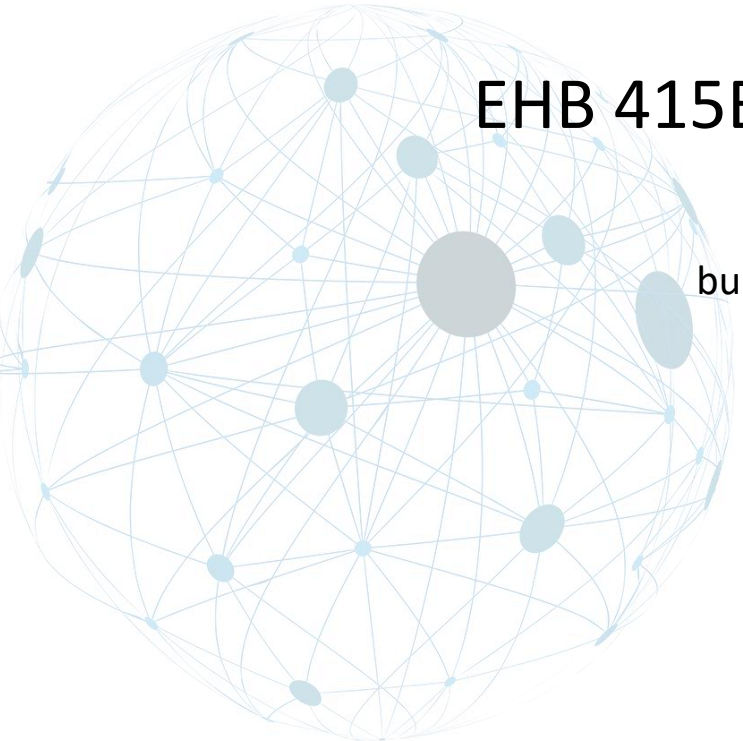

Softwarizing the Network for Tomorrow

EHB 415E Data Communications

Dr. Burak Görkemli

burak.gorkemli@argela.com.tr

December 02, 2019

Outline

- Big Picture: 4G vs. 5G Networks and Slicing
- Fundamentals of Networking
- Software Defined Networking
- OpenFlow
- Network Function Virtualization

Evolution of G's

1G

Analog

Voice only, Limited coverage and mobility. Example: AMPS

2G

Digital

Improved voice, security, coverage. SMS, data. Example GSM, CDMA

3G

Mobile Data

Higher data rates, smartphones, better voice. Example: HSPA / HSPA+

4G

Mobile Broadband

High speed data, better smartphones. Example: LTE / LTE-A

5G

eMBB, mMTC, URLLC

Even higher speeds, ultra-reliable, low latency, high connection density

1980 1990 2000 2010 2020

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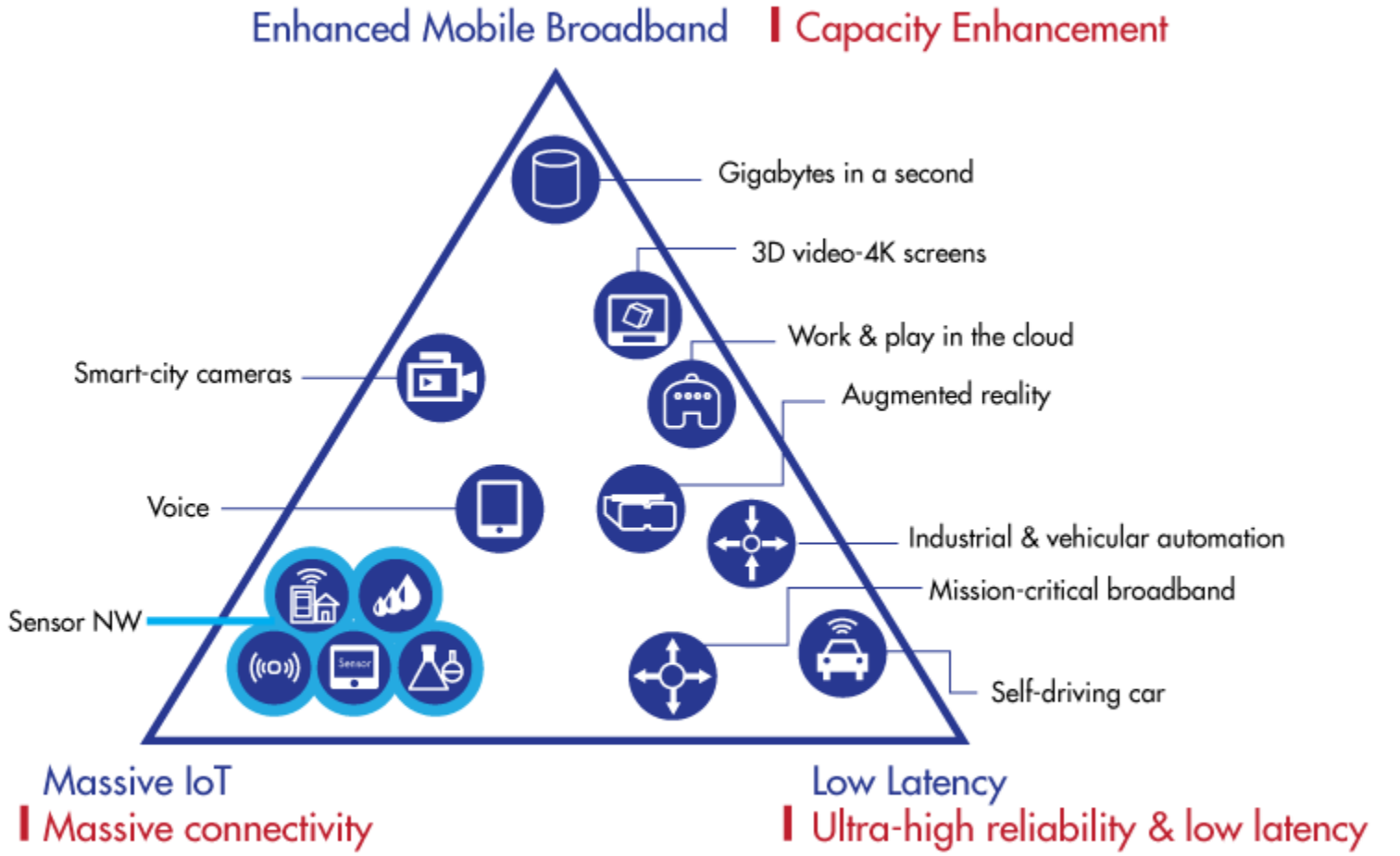
5G



Source: ETRI graphic, from ITU-R IMT 2020 requirements

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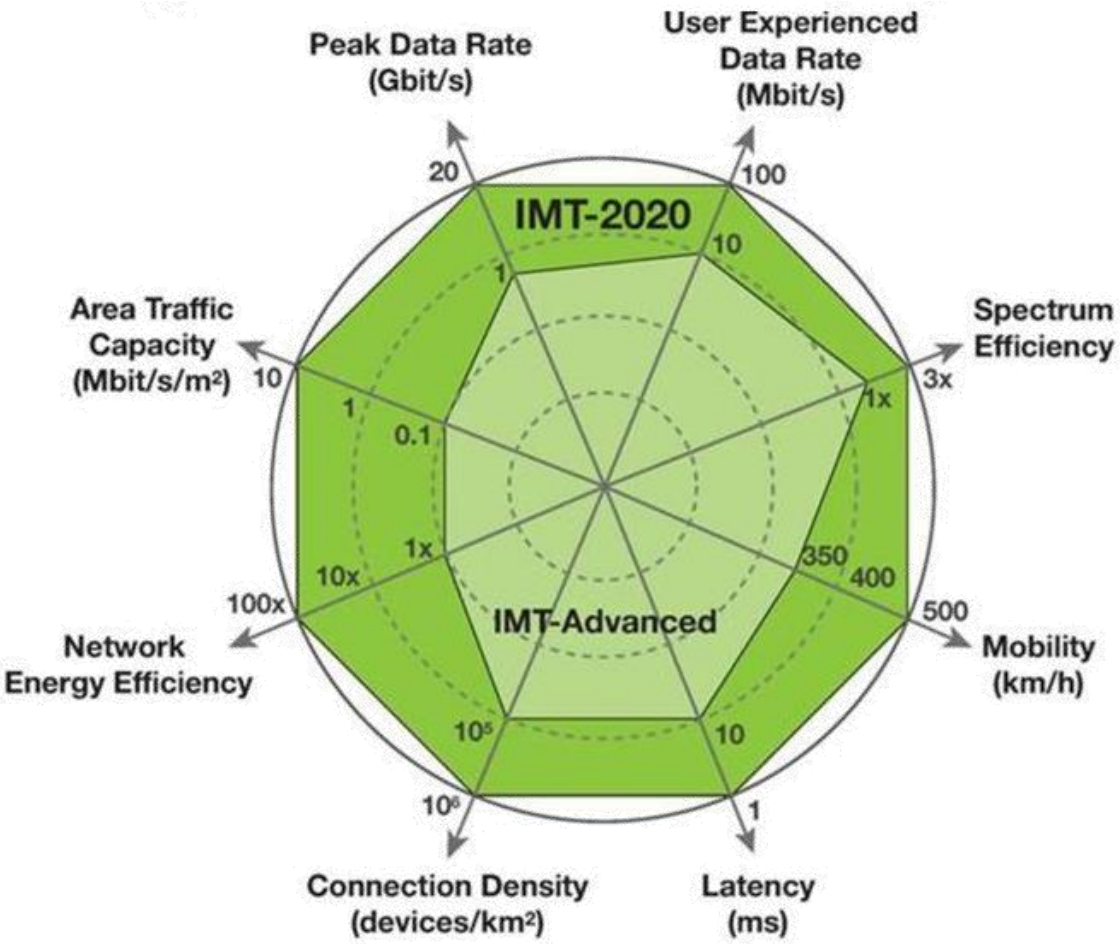
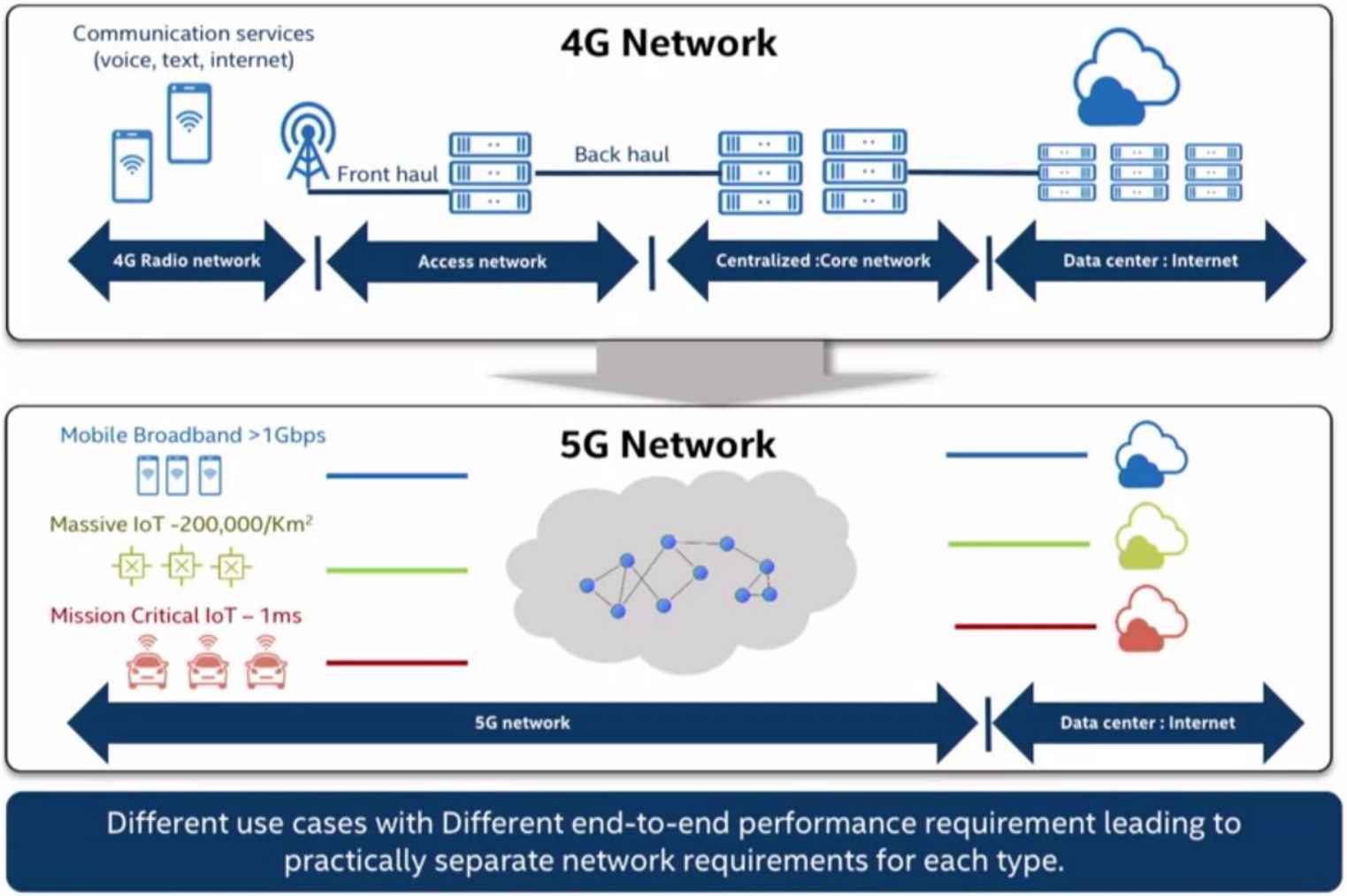
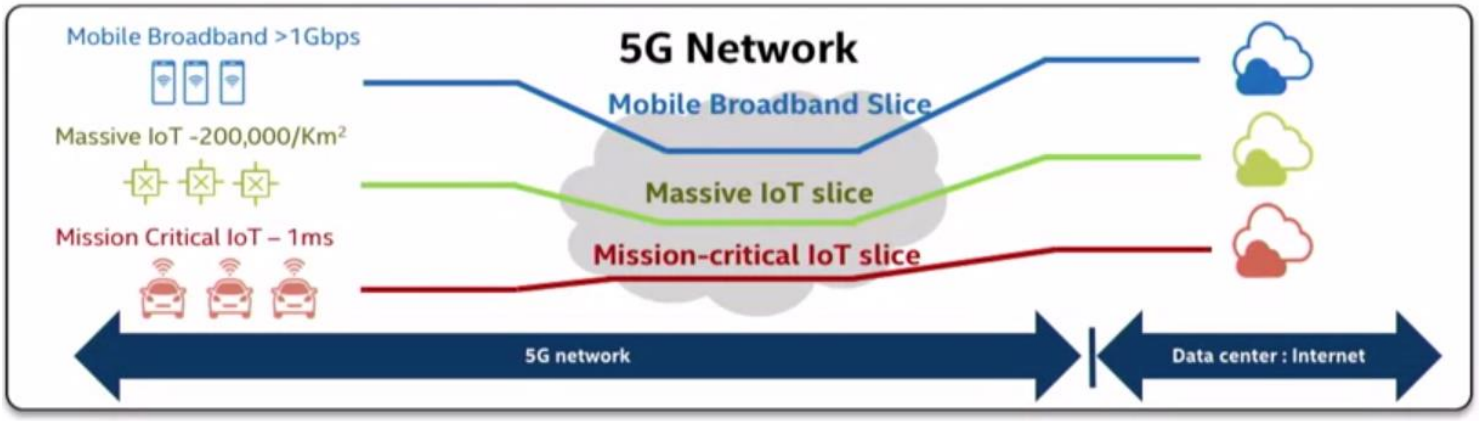
4G vs. 5G

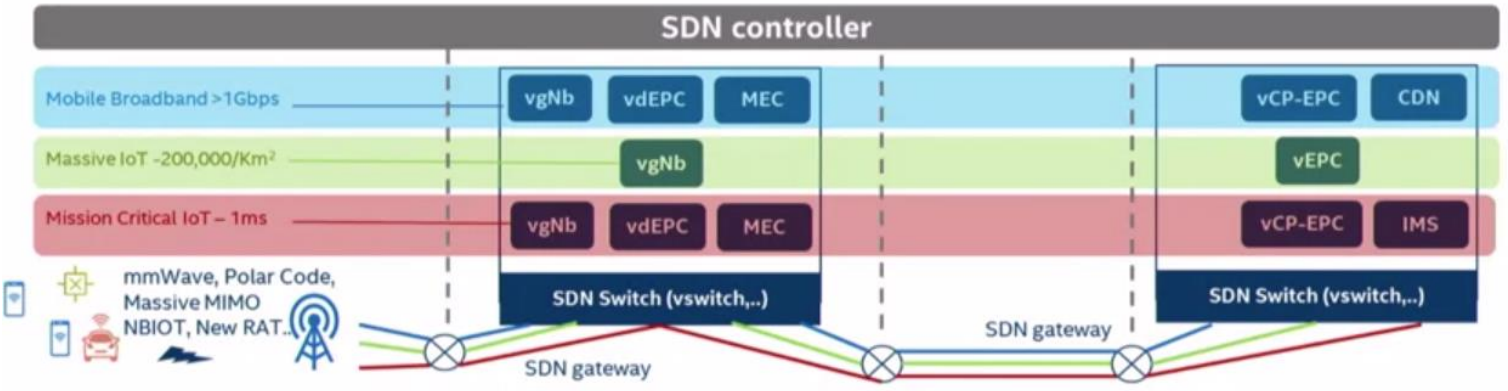

Peak Data Rate
(Gbit/s)
User Experienced
Data Rate
(Mbit/s)
Spectrum
Efficiency
Mobility
(km/h)
Latency
(ms)
Connection Density
(devices/km²)
Network
Energy Efficiency
Area Traffic
Capacity
(Mbit/s/m²)
20
100
10
1
3x
1x
500
400
350
10
1
10⁵
10⁶
100x
10x
1x
0.1
10
1
IMT-2020
IMT-Advanced

4G vs. 5G Network



Slicing in 5G Network: SDN & NFV





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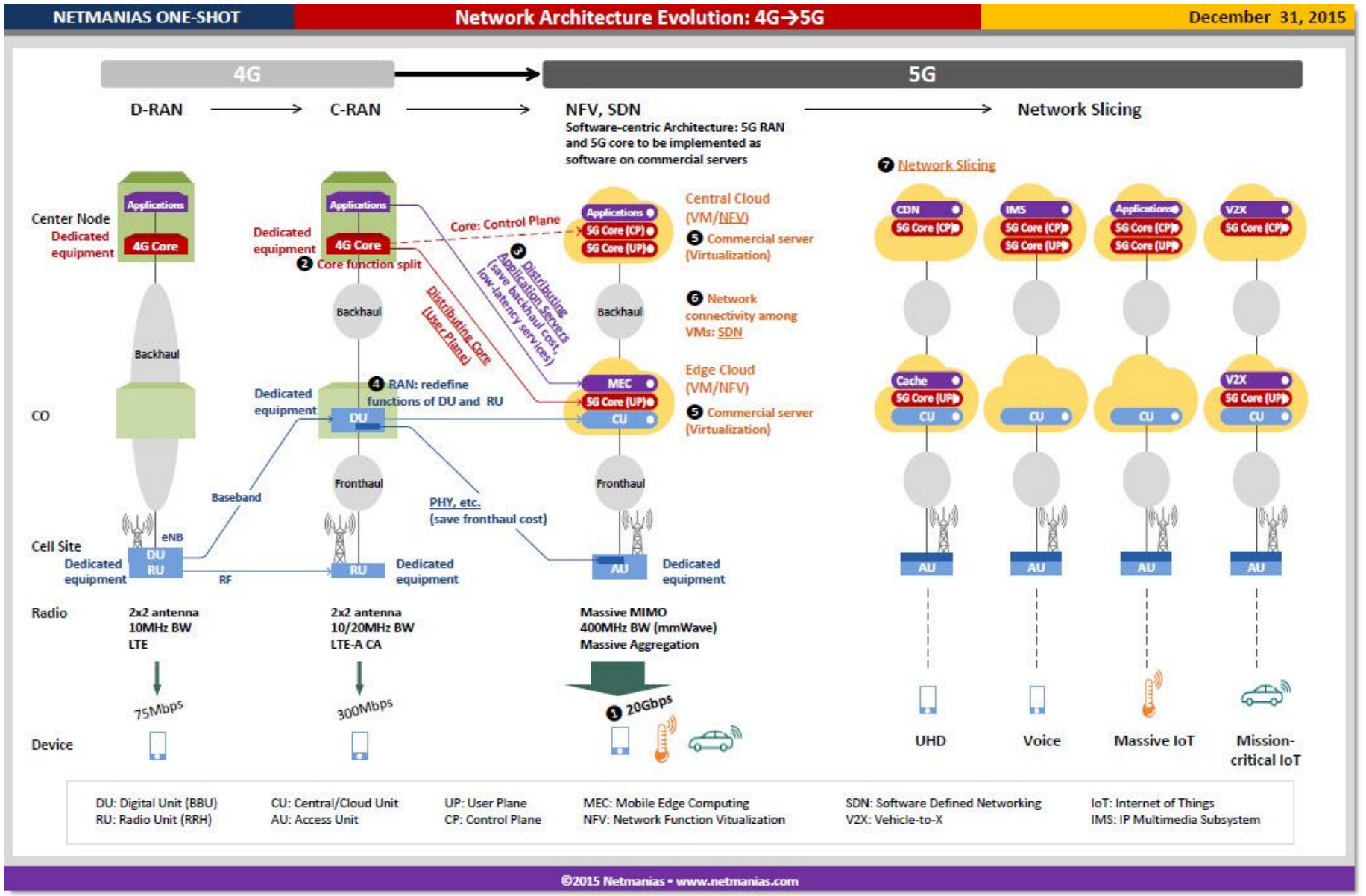
NETMANIAS ONE-SHOT
Network Architecture Evolution: 4G→5G
December 31, 2015
4G
5G
D-RAN
C-RAN
NFV, SDN
Software-centric Architecture: 5G RAN and 5G core to be implemented as software on commercial servers
Network Slicing
7 Network Slicing
Center Node
Dedicated equipment
Applications
4G Core
Backhaul
CO
Cell Site
Dedicated equipment
eNB
DU
RU
Baseband
RF
Dedicated equipment
2 Core function split
Core: Control Plane
Distributing Core (User Plane)
3 Distributing Application Servers (save backhaul cost, low-latency services)
4 RAN: redefine functions of DU and RU
Fronthaul
PHY, etc. (save fronthaul cost)
Central Cloud (VM/NFV)
5 Commercial server (Virtualization)
6 Network connectivity among VMs: SDN
Edge Cloud (VM/NFV)
5 Commercial server (Virtualization)
5G Core (CP)
5G Core (UP)
MEC
CU
AU
Radio
2x2 antenna 10MHz BW LTE
2x2 antenna 10/20MHz BW LTE-A CA
Massive MIMO 400MHz BW (mmWave) Massive Aggregation
75Mbps
300Mbps
1 20Gbps
Device
CDN
IMS
V2X
Cache
UHD
Voice
Massive IoT
Mission-critical IoT
DU: Digital Unit (BBU)
RU: Radio Unit (RRH)
CU: Central/Cloud Unit
AU: Access Unit
UP: User Plane
CP: Control Plane
MEC: Mobile Edge Computing
NFV: Network Function Vitualization
SDN: Software Defined Networking
V2X: Vehicle-to-X
IoT: Internet of Things
IMS: IP Multimedia Subsystem
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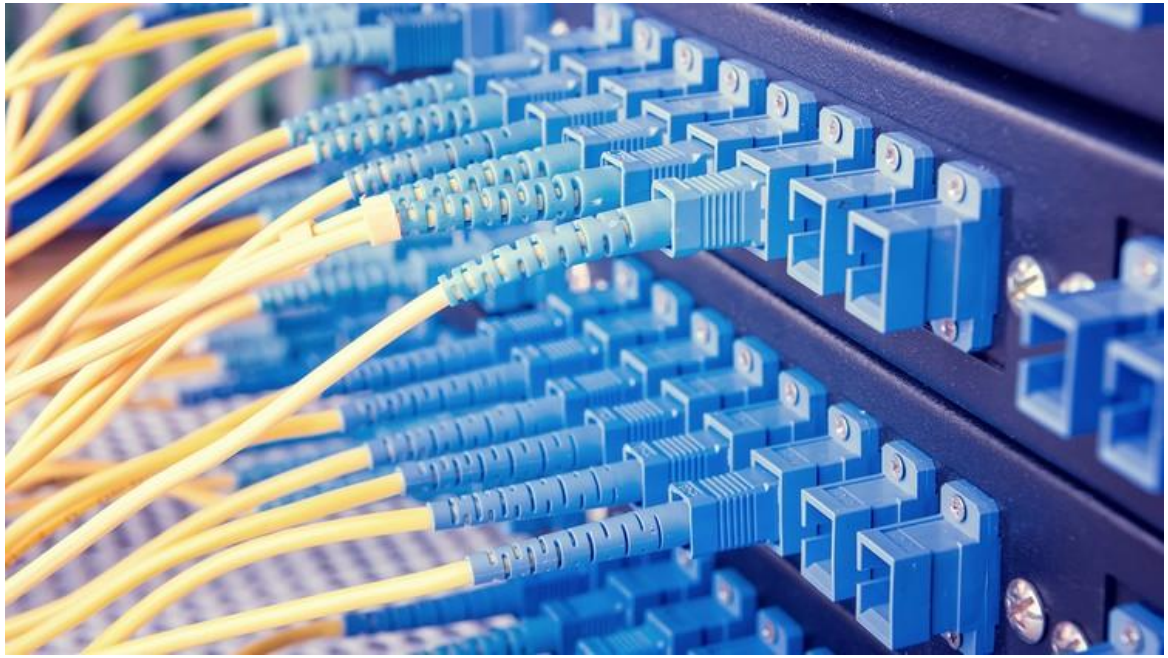
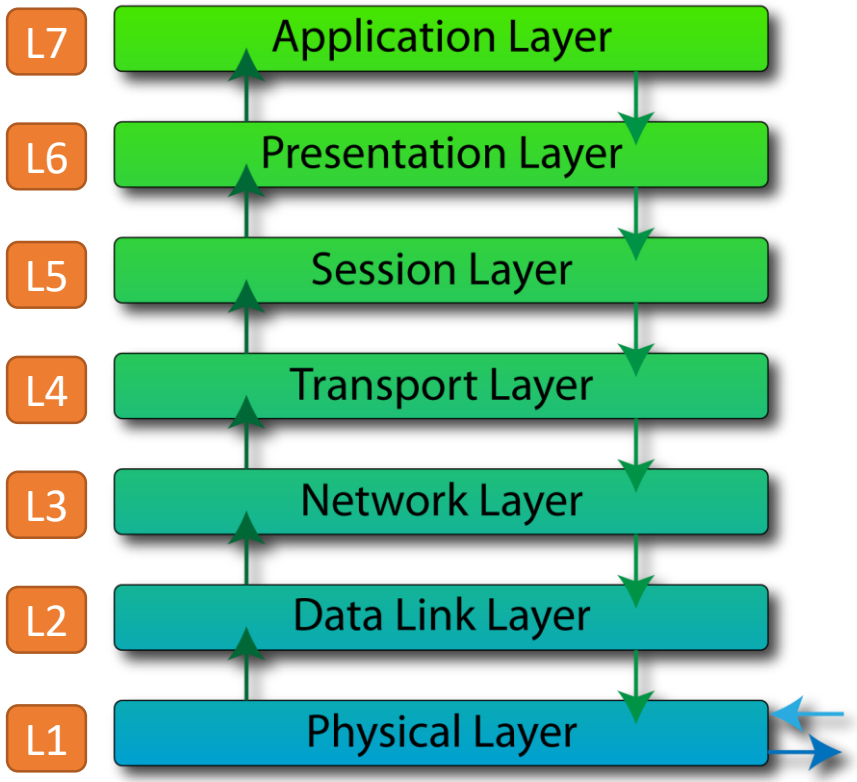


Fundamentals of Networking

OSI Model by ISO

- Open Systems Interconnection Reference Model, ISO 7498 / X.200
- Conceptual model that partitions a communication system into 7 layers
- A layer serves the layer above it and is served by the later below it



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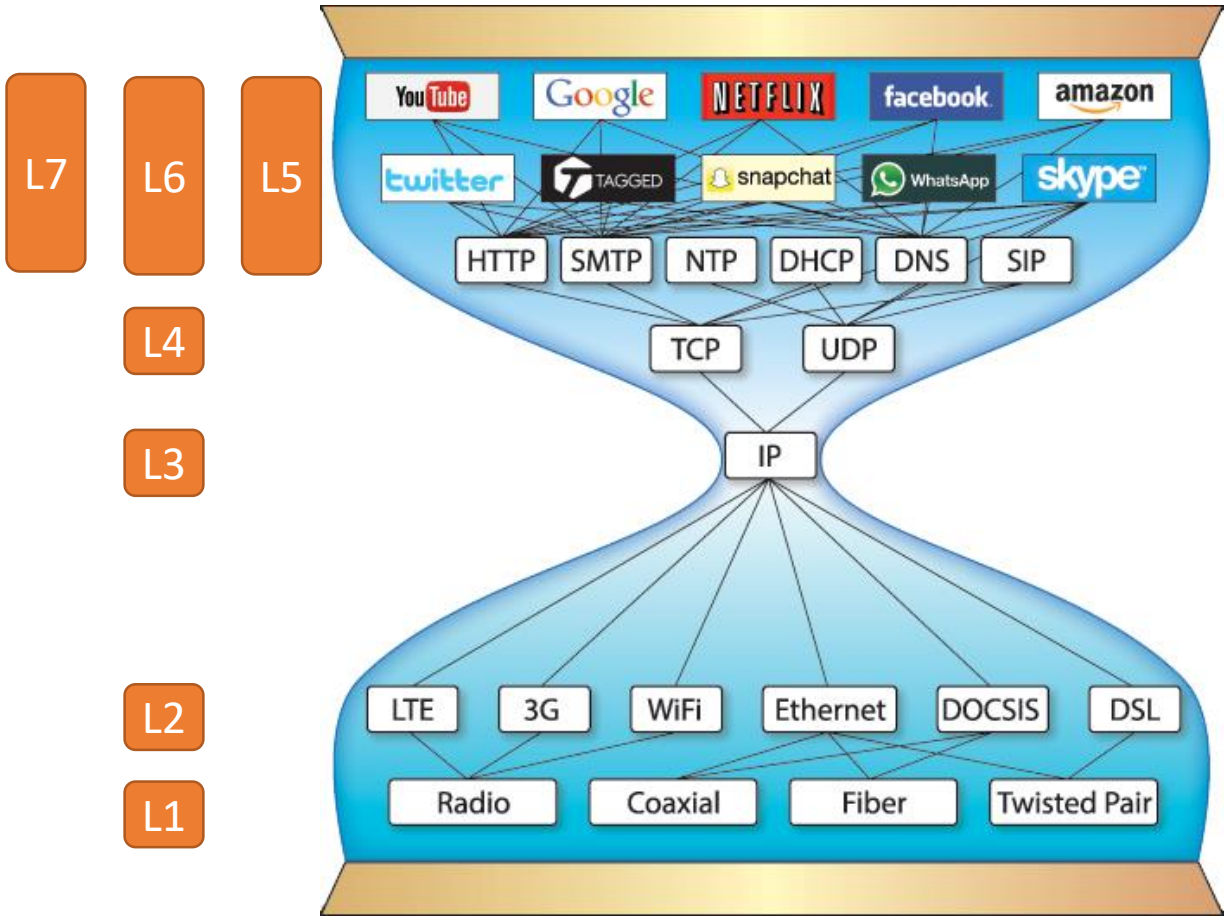
The Internet Protocol



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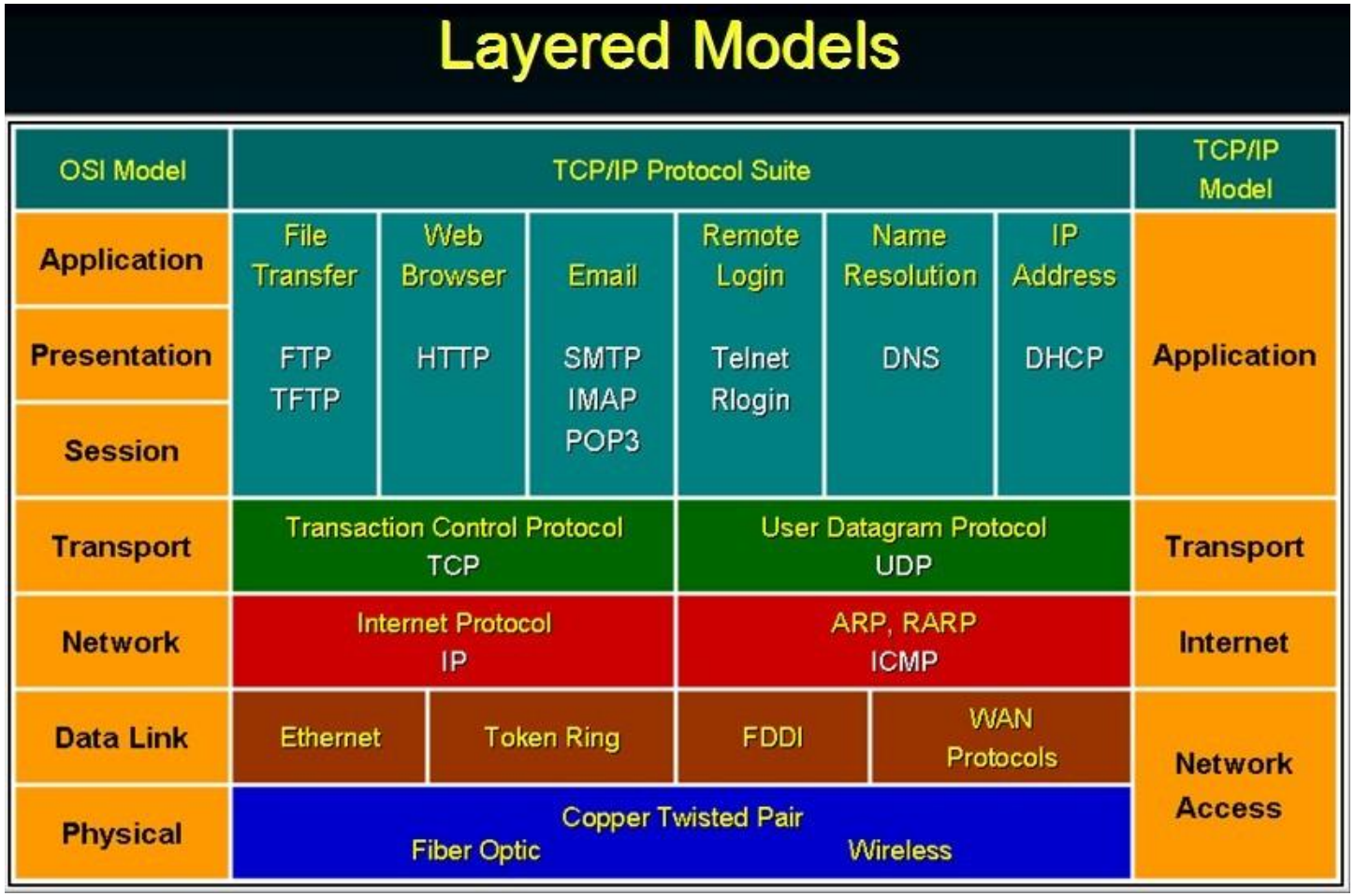
OSI Model vs. TCP/IP Model



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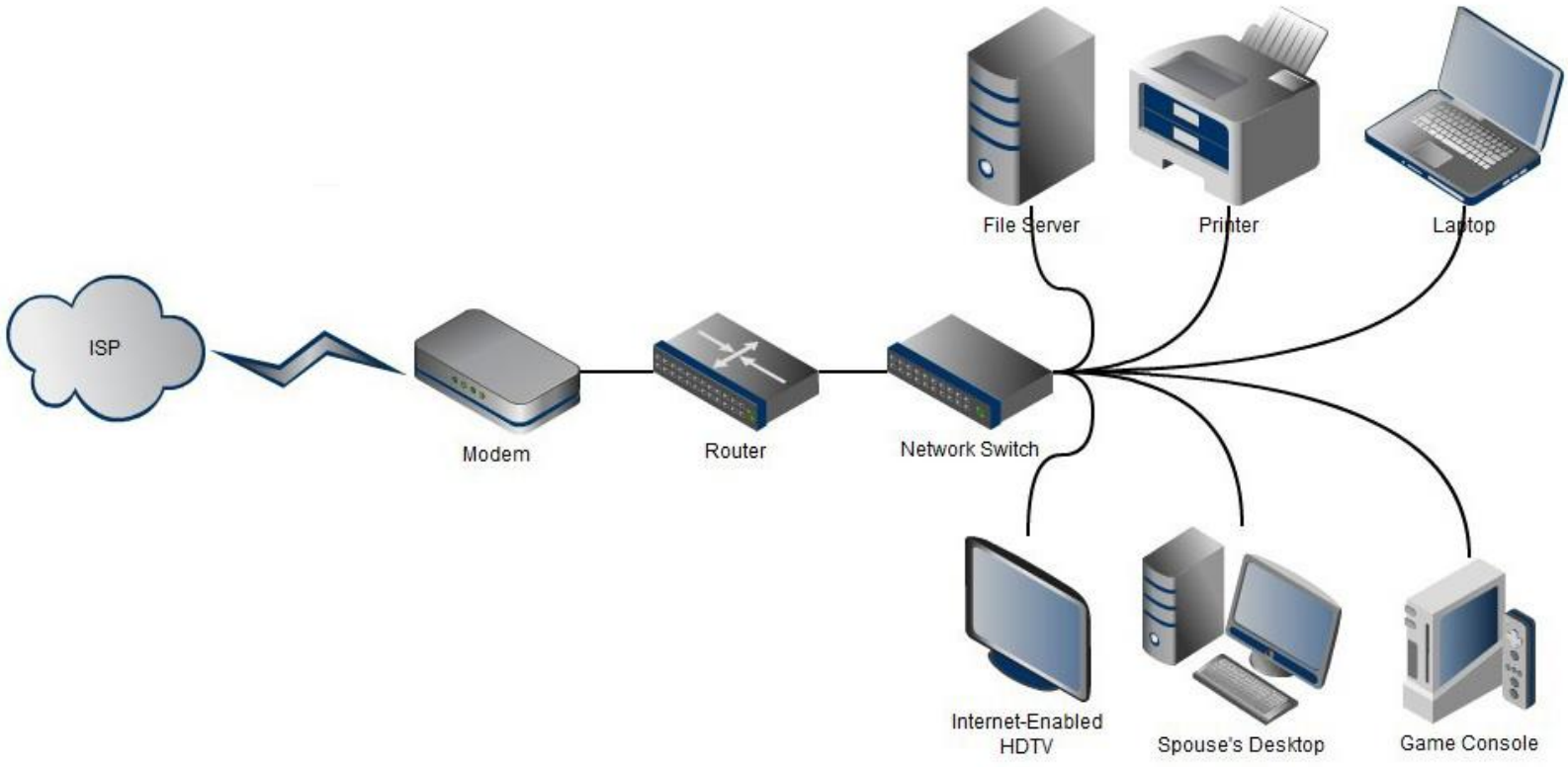
A Typical Home Network



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Routers, Switches, Hubs

Hub
Operates on **Layer 1**

Switch
Operates on **Layer 2**

Router
Operates on **Layer 3**

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Hubs, Switches, Routers

- Hubs
  - Repeat physical signals
  - Operate on Layer 1 (Physical Layer)
- Switches
  - Create networks
  - Operate on Layer 2 (Datalink Layer)
  - Switching done based on MAC addresses (80-19-34-0D-38-B5)
- Routers
  - Connect networks
  - Operate on Layer 3 (Network Layer)
  - Routing done based on IP addresses (95.0.156.2, 2001:db8:85a3:0:0:8a2e:370:7334)

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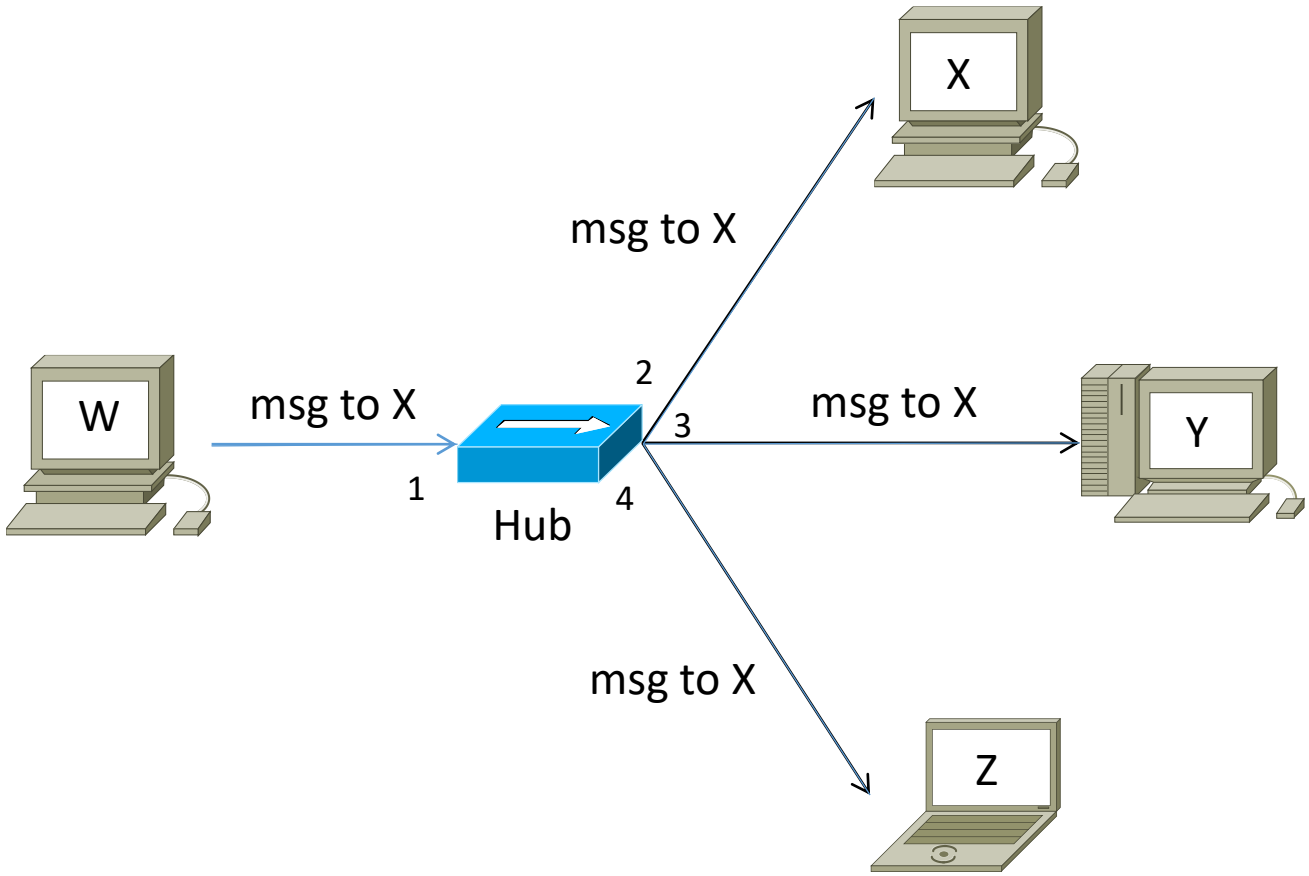
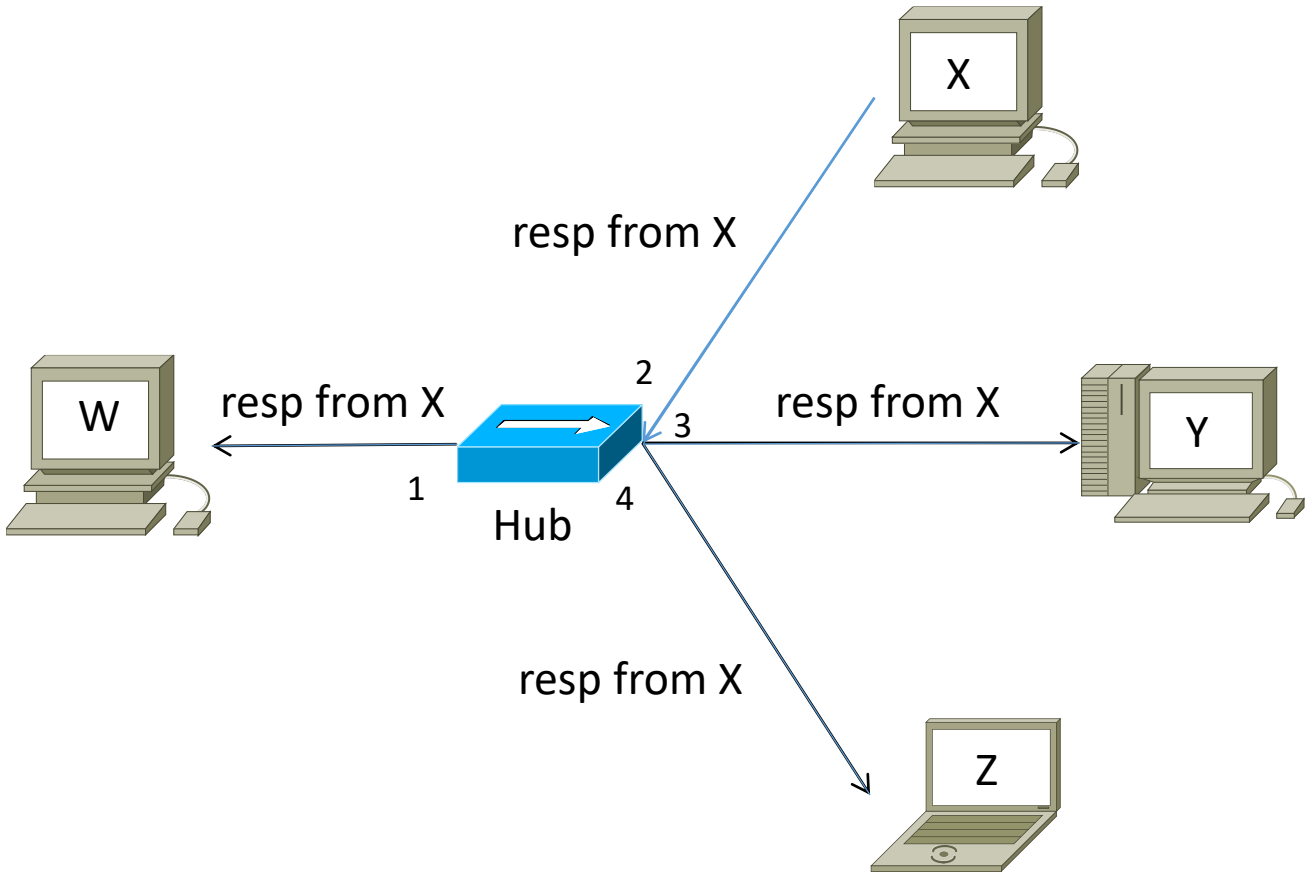
Hubs (L1)



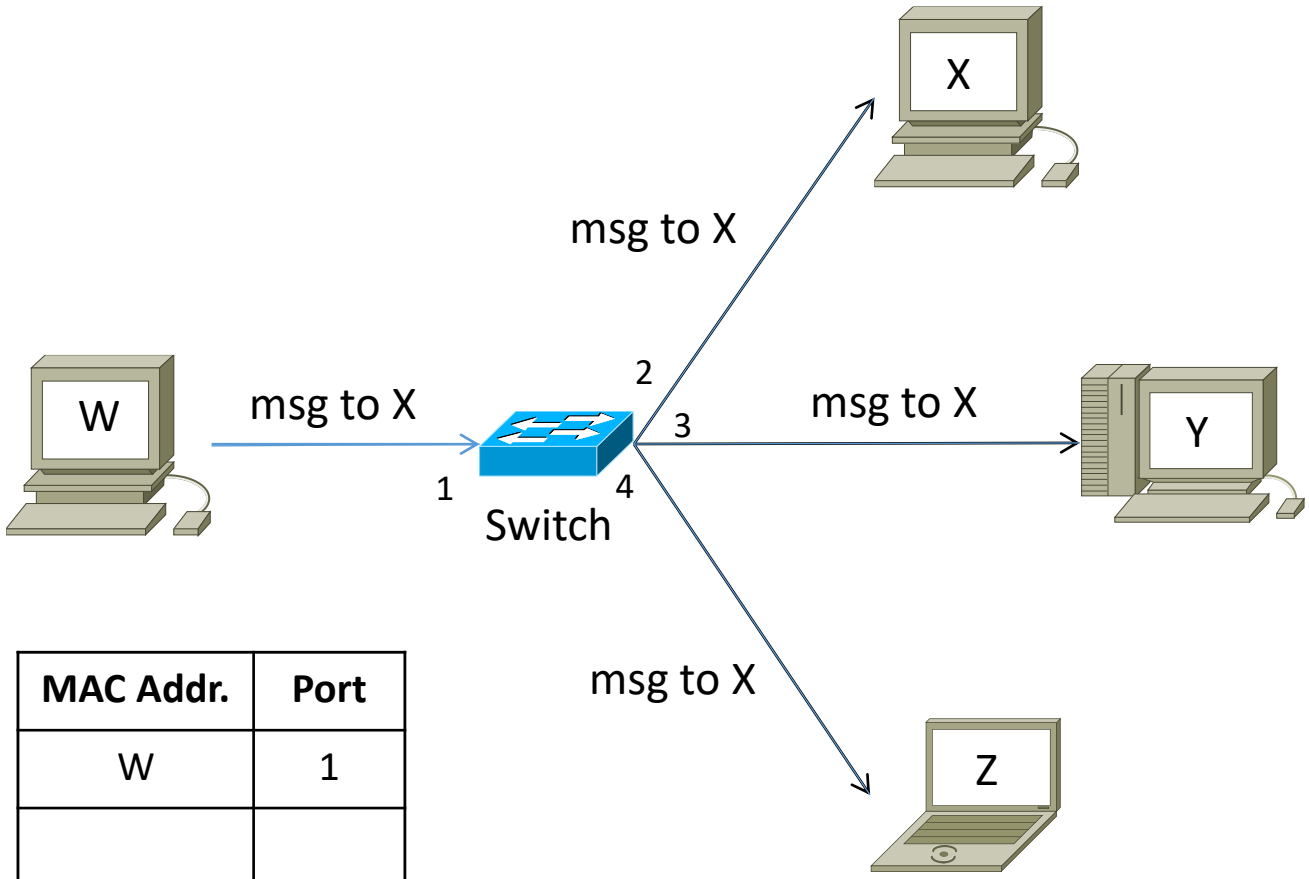
ARGELA

Hubs (L1)



ARGELA

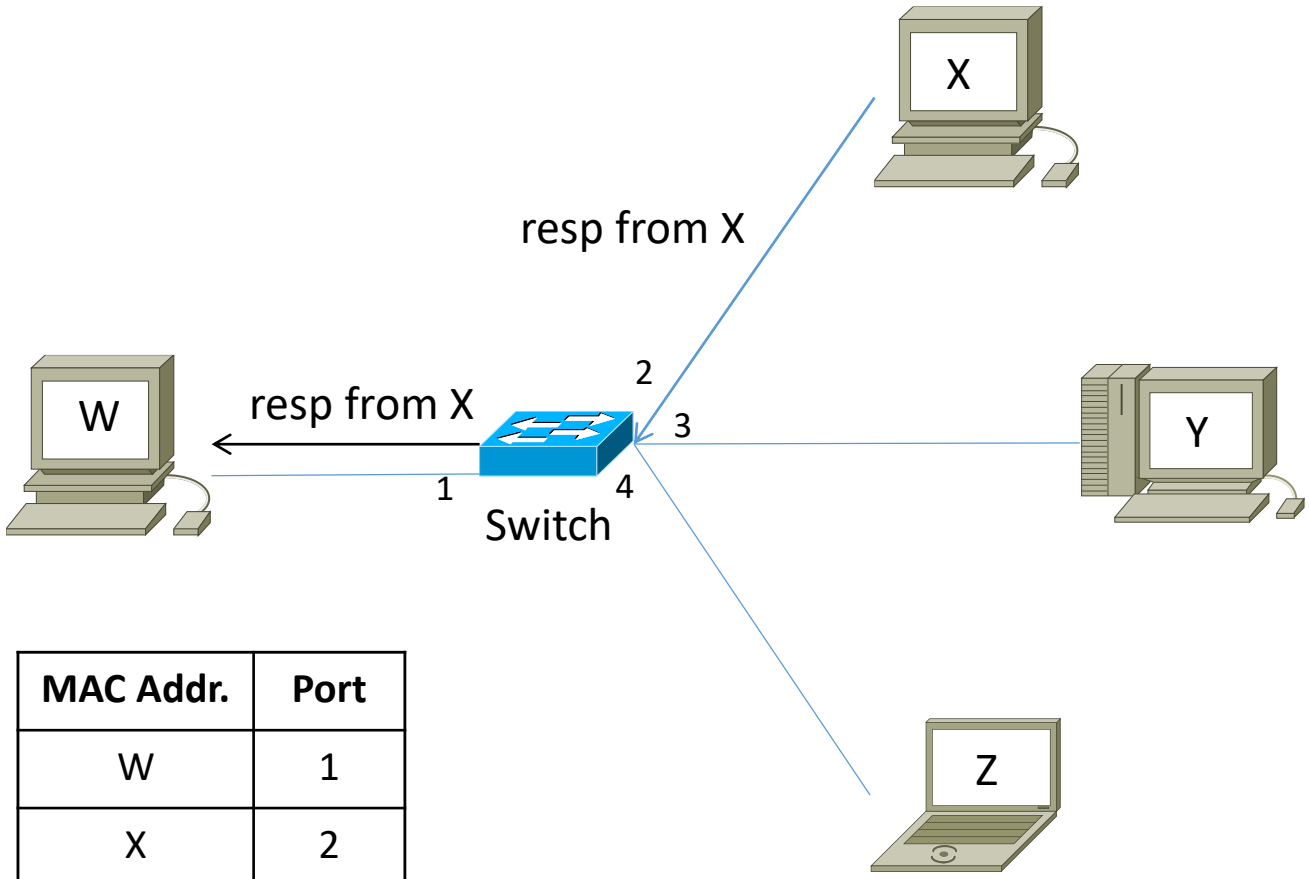
Switches (L2)



MAC Addr.	Port
W	1

ARGELA

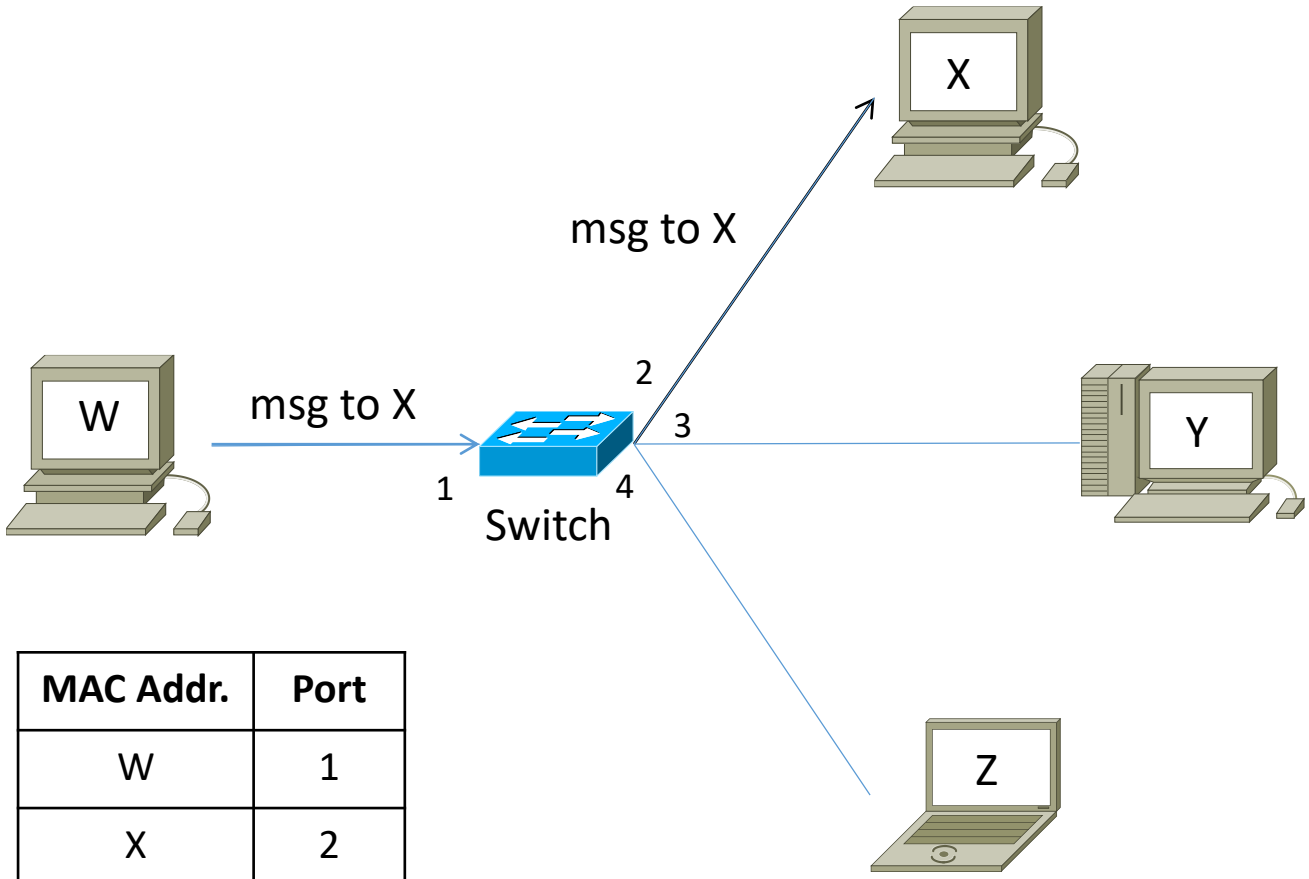
Switches (L2)



MAC Addr.	Port
W	1
X	2

ARGELA

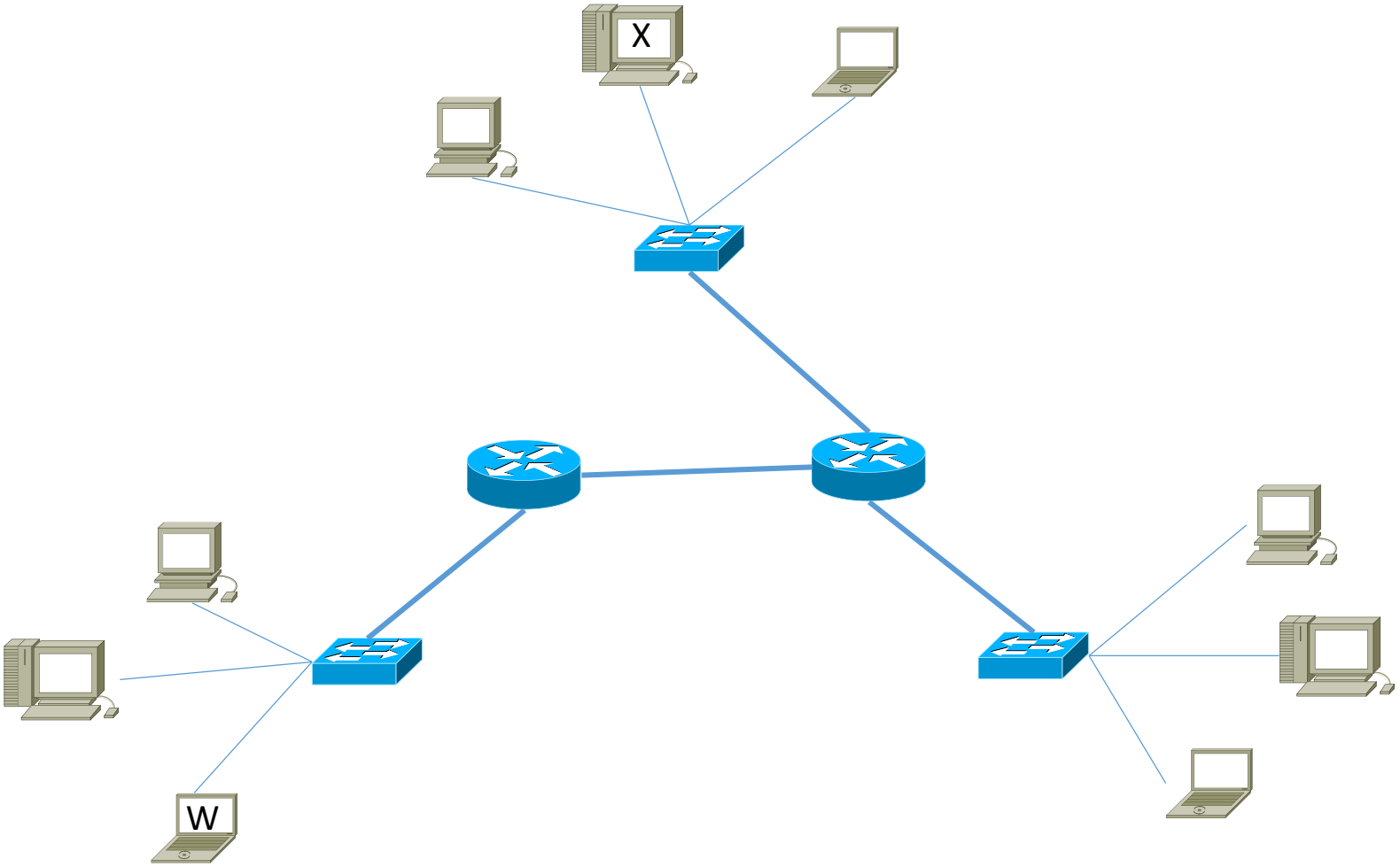
Switches (L2)



MAC Addr.	Port
W	1
X	2

ARGELA

Routers (L3)



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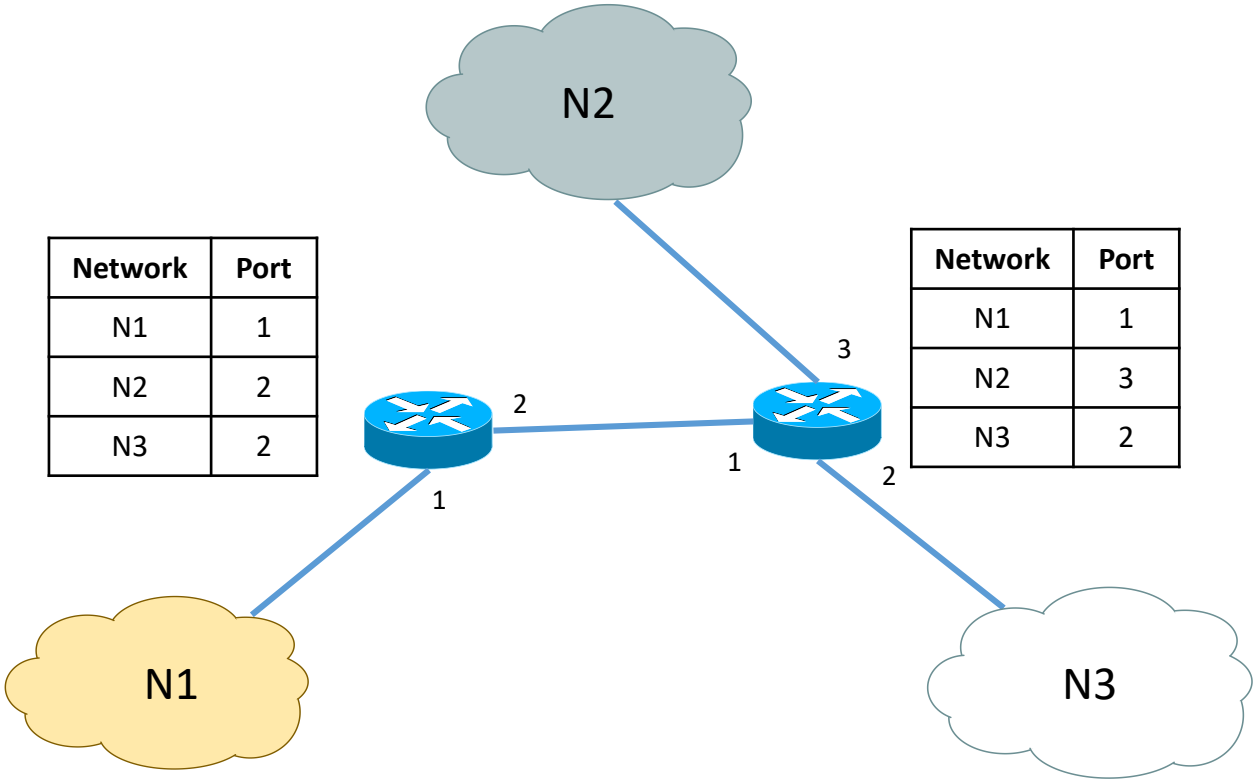
Routers (L3)

Forwarding



Network	Port
N1	1
N2	2
N3	2

Network	Port
N1	1
N2	3
N3	2

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Routers

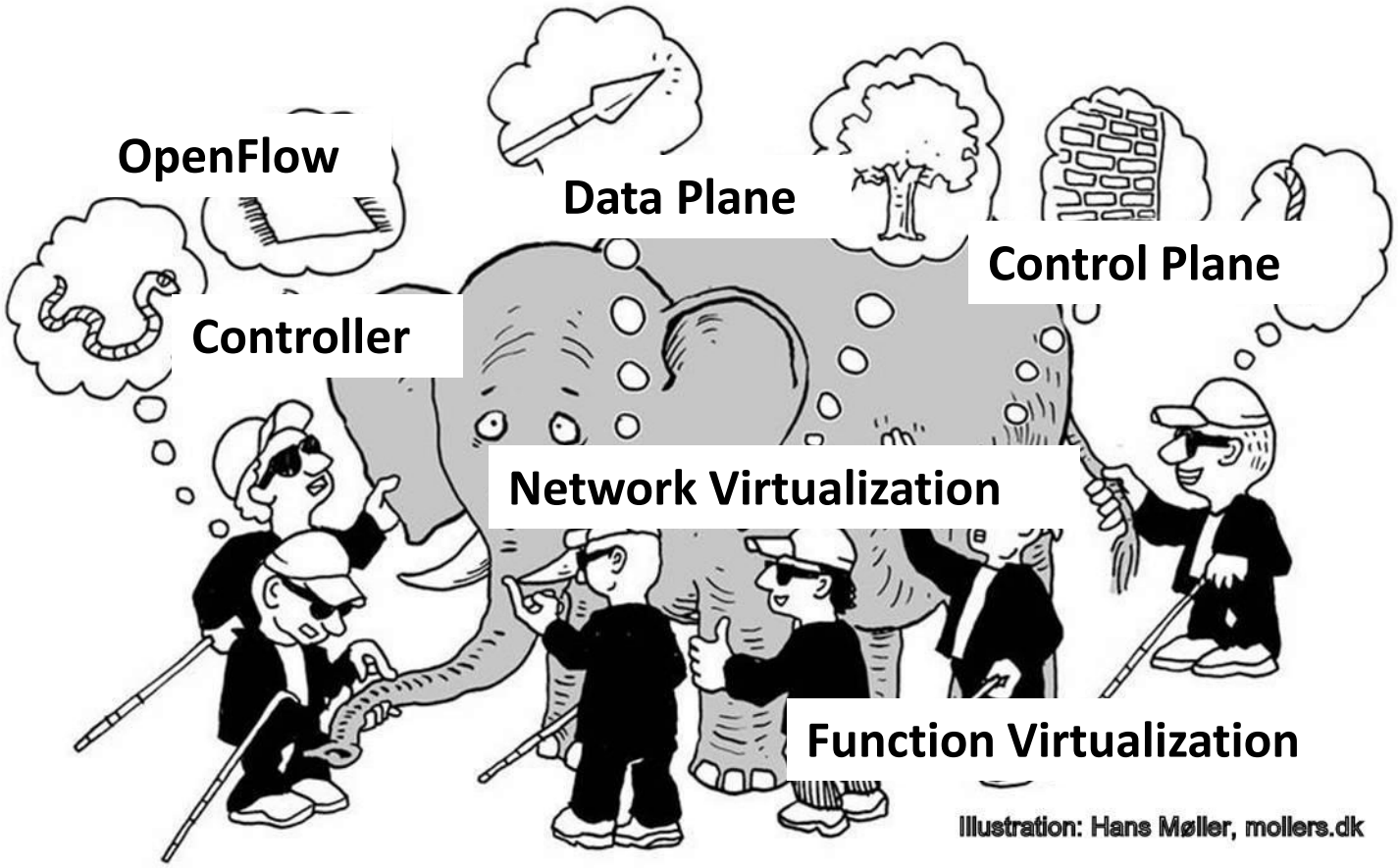
- Populating routing info
  - Learning network routes or static configuration
- Path Determination
  - Finding the best route – best match in routing table
- Forwarding
  - Switch packets between interfaces
- Encapsulation
  - Changing L2 headers

Routers – Populating Routing Info

- Static configuration
- Learning routes
  - Interior Gateway Protocol (IGP)
    - Open Shortest Path First (OSPF),
    - Routing Information Protocol (RIP)
    - Intermediate System to Intermediate System (IS-IS)
  - Exterior Gateway Protocol (EGP)
    - EGP version 3 (EGP3)
    - Border Gateway Protocol (BGP)

Software-Defined Networking (SDN)

SDN – Evolving Definition



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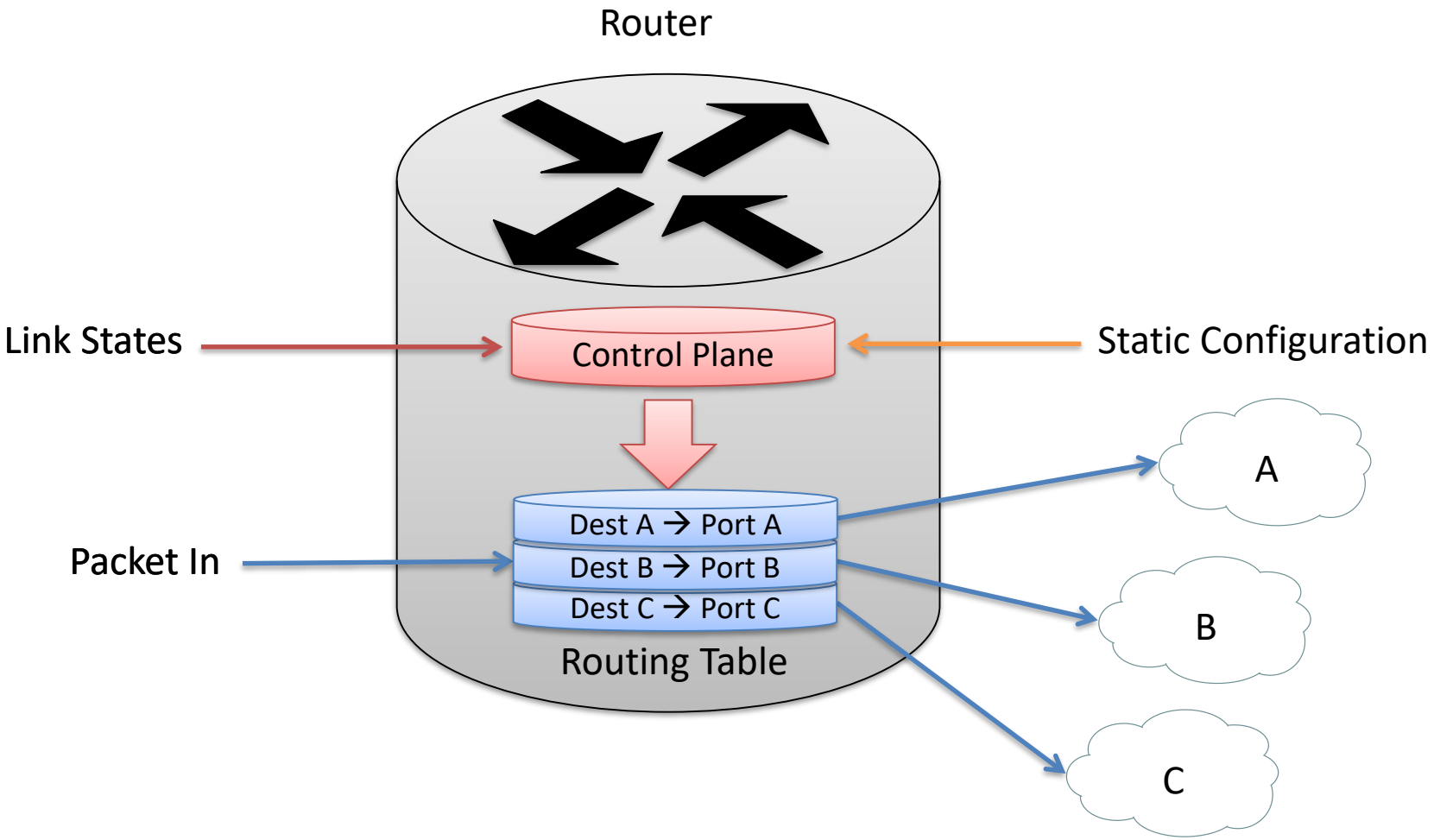
What is SDN?

ONF:

The physical separation of the network control plane from the forwarding plane, and where a control plane controls several devices.

Traditional Network



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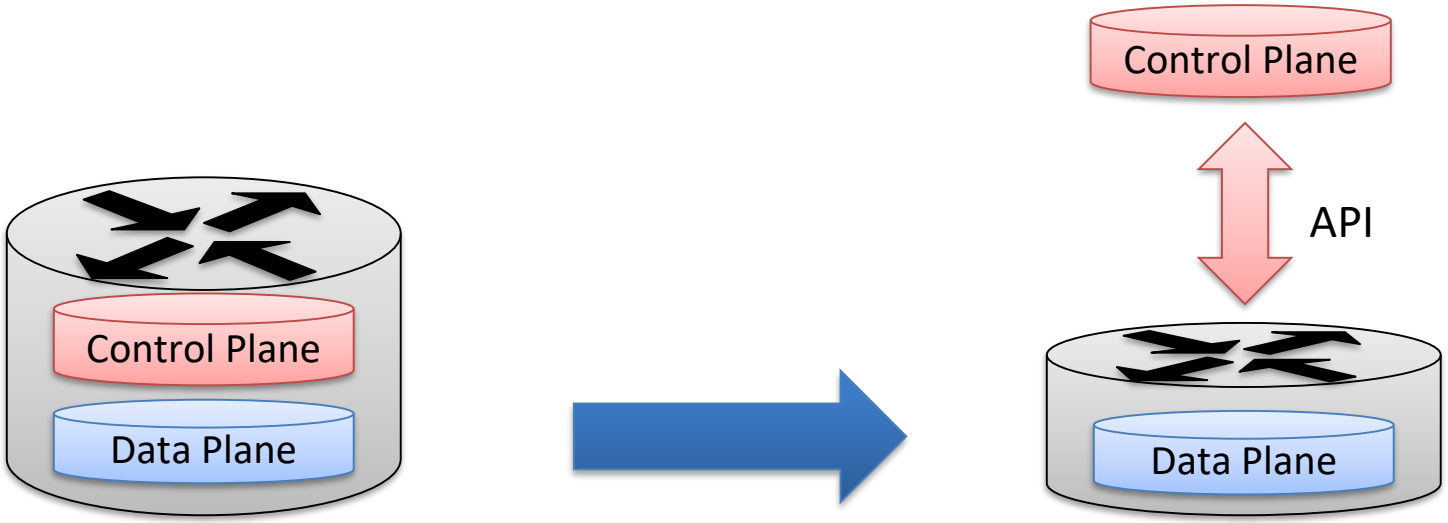
SDN Solution 1/3



1. Decouple control plane
from data plane

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SDN Solution 2/3

2. Generalize data plane

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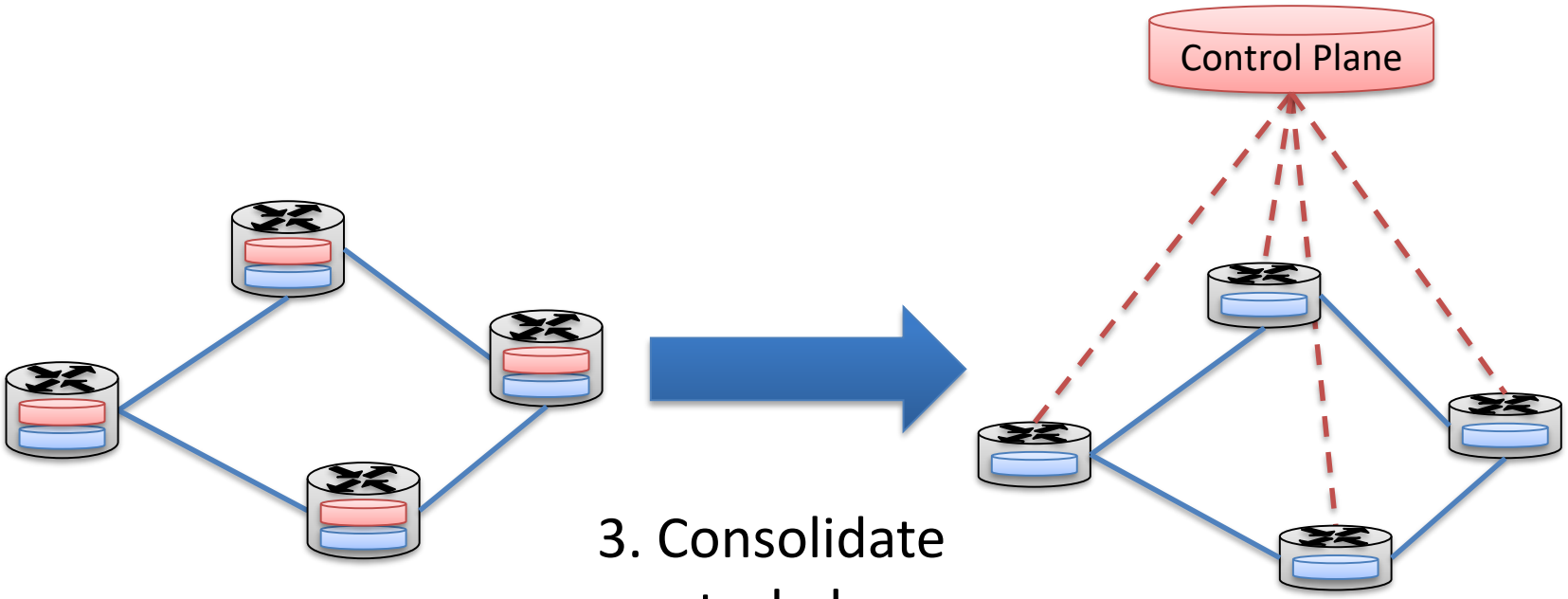
SDN Solution 3/3



3. Consolidate control plane

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Control Plane and Data Plane

Processing Plane	What is does	Where it runs	How fast these processes run	Type of processes performed
Control Plane	Decides how to handle the traffic	Switch CPU	Thousand of packets per second	Routing protocols (OSPF, IS-IS, BGP), Spanning Tree, SYSLOG, AAA, CLI, SNMP
Data Plane	Forwards traffic according to control plane decisions	Dedicated Hardware ASIC's	Millions /Billions of packets per second	Layer 2 switching, Layer 3 (IPv4 | Ipv6) switching, MPLS forwarding, VRF forwarding, QoS marking, Classification, Policing, Security ACLs

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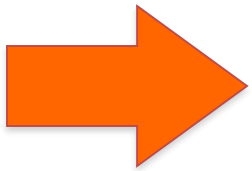
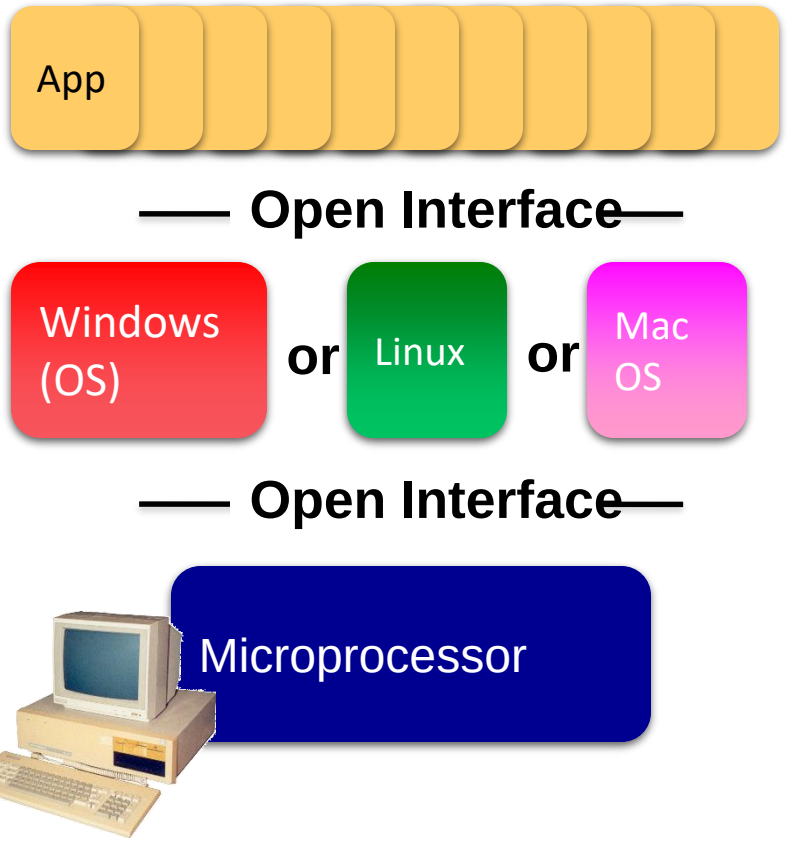
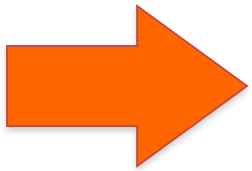
Mainframes

Vertically integrated
Closed, proprietary
Slow innovation
Small industry

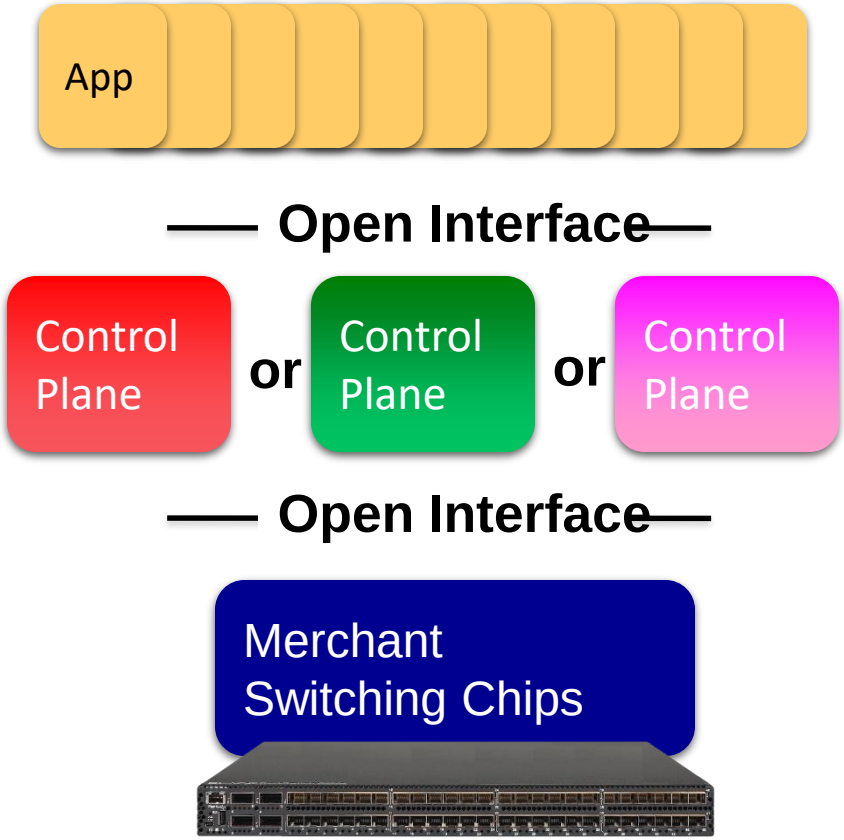






Horizontal
Open interfaces
Rapid innovation
Huge industry

Routers/Switches



Vertically integrated
Closed, proprietary
Slow innovation

Horizontal
Open interfaces
Rapid innovation

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The SDN Architecture is…

- Directly programmable
  - Network control is decoupled from forwarding
- Agile
  - Network-wide traffic, dynamically adjusted to meet changing needs
- Centrally managed
  - Global view of the network
- Programmatically configured
  - Automation via SDN apps that do not depend on proprietary software
- Open standards-based and vendor-neutral

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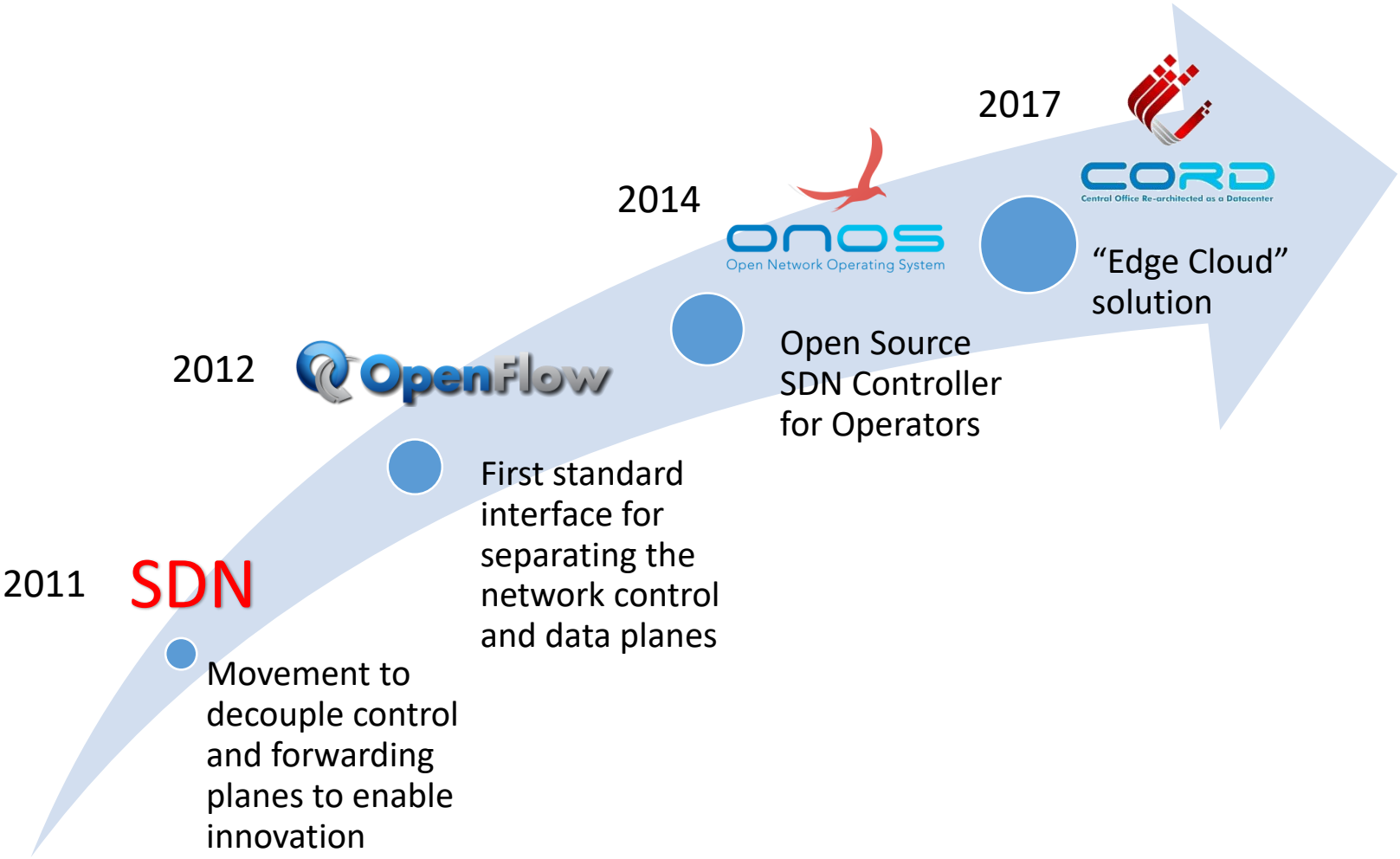
SDN Revolution by ONF



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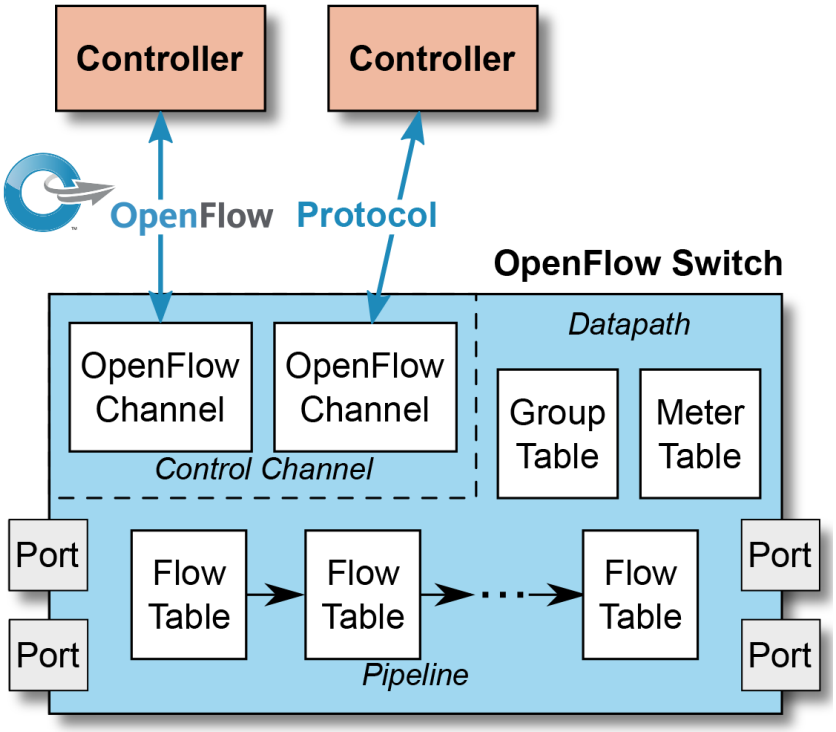
Controller
Controller
OpenFlow
Protocol
OpenFlow Switch
Datapath
OpenFlow Channel
OpenFlow Channel
Group Table
Meter Table
Control Channel
Port
Port
Flow Table
Flow Table
Flow Table
Port
Port
Pipeline


OpenFlow

OpenFlow

OpenFlow is an open communications protocol that gives access to the data plane of a networking switch or router over the network.

Latest version: OpenFlow Switch Spec. v1.5.1, Mar 26, 2015

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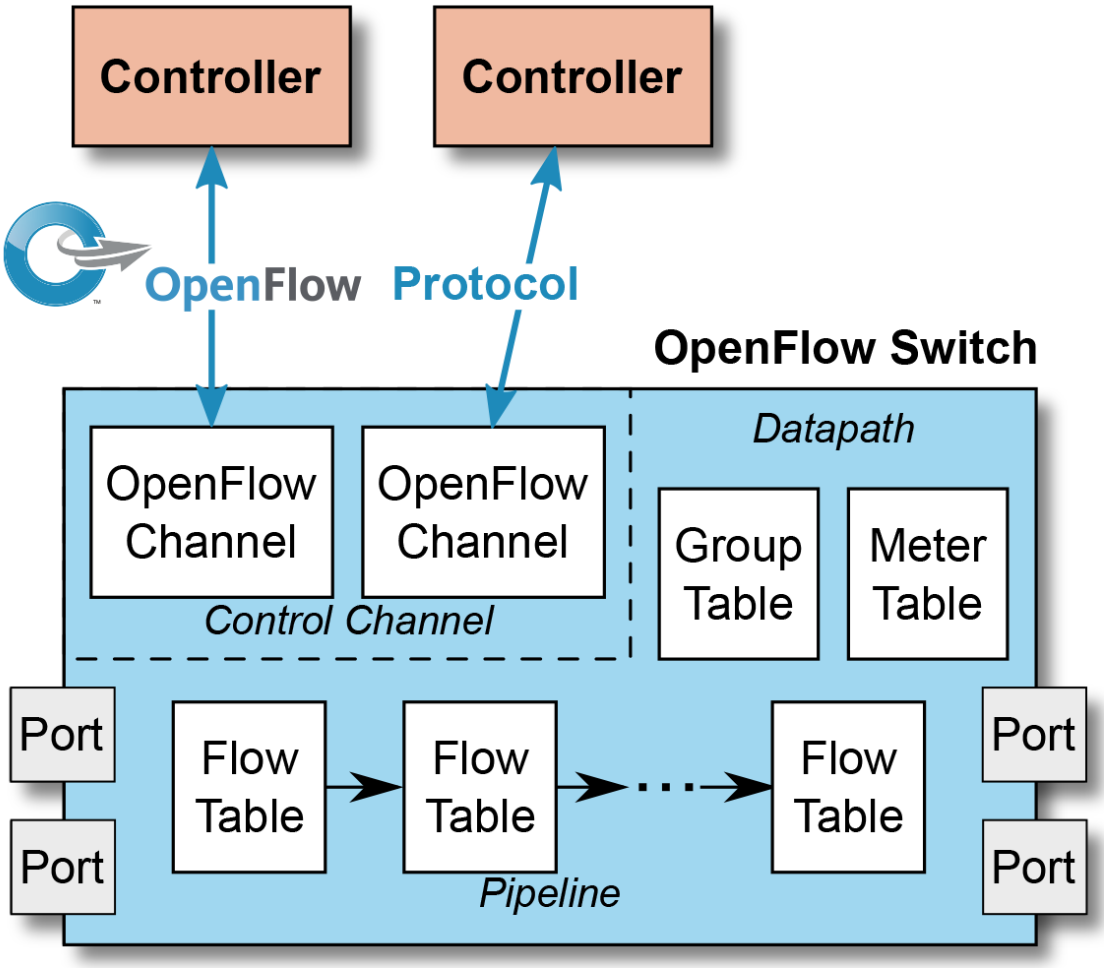
OpenFlow Switch Spec. v1.5.1



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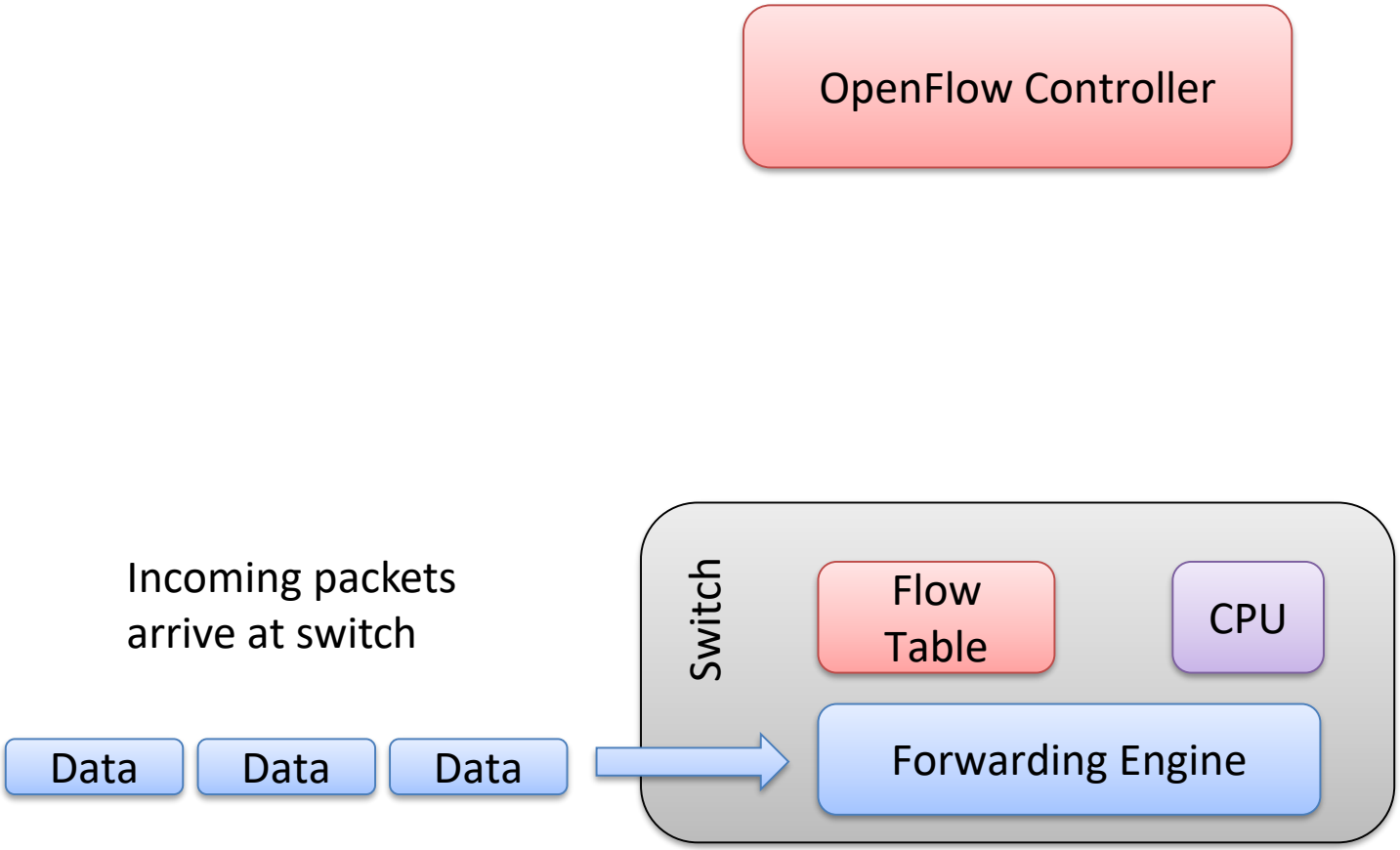
OpenFlow Switch Spec. v1.5.1

- One or more flow tables
- A group table
- One or more OpenFlow channels
  - Main connections over TCP or TLS
  - Auxiliary connections over TLS, DTLS, TCP or UDP
- Match fields, instructions, actions, …

OpenFlow: How does it work? 1/6



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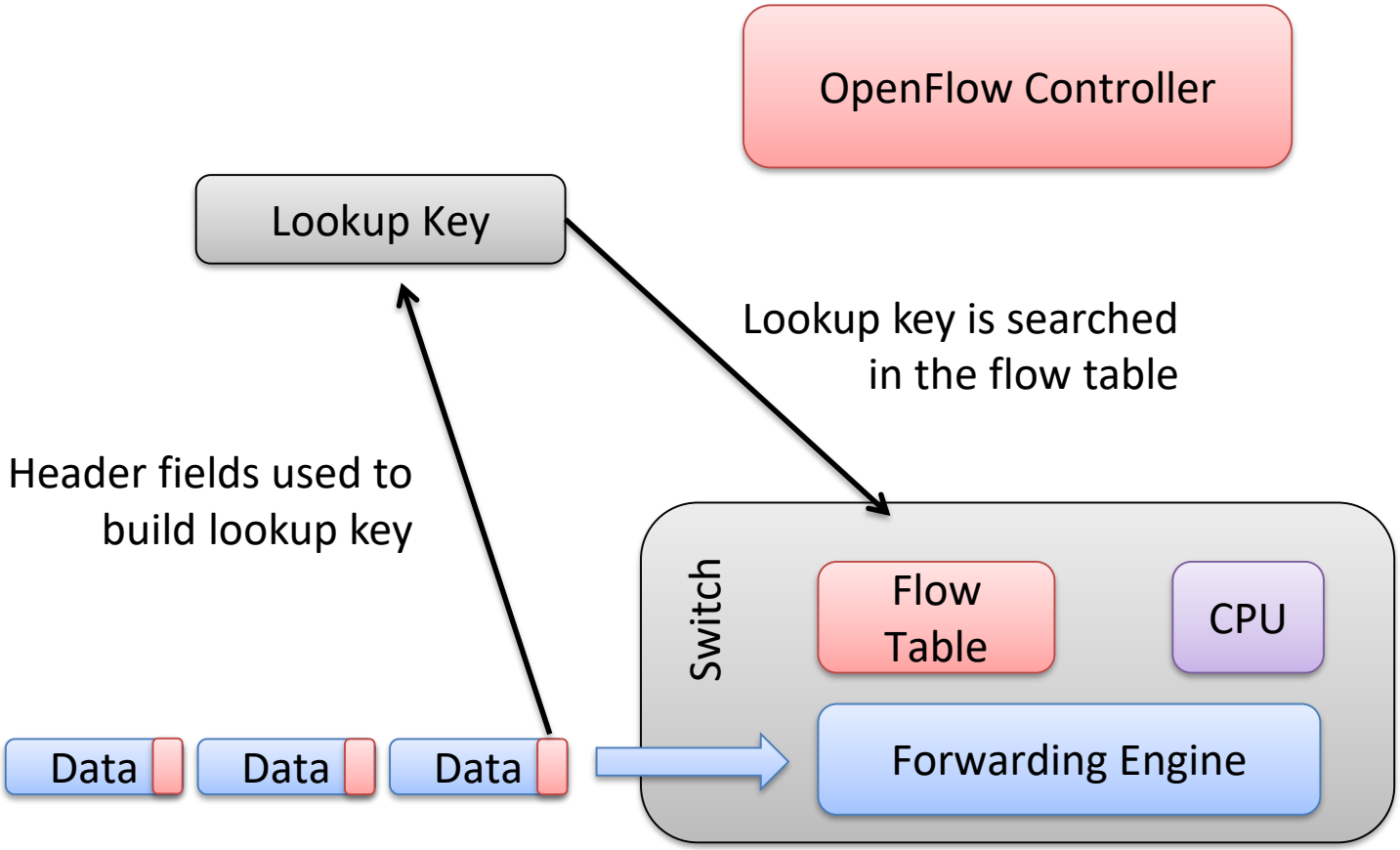
OpenFlow: How does it work? 2/6



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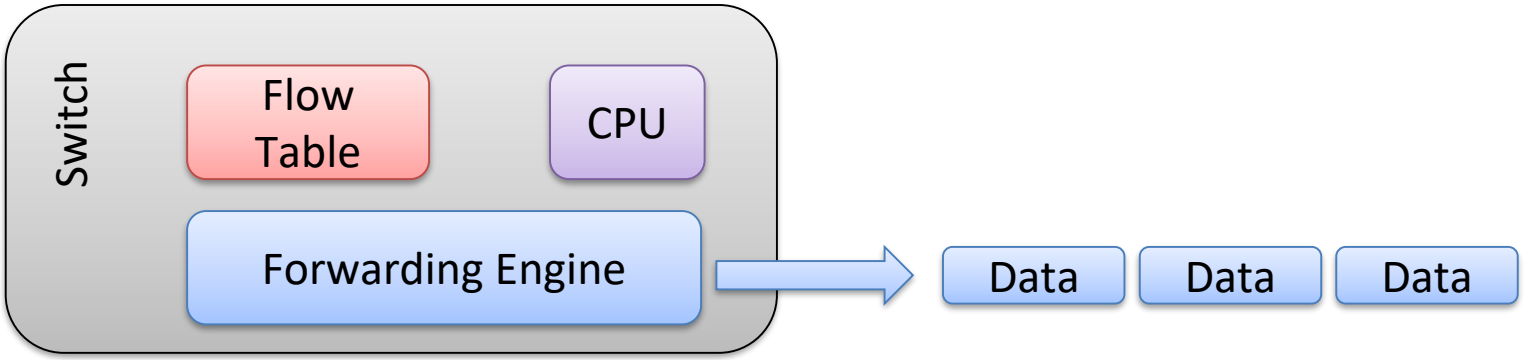
OpenFlow: How does it work? 3/6

If found in the flow table, corresponding action is performed by switch:
- Forward packets out of port x



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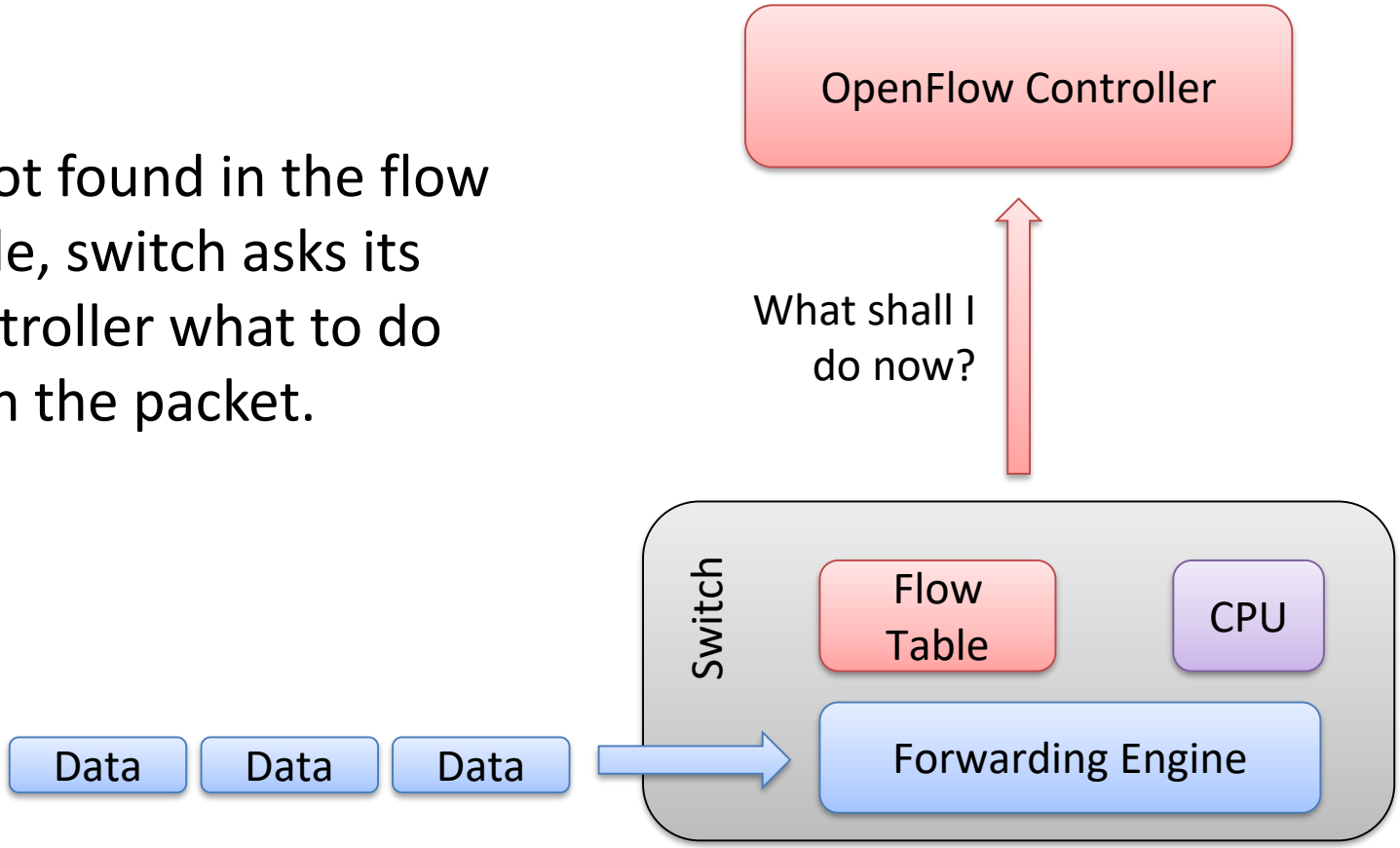
OpenFlow: How does it work? 4/6

If not found in the flow table, switch asks its controller what to do with the packet.



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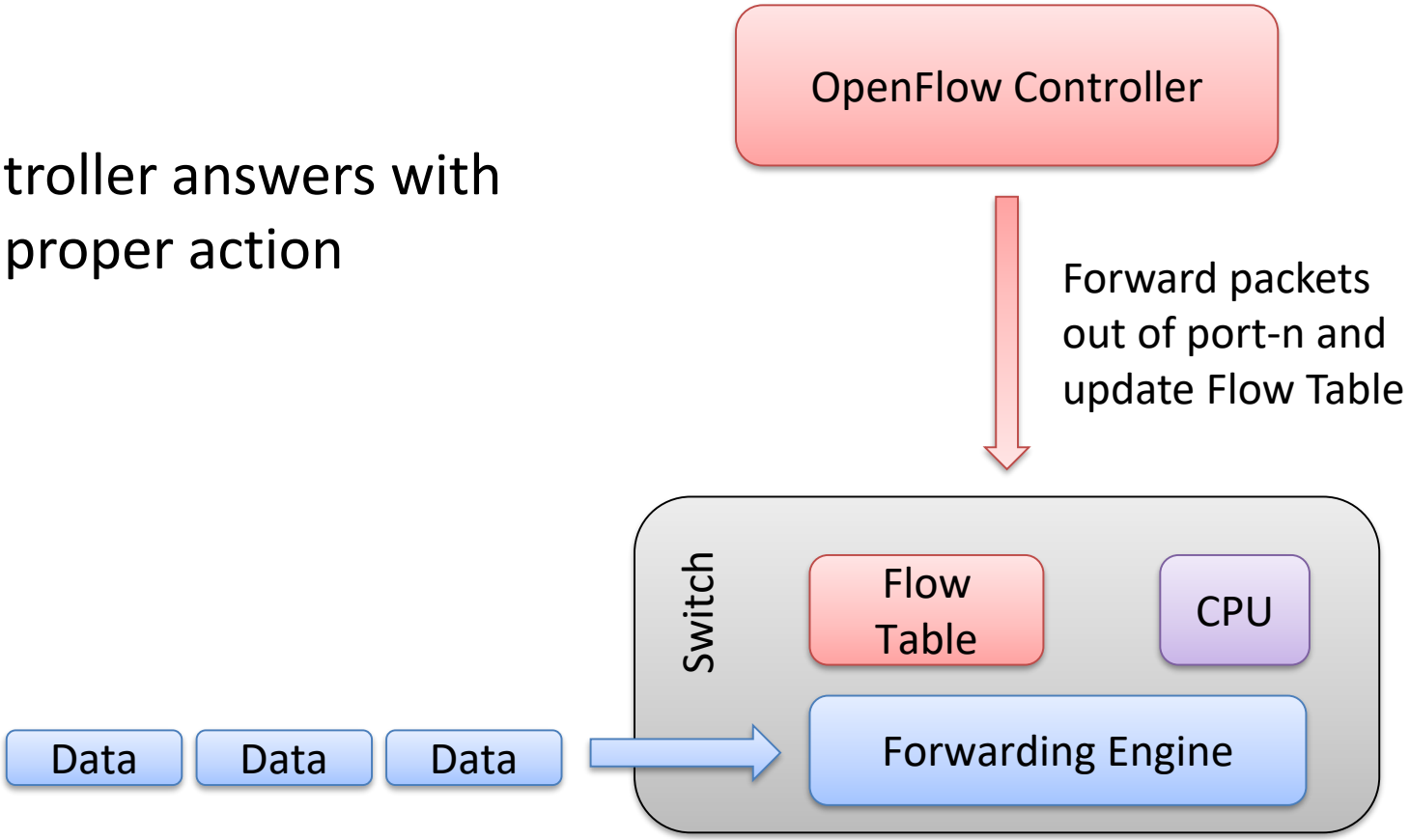
OpenFlow: How does it work? 5/6

Controller answers with the proper action



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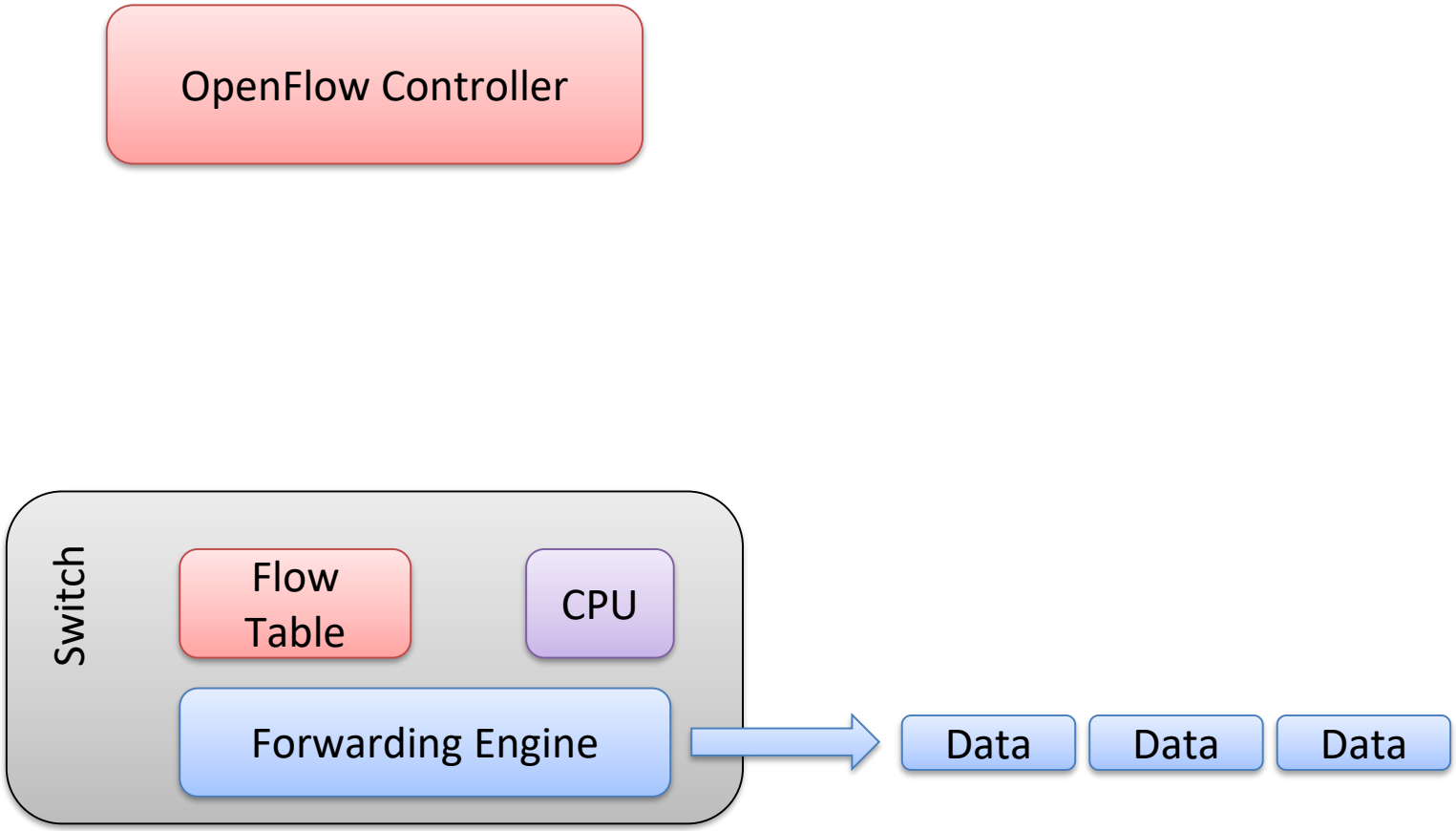
OpenFlow: How does it work? 6/6



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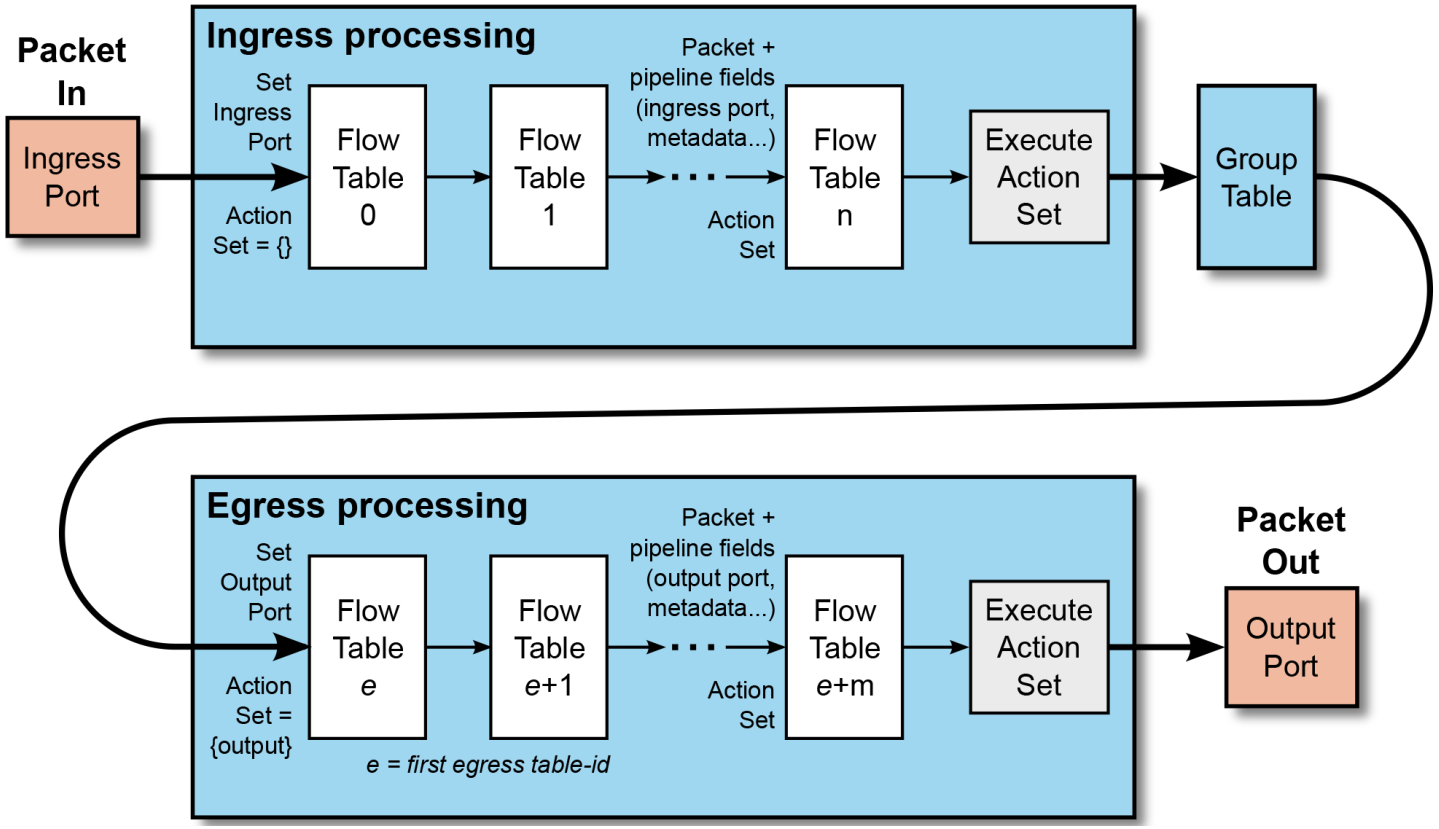
OpenFlow Packet Proc. Pipeline*



* OpenFlow Switch Spec. v1.5.1

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Flow Table Entry

Match Fields	Priority	Counters	Instructions	Timeouts	Cookie	Flags

- **Match Fields**: Consist of ingress port and packet headers
- **Priority**: Matching precedence of the flow entry
- **Counters**: Updated when packets are matched
- **Instructions**: To modify the action set or pipeline processing
- **Timeouts**: Maximum amount of time or idle time before flow rule expires

Required Match Fields for Ethernet

Ingress port
Egress port from action set
Ethernet dst/src address
Ethernet type
IPv4 or IPv6 protocol number
IPv4 src/dst address
IPv6 src/dst address
TCP src/dst port
UDP src/dst port

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Instructions

Apply-Actions *action(s)*	Optional
Clear-Actions	Required
Write-Actions *action(s)*	Required
Write-Metadata *metadata/mask*	Optional
Stat-Trigger *stat-thresholds*	Optional
Goto-Table *next-table-id*	Required

Actions

Output *port-no*	Required
Group *group-id*	Required
Drop	Required
Set-Queue *queue-id*	Optional
Meter *meter-id*	Optional
Push-Tag/Pop-Tag *ethertype*	Optional
Set-Field *field type value*	Optional
Copy-Field *src-field-type dst-field-type*	Optional
Change-TTL *ttl*	Optional

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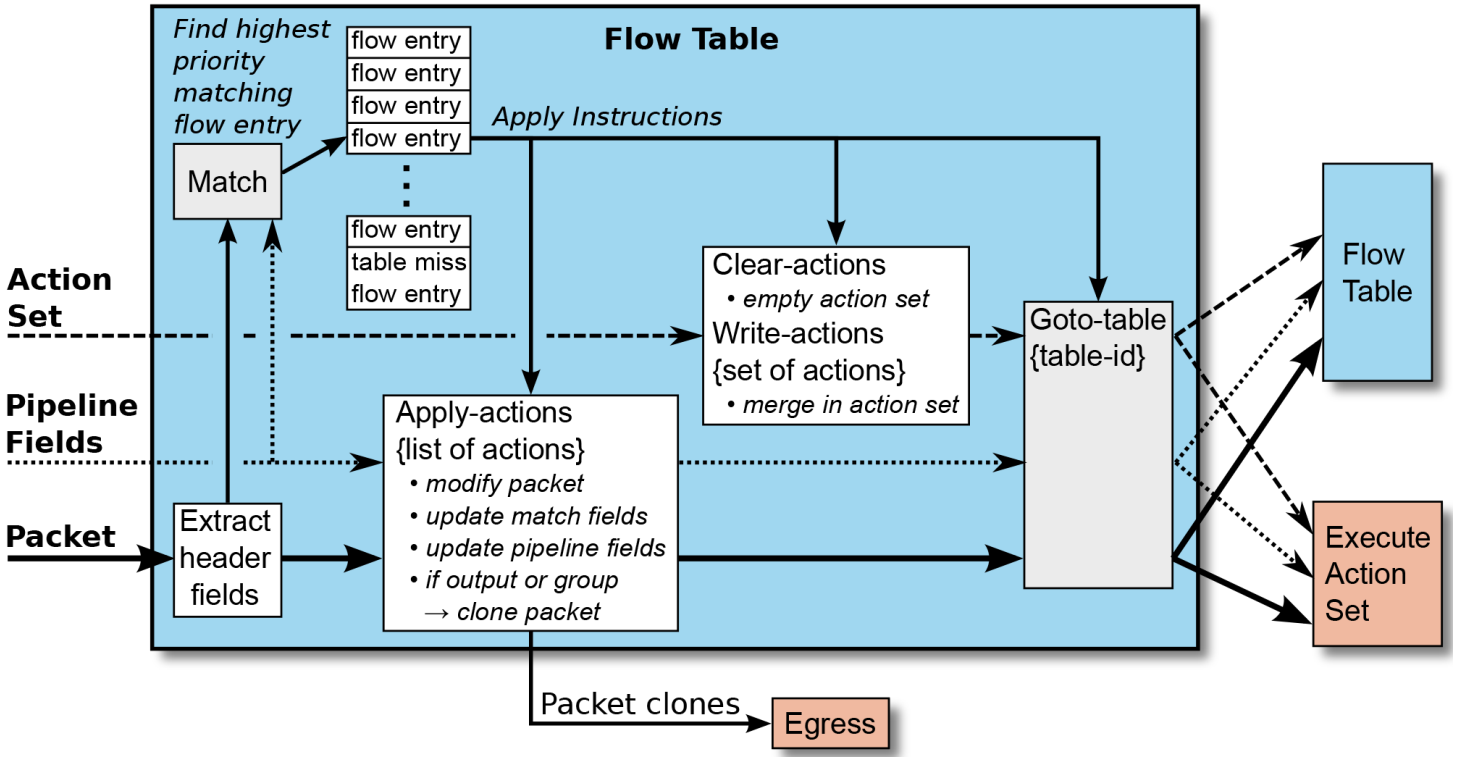
Flow Table Matching and Execution*



* OpenFlow Switch Spec. v1.5.1

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Flow Table 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	Action
*	*	*	*	*	*	*	*	*	22	drop

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Flow Table 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

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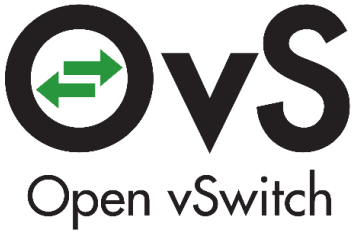
Open Source Projects

Mininet



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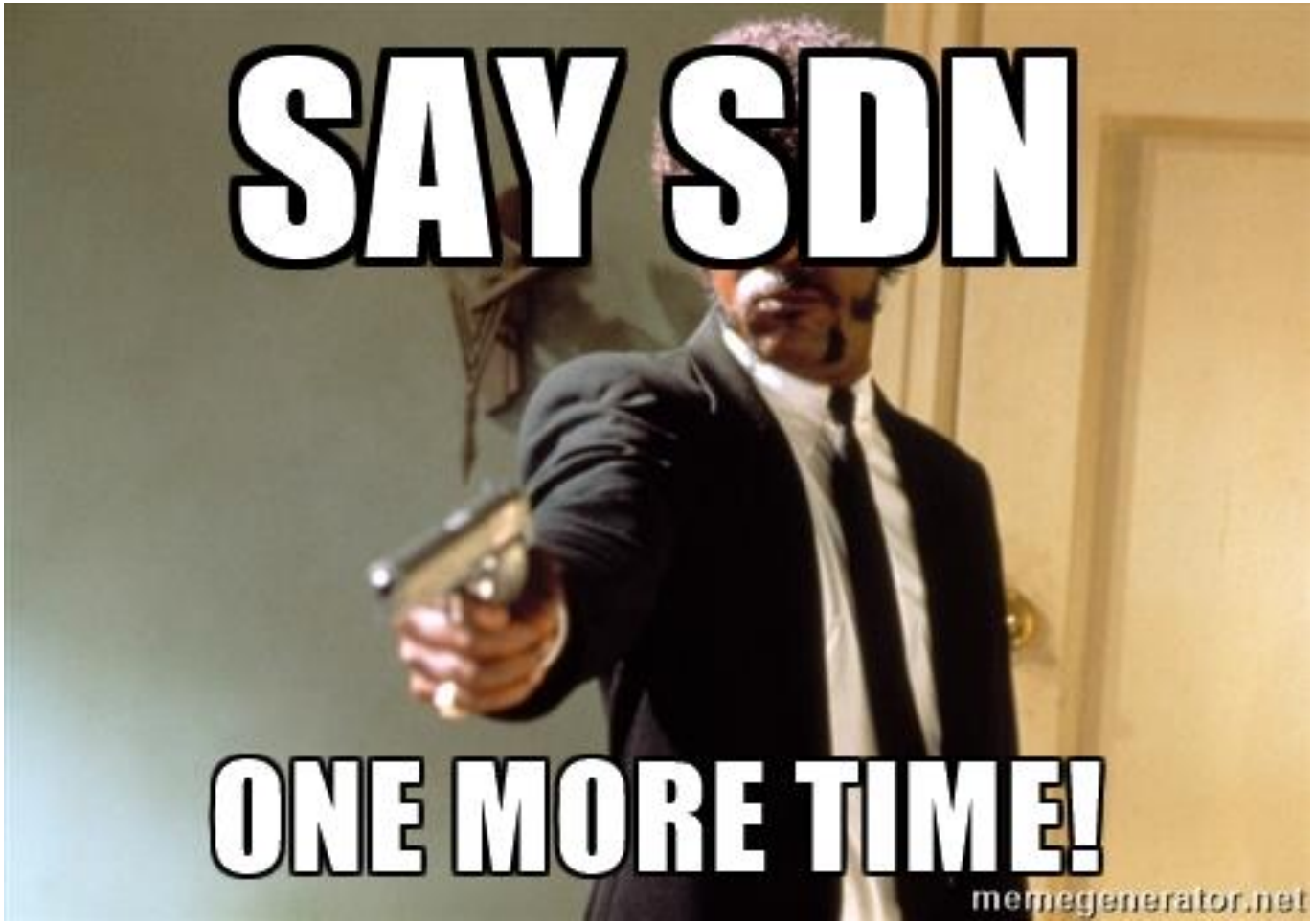
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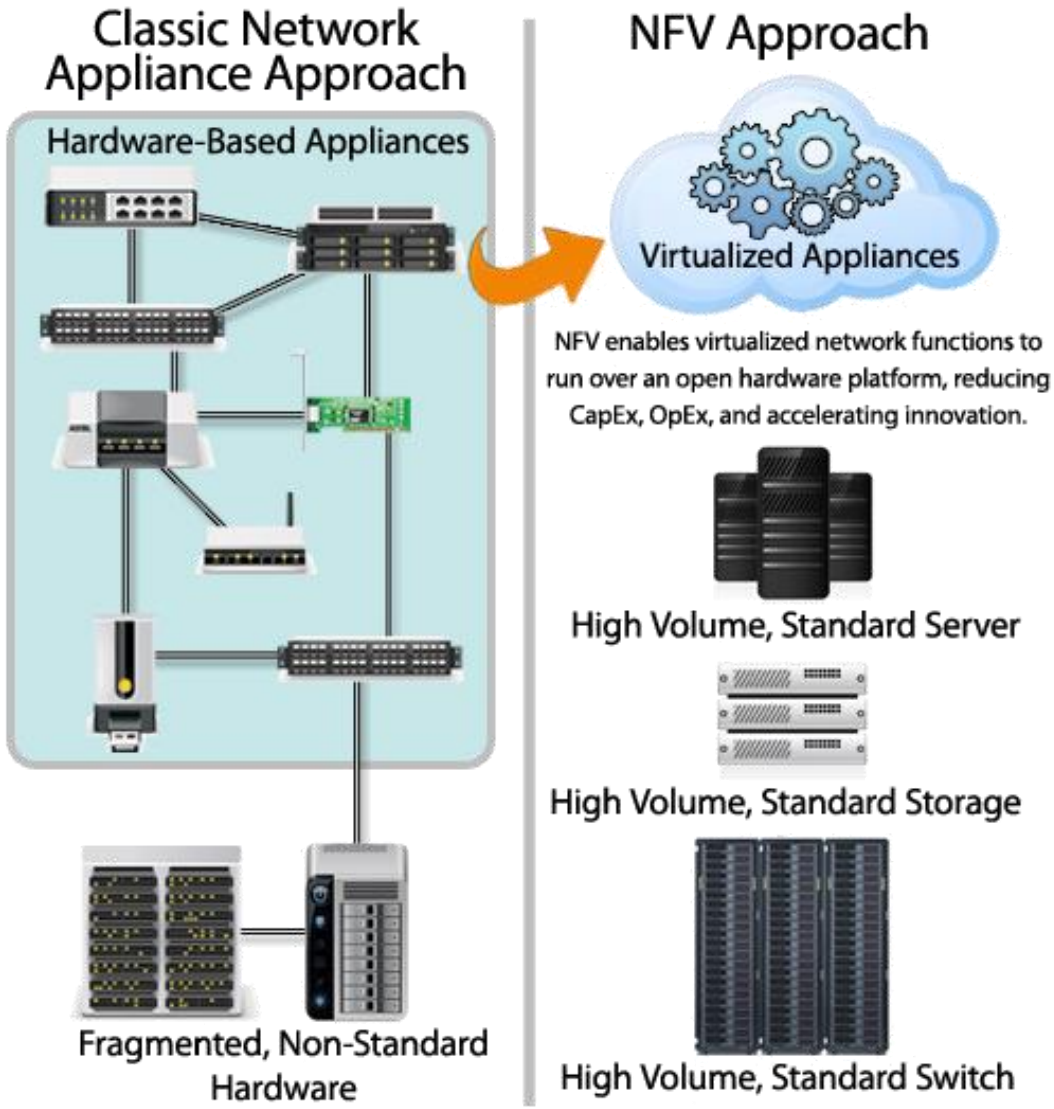
Network Function Virtualization

NFV

- Driven by ETSI NFV group, formed by service providers, to solve the following problems:
  - Networks populated with increasing variety of proprietary hardware
  - Launching a service means adding another propriety hardware, which costs time/money and increases complexity


Classic Network Appliance Approach
Hardware-Based Appliances
Fragmented, Non-Standard Hardware
NFV Approach
Virtualized Appliances
NFV enables virtualized network functions to run over an open hardware platform, reducing CapEx, OpEx, and accelerating innovation.
High Volume, Standard Server
High Volume, Standard Storage
High Volume, Standard Switch

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NFV

- Aims to implement network functions in software
  - that can run in standard servers
  - that can be moved within the network as required
  - without needing proprietary hardware

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