Computer Networks

Lecture on

Software Defined Networking

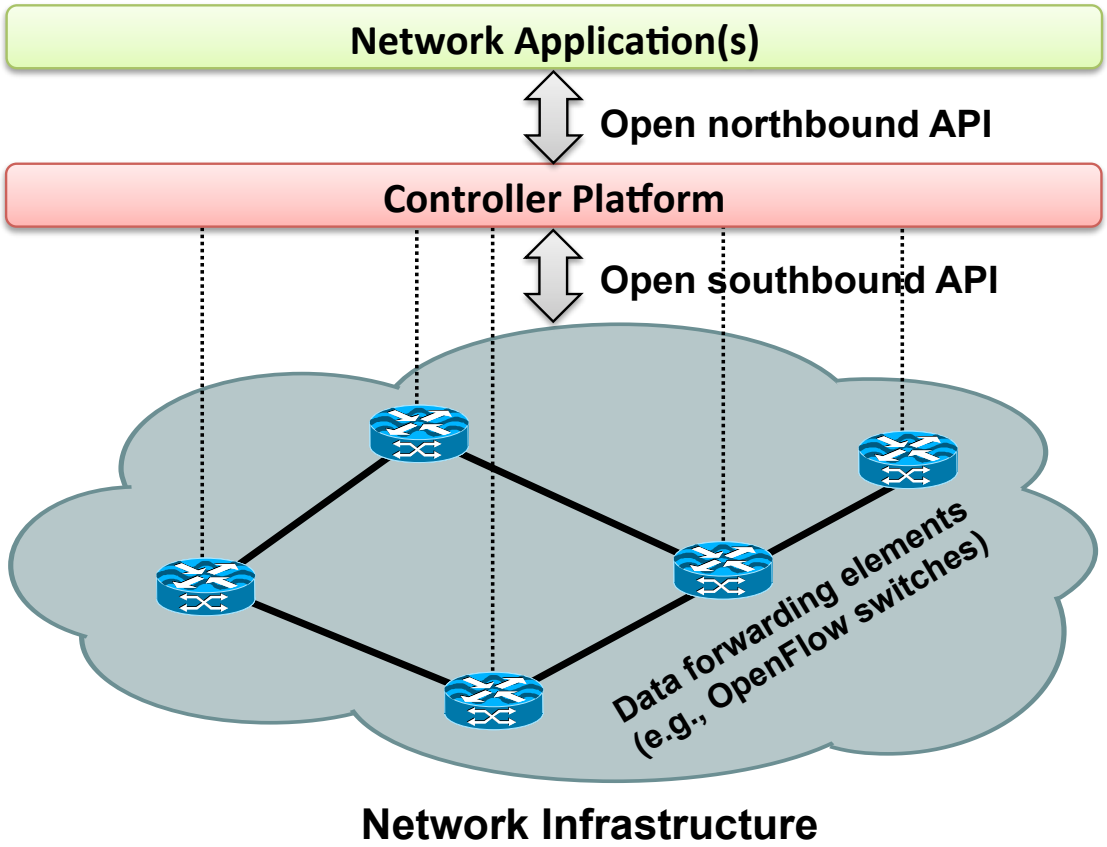
Plan of This Lecture

- Software Defined Networking paradigm
- OpenFlow switch & protocol
- Network Functions Virtualisation

What Is SDN?

The SDN networking paradigm

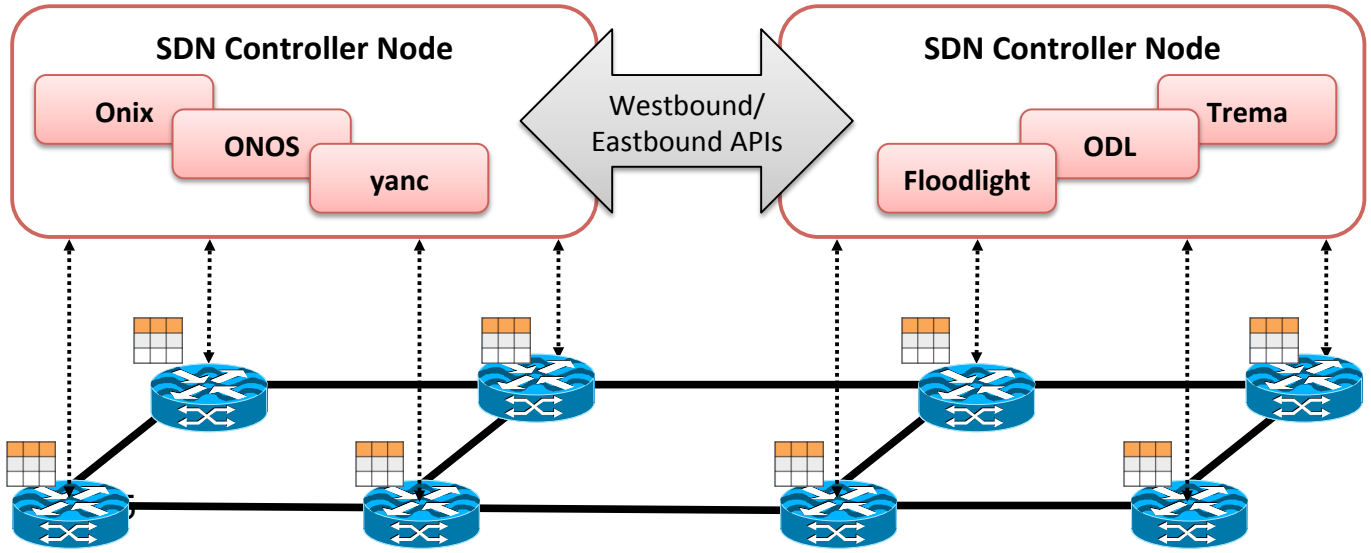
- Separate the network control plane from the data forwarding plane
- User applications have a centralized view of the states of distributed elements
  – the centralisation can be only logical



Routing Information Base
---------- Control Plane ----------
Forwarding Table
---------- Data Plane ----------

The separation of planes

- Implementation practice in many IP routers
- Data plane can be made in hardware



SDN switch

- Can be as simple as possible ⇒ inexpensive
- Enabled on a standard switch – then we call it a hybrid switch

Interface to the Routing System Framework (i2rs) - it is not an SDN approach

SDN Advantages

- Faster provisioning of network access and services
- Possibility of cooperation between cloud applications and network control applications
- Better load balancing
- Improved security
- Possibility of automatic energy savings
- Lower investment and operational costs for network owners
- Enabler of networking innovations

SDN Applications

- Internal networks of big data centres
  - virtual patch panel
  - virtual firewall
  - load balancing of physical servers and paths between them
- Infrastructure for cloud computing
  - infrastructure as a service
  - hosting of virtual servers
  - load balancing of paths to data repositories
- Campus networks, to better support
  - big variance of computation services
  - high mobility of users
- Traffic engineering
  - calendaring for: remote backups, content synchronization, virtual server migration
  - content providing networks

SDN History

Separation of data & control planes inside a switch

- First projects mid 90's
- Forwarding and Control Element Separation (ForCES) Framework, RFC 3746 2004
  - Defined interface between forwarding & control elements

Remote controller

- Martìn Casado's Ph.D. thesis, Stanford Univ. 2007
- Experimental network 2008
- Appearance of new terms:
  - N. McKeown, T. Anderson, H. Balakrishnan, G. Parulkar, L. Peterson, J. Rexford, S. Shenker, and J. Turner, "**OpenFlow**: enabling innovation in campus networks," *SIGCOMM Comput. Commun. Rev.*, vol. 38, no. 2, pp. 69–74, Mar. 2008.
  - K. Greene, "MIT Tech Review 10 Breakthrough Technologies: **Software-defined Networking**," http://www2.technologyreview.com/ article/412194/tr10- software-defined- networking/, 2009.

- Establishment of **Open Networking Foundation** (ONF) 2011

  – for promotion and standardisation of SDN

  www.opennetworking.org

- First big scale deployment

  Google's B4 network 2011

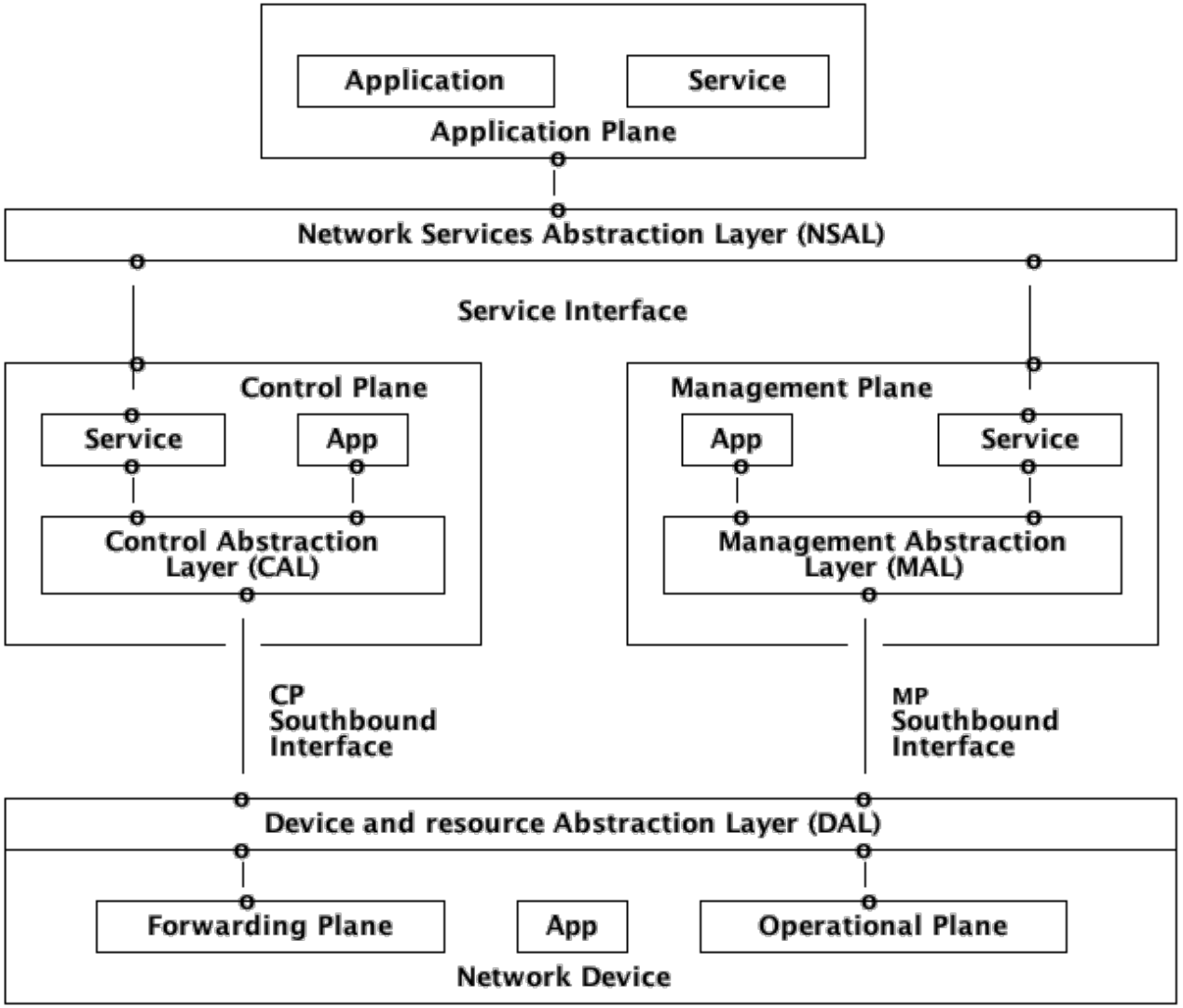
  It proved
  - cost reduction for ISP's services
  - better reliability
  - better QoS over public WANs

SDN is appealing technology for big datacentres & cloud operators

Physical & virtual switches are deployed

SDN – IETF Definition

SDN: Layers and Architecture Terminology RFC 7426 2015



Important features of the architecture

- Program modules can be activated on
  - switches
  - the controller
  - the manager
- The modules enables high flexibility of a given deployment
- A management application should cooperate with the controller & manager
- Abstraction layers enables cooperation between elements with different interfaces

OpenFlow Specification

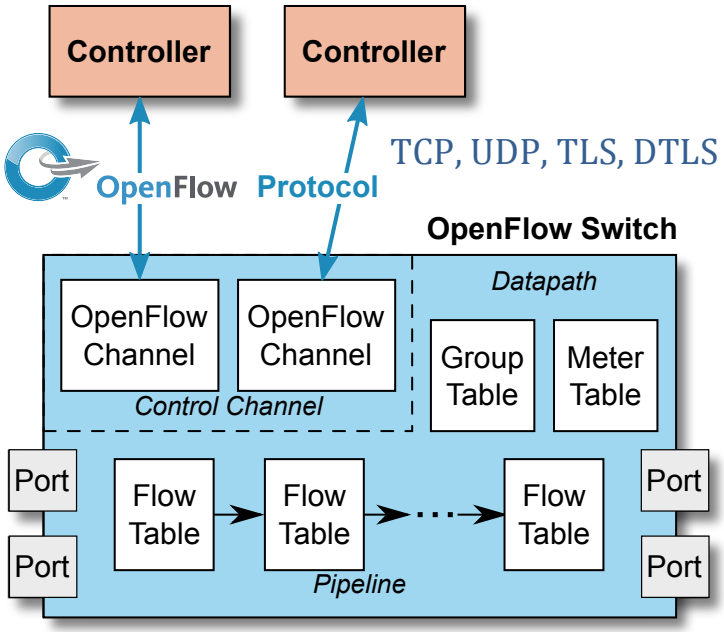
Defines

- Switch architecture
- Control protocol

to control ≠ to manage

Controlling – prompt operations
e.g. forwarding table updates

Management – slow operations
e.g. queuing configuration



Several versions of OF specification
- the last one ver. 1.5.1 from 2015

Controller
- queries switches' states
- adds, alters, removes table records
- controls interfaces – ports

Group table is used for

- multicast
- fast fail-over – controller set it proactively
- load balancing

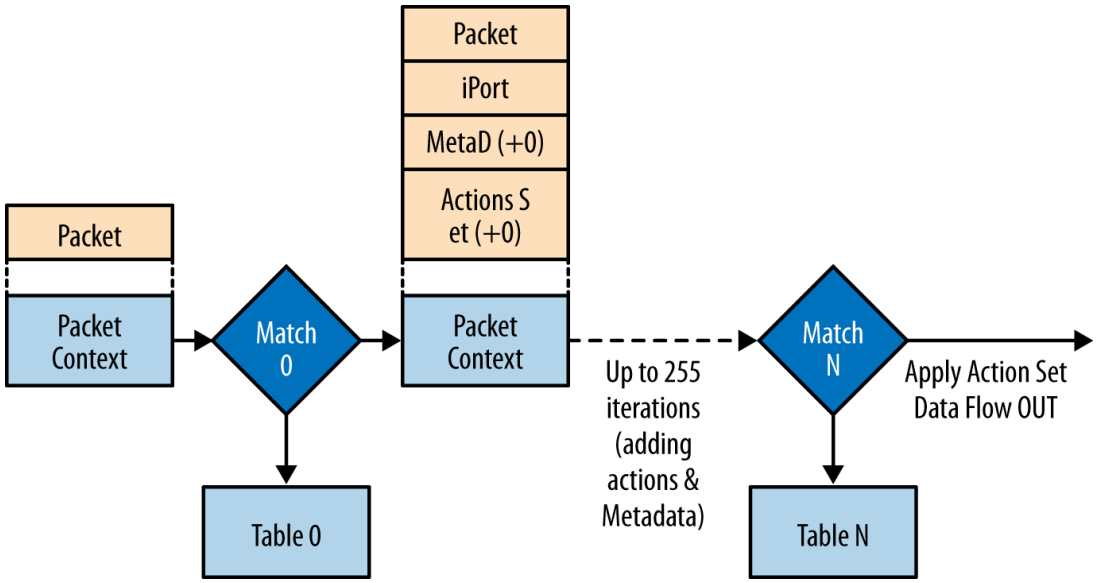
Meter table is used for

- packet/bit rate related operations
  - shaping incoming flows
  - DiffServ
  - advanced statistics

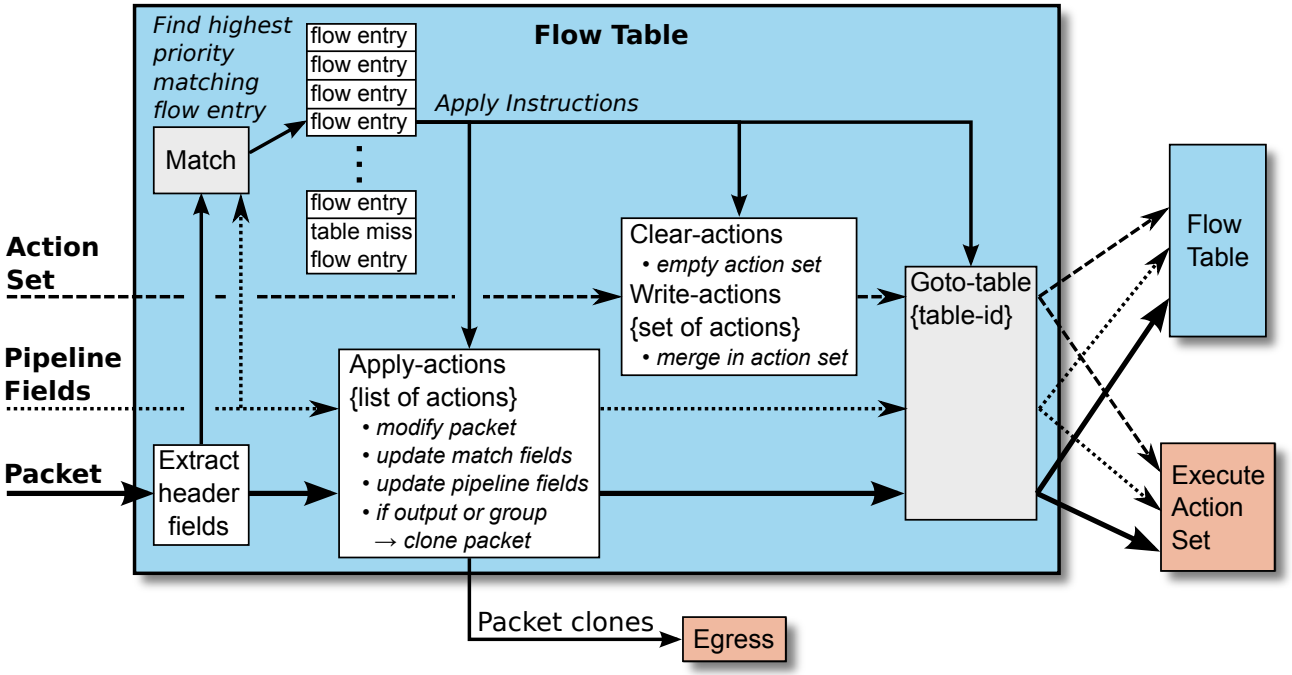
Ports

- physical
- logical
- reserved, e.g. to controller, to all, to the underlying standard switch

Flow Table Pipeline



- Processed headers
  - Ethernet, VLAN, MPLS, IPv4, IPv6, UDP, TCP
- Metadata (e.g. input port number) can pass information between tables
  - metadata can be matched by a bitmask



- Action
  - list – executed immediately while the packet matches a table record
  - set – executed at the end of the table flow
  - basket – executed while the packet is redirected to the group table
- Possible actions
  - modify the packet, e.g. add/remove VLAN header, decrease TTL field, recalculate checksum
  - forward the packet to an output queue
  - move it to next table
  - send it to the controller
  - drop the packet

OF Table Entry

- Bitmasks to select a flow
  – kind of network traffic recognized by the fields of protocol headers
- Instructions – to be applied on the packet
  - Stat-Trigger stat thresholds
  - Apply-Actions action(s)
  - Clear-Actions set
  - Write-Actions action(s) to the set
  - Write-Metadata metadata / mask
  - Goto-Table next-table-id
- Counters – packet and byte statistics
- Timers – to remove unused flows
- Cookie – to pass back information to the controller
- Priority
- Flags

An example

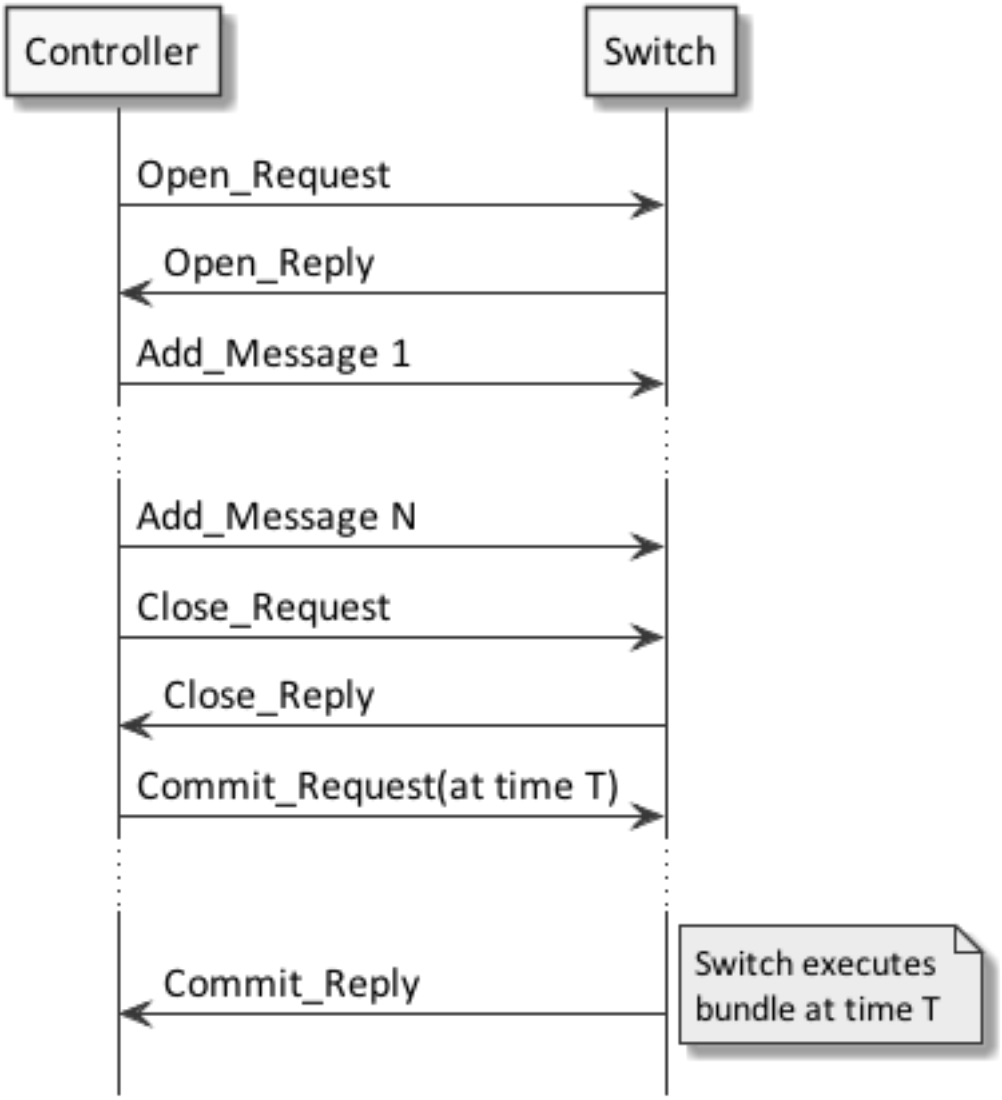
MAC src	MAC dst	IP src	IP dst	TCP dst. port	...	Action	Packet counter
*	10:29:	*	*	*	*	port 1	202
*	*	*	5.6.7.8	*	*	port 2	303
*	*	*	*	25	*	drop	802
*	*	*	100.*	*	*	local	120
*	*	*	*	*	*	controller	11

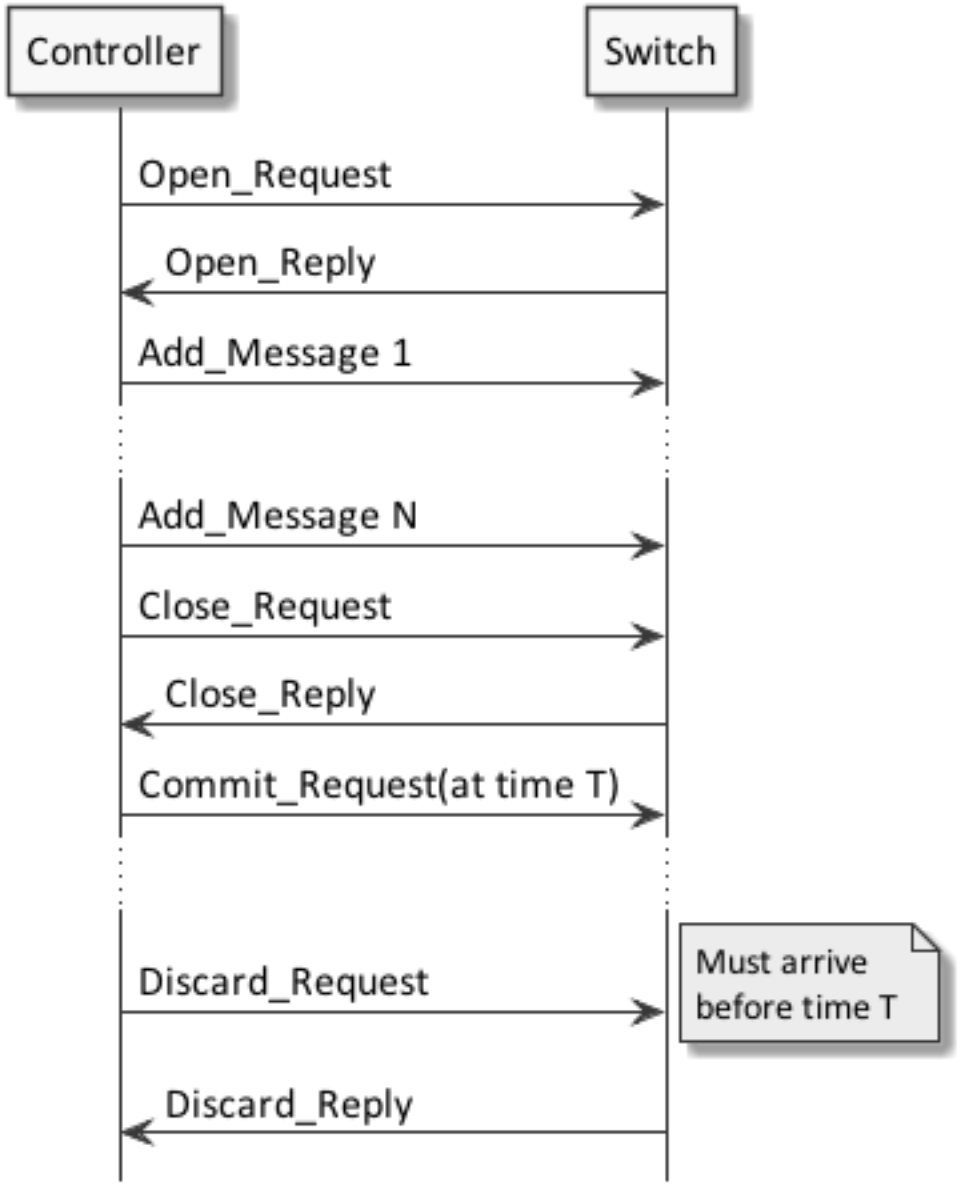
Table-miss flow entry

Bundle Messages

Goals

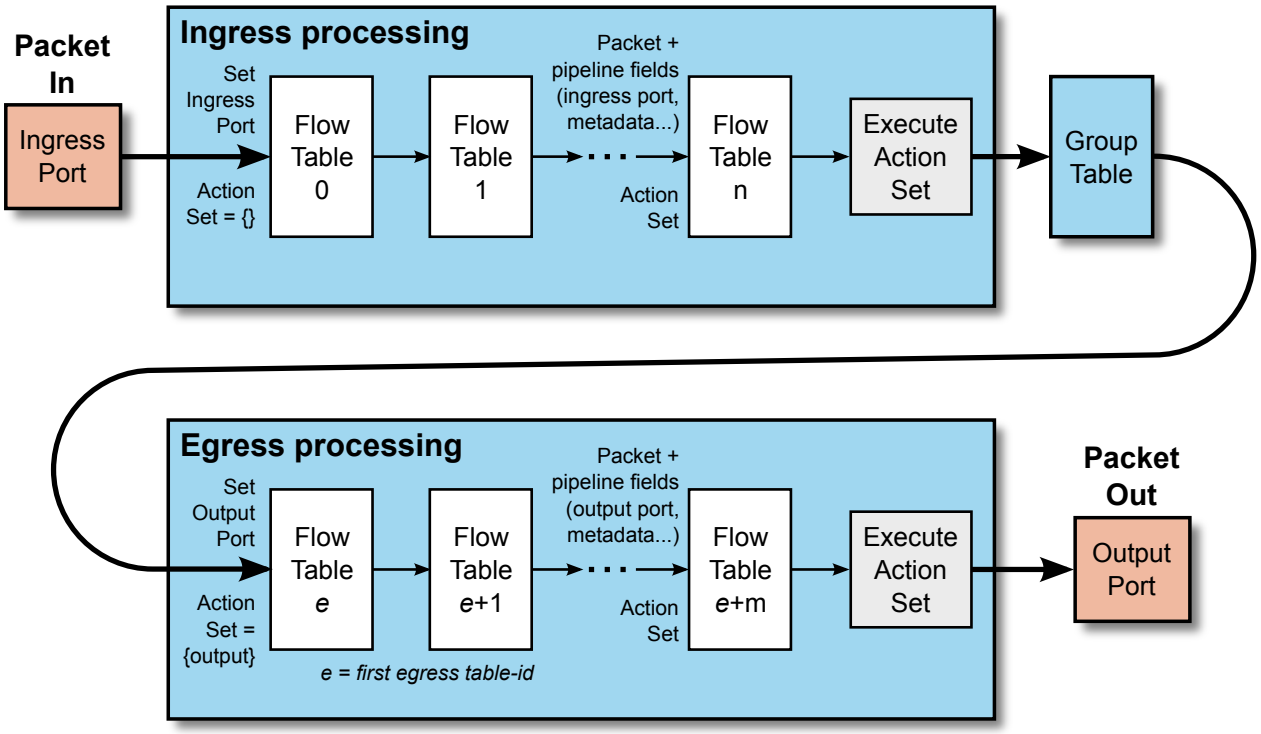
- group related state changes on a switch
  - to execute them together
- synchronize changes across a set of switches
  - applied them approximately at the same time


Controller
Switch
Open_Request
Open_Reply
Add_Message 1
Add_Message N
Close_Request
Close_Reply
Commit_Request(at time T)
Commit_Reply
Switch executes bundle at time T


Controller
Switch
Open_Request
Open_Reply
Add_Message 1
Add_Message N
Close_Request
Close_Reply
Commit_Request(at time T)
Discard_Request
Must arrive before time T
Discard_Reply

OF Evolution

Ver.	Published	Main Selected Features
1.0	2009	One table Ethernet, IPv4, TCP ports
1.1	2011	Table pipeline & group table VLAN, MPLS Counters
1.2	2012	IPv6
1.3	2012	Meter table Provider Backbone Bridges aka. "mac-in-mac" Multi-connection
1.4	2013	Bundle messages Table synchronizations Monitoring by parallel controllers
1.5	2015	Output table pipeline TCP flags Non-ethernet interfaces



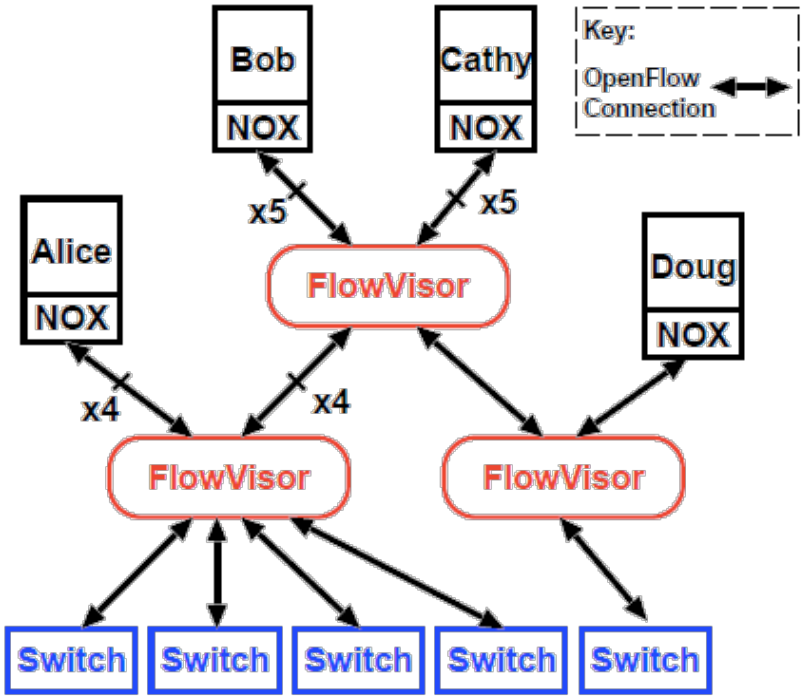
There are a lot of R&D projects related to OF SDN, e.g.:

- Programming Protocol-independent Packet Processors (P4) language & tools
  - P4 allows for switch structure definition
- Solutions for optical and radio interfaces
- Solutions for carrier network operators & for data centre operators

OpenFlow Network Virtualization

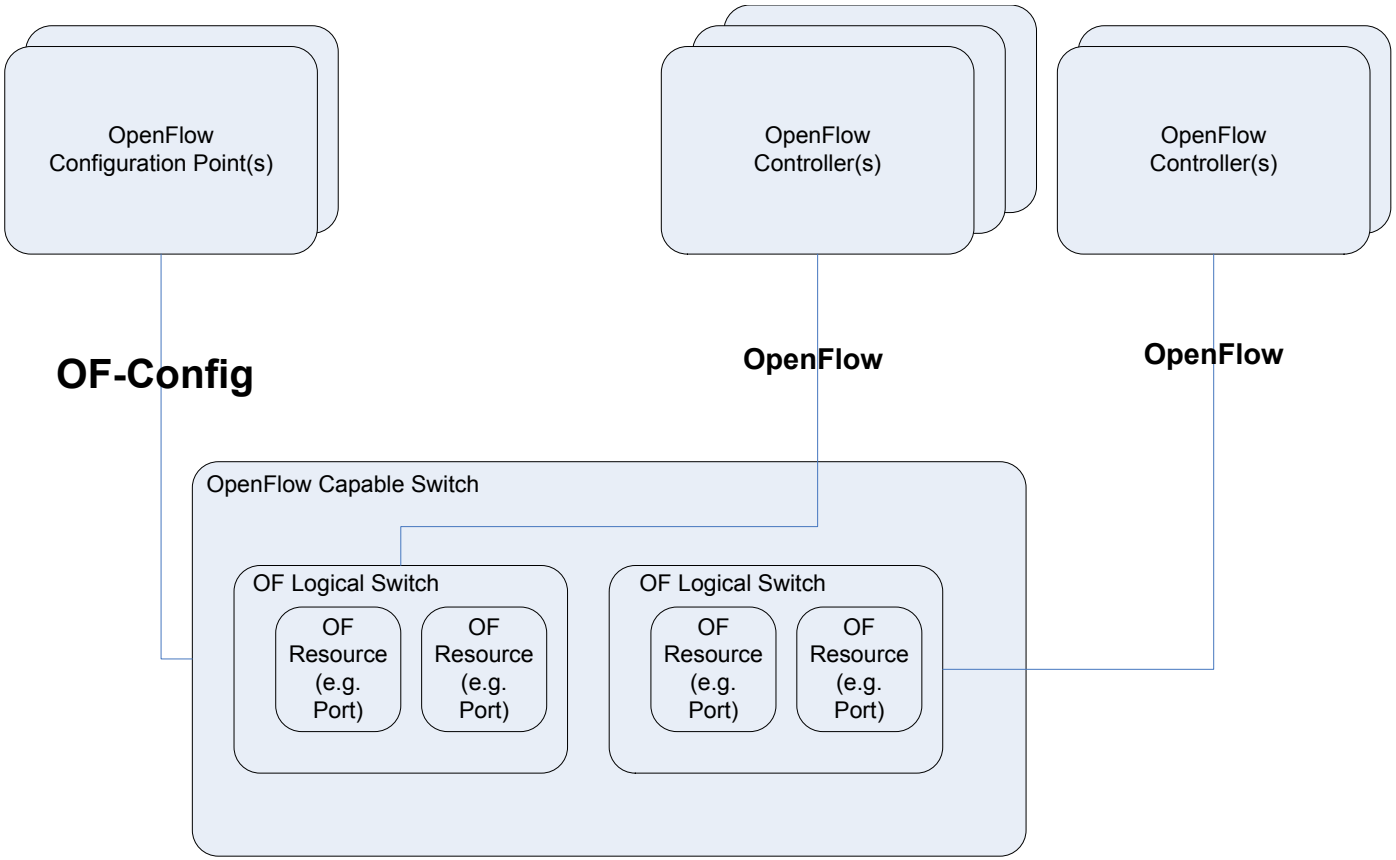
Solution for student laboratories 2009

FlowVisor separates resources of the switches for several controllers

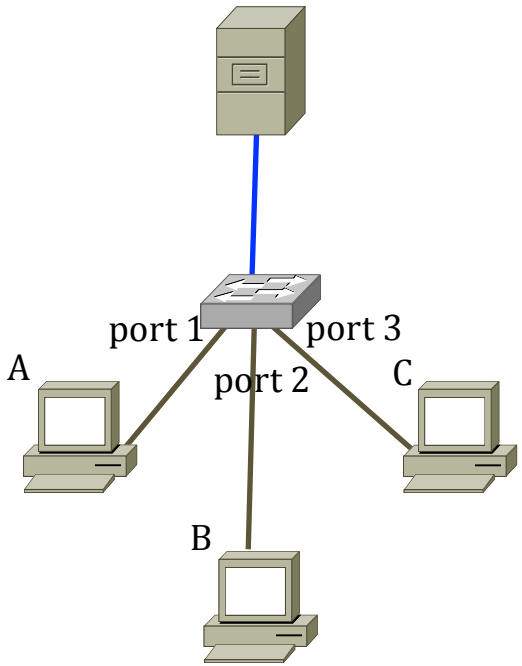


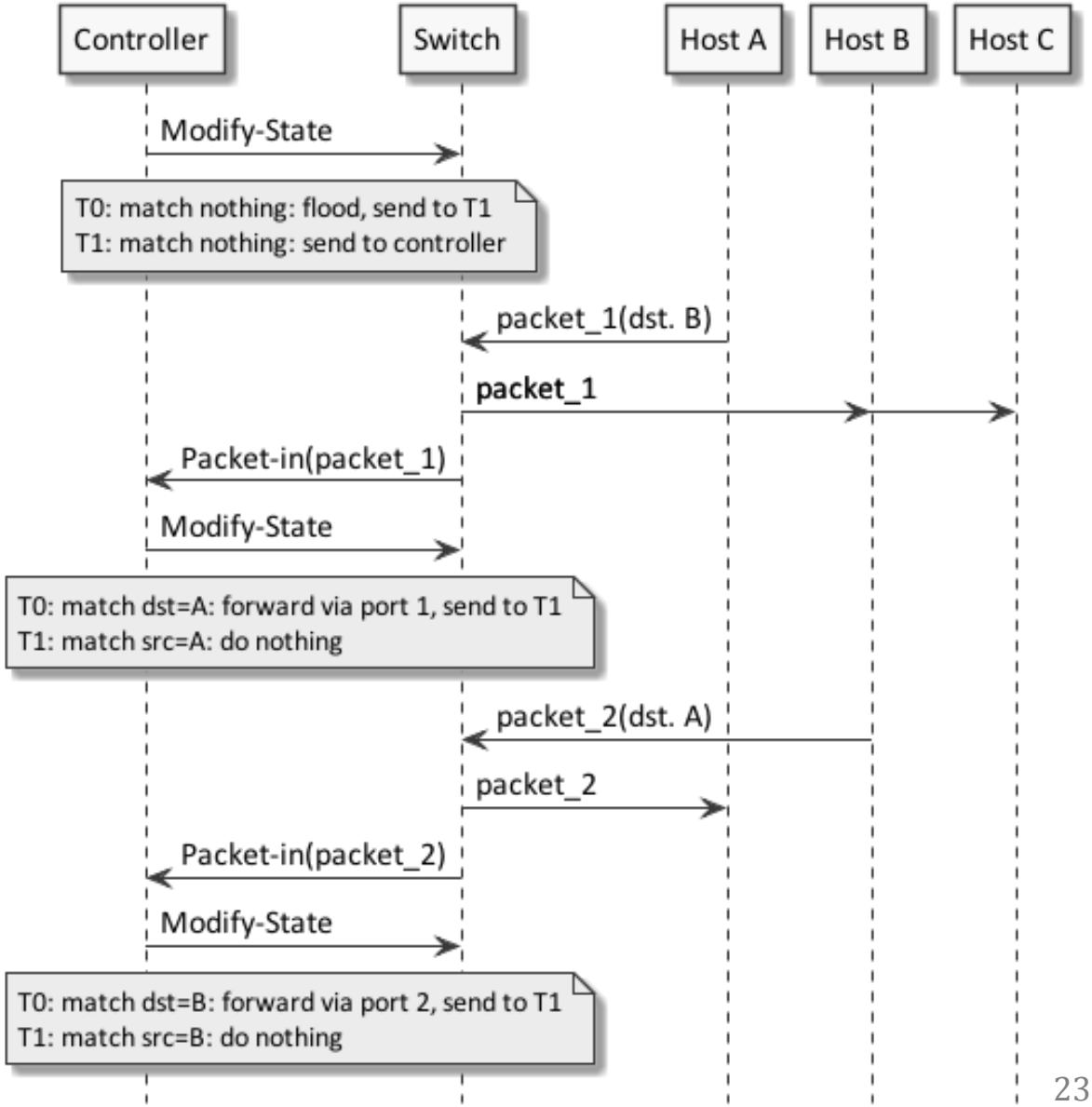
Virtualisation defined by ONF

OpenFlow Management and Configuration ver. 1.2 2014



Learning Switch Example





SDN Deployment Considerations

Links controller–switches must be secure

- Separated management network
  - distinct interfaces and cables
  - no user traffic
- It is possible to use the same links as for user traffic
  - off-line authentication key installation
- Management and control protocols (e.g. OF-Config, OpenFlow) should run over TLS

Efficiency needs careful programming

- Proactive network discovery – e.g. using Link Layer Discovery Protocol
- Proactive forwarding table setting
- Minimizing volume of the traffic controller – switches
- Minimizing the number of forwarding table entries
  - Hardware implementation is expensive – their size is limited

There are many OF switches and controllers

- hardware and software switches
- commercial and open-source projects

Network Functions Virtualisation (NFV)

NFV Industry Specification Group (ISG) in the European Telecommunications Standards Institute (ETSI) 2012

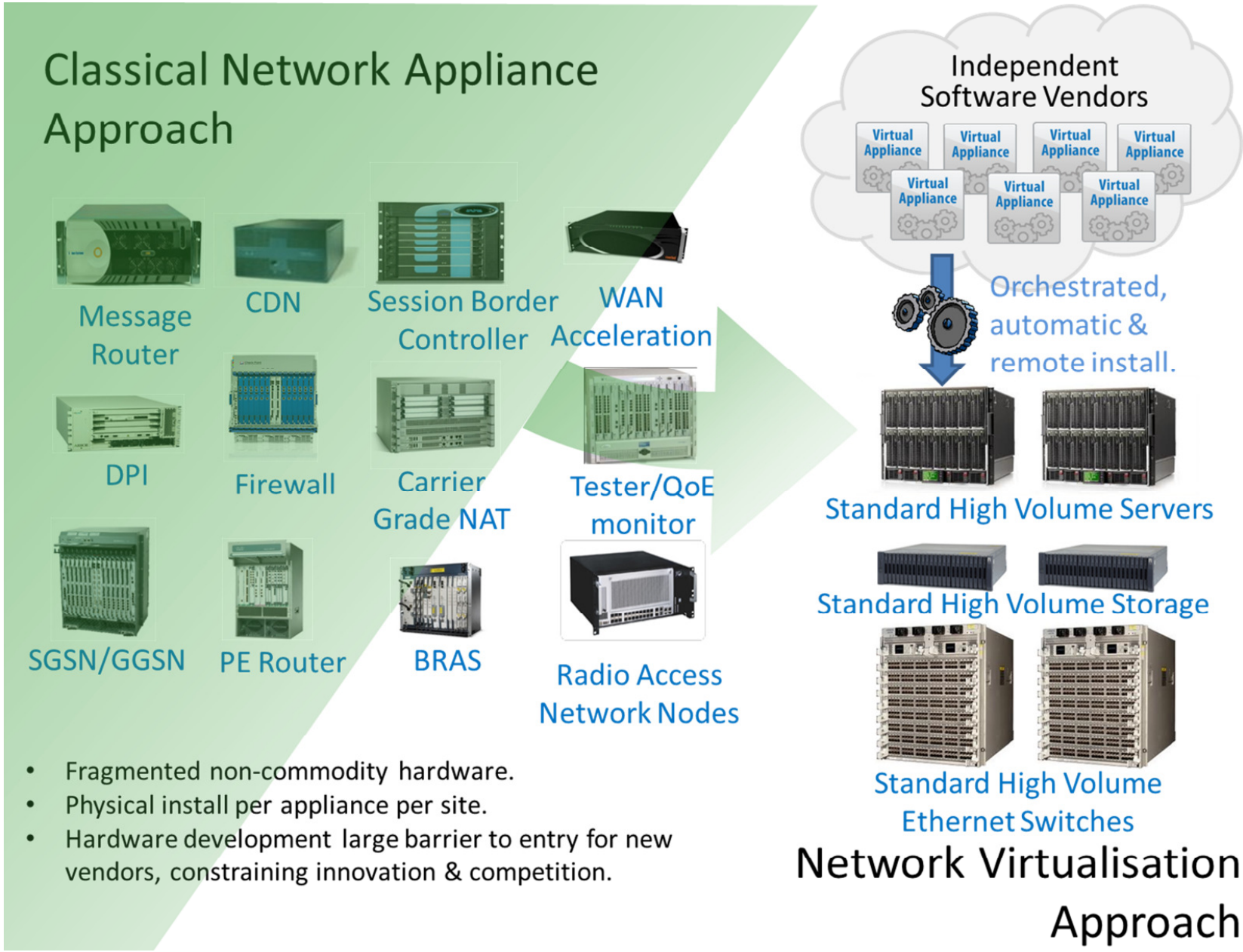
NFV is a network architecture

- uses the technologies of IT virtualization
  to virtualize entire classes of network node functions

Network function examples:

- NAT
- Firewall
- IDS
- WAN accelerator
- Service-Level-Agreement monitoring
- Authentication-Authorization-Accounting service
- Spam filter
- Content-Delivery-Network element
- IP-Multimedia-Subsystem signalization
- Endpoint of IPSec/SSL tunnels
- Load balancer

An appliance → A virtual machine image



Source: portal.etsi.org/NFV/NFV_White_Paper.pdf

NFV Rationale & Advantages

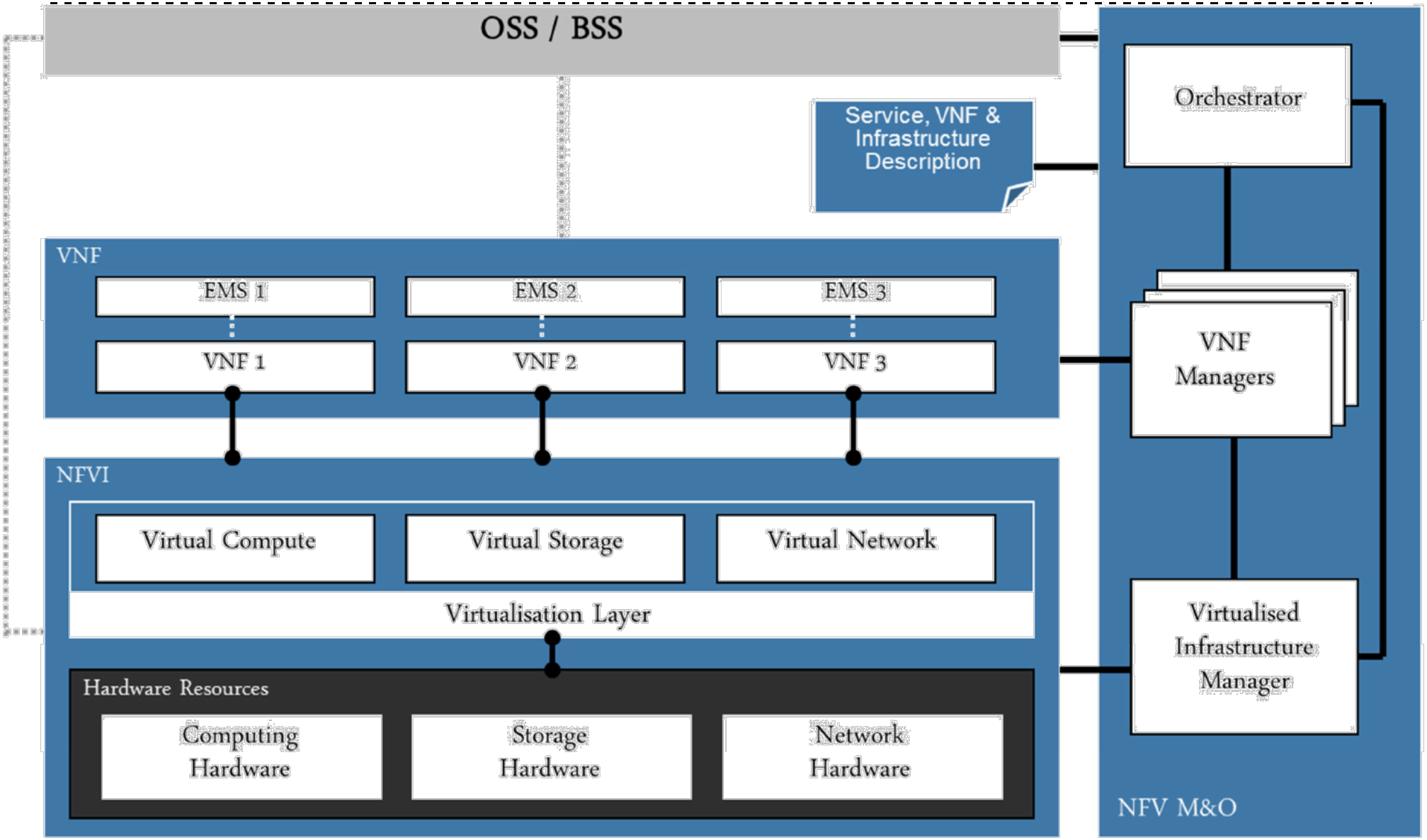
Rationale

- Short live-time of network appliances ⇒ replacement costs
- Raising number of appliances in racks ⇒ place, power supply, air-conditioning problems
- Fast evolution on network functions ⇒ arrival of a new appliance is not so prompt
- Needs for experimentation with new solutions

Advantages

- Improved scalability
- Easier dislocation of network functions
- Automation of network function administration
- Manageable power consumption
- Lower CAPEX & OPEX
- Openness for innovations

NFV Architecture

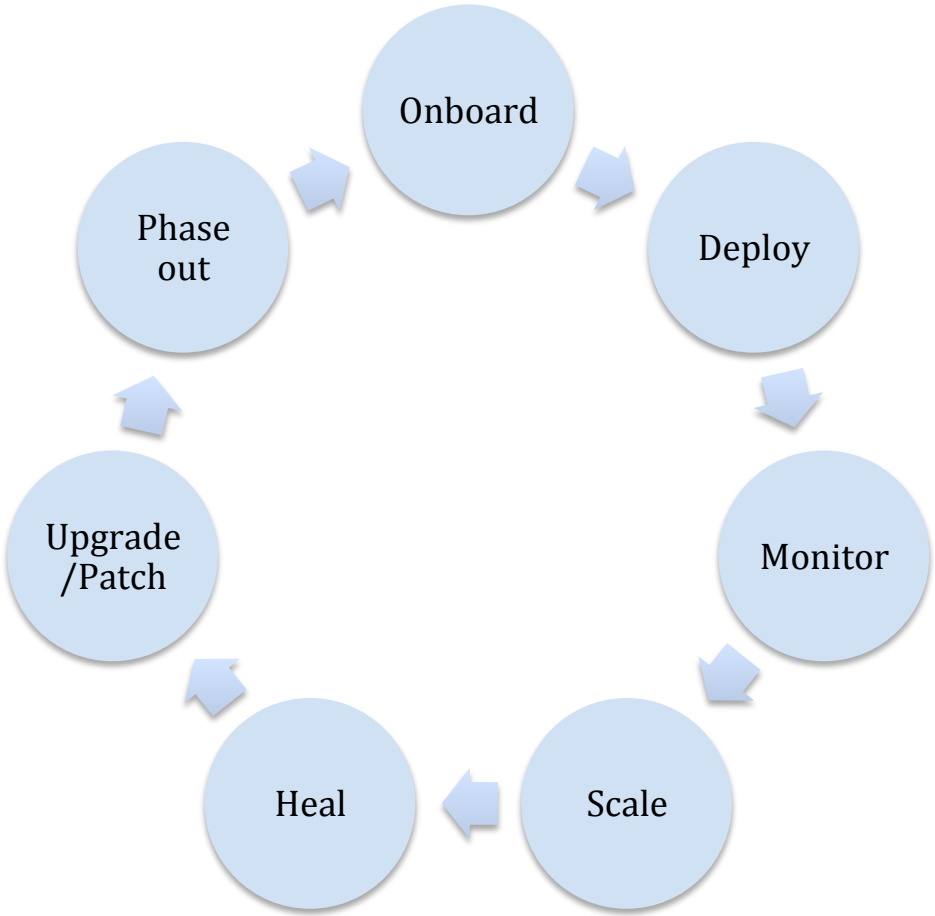


Source: portal.etsi.org/NFV/NFV_White_Paper2.pdf

NFV Orchestrator Functions

- Manages the live-cycle of network functions
- Coordinates VNF managers

Network Function Live-Cycle



NFV Versus SDN

SDN can be a subject or an object of NFV deployments

As a subject

- SDN switches and controllers are network functions
  - They can be virtual machines

As an object

- SDN controller can provide a virtual network image
  - The network can be built from physical and virtual switches
  - An application working over the controller can be the NFV network manager

Summary

- What is SDN?
  - Advantages
  - Applications
  - History
  - SDN – IETF definition
- OpenFlow switch & protocol
  - Flow table pipeline
  - Table entry
  - Bundle messages
  - Evolution
- OpenFlow network virtualization
- Learning switch example
- SDN deployment considerations
- Network Functions Virtualisation
  - Rationale & advantages
  - Architecture
    - NFV Orchestrator Functions
  - NFV versus SDN

Questions

1. What is Software Defined Networking?
2. What are the SDN advantages?
3. What are the applications of SDN networks?
4. Describe the history of SDN evolution.
5. What are the important features of the SDN architecture defined by IETF?
6. What is it a flow in SDN?
7. Sketch the architecture of an OF switch.
8. What information is stored in OF table records?
9. What actions can be performed on a packet?
10. What is the reason for bundle messages?
11. What is the purpose of P4 language?
12. Sketch the architecture of the OF virtualisation defined by ONF.

Questions for curious minds

1. What information does LLDP provide?
2. What is Protocol-Oblivious Forwarding defined by Huawei?