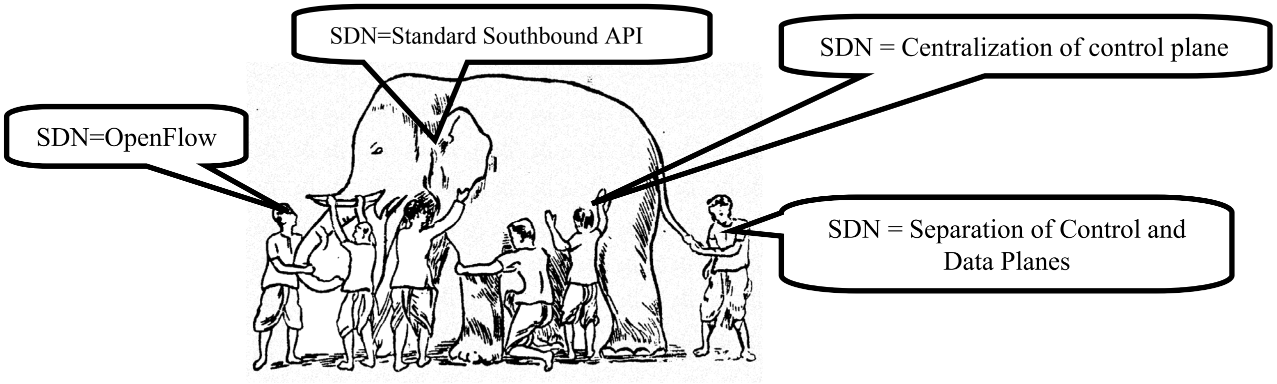
Introduction to Software Defined Networking (SDN)


SDN=Standard Southbound API
SDN = Centralization of control plane
SDN=OpenFlow
SDN = Separation of Control and Data Planes

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These slides and audio/video recordings of this class lecture are at:

http://www.cse.wustl.edu/~jain/cse570-15/

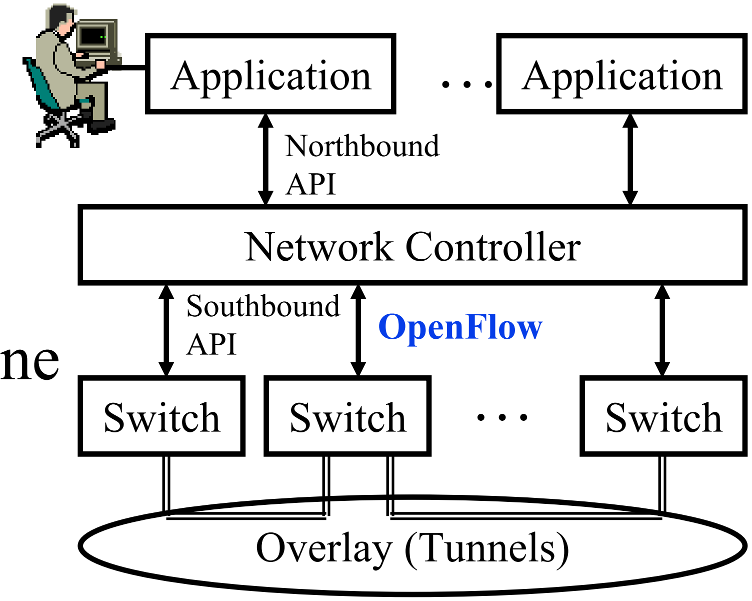
Overview

1. What is SDN?
2. SDN Controllers
3. Alternative APIs: XMPP, PCE, ForCES, ALTO
4. RESTful APIs and OSGi Framework

Note: This is the second module of three modules on OpenFlow, SDN and NFV in this course.

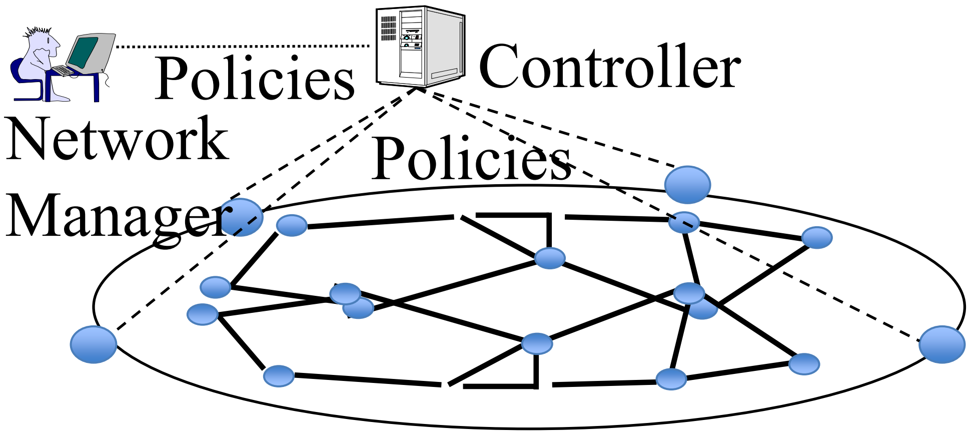
Origins of SDN

- ❑ SDN originated from OpenFlow
- ❑ Centralized Controller
  ⇒ Easy to program
  ⇒ Change routing policies on the fly
  ⇒ Software Defined Network (SDN)
- ❑ Initially, SDN=
  - ➢ Separation of Control and Data Plane
  - ➢ Centralization of Control
  - ➢ OpenFlow to talk to the data plane
- ❑ Now the definition has changed significantly.



Three Features that Define SDN

1. **Abstract the Hardware**: No dependence on physical infrastructure. Software API.
2. **Programmable**: Shift away from static manual operation to fully configurable and dynamic
3. **Centralized Control of Policies**: Policy delegation and management



What = Why We need SDN?

1. **Virtualization**: Use network resource without worrying about where it is physically located, how much it is, how it is organized, etc. Abstraction ⇒ Virtualization.
2. **Orchestration**: Should be able to control and manage thousands of devices with one command.
3. **Programmable**: Should be able to change behavior on the fly.
4. **Dynamic Scaling**: Should be able to change size, quantity Virtualization ⇒ Scaling
5. **Automation**: To lower OpEx minimize manual involvement
   - Troubleshooting
   - Reduce downtime
   - Policy enforcement
   - Provisioning/Re-provisioning/Segmentation of resources
   - Add new workloads, sites, devices, and resources

Why We need SDN? (Cont)

6. **Visibility**: Monitor resources, connectivity
7. **Performance**: Optimize network device utilization
   - Traffic engineering/Bandwidth management
   - Capacity optimization
   - Load balancing
   - High utilization
   - Fast failure handling
8. **Multi-tenancy**: Tenants need complete control over their addresses, topology, and routing, security
9. **Service Integration**: Load balancers, firewalls, Intrusion Detection Systems (IDS), provisioned on demand and placed appropriately on the traffic path

Why We need SDN? (Cont)

10. **Openness**: Full choice of “How” mechanisms
⇒ Modular plug-ins
⇒ Abstraction:

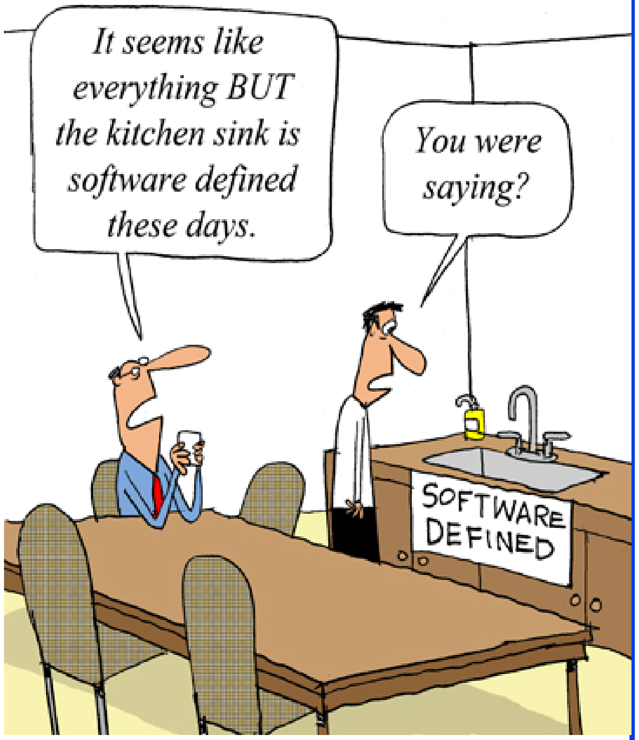
- Abstract = Summary = Essence = General Idea
⇒ Hide the details.
- Also, abstract is opposite of concrete
⇒ Define tasks by APIs and not by how it should be done. E.g., send from A to B. Not OSPF.

Ref: http://www.networkworld.com/news/2013/110813-onug-sdn-275784.html

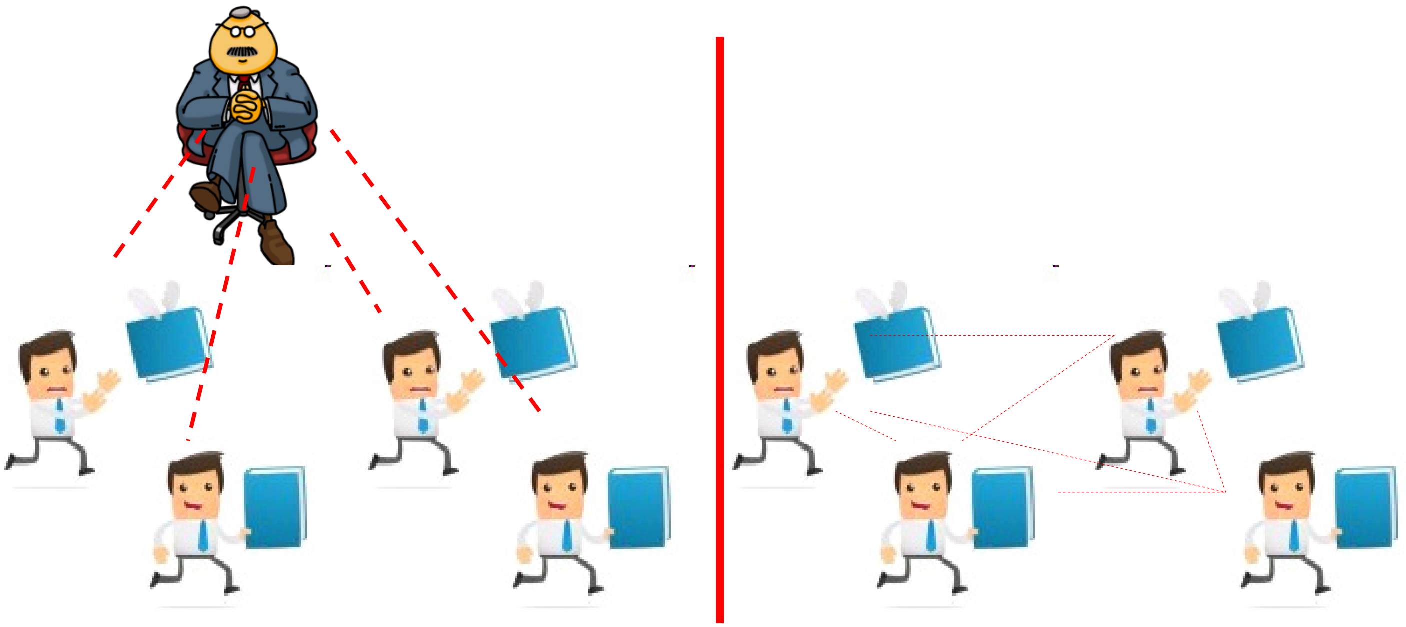
Ref: Open Data Center Alliance Usage Model: Software Defined Networking Rev 1.0,” http://www.opendatacenteralliance.org/docs/Software_Defined_Networking_Master_Usage_Model_Rev1.0.pdf

Software Defined Anything (SDx)

- Tsunami of software defined things
  - Software Defined Networking (SDN)
  - Software Defined Datacenter (SDDC)
  - Software Defined Storage (SDS)
  - Software Defined Compute (SDC)
  - Software Defined Infrastructure (SDI)


It seems like everything BUT the kitchen sink is software defined these days.
You were saying?
SOFTWARE DEFINED

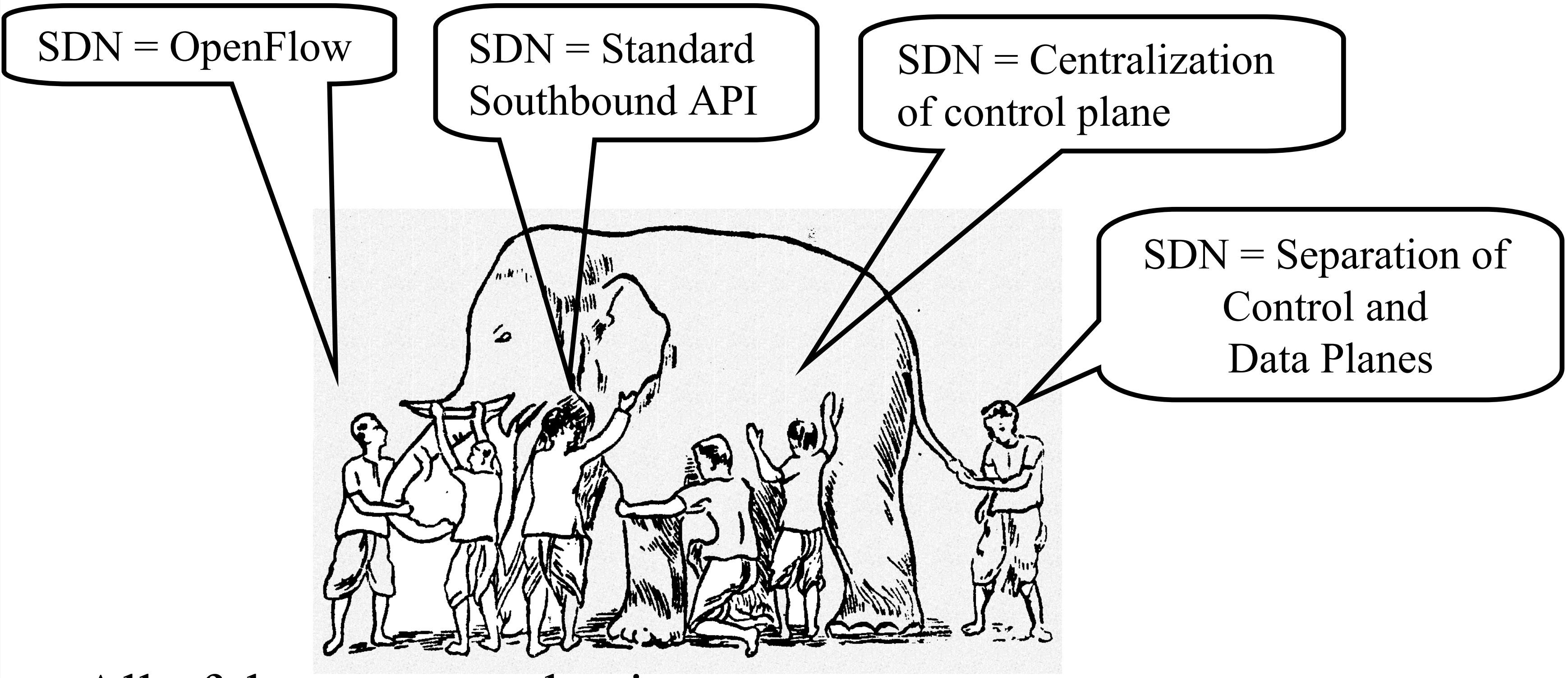
Centralized vs. Distributed



- ❑ Fast Response to changes
- ❑ Fast Consistency
- ❑ Less overhead ⇒ Scalable
- ❑ Single Point of Failure

- ❑ Time to converge
- ❑ Slow consistency
- ❑ Not scalable
- ❑ Fault Tolerant

What SDN is Not?



SDN = OpenFlow

SDN = Standard Southbound API

SDN = Centralization of control plane

SDN = Separation of Control and Data Planes

- ❑ All of these are mechanisms.
- ❑ SDN is *not* about a mechanism.
- ❑ It is a framework ⇒ Many solutions

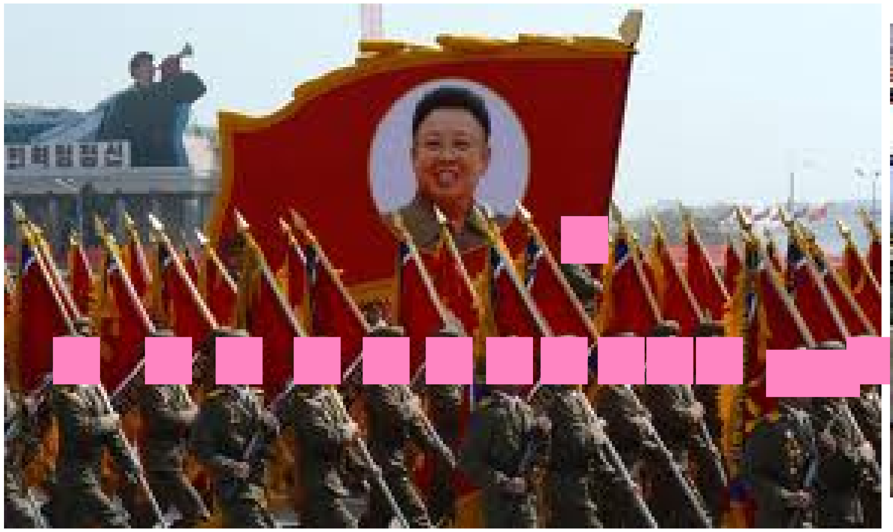
Four Confusions About SDN

1. Policies vs. Control:
   Control = All bits and messages not sent by the user
   In IP, control includes all header bits and all routing messages.
2. Separation of Control Plane:
   Elements have only data plane and have no brains
3. SDN vs. OpenFlow:
   OpenFlow is the father of SDN but not SDN.
4. Need OpenFlow:
   - OpenFlow is micro-management.
   - It is not scalable.
   - For large infrastructure, need scalable solutions.

Separation vs. Centralization

Separation of Control Plane

Centralization of Policies



Micromanagement is not scalable

Current SDN Debate: What vs. How?

1. SDN is easy if control is centralized but not necessary. Distributed/hierarchical solutions may be required for fail-safe operation.
2. Complete removal of control plane may be harmful. Exact division of control plane between centralized controller and distributed forwarders is yet to be worked out

Current SDN Debate: What vs. How? (Cont)

3. SDN is easy with a standard southbound protocol like OpenFlow but one protocol may not work/scale in all cases
    1. Diversity of protocols is a fact of life.
    2. There are no standard operating systems, processors, routers, or Ethernet switches.
4. If industry finds an easier way to solve the same problems by another method, that method may win. E.g., ATM vs. MPLS.

Flavors of SDN

1. OpenDaylight: Multi-Protocol Southbound
2. Bare Metal Switches + Network Operating System
   1. Switches from Dell, Edgecore, HP, Penguin, QCT, Agema, Supermicro
   2. Open Network Install Environment (ONIE)
   3. Network operating system: Alcatel-Lucent, Arista, Big Switch, Broadcom, Brocade, Cisco, Cumulus, Dell, Ericsson, Extreme, HP, Juniper, OCP, Pica8, Pluribus
3. Network Virtualization/Overlay: VMWare's NSX
4. ONF SDN: OpenFlow southbound

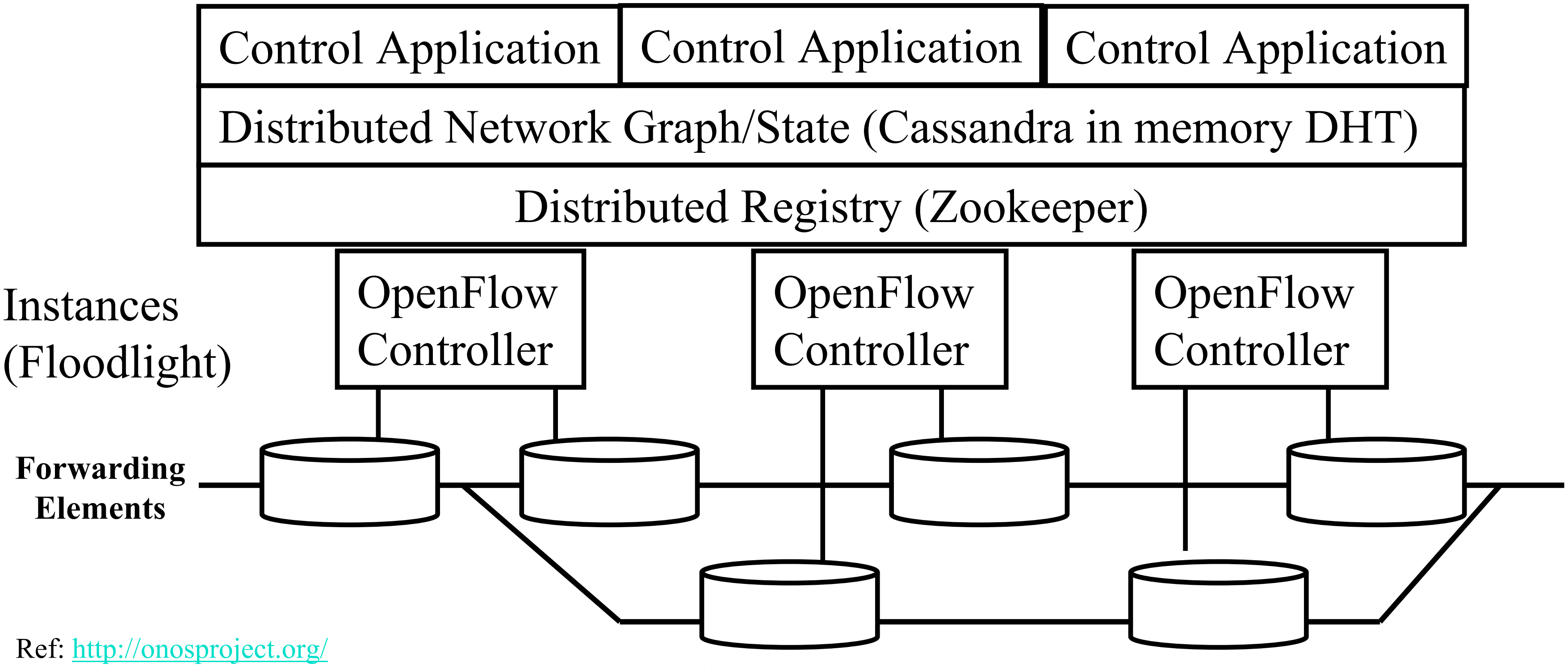
All provide: Abstraction, Programmability, and Centralization

Ref: http://cumulusnetworks.com/support/linux-hardware-compatibility-list/ , http://onie.org/

Source: Alan J Weissberger

ONOS

- Open Network Operating System:
  Distributed OpenFlow OS for a large WAN
- 8-10 instances in a cluster.
  Each Instance responsible for a part of a network



Control Application | Control Application | Control Application

Distributed Network Graph/State (Cassandra in memory DHT)

Distributed Registry (Zookeeper)

Instances (Floodlight)

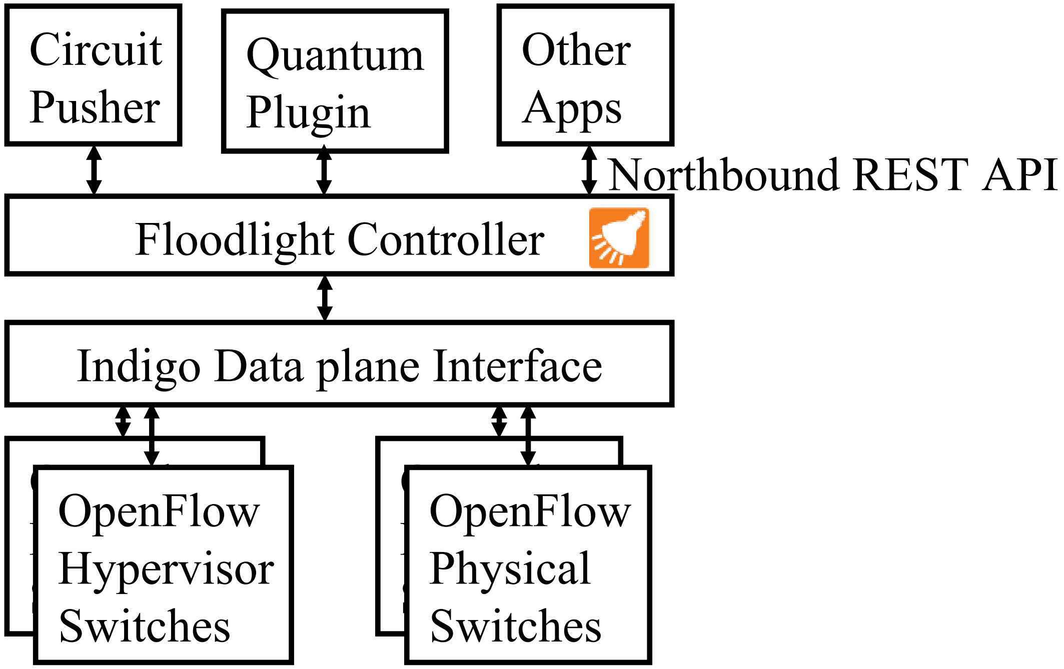
OpenFlow Controller | OpenFlow Controller | OpenFlow Controller

Forwarding Elements

Ref: http://onosproject.org/

Floodlight

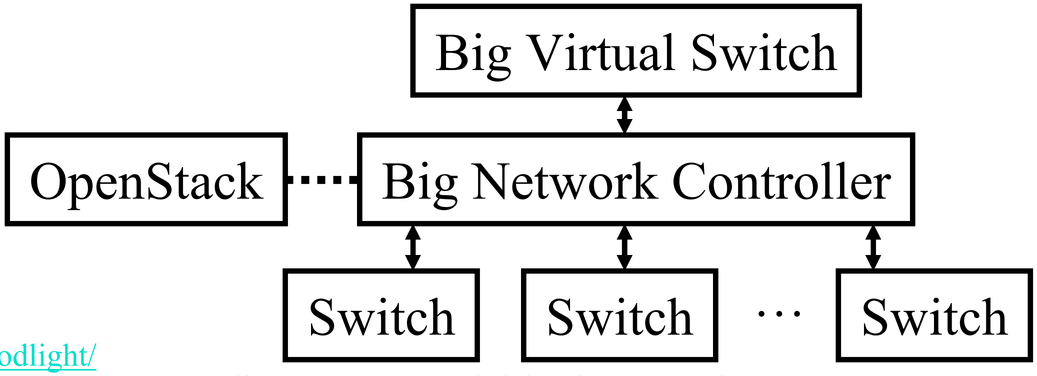
- **Java** based OpenFlow controller based on Beacon runs within a JVM. Developers from Big Switch Networks
- Indigo: Software to make switch hardware OpenFlow compatible
- Floodlight is the core of Big Switch Controller from Big Switch Networks


Circuit Pusher
Quantum Plugin
Other Apps
Northbound REST API
Floodlight Controller
Indigo Data plane Interface
OpenFlow Hypervisor Switches
OpenFlow Physical Switches

Ref: S. Azodolmolky, "Software Defined Networking with OpenFlow," Packt Publishing, October 2013, 152 pp., ISBN:978-1-84969-872-6 (Safari Book)

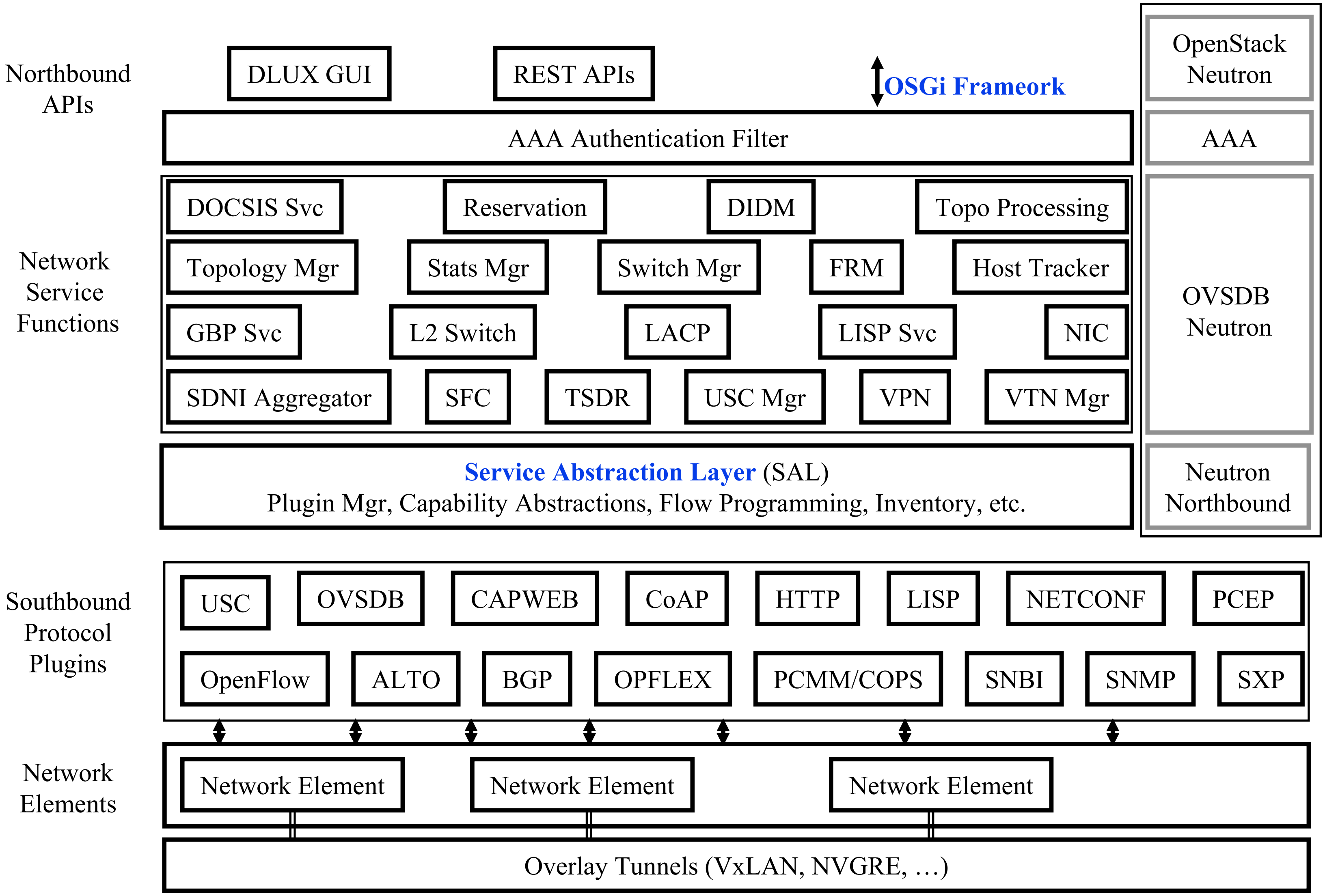
Floodlight (Cont)

- A number of real-world networking applications
  - **Neutron plug-in** for OpenStack cloud management system
  - **Static Flow Pusher**: Allows users to manually insert flows
  - **Circuit Pusher**: Creates permanent entries on all switches along the path
  - **Firewall**: Enforces access control list (ACL) rules on packets
  - **Big Virtual Switch:** Automates network provisioning for a large scale data centers. Includes provisioning, multi-tenant partitioning



Ref: http://www.projectfloodlight.org/floodlight/

OpenDaylight: Multi-Protocol SDN



OpenDaylight SDN Controller Platform (OSCP)

- Multi-company collaboration under Linux foundation
- Many projects including OpenDaylight Controller
- **NO-OpenFlow** (Not Only OpenFlow): Supports multiple southbound protocols via plug-ins including OpenFlow
- Dynamically linked in to a Service Abstraction Layer (SAL) Abstraction ⇒ SAL figures out how to fulfill the service requested by higher layers irrespective of the southbound protocol
- Modular design using **OSGI framework**
- A rich set of North-bound APIs via RESTful services for loosely coupled applications and OSGI services for co-located applications using the same address space

Ref: https://wiki.opendaylight.org/view/Main_Page

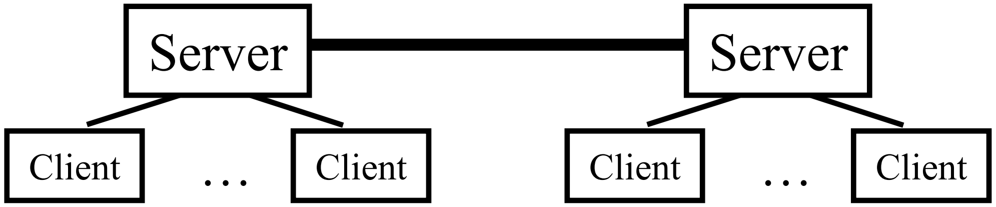
Examples Alternative APIs

- Southbound APIs: XMPP (Juniper), OnePK (Cisco)
- Northbound APIs: I2RS, I2AEX, ALTO,
- Overlay: VxLAN, TRILL, LISP, STT, NVO3, PWE3, L2VPN, L3VPN
- Configuration API: NETCONF
- Controller: PCE, ForCES

Ref: T. Nadeau and K. Gray, "SDN," O'Reilly, 2013, 384 pp, ISBN:978-1-449-34230-2 (Safari Book)

XMPP

- Extensible Messaging and Presence Protocol
- **Extensible** ⇒ Using XML
- Similar to SMTP email protocol but for near real-time communication
- Each client has an ID, e.g., john@wustl.edu/mobile (John's mobile phone)
- Client sets up a connection with the server ⇒ Client is online
- **Presence**: Server maintains contact addresses and may let other contacts know that this client is now on-line
- **Messaging**: When a client sends a "chat" message to another clients, it is forwarded to these other clients
- Messages are "*pushed*" (⇒ real-time) as opposed to "*polled*" as in SMTP/POP emails.



Ref: P. Saint-Andre, et al., "XMPP: The Definitive Guide," O'Reilly, 2009, 320 pp., ISBN:9780596521264 (Safari Book)

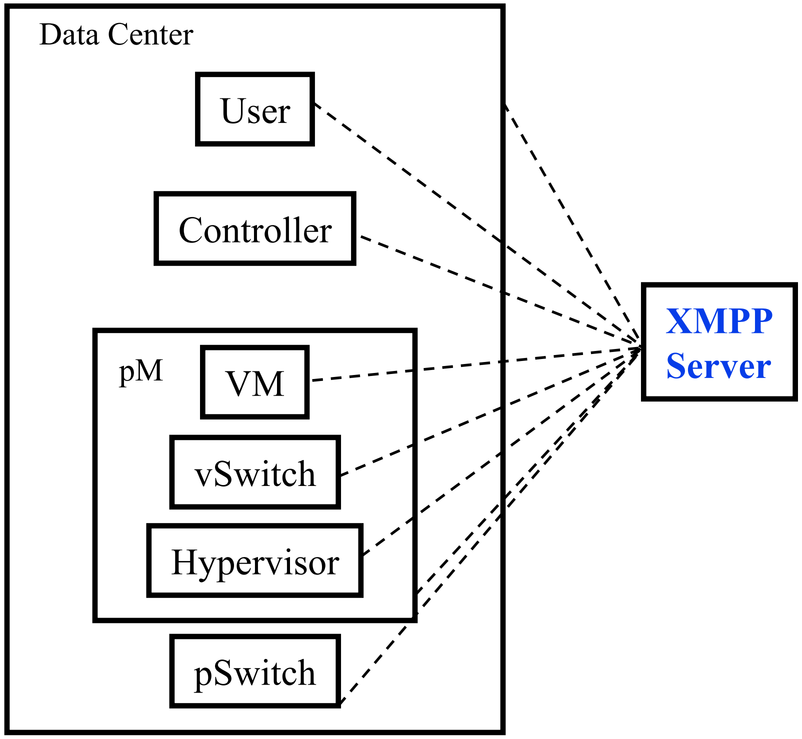
XMPP (Cont)

- XMPP is IETF standardization of Jabber protocol
- RFC 6121 defines XMPP using TCP connections.
  But HTTP is often used as transport to navigate firewalls
- All messages are XML encoded
  ⇒ Not efficient for binary file transfers
  ⇒ Out-of-band binary channels are often used with XMPP.
- A number of open-source implementations are available
- Variations of it are widely used in most instant messaging programs including Google, Skype, Facebook, …, many games
- Used in IoT and data centers for management. Network devices have XMPP clients that respond to XMPP messages containing CLI management requests ⇒ You can manage your network using any other XMPP client, e.g., your mobile phone
- Arista switches can be managed by XMPP, Juniper uses XMPP as a southbound protocol for SDN

Ref: http://en.wikipedia.org/wiki/XMPP

XMPP in Data Centers

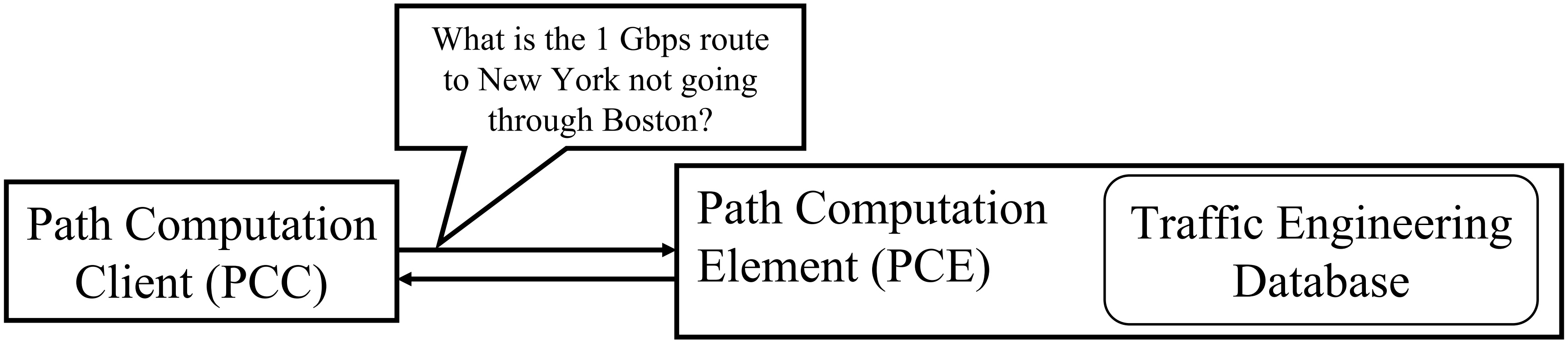
- Everything is an XMPP entity.
  It has its own contact list and authorizations.



Ref: https://github.com/ArchipelProject/Archipel/wiki/Architecture-%26-Concepts

Path Computation Element (PCE)

- MPLS and GMPLS require originating routers to find paths that satisfy multiple constraints including not using any backup routers and having a given bandwidth etc.
- This may require more computer power or network knowledge than a router may have.
- IETF PCE working group has developed a set of protocols that allow a Path computation client (PCC), i.e., router to get the path from path computation element (PCE)
- PCE may be centralized or may be distributed in many or every router.


What is the 1 Gbps route to New York not going through Boston?

Path Computation Client (PCC)
Path Computation Element (PCE)
Traffic Engineering Database

PCE (Cont)

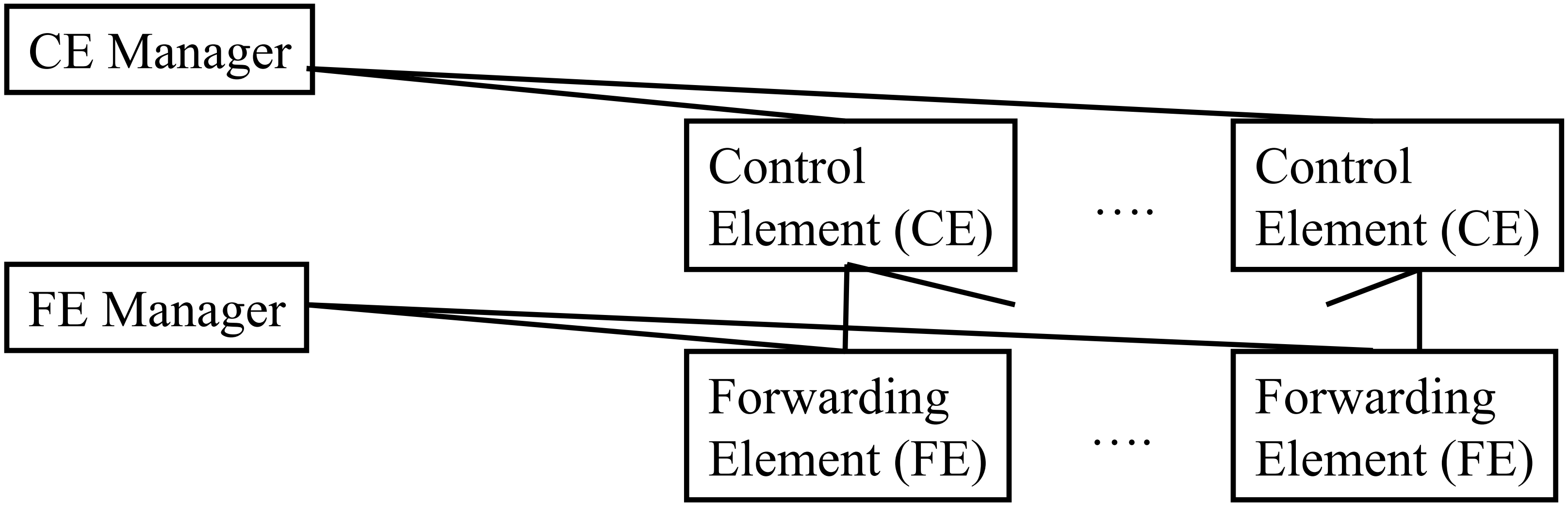
- PCE separates the route computation function from the forwarding function.
- Both functions may be resident in the same box or different boxes.
- 25+ RFCs documenting protocols for:
  - PCE-to-PCC communication
  - PCE-to-PCE communication (Multiple PCEs)
  - PCE discovery

Ref: http://datatracker.ietf.org/wg/pce/

Ref: http://en.wikipedia.org/wiki/Path_computation_element

Forwarding and Control Element Separation (ForCES)

- IETF working group since July 2001
- Control Elements (CEs) prepare the routing table for use by forwarding elements (FEs).
- Each CE may interact with one or more FEs
- There may be many CEs and FEs managed by a CE manager and a FE manager

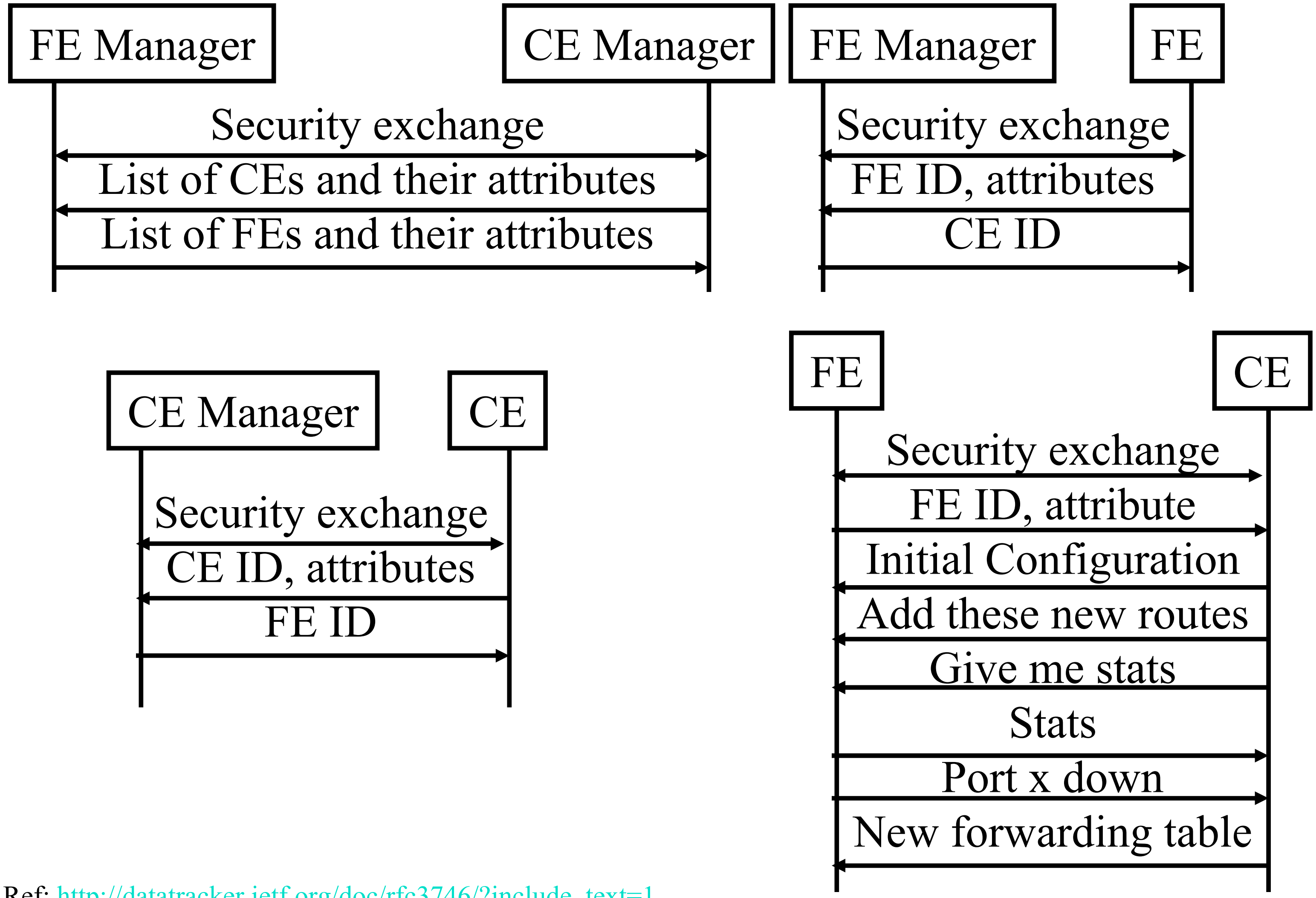


ForCES (Cont)

- Idea of control and data plane separation was used in BSD 4.4 *routing sockets* in early 1990s. It allowed routing tables to be controlled by a simple command line or by a route daemon.
- ForCES protocol supports exchange of:
  - Port type, link speed, IP address
  - IPv4/IPv6 unicast/multicast forwarding
  - QoS including metering, policing, shaping, and queueing
  - Packet classification
  - High-touch functions, e.g., Network Address Translation (NAT), Application-level Gateways (ALG)
  - Encryptions to be applied to packets
  - Measurement and reporting of per-flow traffic information

Ref: http://datatracker.ietf.org/doc/rfc3654/?include_text=1

Sample ForCES Exchanges



FE Manager

CE Manager

Security exchange

List of CEs and their attributes

List of FEs and their attributes

FE Manager

FE

Security exchange

FE ID, attributes

CE ID

CE Manager

CE

Security exchange

CE ID, attributes

FE ID

FE

CE

Security exchange

FE ID, attribute

Initial Configuration

Add these new routes

Give me stats

Stats

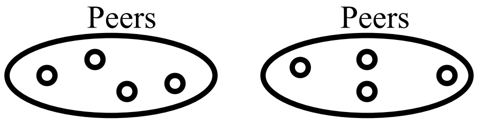
Port x down

New forwarding table

Ref: http://datatracker.ietf.org/doc/rfc3746/?include_text=1

Application Layer Traffic Optimization (ALTO)

- IETF working group to optimize P2P traffic
  ⇒ Better to get files from nearby peers



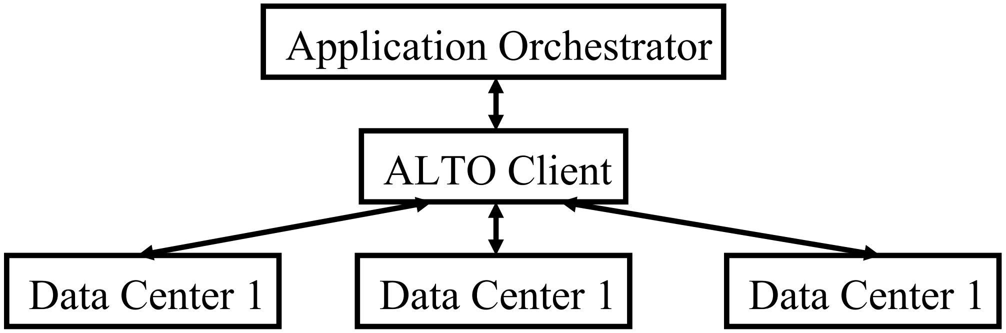
- Provide guidance in peer selection
- ALTO Server: Has knowledge of distributed resources
- ALTO Client: Requests information from servers about the appropriate peers
- Ratio Criteria: Topological distance, traffic charges, …
- ALTO Server could get information from providers or from nodes about their characteristics, e.g., flat-rate or volume based charging
- A client may get the list of potential peers and send it to the server, which can return a ordered list
- Also need a protocol for ALTO server discovery

Ref: J. Seedorf and E. Berger, "ALTO Problem Statement," http://datatracker.ietf.org/doc/rfc5693/?include_text=1

Ref: Y. Lee, et al., "ALTO Extensions for collecting Data Center Resource Information," http://datatracker.ietf.org/doc/draft-lee-alto-ext-dc-resource/?include_text=1

ALTO Extension

- Now being extended to locate resources in data centers
- Need to be able to express
  - resource (memory, storage, CPU, network) availability
  - Cost of these resources
  - Constraints on resources, e.g., bandwidth
  - Constraints on structure, e.g., Power consumption
- ALTO client gets the info from various providers
- Issue of privacy of resource and cost info for the provider



OpenDaylight Tools

1. **Applications**: Provides Virtual Network Segments (VNS) for each tenant
    1. OpenDaylight Network Virtualization (ONV):
    2. OpenDaylight Virtual Tenant Network (VTN)
2. **Services**:
    1. Defense4All: Security
3. **Northbound APIs**:
    1. **REST**
    2. **Dlux**: Northbound API using AngularJS, an extension of HTML by Google for dynamic views

OpenDaylight Tools (Cont)

4. **Southbound APIs**:
   1. OpenFlow Plug-in + Protocol Library (V1.0, V1.1,…)
   2. Locator ID Separation Protocol (LISP) Mapping Service
   3. SNMP4SDN
   4. BGP Link State Path Control Element Protocol
5. **Overlay**:
   1. Open Distributed Overlay Virtual Ethernet (DOVE): Like VxLAN but does not use IP Multicast
6. **Configuration**:
   1. OpenDaylight YANG Tools: NETCONF
   2. Open vSwitch Database (OVSDB) Integration
   3. Affinity Metadata Service

Affinity Metadata Service

- API to create an abstract topology and implementation independent description of infrastructure needs and behaviors of network workloads
- Allows intent to be specified in application and service terms independent of where and how the workloads attach to the network.
- SDN controllers and application can use "affinity" information to *automatically* provision the VMs and network for the user
- Users don't need to know about bridges, routers, VLANs, and tunnels

Ref: https://wiki.opendaylight.org/view/Project_Proposals:Affinity_Metadata_Service

Key SDN Related Software

- Mininet (Current)
- OpenVirteX
- Ryu (current)
- Trema
- RouteFlow (Last commit March 19, 2014)
- Luxoft Twister

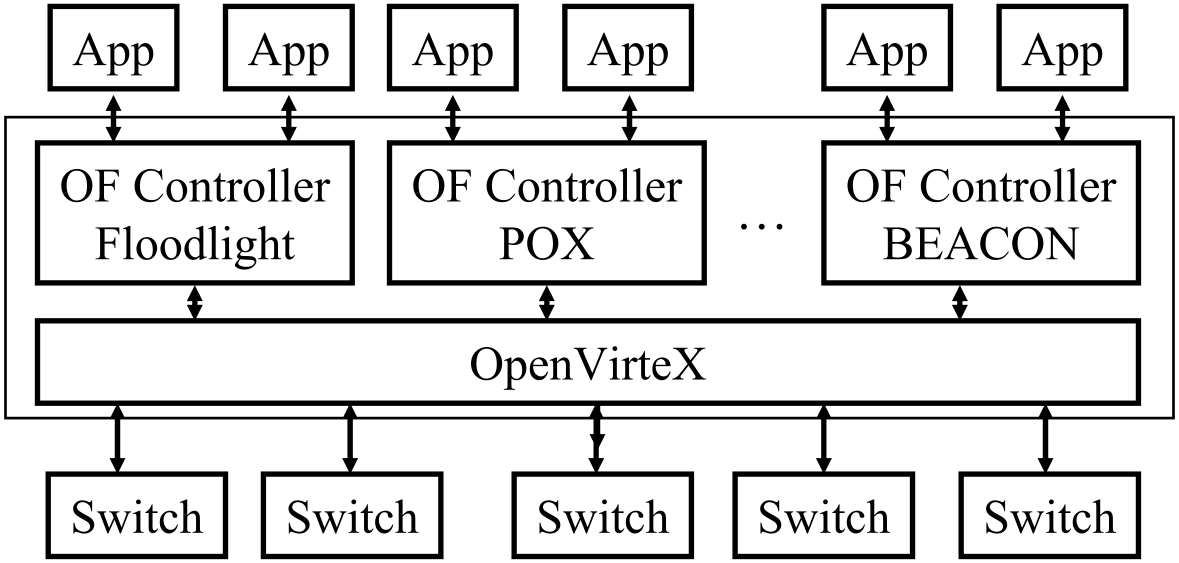
Mininet

- Widely used open source network emulation environment.
- Can simulate a number of end-hosts, switches, routers, links on a Linux
- Used for rapid prototyping of software define networks
- Built-in Open vSwitch, and a OpenFlow capable switch
- Command line launcher and Python API for creating networks of varying sizes, e.g., *mn –topo tree,depth=2,fanout=3*
- Useful diagnositc commands like iperf, ping, and other commands in a host, e.g., *mininet> h11 ifconfig –a*
- Mininet code for several popular commercial switches are available.

Ref: https://github.com/mininet/mininet

OpenVirteX (OVX)

- ❑ Transparent Proxy between OpenFlow switches and multiple OpenFlow Controllers. Slices defined by header fields.
- ❑ Creates network slices that can be managed by different controllers ⇒ Isolates slices from each other
- ❑ All control traffic goes through OVX ⇒ Slight latency



Ref: http://ovx.onlab.us/

Ryu

- Component-based framework that integrates with OpenStack and supports OpenFlow
- Provides software component with well defined API for network management and control applications
- Supports various versions of OpenFlow, OF-Config, Nicira extensions
- Developed by NTT laboratories
- Can easily setup a multi-node OpenStack environment using pre-configured Ryu VM image file

Ref: http://osrg.github.io/ryu/

Trema

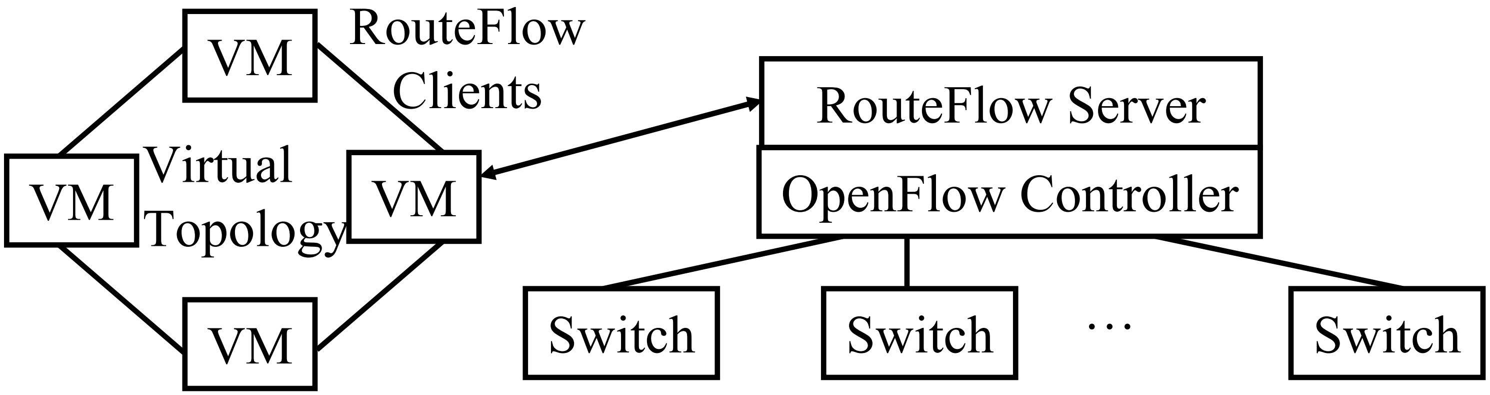
- Full-stack easy-to-use framework for developing OpenFlow controllers in **Ruby and C**
- Open source. Developed by NEC Research Lab.
- Modular extensible architecture
- Integrated development environment for testing and debugging

Ref: http://github.com/trema/

Ref: http://trema.github.com/trema/

RouteFlow

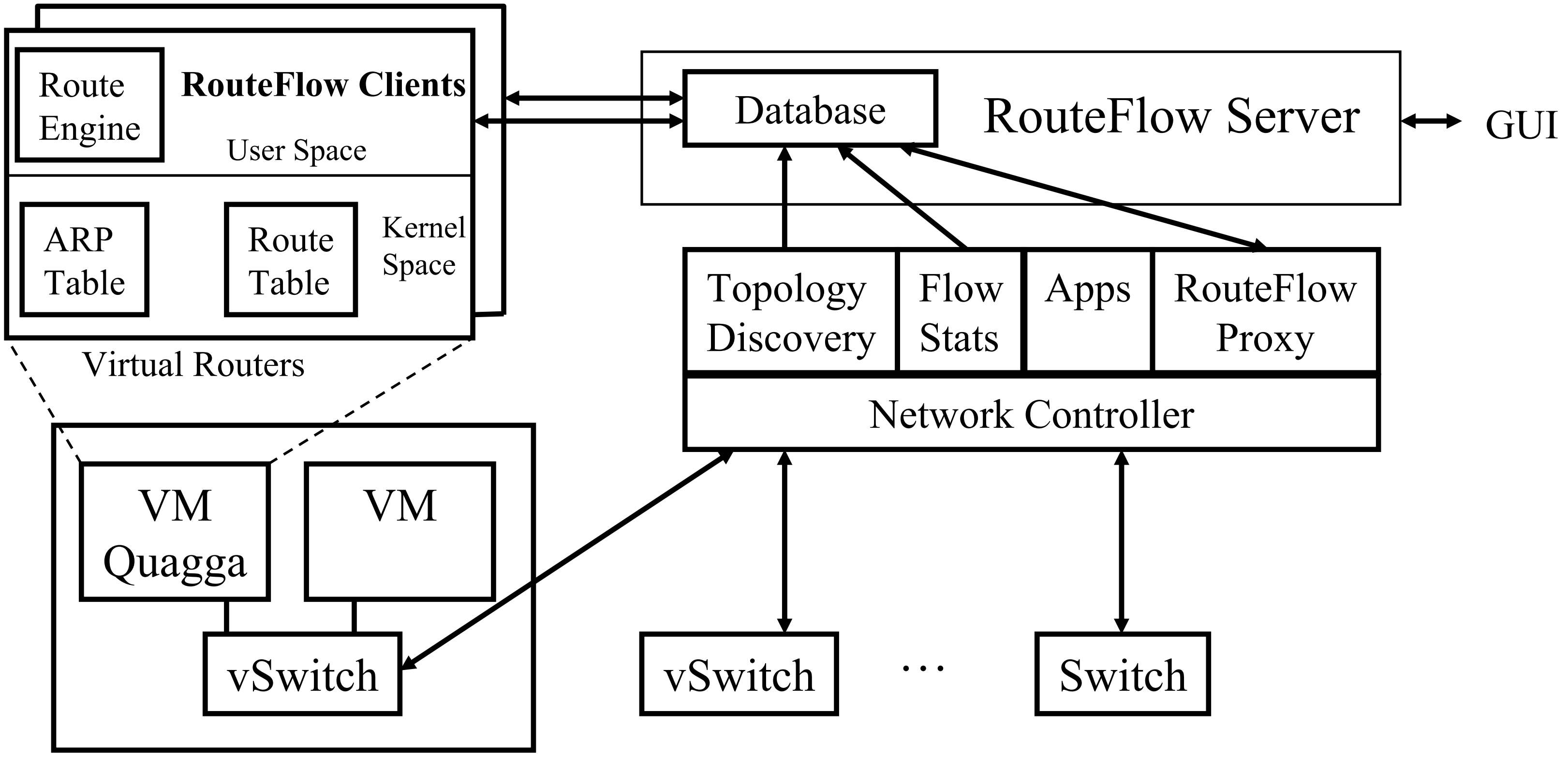
- Provides virtualized IP routing services over OpenFlow enabled hardware
- IP routing engines (e.g., Quagga) in the networking devices generate the forwarding information base (FIB) into the Linux IP tables using OSPF, BGP, etc.
- RouteFlow Client processes collect the IP and ARP tables and translate into OpenFlow tuples that are installed in the OpenFlow devices in the forwarding plane



Ref: https://sites.google.com/site/routeflow/home

RouteFlow (Cont)

- Key components: RouteFlow Client, RouteFlow Server, and RouteFlow Proxy



Ref: https://sites.google.com/site/routeflow/home

Luxoft Twister

- Test automation framework to manage and drive test cases written in shell scripting languages.
- Supports TCL, Python, and Perl
- Web-based user interface
- Remote access capability

Ref: http://github.com/Luxoft/Twister

Open Source Routing Software

- **Bird Internet Routing Daemon (BIRD)**:
  - TCP/IP routing daemon for Unix-like systems
  - Developed at Charles University, Prague
  - Provides BGP, RIP, OSPF for IPv4 and IPv6
  - Included in many Linux distributions
  - Used in several internet exchanges as a route server and has replaced Quagga because of its scalability issues
- **Quagga**: Includes OSPF, RIP, BGP, IS-IS on Unix-like OSs
- **eXensible Open Router Platform (XORP):**
  - Designed at ICSI in Berkeley
  - Supports OSPF, BGP, RIP, PIM, IGMP, OLSR
  - Generally replace by Quagga

Ref: http://en.wikipedia.org/wiki/Bird_Internet_routing_daemon

RESTful APIs

- Software architecture style developed by W3C.
- Introduced by Roy Fielding in his PhD thesis.
- WWW uses this sytle. Very popular in other applications.
- Goals: Scalability, Generality, Independence, and allow intermediate components
- Client-Server Model: Clients and servers can be developed undependably.
- Server is stateless
- Responses can be cached for the specified time
- Intermediate Servers (Proxies) can respond. End point is not critical.

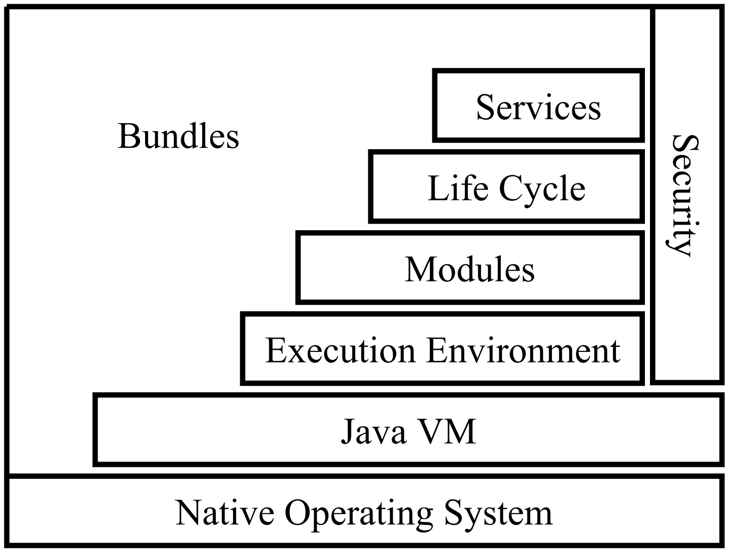
REST (Cont)

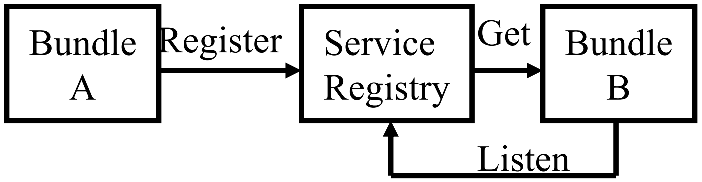
- Create, Read, Update, Delete (CRUD) Operations
- Uniform Interface: GET (Read), POST (Insert), PUT (write), DELETE
- Resources identified by global identifiers, e.g., URI in Web.
- Get http://<fqdn-or-ip-address>/rest/v1/model/<data-type>/<optional-id>?<optional-query-params>
  E.g., GET http://odcp.org/rest/v1/model/controller-node
- Data Types: Controller node, Firewall rule, Topology configuration, Switch, Port, link, flow entry, VLAN, …
- Data types can include commercial entities, such as, Big Virtual Switch from Big Switch Networks, vCenter from VMware, …
- If optional-id and query parameters are omitted, the returned text includes all of the items of the given data type.

Ref: http://en.wikipedia.org/wiki/Representational_state_transfer

OSGi Framework

- Initially, Open Services Gateway initiative
- A set of specifications for dynamic application composition using reusable Java components called bundles
- Bundles publish their services with OSGi services registry and can find/use services of other bundles





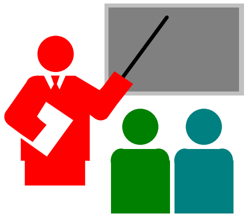
Ref: http://www.osgi.org/Technology/WhatIsOSGi

OSGi (Cont)

- ❑ Bundles can be installed, started, stopped, updated or uninstalled using a lifecycle API
- ❑ Modules defines how a bundle can import/export code
- ❑ Security layer handles security
- ❑ Execution environment defines what methods and classes are available in a specific platform
- ❑ A bundle can get a service or it can listen for a service to appear or disappear.
- ❑ Each service has properties that allow others to select among multiple bundles offering the same service
- ❑ Services are dynamic. A bundle can decide to withdraw its service. Other bundles should stop using it

  ⇒ Bundles can be installed and uninstalled on the fly.

Summary



1. SDN =Abstraction+Programmability+Centralization
2. OpenFlow originated SDN but now many different southbound and northbound APIs, intermediate services and tools are being discussed and implemented by the industry, e.g., XMPP, ForCES, PCE, ALTO
3. OpenDaylight, ONOS, and FloodLight are SDN Controllers. Differ on how much open.
4. Mininet for network simulation
5. REST=HTTP APIs
   OSGI framework for modularity

Reading List

- T. Nadeau and K. Gray, “SDN,” O’Reilly, 2013, 384 pp, ISBN:978-1-449-34230-2 (Safari book)
- V. Josyula, M. Orr, and G. Page, “Cloud Computing: Automating the Virtualized Data Center,” Cisco Press, 2012, 392 pp., ISBN: 1587204347 (Safari Book).
- J. Seedorf and E. Berger, “ALTO Problem Statement,” http://datatracker.ietf.org/doc/rfc5693/?include_text=1
- Y. Lee, et al., “ALTO Extensions for collecting Data Center Resource Information,” http://datatracker.ietf.org/doc/draft-lee-alto-ext-dc-resource/?include_text=1
- B. Martinussen (Cisco), “Introduction to Software Defined Networks (SDN),” April 2013, http://www.cisco.com/web/europe/ciscoconnect2013/pdf/DC_3_SDN.pdf
- http://www.osgi.org/Technology/WhatIsOSGi
- http://www.sdncentral.com/sdn-use-cases /
- https://wiki.opendaylight.org/view/OpenDaylight_SDN_Controller_Platform_%28OSCP%29:Proposal
- http://datatracker.ietf.org/wg/pce/
- https://wiki.opendaylight.org/view/Main_Page

Wikipedia Links

- http://en.wikipedia.org/wiki/Software-defined_networking
- http://en.wikipedia.org/wiki/Representational_state_transfer
- http://en.wikipedia.org/wiki/OSGI
- http://en.wikipedia.org/wiki/XMPP
- http://en.wikipedia.org/wiki/Path_computation_element

References

- P. Saint-Andre, et al., “XMPP: The Definitive Guide,” O’Reilly, 2009, 320 pp., ISBN:9780596521264 (Safari Book)
- OpenDaylight Components and Tools:
  - https://wiki.opendaylight.org/view/Open_DOVE:Proposal
  - https://wiki.opendaylight.org/view/OpenDaylight_Network_Virtualization_%28ONV%29:Main
  - https://wiki.opendaylight.org/view/OpenDaylight_OpenFlow_Plugin:Overview
  - https://wiki.opendaylight.org/view/OpenDaylight_Virtual_Tenant_Network_%28VTN%29:Overview
  - https://wiki.opendaylight.org/view/Openflow_Protocol_Library:Main
  - https://wiki.opendaylight.org/view/OVSDB_Integration:Design
  - https://wiki.opendaylight.org/view/Project_Proposals:Affinity_Metadata_Service
  - https://wiki.opendaylight.org/view/Project_Proposals:BGP_and_PCEP
  - https://wiki.opendaylight.org/view/Project_Proposals:Defense4All
  - https://wiki.opendaylight.org/view/Project_Proposals:Dlux

References (Cont)

  - https://wiki.opendaylight.org/view/Project_Proposals:LispMappingService
  - https://wiki.opendaylight.org/view/Project_Proposals:SNMP4SDN
  - https://wiki.opendaylight.org/view/YANG_Tools:Main
- https://www.opennetworking.org/index.php?option=com_content&view=article&id=686&Itemid=272&lang=en
- Open Data Center Alliance Usage Model: Software Defined Networking Rev 1.0,” http://www.opendatacenteralliance.org/docs/Software_Defined_Networking_Master_Usage_Model_Rev1.0.pdf

Acronyms

ACI	Application Policy Infrastructure
ACL	Access Control List
AEX	Application Information Exposure
ALG	Application Level Gateway
ALTO	Application Layer Traffic Optimization
ANDSF	Access Network Discovery and Selection Function
API	Application Programming Interface
APIC	Application Policy Infrastructure Controller
ARP	Address REsolution Protocol
ATIS	Association for Telecom Industry Solutions
ATM	Asynchronous Transfer Mode
AVNP	Active Virtual Network Management Protocol
BGP	Border Gateway Protocol
BNC	Big Switch Network Controller
BSD	Berkeley Software Distribution
BUM	Broadcast, Unknown, and Multicast

Acronyms (Cont)

CDN	Content Distribution Network
CDNI	Content Distribution Network Interconnection
CE	Control Element
CLI	Command Line Interface
CMS	Content Management System
CPU	Central Processing Unit
CRUD	Create, Read, Update, Delete
CSP	Cloud Service Provider
DHCP	Dynamic Host Control Protocol
DNS	Domain Name System
DOVE	Distributed Overlay Virtual Ethernet
DVS	Distributed Virtual Switch
EID	Endpoint Identifier
ETSI	European Telecommunications Standards Institute
FCAPS	Faults, configuration, accounting, performance , and security
FE	Forwarding Element

Acronyms (Cont)

FE	Forwarding Element
ForCES	Forwarding and Control Element Separation
GMPLS	Generalized Multi-Protocol Label Switching
GUI	Graphical User Interface
HTML	Hypertext Markup Language
HTTP	Hypertext Tranfer Protocol
I2AEX	Infrastructure to Application Information Exposure
IaaS	Infrastructure as a Service
ID	Identifier
IDS	Intrusion Detection System
IEEE	Institution of Electrical and Electronic Engineers
IETF	Internet Engineering Task Force
IGP	Interior Gateway Protocol
IoT	Internet of Things
IP	Internet Protocol
IPv4	Internet Protcol version 4

Acronyms (Cont)

IPv6	Internet Protcol version 6
IRTF	Internet Research Taskforce
IS-IS	Intermediate System to Intermediate System
ISO	International Standards Organization
LAN	Local Area Network
LISP	Locator-ID Separation Protocol
LS	Link State
MAC	Media Access Control
MPLS	Multi-protocol Label Switching
NAT	Network Address Translation
NFV	Network Function Virtualization
NTP	Network Time Protocol
NVGRE	Network Virtualization using Generic Routing Encapsulation
NVO3	Network Virtualization over L3
NVP	Network Virtualization Platform

Acronyms (Cont)

OF	OpenFlow
OnePK	Open Network Environment Platform Kit
ONF	Open Networking Forum
ONV	OpenDaylight Network Virtualization
OpEx	Operational Expences
OS	Operating System
OSCP	OpenDaylight SDN Controller Platform
OSGi	Open Services Gateway Initiative
OSPF	Open Shortest Path First
OVS	Open Virtual Switch
OVSDB	Open Virtual Switch Database
PCC	Path Computation Client
PCE	Path Computation Element
PCEP	Path Computation Element Protocol
POP	Post Office Protocol
PWE3	Pseudowire Emulation Edge to Edge

Acronyms (Cont)

QoS	Quality of Service
REST	Representational State Transfer
RFC	Request for Comments
RLOC	Routing Locator
RLOC	Routing Locator
RS	Routing System
SAL	Service Abstraction Layer
SDN	Software Defined Networking
SMTP	Simple Mail Transfer Protocol
SNMP	Simple Network Management Protocol
SSH	Secure Socket Host
STT	Stateless TCP-like Transport
TCP	Transmission Control Protocol
TE	Traffic Engineering
TIA	Telecom Industry Association
TRILL	Transparent Interconnection of Lots of Links

Acronyms (Cont)

URI	Uniform Resource Identifier
vBridge	Virtual Bridge
VIRL	Virtual Internet Routing Lab
VLAN	Virtual Local Area Network
VM	Virtual Machine
VNS	Virtual Network Segement
VPN	Virtual Private Network
vTep	Virtual Tunnel End Point
VTN	Virtual Tenant Network
VxLAN	Virtual Extensible Local Area Network
WAN	Wide Area Network
XML	Extensible Markup Language
XMPP	Extensible Messaging and Presence Protocol

SDN Related Organizations and Projects

- Open Networking Foundation (ONF): www.opennetworking.org
- Telecom Industry Association (TIA): www.tiaonline.org
- European Telecommunications Standards Institute (ETSI): www.etsi.org/
- Association for Telecom Industry Solutions (ATIS): www.atis.org/topsc/sdn.asp
- Internet Engineering Task Force (IETF): www.ietf.org
- Open Data Center Alliance, http://www.opendatacenteralliance.org
- OpenStack Quantum: https://wiki.openstack.org/wiki/Quantum
- OpenDaylight: www.opendaylight.org

SDN Web Sites

- SDN Central, http://www.sdncentral.com
- SDN Open Source Projects, http://www.sdncentral.com/comprehensive-list-of-open-source-sdn-projects/
- SDN Products and Services, http://www.sdncentral.com/announced-sdn-products/
- SDN Reading List, http://www.nec-labs.com/~lume/sdn-reading-list.html
- HotSDN 2012, http://yuba.stanford.edu/~casado/of-sw.html (Papers downloadable)
- European Workshop on SDN, http://ewsdn.eu/ewsdn12.html (Papers downloadable)