INTERNET SYSTEMS

6CCS3INS

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Internet Paradigm Shift

Outline

- Innovations Constraints in the Internet
- Virtualisation & Cloud Computing
- Introduction to Software-defined Networking (SDN)
- Virtualisation and SDN

The Internet: A Remarkable Story

- Tremendous success
  - From research experiment to global communications infrastructure
- The brilliance of under-specifying
  - Best-effort packet delivery service
  - Key functionality at programmable end hosts
- Enabled massive growth and innovation
  - Ease of adding hosts and link technologies
  - Ease of adding services (Web, P2P, VoIP, …)
- But, change is easy only at the edge!!

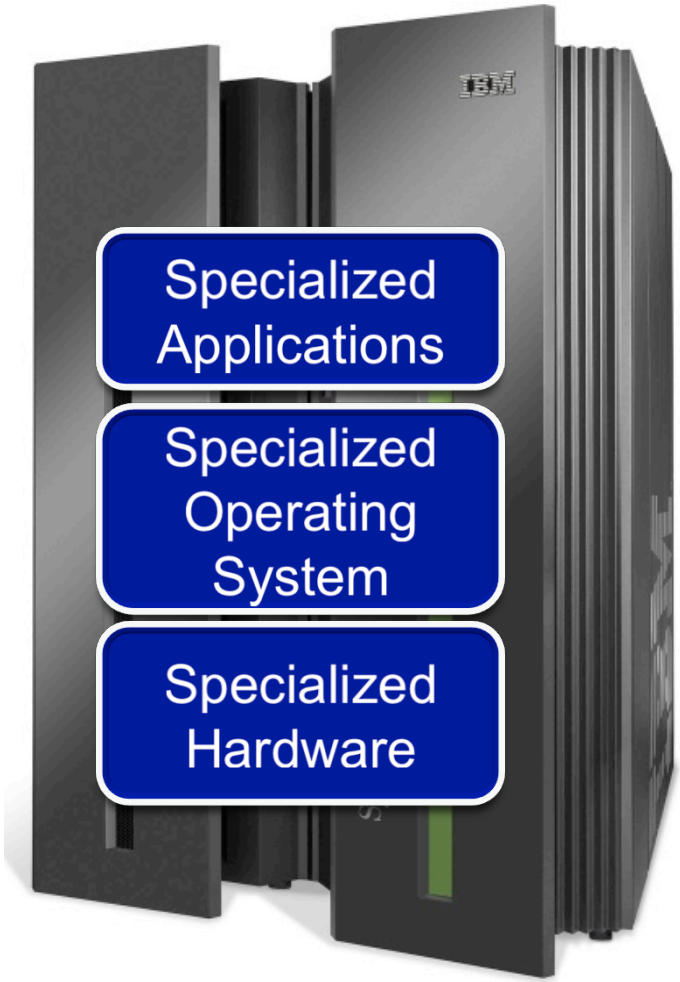
Innovation – Computers vs. Networks

- How difficult is it to create/modify a computer application?
- How difficult is it to create/modify a network feature?
  - What is the difference?
  - What are the tools available for each?

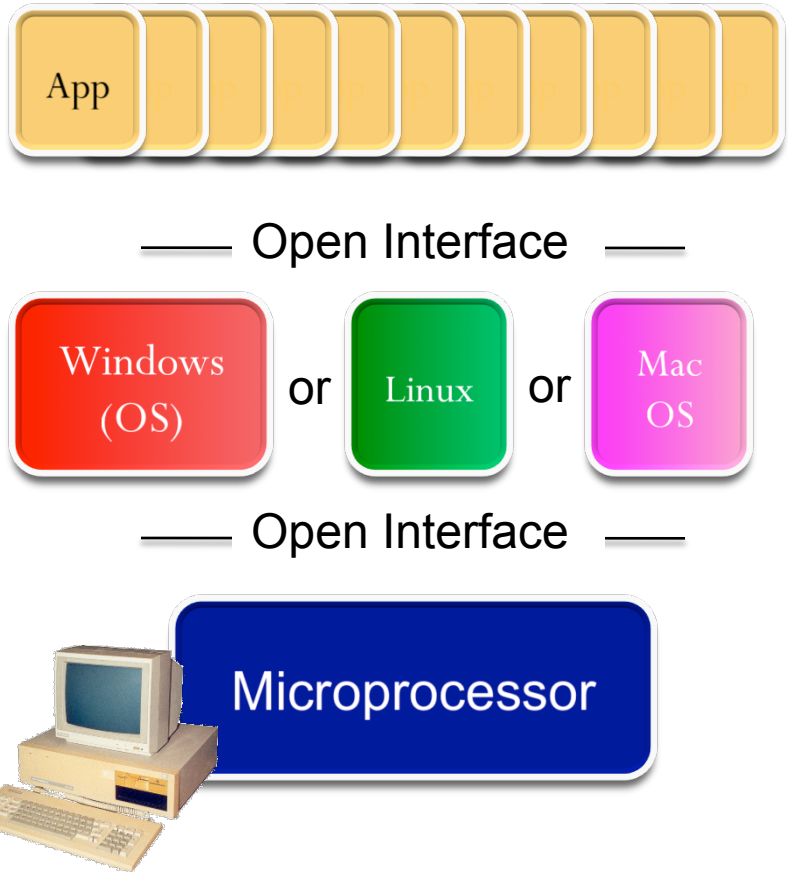
Once Upon a Time

- "AT&T Eyes Flexibility, Cost Savings With New Network Design", Wall Street journal, 2014.
  - Upgrade their internal network infrastructure (routers and switches) every 18 months to keep up with the current demands for network.
  - Cost Billions USD to upgrade.
    - Cisco top of the line switch cost $27K USD
  - Other high cost: Involved many men power to upgrade the network.
  - *In Summary*: AT&T was eyeing for SDN capable switches (only **$11K USD** each).

- ✓ Vertically integrated
- ✓ Closed, proprietary
- ✓ Slow innovation
- ✓ Small industry



- ✓ Horizontal
- ✓ Open interfaces
- ✓ Rapid innovation
- ✓ Huge industry



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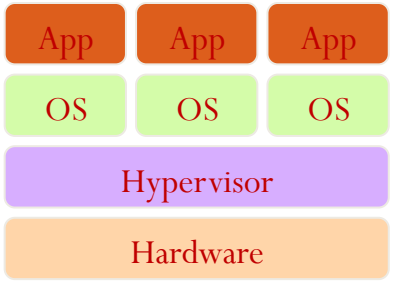
Virtualisation

- Virtualisation was developed in the 1970s as a way to run legacy software on newer mainframe hardware.
  - The new systems being developed did not have an identical architecture to older ones, so they could not run applications from older systems without modification.
  - Virtualisation tried to solve this problem by creating an interface within the system that would mimic the behavior of the legacy system being reproduced.

- Virtualisation can be used to provide
  - isolated containers within which to run an application, or
  - a full "virtual machine" composed of an operating system and all of its applications.

Virtualization

- Virtual workspaces:
  - An abstraction of an execution environment that can be made dynamically available to authorized clients by using well-defined protocols,
  - Resource quota (e.g. CPU, memory share),
  - Software configuration (e.g. O/S, provided services).
- Implement on Virtual Machines (VMs):
  - Abstraction of a physical host machine,
  - Hypervisor intercepts and emulates instructions from VMs, and allows management of VMs,
  - VMWare, Xen, etc.
- Provide infrastructure API:
  - Plug-ins to hardware/support structures



Virtualized Stack

Virtualisation in DataCentres

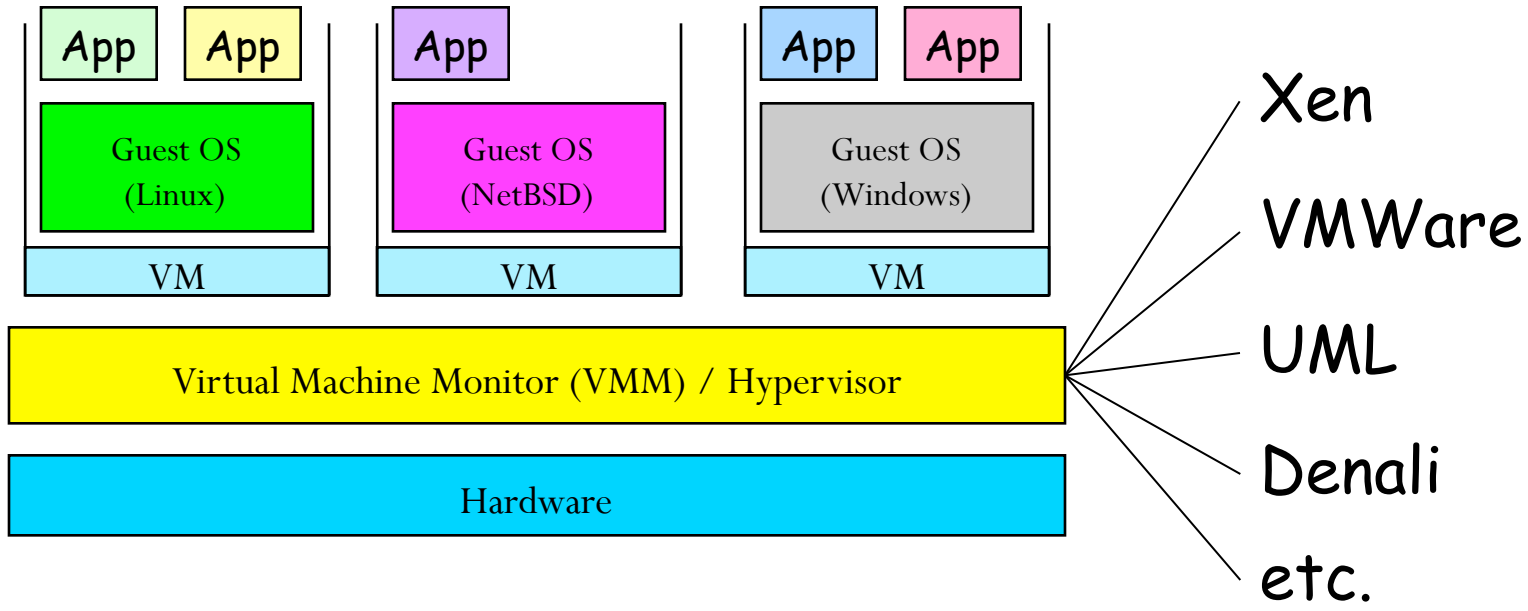
- In a traditional data centre, each physical server typically runs a single application, e.g. a web or database server.

- Virtualisation software is used to run multiple Virtual Machines (VMs) on a single physical server to provide the same functions as multiple physical machines.

- The software is known as a **hypervisor**, which performs the abstraction of the hardware to the individual VMs.
  - The hypervisor is very similar to an operating system.
    - manages how resources are allocated to each virtual machine;
    - provides protection and security between them;

Virtual Machines

- VM technology allows multiple virtual machines to run on a single physical machine.



Performance: Para-virtualization (e.g. Xen) is very close to raw physical performance!

Cloud Computing

- Virtualisation is the key to the success of Cloud Computing.
- Cloud computing is Internet-based computing, whereby shared resources, software and information are provided to computers and other devices on-demand.
- It hides the complexity and details of the underlying infrastructure from users and applications by providing very simple graphical interface or API (Applications Programming Interface).
- Cloud services are invoked only when you need them. They are not permanent parts of your IT infrastructure—a significant advantage.
  - On-demand resources.
  - No need to have dedicated resources waiting to be used.

Cloud Service Models

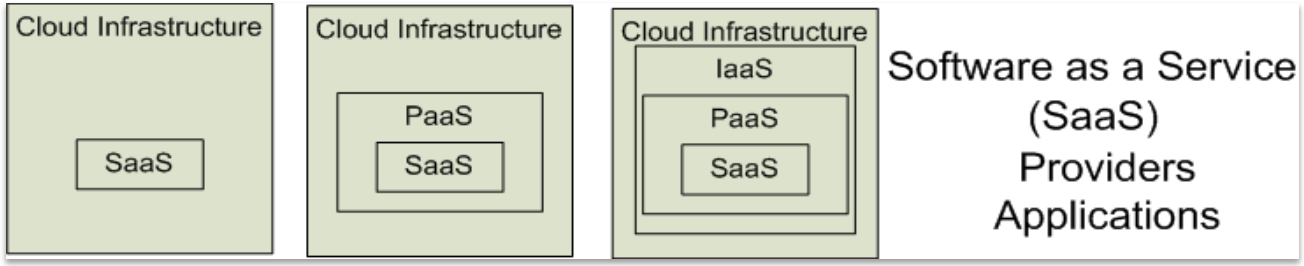
Software as a Service (SaaS)

Platform as a Service (PaaS)

Infrastructure as a Service (IaaS)

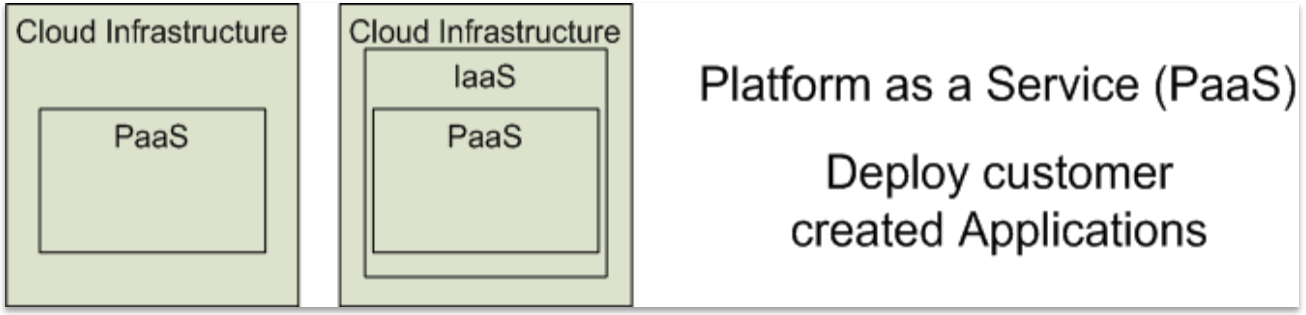
SalesForce CRM

LotusLive



Google App

Windows Azure
The Future Made Familiar



amazon web services

rackspace HOSTING

Software as a Service (SaaS)

- Software that is deployed over the internet. With SaaS, a provider licenses an application to customers either as a service on demand, through a subscription.
- Web access to commercial software.
- Software is managed from a central location.
- Software delivered in a “one to many” model.
- Users not required to handle software upgrades and patches.
- Application Programming Interfaces (APIs) allow for integration between different pieces of software.

Salesforce

- Salesforce is a customer relationship management tool (CRM).

- Employ five main data objects to keep track of sales process. These objects are accounts, contact, opportunities, leads, and campaigns.
  - Accounts are the companies you deal with;
  - Contacts are the people at those companies;
  - Opportunities are the deals you're making with those companies to sell them your product or service.
  - Leads are the people who have shown some interest in your company, but not enough to take the next step in the sales process.
  - Campaigns are Salesforce's way of keeping track of marketing efforts. Campaigns are a good way to track where your leads are coming from, and how your marketing efforts are doing.

Platform as a Service (PaaS)

- PaaS can be defined as a computing platform that allows the creation of web applications quickly and easily and without the complexity of buying and maintaining the software and infrastructure underneath it.
- Services to develop, test, deploy, host and maintain applications in the same integrated development environment.
- Web based user interface creation tools help to create, modify, test and deploy different UI scenarios.
- Multi-tenant architecture where multiple concurrent users utilize the same development application.
- Integration with web services and databases via common standards.
- Support for development team collaboration – some PaaS solutions include project planning and communication tools.

Google App Engine

- Google App Engine is a platform for developing and hosting web applications in Google-managed data centers.
- It requires that apps be written in Java or Python.
- It stores data in Google BigTable.
- It uses the Google query language.
- Non-compliant applications require modification to use App Engine.
- The App Engine also eliminates some system administration and developmental tasks to make it easier to write scalable applications.
- Google App Engine is free up to a certain amount of resource usage.

Infrastructure as a Service (IaaS)

- Infrastructure as a Service (IaaS) is a way of delivering Cloud Computing infrastructure – servers, storage, network and operating systems – as an on-demand service.
- Rather than purchasing servers, software, datacenter space or network equipment, clients instead buy those resources as a fully outsourced service on demand.
- Resources are distributed as a service.
- Allows for dynamic scaling.
- Has a variable cost, utility pricing model.
- Generally includes multiple users on a single piece of hardware.

Amazon Elastic Compute Cloud (EC2)

- Amazon EC2 is an Amazon Web Service (AWS) you can use to access servers, software, and storage resources across the Internet in a self-service manner.
- Amazon Machine Image (AMI) is a template for software configuration (Operating System, Application Server, and Applications).
- Amazon have data centers in different region across the globe.
- Security Group - enables you to specify the protocols, ports, and source IP ranges that are allowed to reach your instances.
- Automatically scales amazon EC2 capacity up and down based on rules.
  - Add and remove compute resource based on demand.
  - Distribute incoming traffic across multiple instances.

Cloud Computing Pros

- **Elasticity** and **scalability**: Expand and reduce resources according to specific service requirement.
- **Workload movement**: Cloud-computing providers can migrate workloads across servers—both inside the data centre and across data centres.
- **Resiliency**: Completely isolate the failure of server and storage resources from cloud users.
  - Specific work can be migrated to a different physical resource in the cloud with or without user awareness and intervention.
- **Multi-tenancy**: Can host the cloud services for multiple users with different requirements within the same infrastructure.

Cloud Computing Concerns

- Performance, reliability, and SLAs.
- Control of data, and service parameters.
- Application features and choices.
- Interaction between Cloud providers.
- No standard API – mix of SOAP and REST!
- Privacy, security, compliance, trust…

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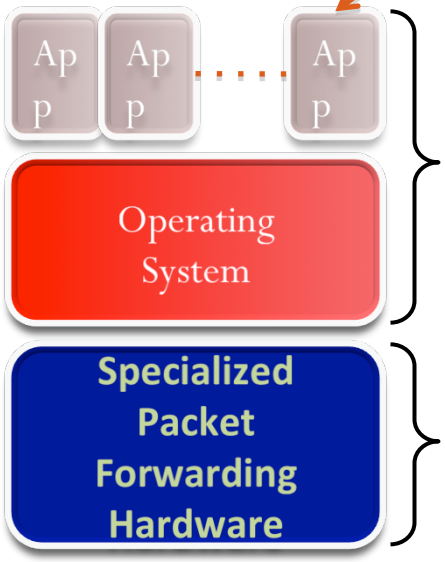
The Networking Industry (2007)

Routing, management, mobility management, access control, VPNs, …



Million of lines of source code

Manage by 5400 RFCs

500M gates
10Gbytes RAM

Power Hungry

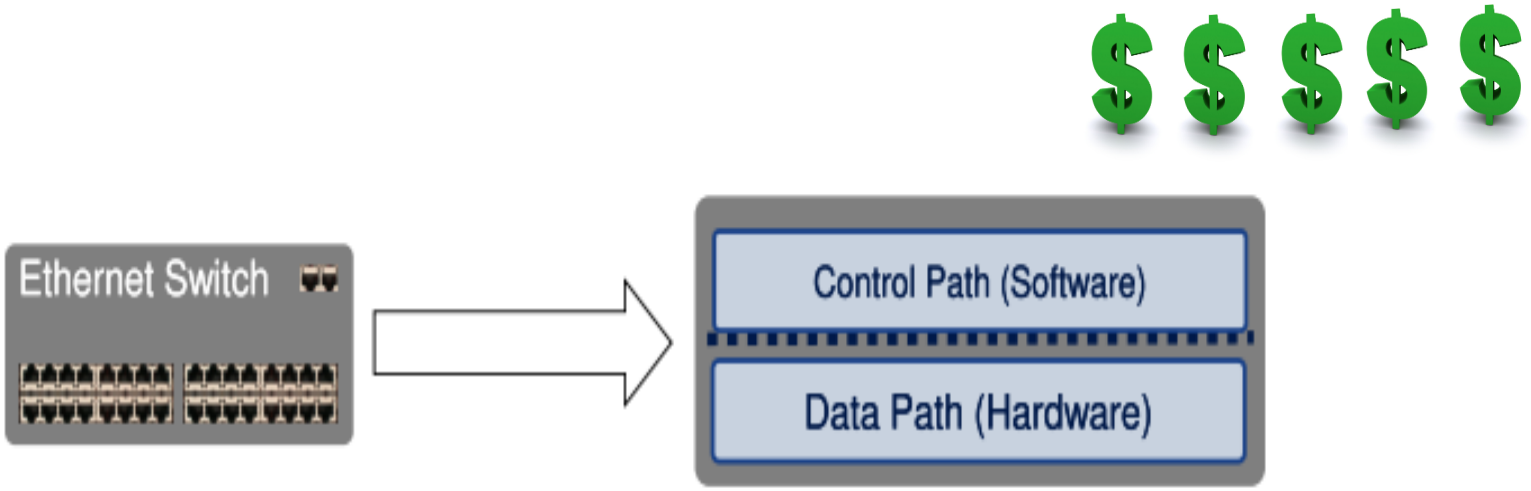
Many complex functions baked into the infrastructure

OSPF, BGP, multicast, differentiated services, Traffic Engineering, NAT, firewalls, MPLS, redundant layers, …

An industry with a "mainframe-mentality"

Traditional network Router In Summary

- Typical Networking Software
  - Control Plane – The brain/decision maker
  - Data Plane – Packet forwarder



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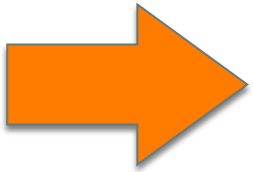
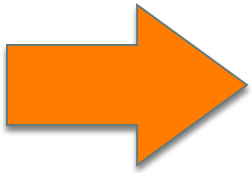
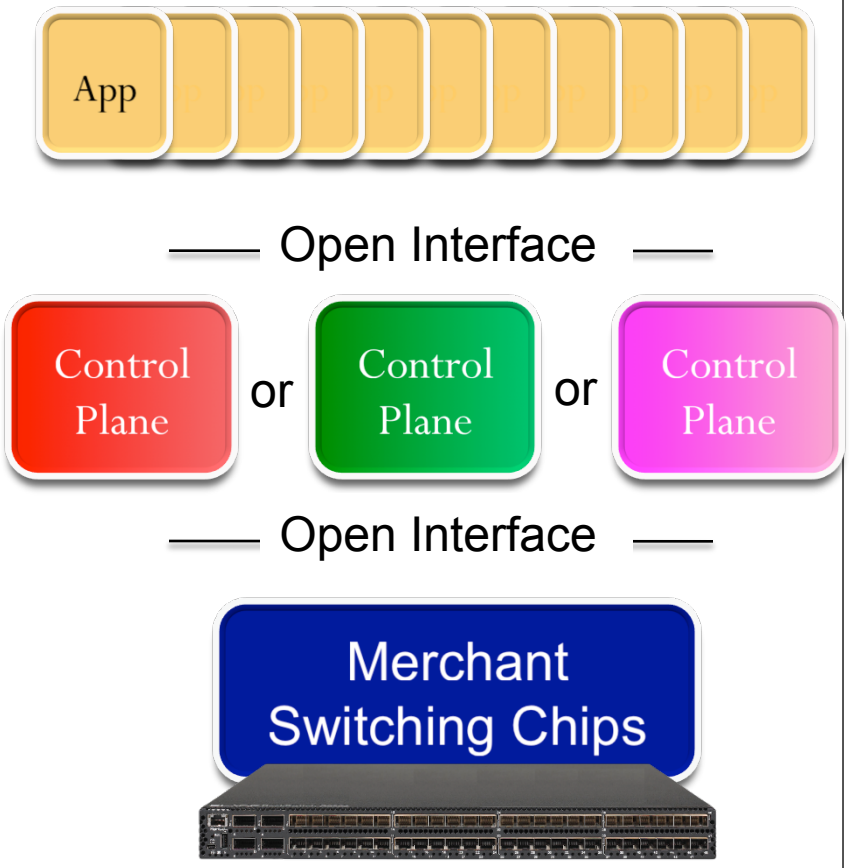
- ✓ Slow innovation

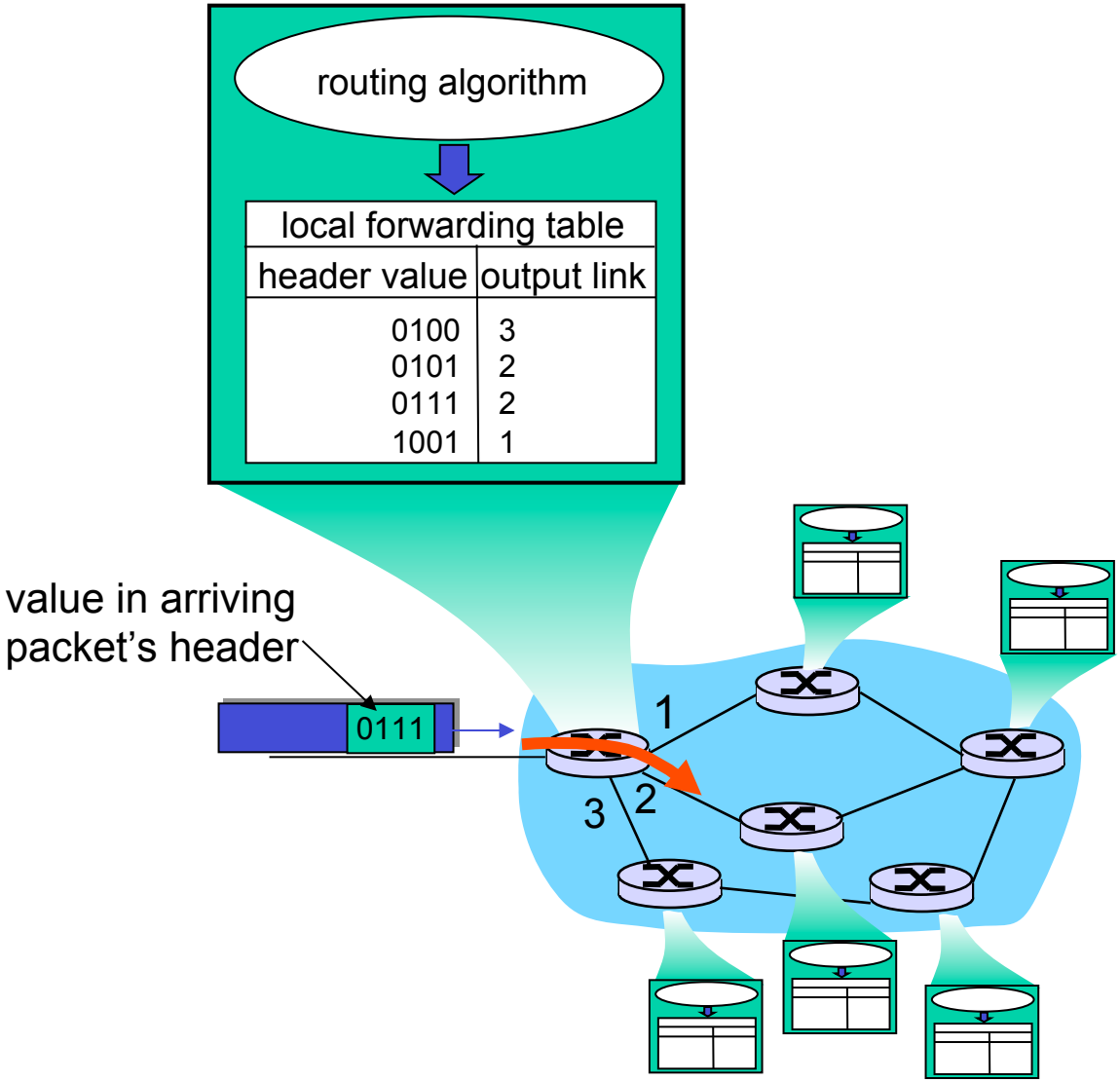


- ✓ Horizontal
- ✓ Open interfaces
- ✓ Rapid innovation

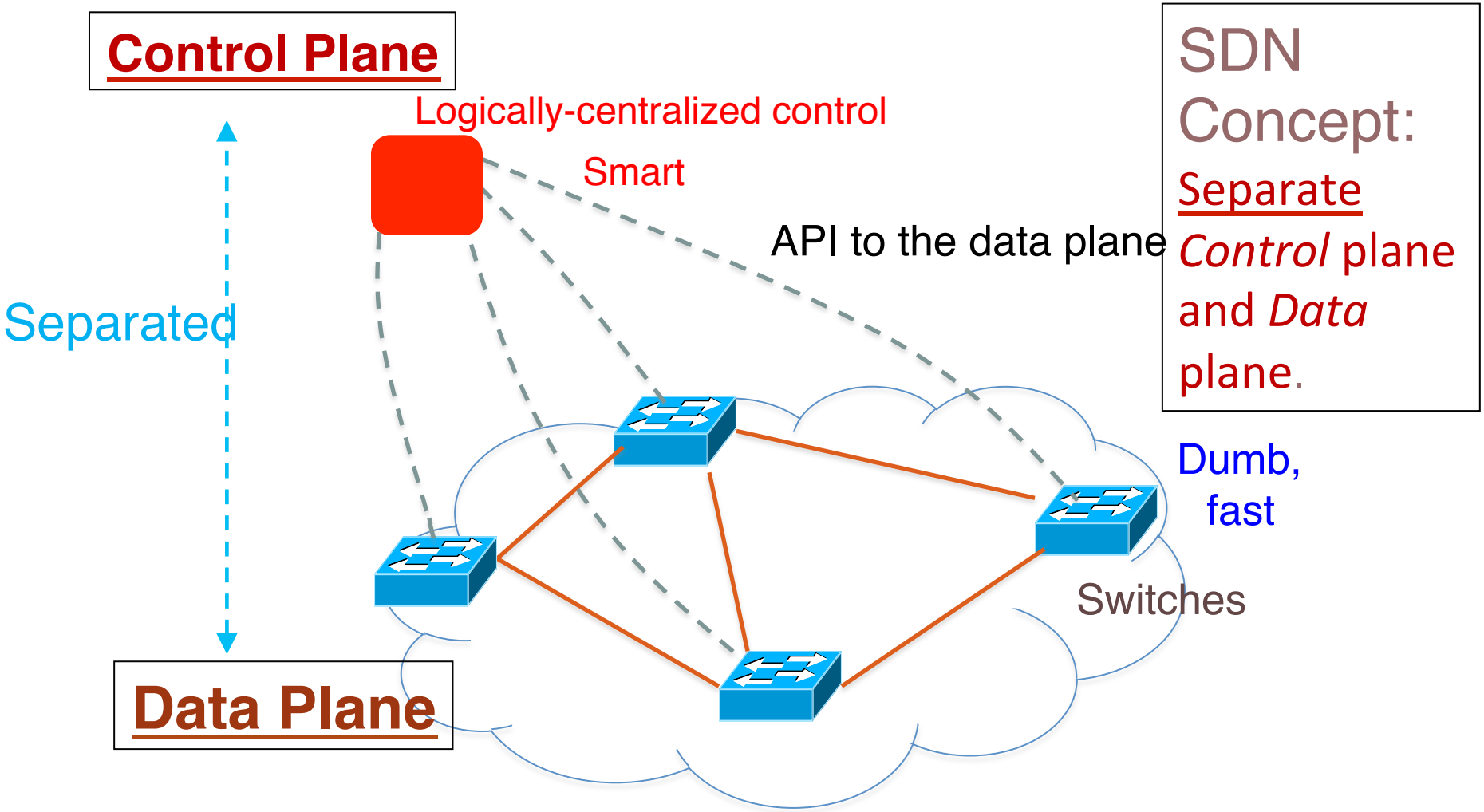




Review: How a Router Works



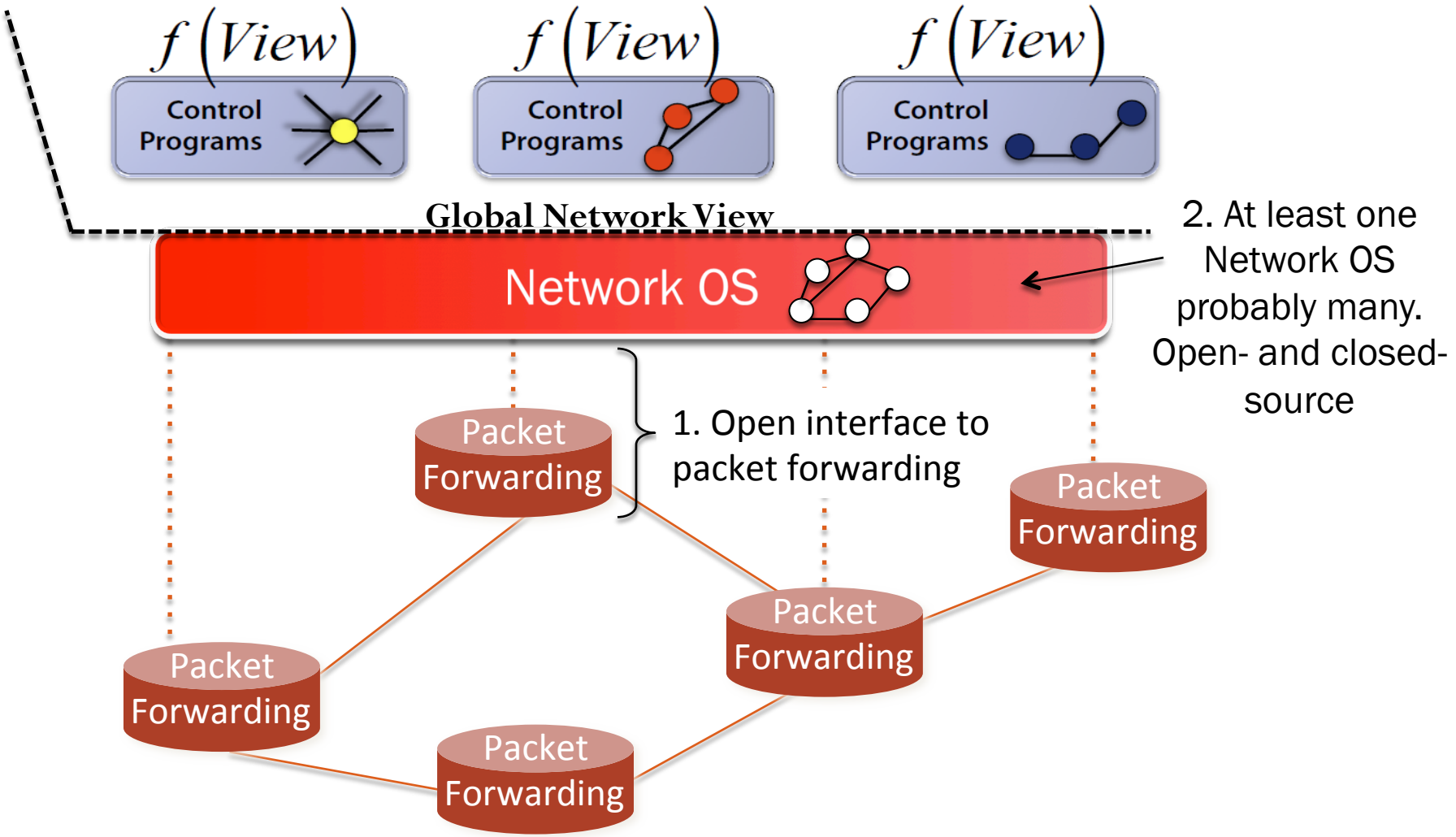
Imagine IF The Network is.....!!!



SDN Concept: Separate *Control* plane and *Data* plane.

Software Defined Network (SDN)

3. Consistent, up-to-date global network view



SDN Basic Concept

- Separate Control plane and Data plane entities.
  - Network intelligence and state are logically centralized.
  - The underlying network infrastructure is abstracted from the applications.
- Execute or run Control plane software on general purpose hardware.
  - Decouple from specific networking hardware.
  - Use commodity servers and switches.
- Have programmable data planes.
  - Maintain, control and program data plane state from a central entity.
- An architecture to control not just a networking device but an entire network.

SDN in Real World – Google's Story

- The industries were skeptical whether SDN was possible.
- Google had big problems:
  - **High financial cost** managing their datacenters: Hardware and software upgrade, over provisioning (fault tolerant), manage large backup traffic, time to manage individual switch, and a lot of men power to manage the infrastructure.
  - **Delay** caused by rebuilding connections after link failure.
    - Slow to rebuild the routing tables after link failure.
    - Difficult to predict what the new network may perform.
- Google went a head and implemented SDN.
  - Built their hardware and wrote their own software for their internal datacenters.
  - Surprised the industries when Google announced SDN was possible in production.
- How did they do it?
  - Read "*B4: Experience with a Globally-Deployed Software Defined WAN*", ACM Sigcomm 2013.

Consequences

- More innovation in network services
  - Owners, operators, 3rd party developers, researchers can improve the network
  - E.g. energy management, data center management, policy routing, access control, denial of service, mobility
- Lower barrier to entry for competition
  - Healthier market place, new players
- Lower cost
  - Infrastructure
  - Management

Network OS & Control Program

- Network OS
  - distributed system that creates a consistent, up-to-date network view
  - Runs on servers (controllers) in the network
  - NOX, ONIX, Floodlight, Trema, HyperFlow, Kandoo, Beehive, Beacon, Maestro, … + more

- Control program
  - Operates on view of network
  - **Input**: global network view (graph/database)
  - **Output**: configuration of each network device

Forwarding

- Flow-based Forwarding

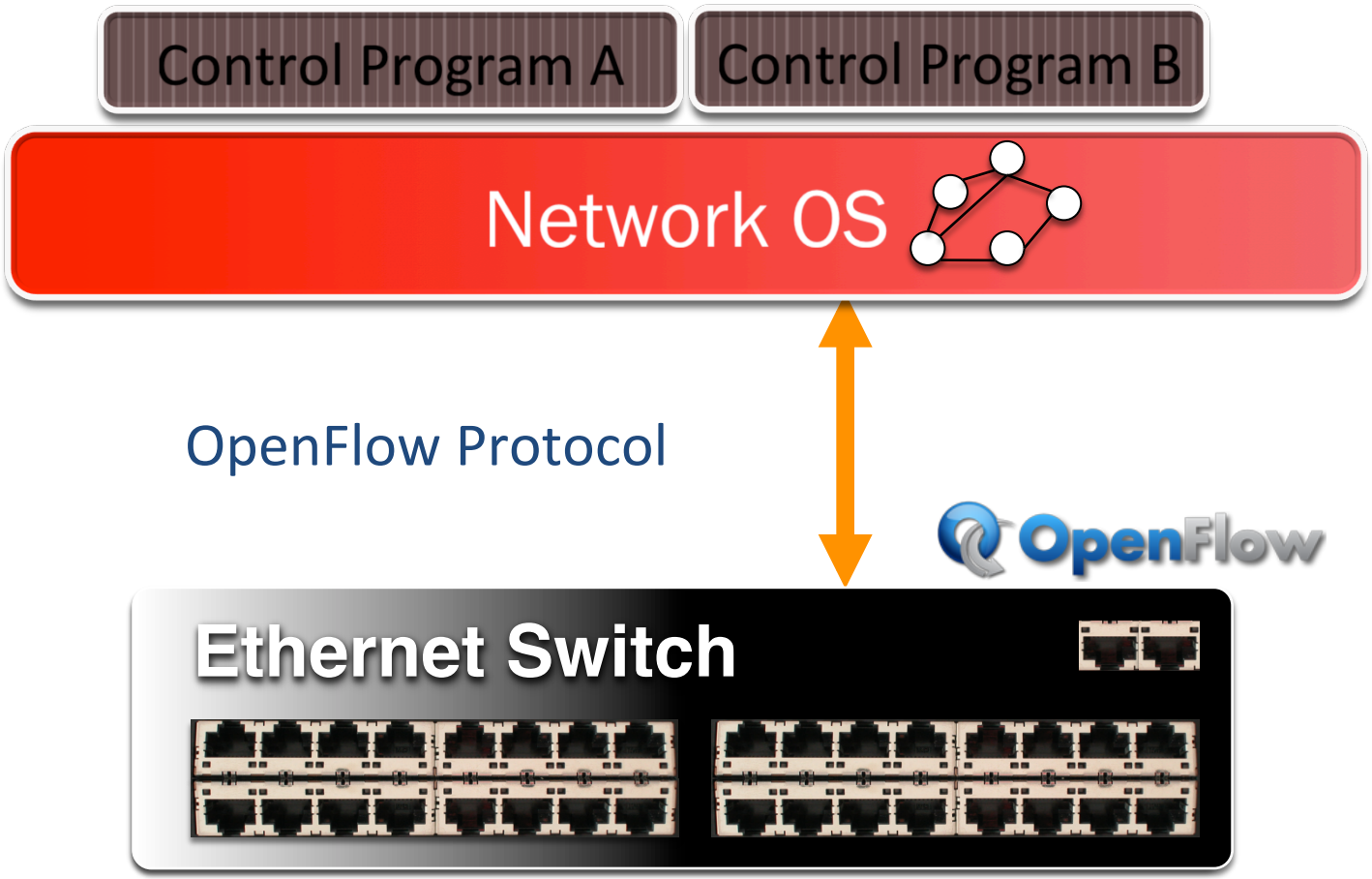
What is a flow?

- Application flow
- All http traffic
- John's traffic
- All packets to London
- …

Types of action

- Allow/deny flow
- Route & re-route flow
- Isolate flow
- Make flow private
- Remove flow

OpenFlow Switch



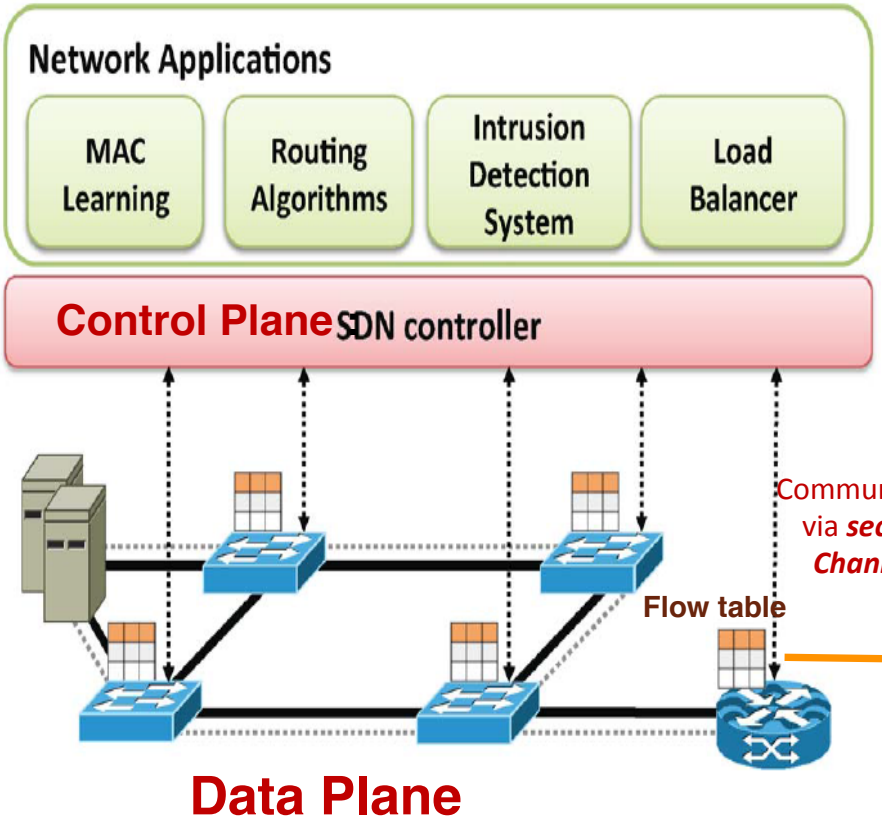
What is OpenFlow?

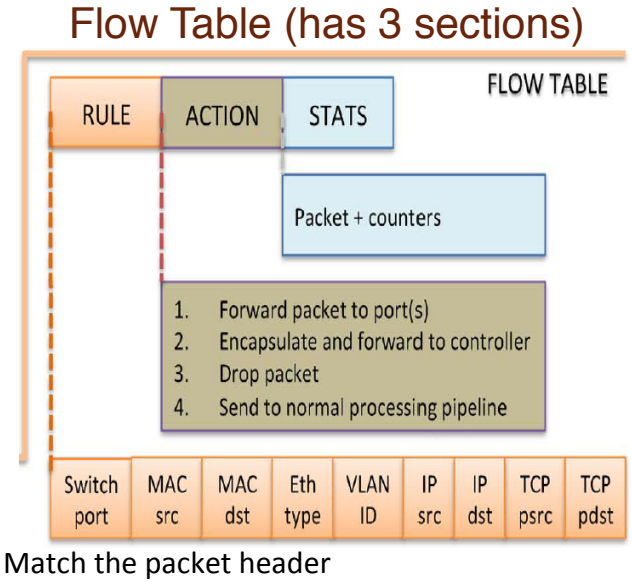
- Allow separation of control and data planes.
- Centralization of control.
- Flow based control.
- Takes advantage routing tables in Ethernet switches and routers.

- SDN is not OpenFlow.
  - **SDN** is a concept of the physical separation of the network control plane from the forwarding plane, and where a control plane controls several devices.
  - ***OpenFlow*** is communication interface between the control and data plane of an *SDN architecture*.
    - Allows direct access to and manipulation of the forwarding plane of network devices such as switches and routers, both physical and virtual.
    - Think of as a protocol used in switching devices and controllers interface.

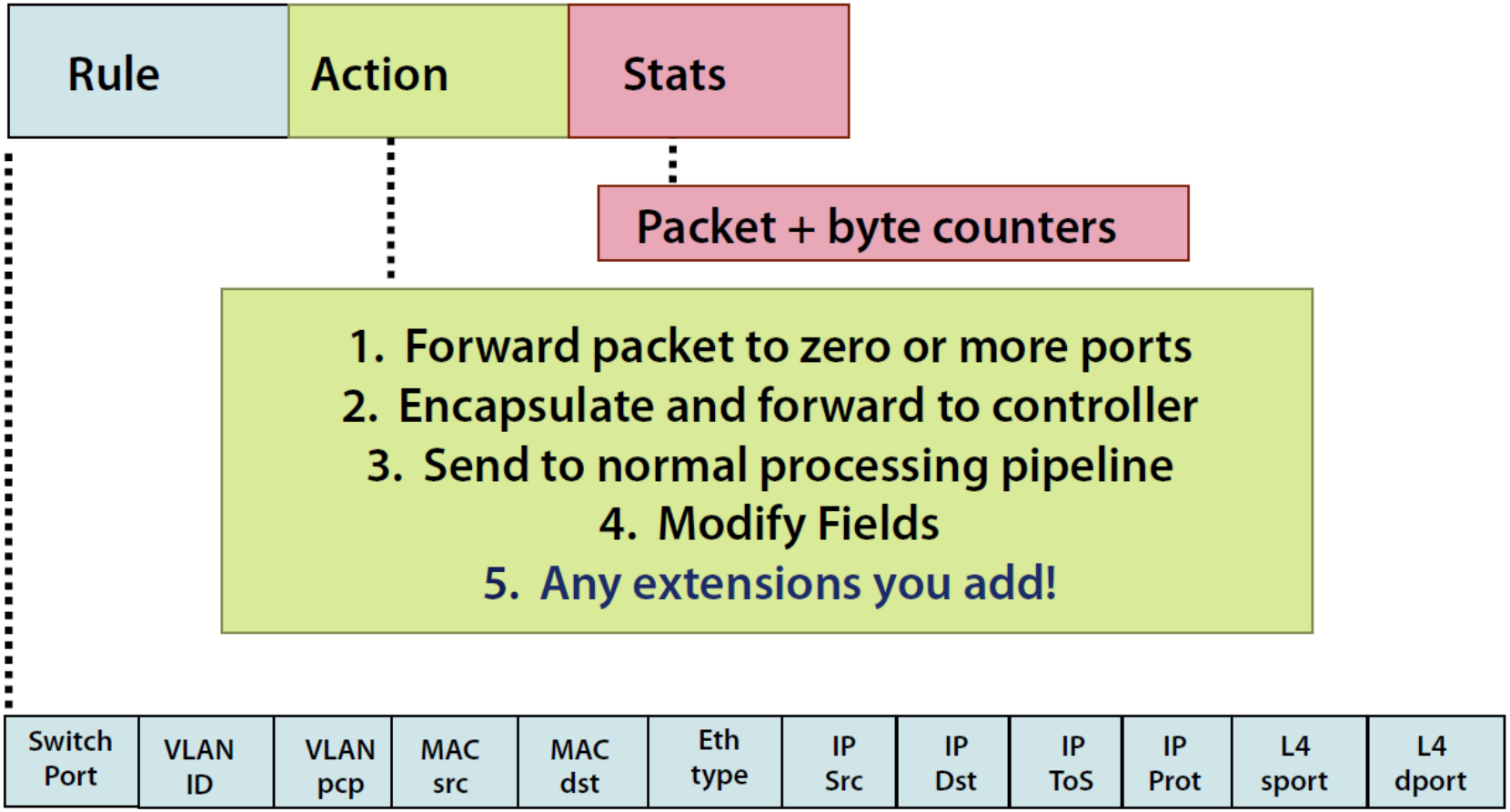
Basic OpenFlow: How Does it Work?

- Controller manages the traffic (network flows) by manipulating the flow table at switches.
  - Instructions are stored in flow tables.
- When packet arrives at switch, match the header fields with flow entries in a flow table.
- If any entry matches, performs indicated actions and update the counters.
- If Does not match, Switch asks controller by sending a message with the packet header.

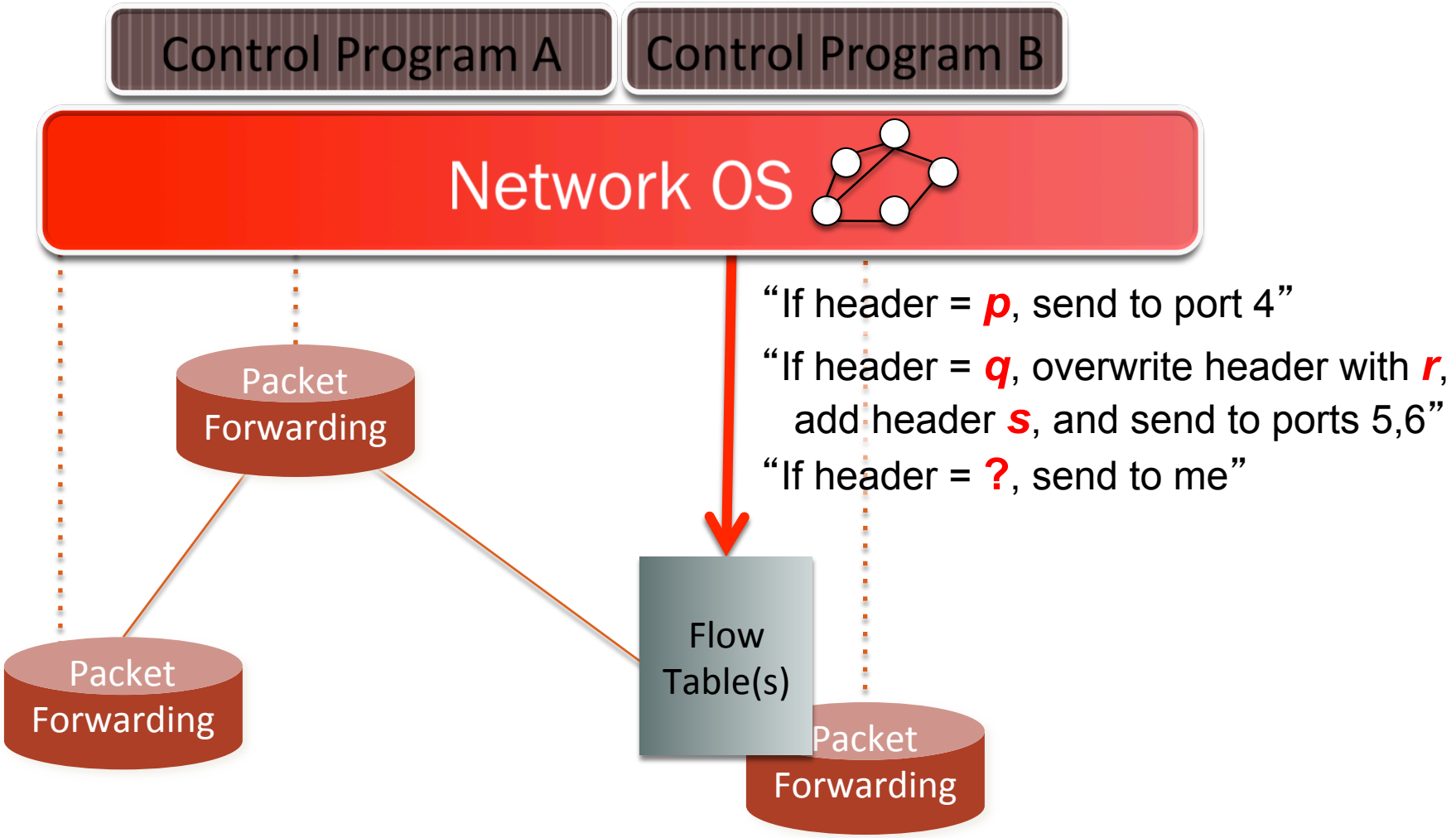




Flow Table


Rule
Action
Stats
Packet + byte counters
1. Forward packet to zero or more ports
2. Encapsulate and forward to controller
3. Send to normal processing pipeline
4. Modify Fields
5. Any extensions you add!
Switch Port
VLAN ID
VLAN pcp
MAC src
MAC dst
Eth type
IP Src
IP Dst
IP ToS
IP Prot
L4 sport
L4 dport

OpenFlow Rules



OpenFlow Table: Basic Actions

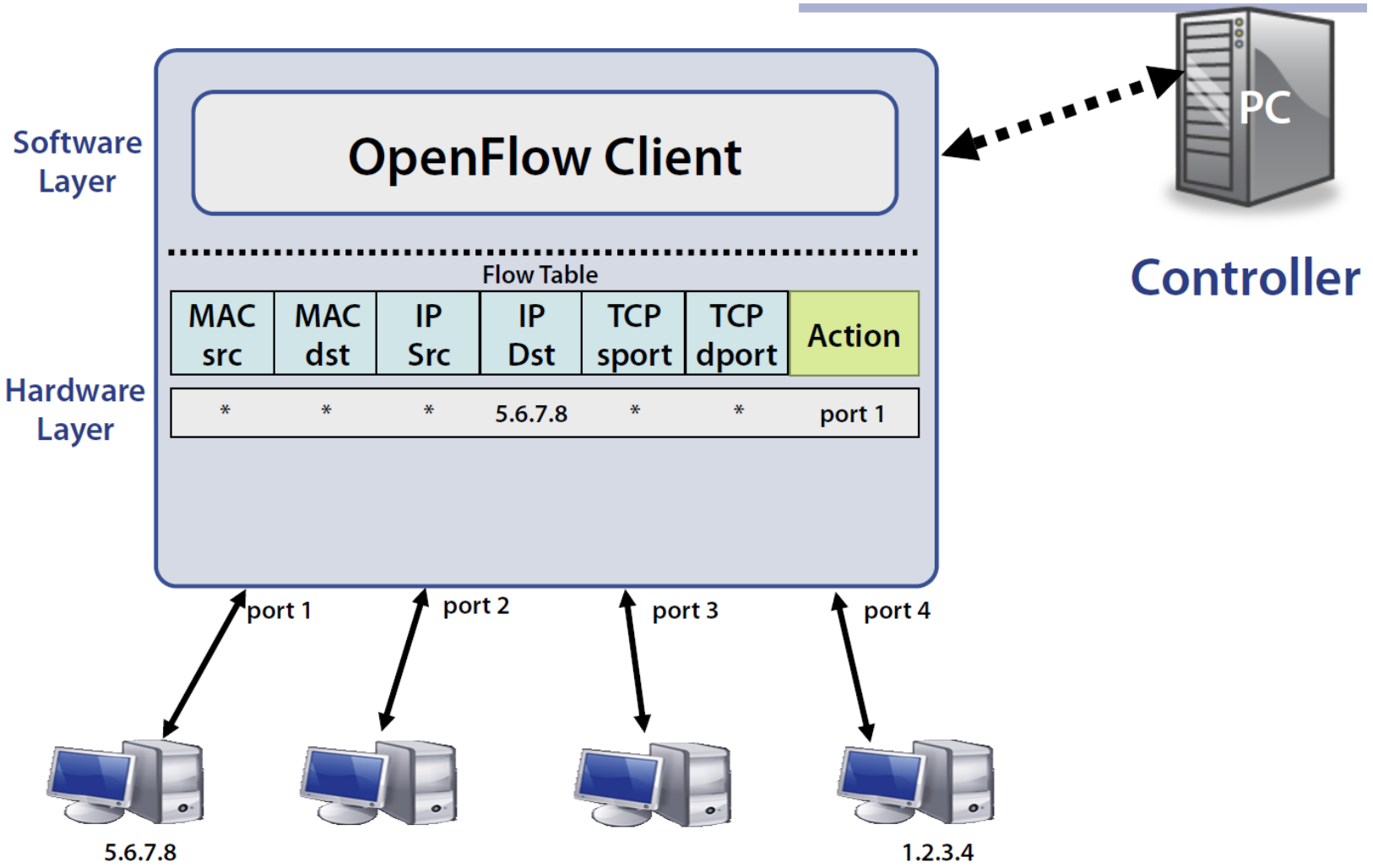
- All: To all interfaces except incoming interface.
- Controller: Encapsulate and send to controller.
- Local: send to its local networking stack.
- Table: Perform actions in the next flow table (table chaining or multiple table instructions).
- In_port: Send back to input port.
- Normal: Forward using traditional Ethernet.
- Flood: Send along minimum spanning tree except the incoming interface.

OpenFlow Table: Basic Stats

Per Table	Per Flow	Per Port	Per Queue
Active Entries	Received Packets	Received Packets	Transmit Packets
Packet Lookups	Received Bytes	Transmitted Packets	Transmit Bytes
Packet Matches	Duration (Secs)	Received Bytes	Transmit overrun errors
	Duration (nanosecs)	Transmitted Bytes	
		Receive Drops	
		Transmit Drops	
		Receive Errors	
		Transmit Errors	
		Receive Frame Alignment Errors	
		Receive Overrun erorrs	
		Receive CRC Errors	
		Collisions	

- Provide counter for incoming flows or packets.
- Information on counter can be retrieved to control plane.
- Can be used to monitor network traffic.

Example


Software Layer
OpenFlow Client
Flow Table
MAC src
MAC dst
IP Src
IP Dst
TCP sport
TCP dport
Action
Hardware Layer
* * * 5.6.7.8 * * port 1
PC
Controller
port 1
port 2
port 3
port 4
5.6.7.8
1.2.3.4

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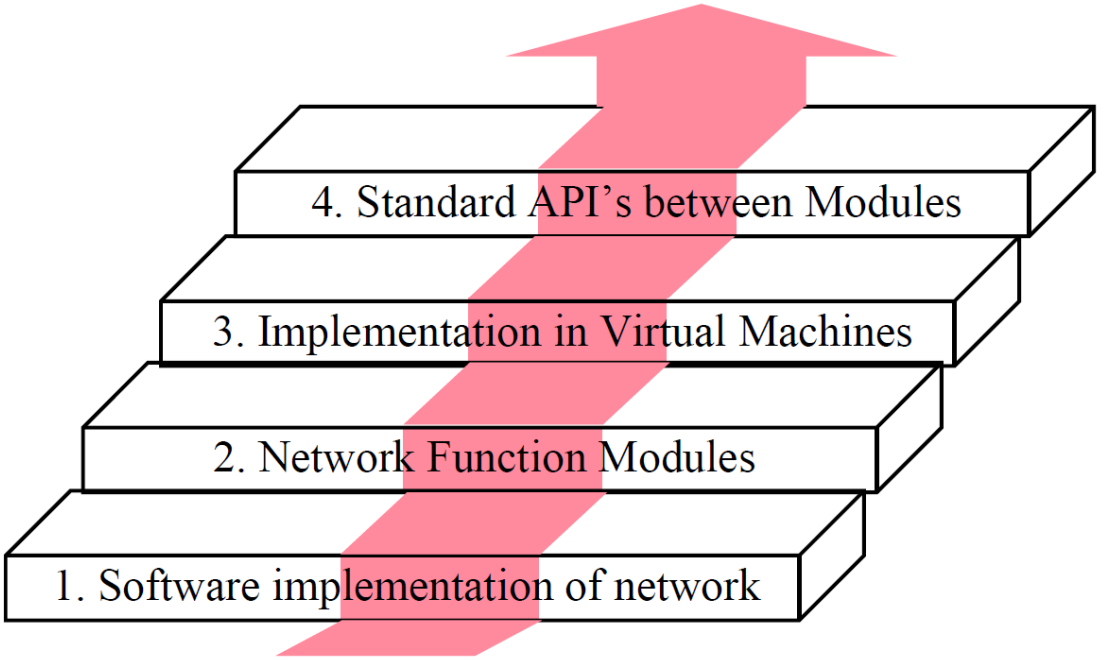
Virtualisation in the Networks

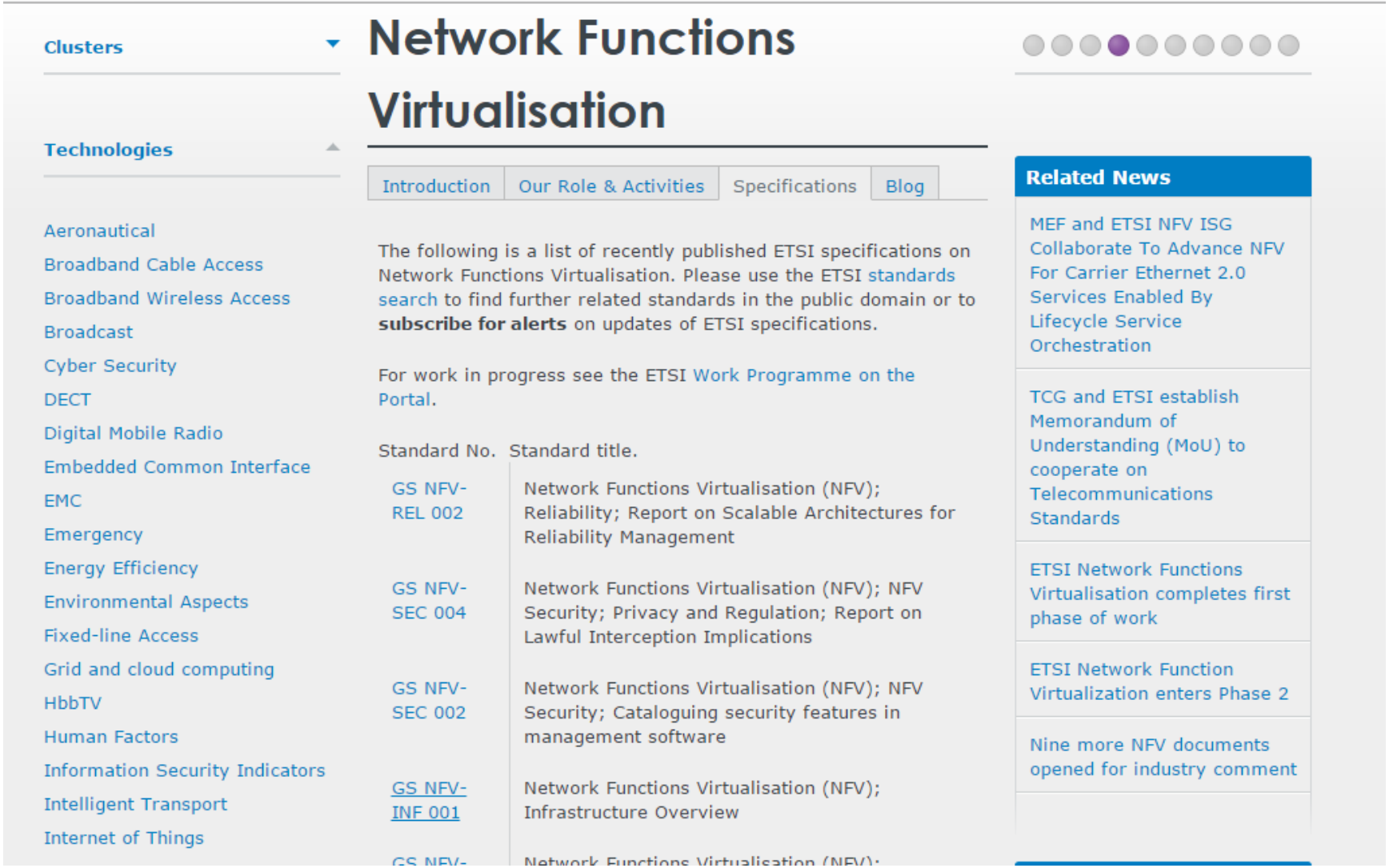
- Implementing Network Functions in Software – in VMs
- Similar advantages of virtualisation in other domains:
  - Better utilisation of resources
    - Using network resource without worrying about where it is physically located, how much it is, how it is organised, etc.
  - Programmability
    - Ability to change behaviour on the fly.
  - Dynamic Scaling
    - Ability to change size, quantity.
  - Performance
    - Optimising network device utilisation
  - Many others.

Network Function Virtualisation (NFV)

- Network Function Virtualisation (NFV)
- New ISG (Industry Specification Group) in ETSI (European Telecom Standards Institute) set up in November 2012.



ETSI NFV



Clusters

Technologies

- Aeronautical
- Broadband Cable Access
- Broadband Wireless Access
- Broadcast
- Cyber Security
- DECT
- Digital Mobile Radio
- Embedded Common Interface
- EMC
- Emergency
- Energy Efficiency
- Environmental Aspects
- Fixed-line Access
- Grid and cloud computing
- HbbTV
- Human Factors
- Information Security Indicators
- Intelligent Transport
- Internet of Things

Network Functions Virtualisation

Introduction | Our Role & Activities | Specifications | Blog

The following is a list of recently published ETSI specifications on Network Functions Virtualisation. Please use the ETSI standards search to find further related standards in the public domain or to **subscribe for alerts** on updates of ETSI specifications.

For work in progress see the ETSI Work Programme on the Portal.

Standard No.	Standard title.
GS NFV-REL 002	Network Functions Virtualisation (NFV); Reliability; Report on Scalable Architectures for Reliability Management
GS NFV-SEC 004	Network Functions Virtualisation (NFV); NFV Security; Privacy and Regulation; Report on Lawful Interception Implications
GS NFV-SEC 002	Network Functions Virtualisation (NFV); NFV Security; Cataloguing security features in management software
GS NFV-INF 001	Network Functions Virtualisation (NFV); Infrastructure Overview

Related News

- MEF and ETSI NFV ISG Collaborate To Advance NFV For Carrier Ethernet 2.0 Services Enabled By Lifecycle Service Orchestration
- TCG and ETSI establish Memorandum of Understanding (MoU) to cooperate on Telecommunications Standards
- ETSI Network Functions Virtualisation completes first phase of work
- ETSI Network Function Virtualization enters Phase 2
- Nine more NFV documents opened for industry comment

http://www.etsi.org/technologies-clusters/technologies/nfv

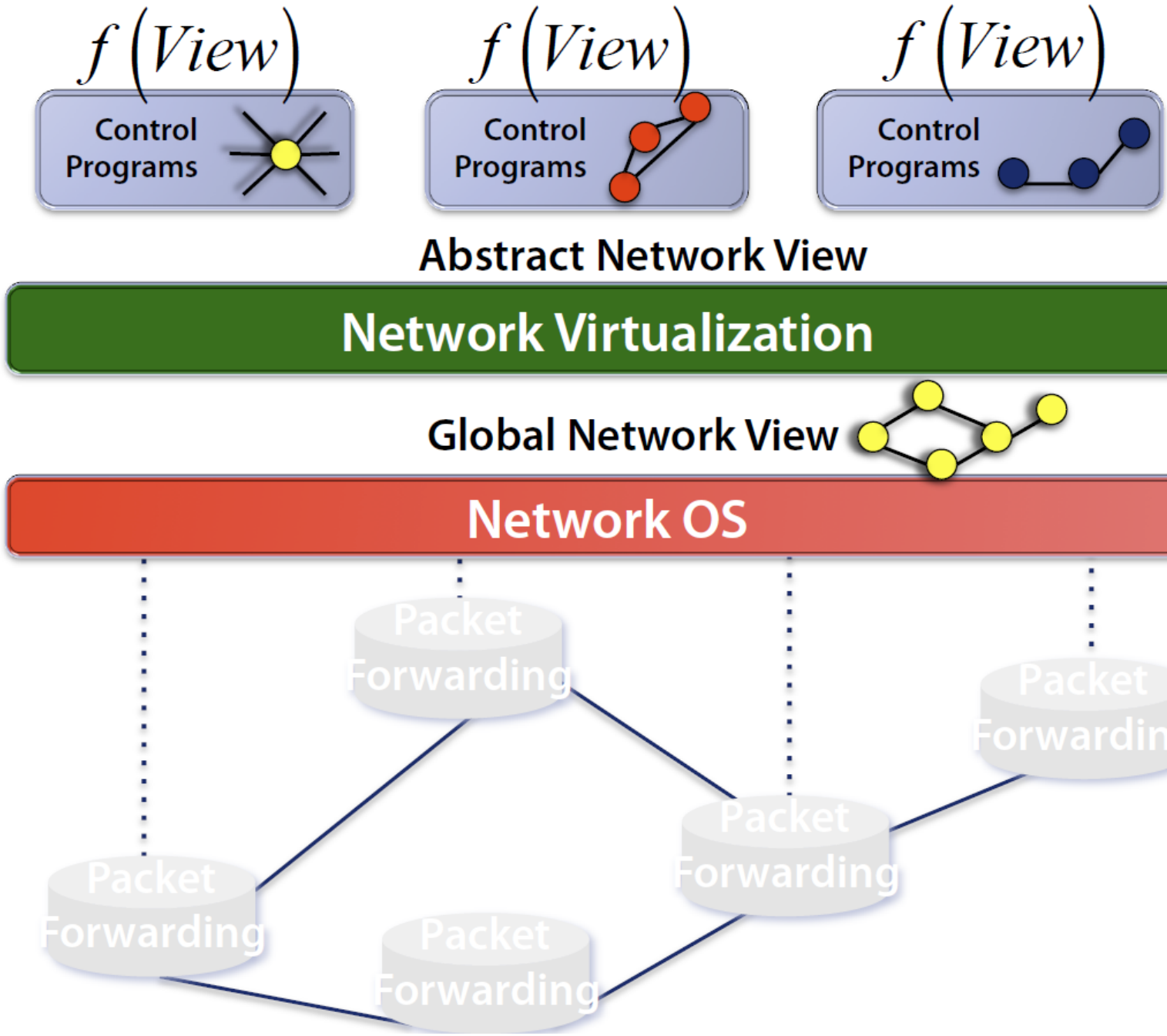
Example: Ways to Exploit Router Virtualisation

- Exploiting the new capabilities in routers
  - Separation of the physical from the logical
  - Ability to run multiple routers in parallel
- Example: virtual router migration
  - Moving router from one physical node to another
  - E.g., for planned maintenance or service roll-out
- Example: bug-tolerant routers
  - Running multiple instances of routing software
  - … and "voting" to protect the system from bugs

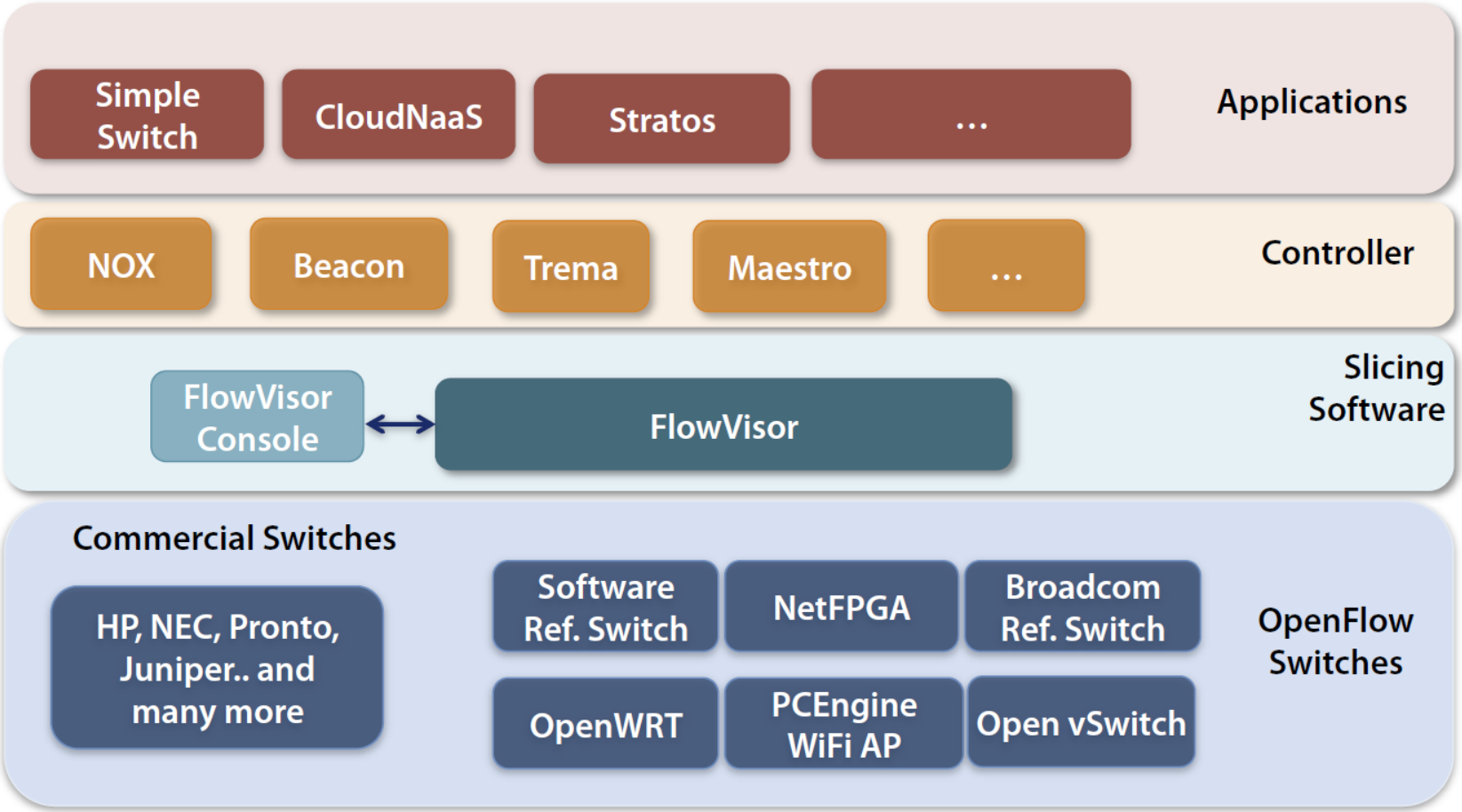
Current Internet & NFV

- Internet architecture
  - End-to-end argument
  - Best-effort packet-delivery service
  - Narrow waist of IP
  - Separation of intra-domain from inter-domain

- Virtualised networks
  - Complete control within a virtual network
  - Different (virtual) networks for different services


f (View)
Control Programs
f (View)
Control Programs
f (View)
Control Programs
Abstract Network View
Network Virtualization
Global Network View
Network OS
Packet Forwarding
Packet Forwarding
Packet Forwarding
Packet Forwarding
Packet Forwarding

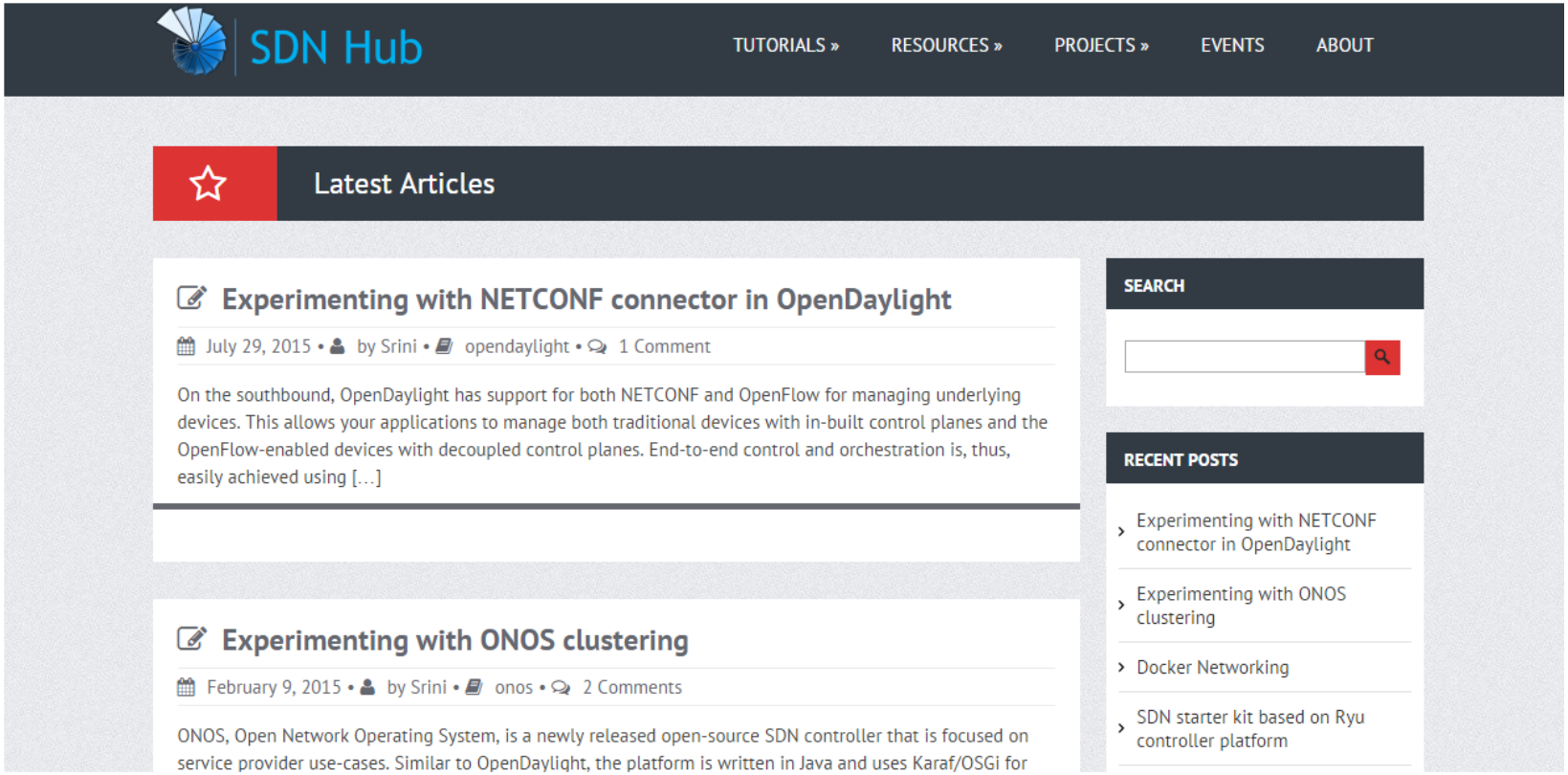
SDN Stack


Simple Switch
CloudNaaS
Stratos
…
Applications
NOX
Beacon
Trema
Maestro
…
Controller
FlowVisor Console
FlowVisor
Slicing Software
Commercial Switches
HP, NEC, Pronto, Juniper.. and many more
Software Ref. Switch
NetFPGA
Broadcom Ref. Switch
OpenWRT
PCEngine WiFi AP
Open vSwitch
OpenFlow Switches

Highlights

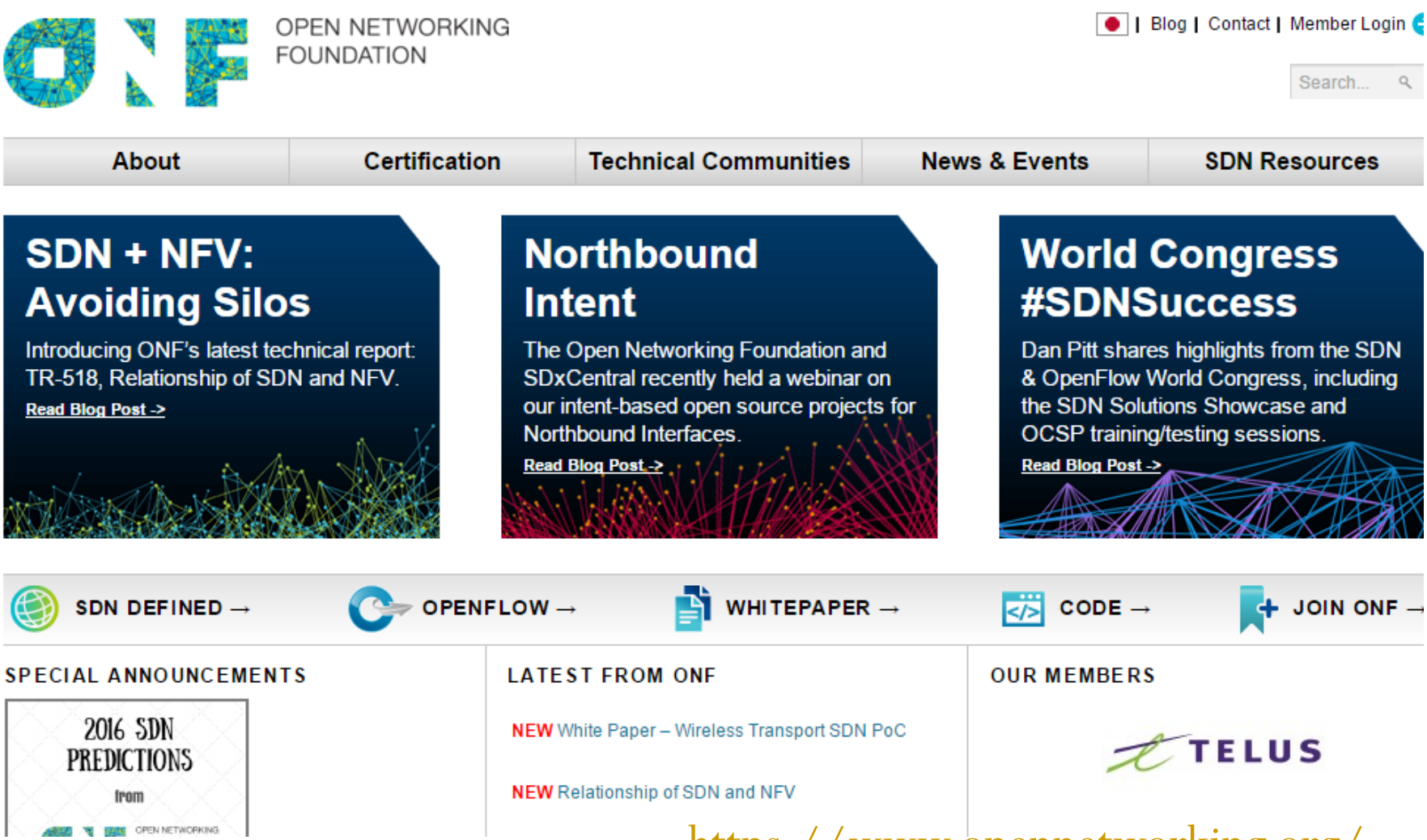
- SDN empower network owners and operators
  - Customise networks to local needs
  - Eliminate unneeded features
  - Creation of virtual, isolated networks
- Increase the pace of innovation
  - Innovation at software speed
  - Technology exchange with partners
  - Technology transfer from universities
- Networks becoming
  - More programmable
  - Faster changing, to meet operator needs
  - Lower cost, power, etc.

tips and tutorials for practical works



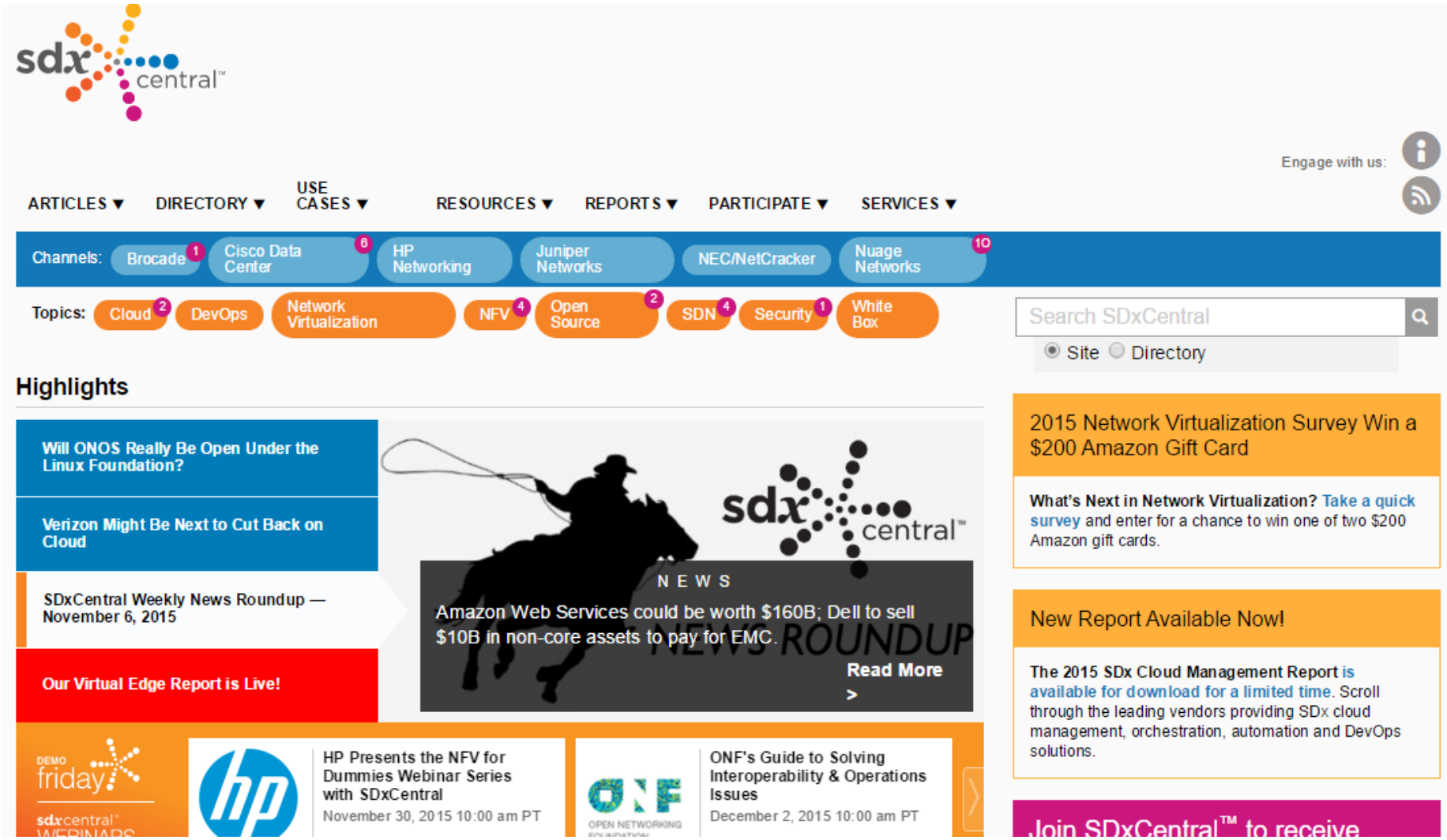
http://sdnhub.org/

standards as they evolve



https://www.opennetworking.org/

On Topic discussions



https://www.sdncentral.com/

The Internet: A Remarkable Story

- Tremendous success
- The brilliance of under-specifying
  - Best-effort packet delivery service
  - Key functionality at programmable end hosts
- Enabled massive growth and innovation
- But, change is easy only at the edge!!

Other Approaches

A New Way to Look at Networking by Van Jacobson

https://www.youtube.com/watch?v=oCZMoY3q2uM

Extra Reading

- SDN and OpenFlow, A Tutorial
  - https://www.clear.rice.edu/comp529/www/papers/tutorial_4.pdf

- Part 1: Cloud Computing – A Premier
  - http://www.cisco.com/web/about/ac123/ac147/archived_issues/ipj_12-3/123_cloud1.html