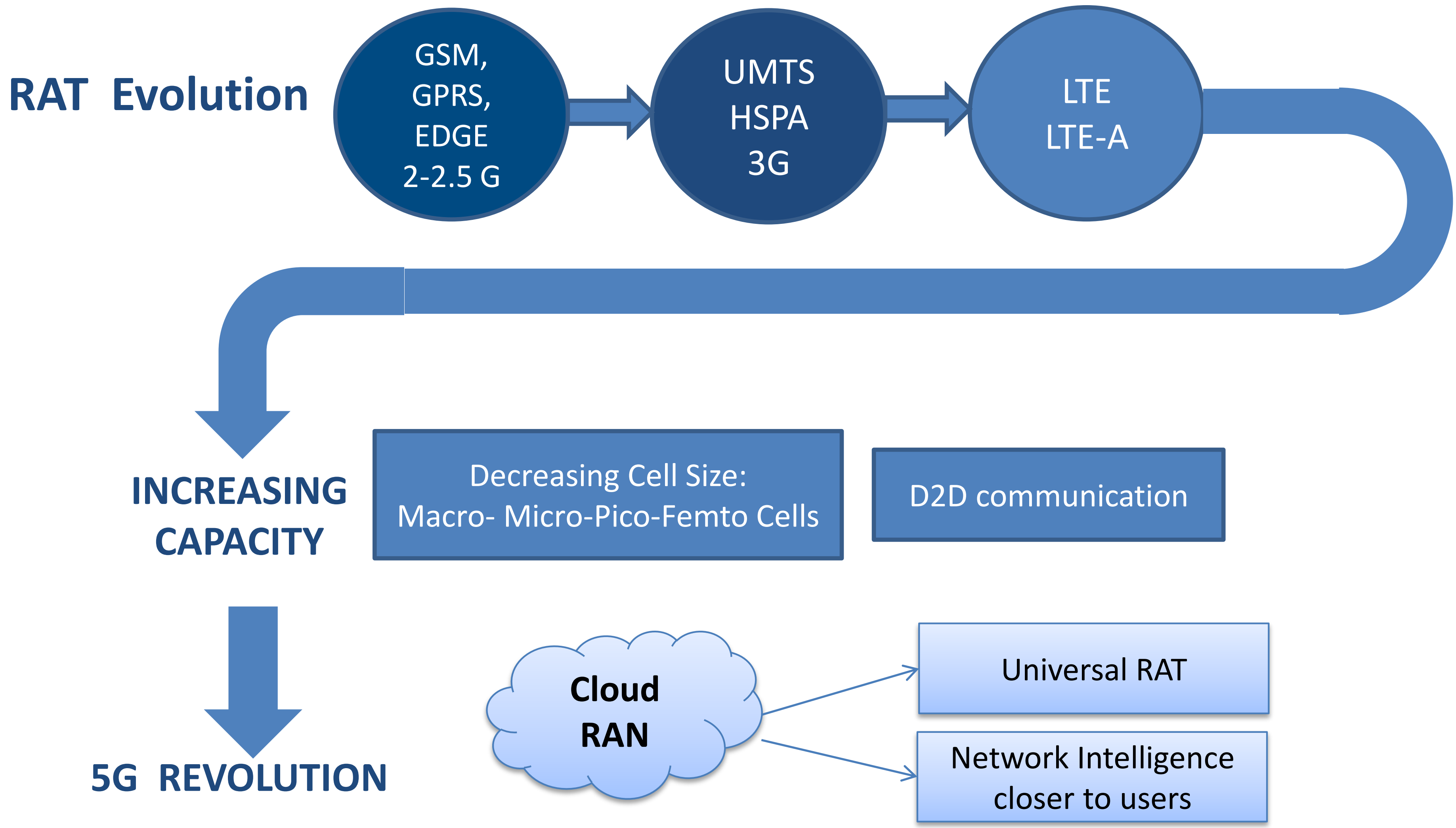


- The major drawbacks of the 3GPP–EPC architecture are the high volume of control signaling
- **SDN enables efficient control signaling mechanisms!**

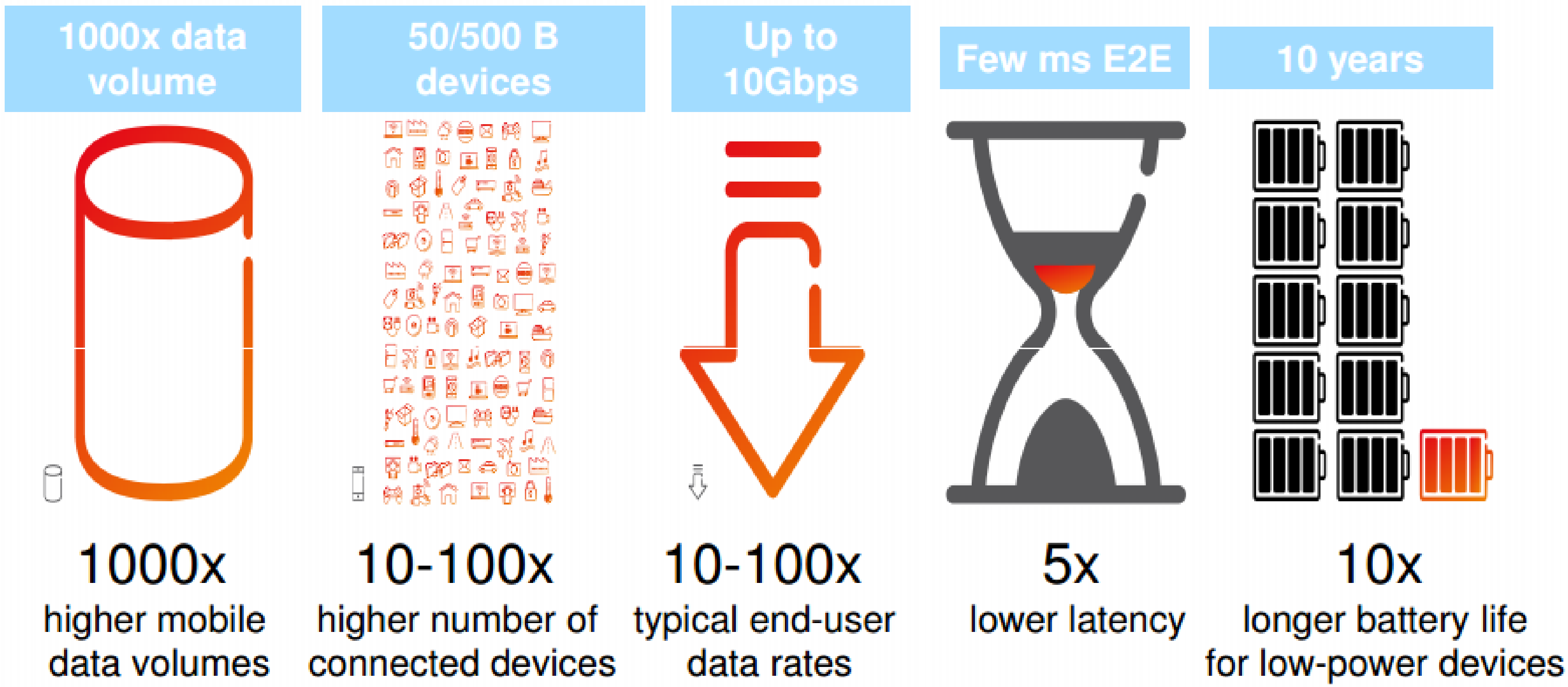
The road towards 5G…



(R)Evolution towards 5G



Are we ready for the 5G objectives?



Summary

We looked at the concept of virtualization and architectures and paradigms for enabling elasticity in the future networks:

- Network Virtualization offers:
  - transparent abstraction of networking platform and resources
  - multiple logical interpretations of the physical characteristics
  - resource partitioning
  - resource sharing
- Network Functions Virtualization offers the potential to transform carrier/network operator operations while achieving significant agility and cost reduction.
- SDN is emerging as the key enabler for NFV, offering the dynamic behavior, automation, and openness required for handling the networks in the future.

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Thank you