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Software Defined Networks

General Concepts

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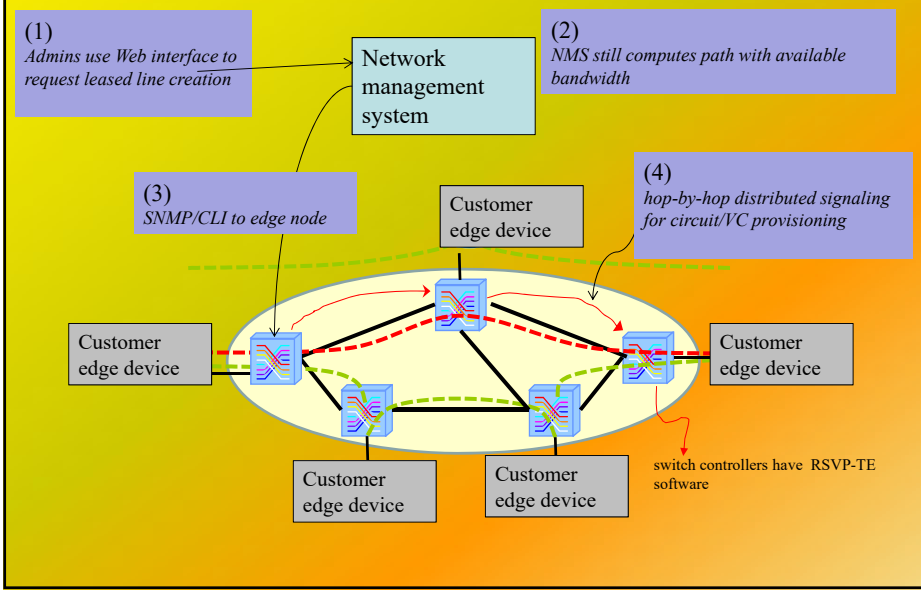
Recall: Management plane + control plane



Recall: Data plane and control plane

- Data plane: determines data packet behavior
  - Packet forwarding (e.g. inside a router)
  - Packet differentiation (e.g., ACLs)
  - Link scheduling
  - Multimedia **transport** (e.g. the codec)
- Control plane: controls the state of network elements
  - Route selection (e.g. routing protocols)
  - RSVP, capability signaling, etc.
  - Multimedia **signaling** (e.g. the ringing tone)

In advanced architectures, these two planes often impact different functional units (boxes)

Recall: Data+control

- Multimedia is associated to the notion of "session"
  - Requires both data (multimedia) and control information
    - E.g. voice is data, and #busy signal" is control
- In-band signaling
  - Sending of metadata and/or control information in the same "channel" than the data
- Out-band signaling
  - There is a dedicated "channel" created for the transmission of metadata and/or control

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Recall: Data+control

Most commercial services are

- Multimedia is associated to the notion of "session"
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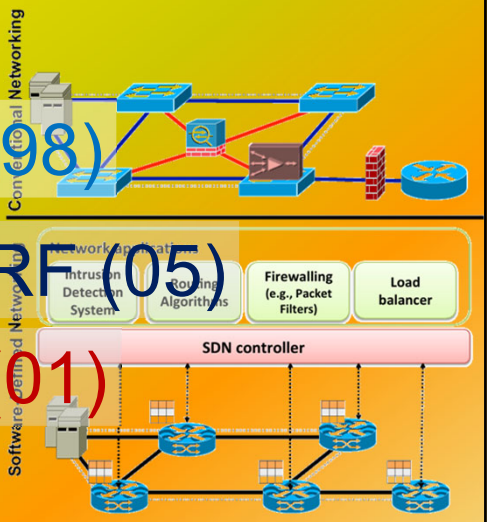
Software-Defined Networks

- Developed at Stanford in 2008
- Concept "new"
  - Although is hard to define what is the difference from previous telecom strategies.
- Decoupling data plane from control plane
- Overlay network

IETF COPS (98)

3GPP PCRF (05)

IETF Forces (01)



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Characteristics of SDN

- Plane separation
- Simpler device
  - more efficient and faster
- Centralized control
  - Optimal decisions
- Network automation and virtualization
- Openness

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Plane Separation

- Separation of the data (forwarding) and control planes
- Forwarding plane:
  - logic and tables for choosing how to deal with incoming packets based on characteristics such as MAC address, IP address, and VLAN ID
  - Forward, drop, consume, or replicate an incoming packet
  - Device determines the correct output port by performing a lookup in the address table in the hardware
  - Special-case packets that require processing by the control or management planes are consumed and passed to the appropriate plane

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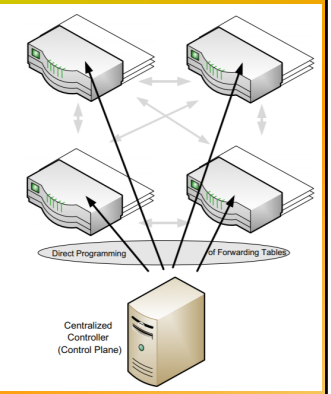
Plane Separation

- Control plane
  - Determines how the forwarding tables and logic in the data plane should be programmed
  - Run routing or switching protocols
  - In SDN is performed in a centralized controller
  - Can be co-located in the switches



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Simplified Device and Centralized Control

- Control software is removed from the device and placed in a centralized controller
- Software-based controller manages the network using higher-level policies
- Controller provides primitive instructions to the simplified devices when appropriate
  - Allow devices to make fast decisions about how to deal with incoming packets.

Network Automation and Virtualization

- SDN is said to be a natural evolution for the problem of network control
- Distributed state abstraction provides the network programmer with a global network view
  - Specify the necessary forwarding behaviors without any knowledge of vendor-specific hardware
  - Express the desired goals of the overall network without getting lost in the details of how the physical network will implement those goals
- Open interface on the controller to allow for automated control of the network
  - Northbound and southbound: interface is to the applications or to the devices

Network Automation and Virtualization

- Southbound API is the OpenFlow interface to program the network devices
- Northbound API for software applications to be plugged into the controller
  - Algorithms and protocols
  - Can quickly and dynamically make network changes as the need arises
  - Interface that allows the software above it to operate without knowledge of the individual characteristics and of the network devices themselves
  - Applications can be developed that work over a wide array of manufacturers' equipment that may differ substantially in their implementation details.
  - Ability to virtualize the network, decoupling the network service from the underlying physical network
    - Unaware if network resources are virtual or physical

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Openness

- Standard interfaces should remain standard, well documented, and not proprietary
- APIs to give software sufficient control to experiment with and control various control plane options
- Northbound and southbound interfaces
  - Easily experiment with and test new ideas
  - Resulting in better and faster technological advancement in the structure and functioning of networks
  - Open interfaces also encourages SDN-related open source projects, and permit equipment from different vendors to interoperate

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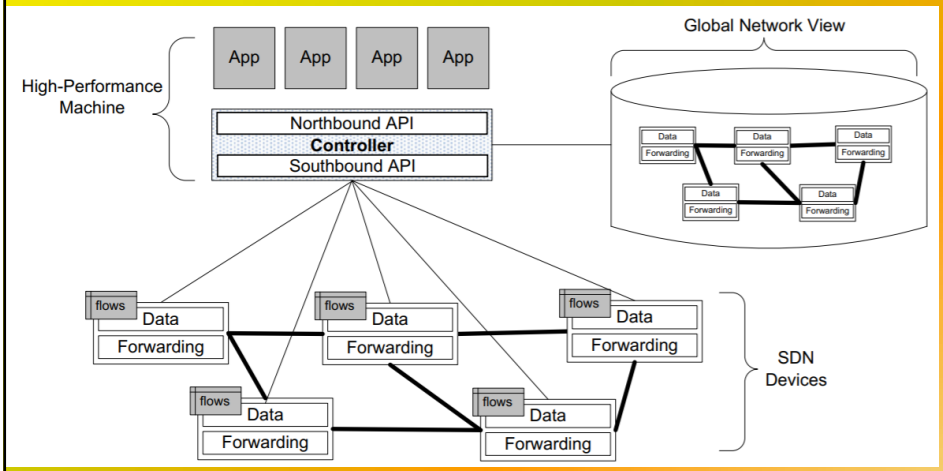
SDN: Architecture and Operation



Flow describes a set of packets transferred from one network endpoint (or set of endpoints) to another endpoint (or set of endpoints).

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SDN Operation: Applications

- Part of network layers two and three
- Use SDN controller to set proactive flows on the devices and to receive packets that have been forwarded to the controller
- Flows defined in response to a packet forwarded to the controller
  - SDN application will instruct the controller as to how to respond to the packet
  - If appropriate, will establish new flows on the device in order to allow that device to respond locally the next time it sees a packet belonging to that flow: reactive flows
- Software applications: forwarding, routing, overlay, multipath, and access control functions, among others
- Controller can insert flows reactively in response to other data sources such as intrusion detection systems (IDS) or traffic analyzer

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SDN Operation: SDN controller

- Device and topology discovery and tracking
  - Learning of the existence of switches (SDN devices) and end-user devices and tracking the connectivity between them
- Flow management, device management, and statistics tracking
  - Maintains a flow cache that mirrors the flow tables on the various switches it controls
  - Locally maintains per-flow statistics that it has gathered from its switches

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SDN Operation: Flows

- IP address-TCP/UDP pairs, VLAN endpoints, layer three tunnel endpoints, and input ports, among other things
- Rules describes the forwarding actions that the device should take for all packets belonging to that flow
- Flows are unidirectional, opposite direction is a separate flow
- Flow table: series of flow entries and the actions to perform when a packet matching that flow arrives at the device; if it does match any flow, it is discarded or decision does to the controller

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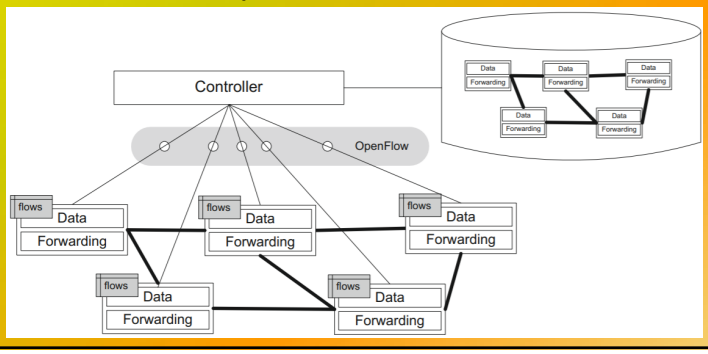
SDN Operation: Controller

- Allows the SDN application to define flows on devices
- Helps the application respond to packets that are forwarded to the controller by the SDN devices
- Calculates optimal forwarding solutions for the network in a deterministic, predictable manner



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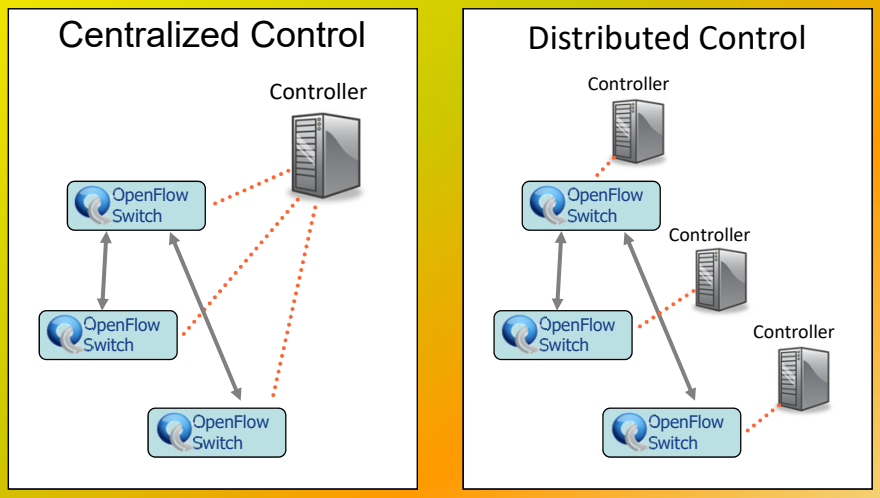
Centralized vs Distributed Control



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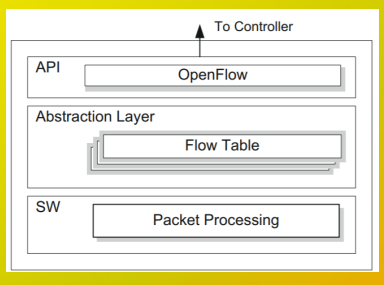
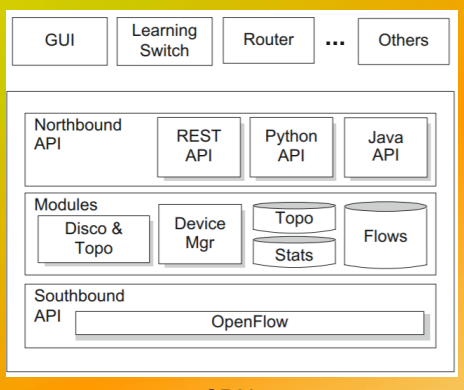
SDN Operation: OpenFlow

- Means of communication between the controller and the device



SDN switch



SDN controller

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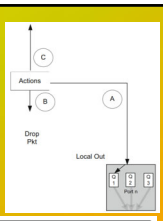
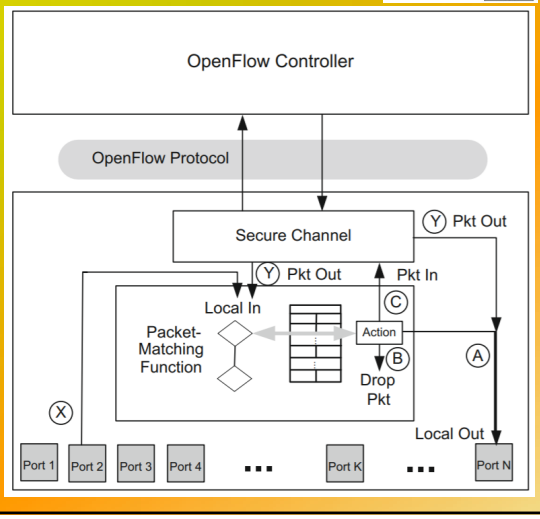
OpenFlow: base



- Interface between switches and network controller

- A. Forward the packet out a local port, possibly modifying certain header fields first.
- B. Drop the packet
- C. Pass the packet to the controller



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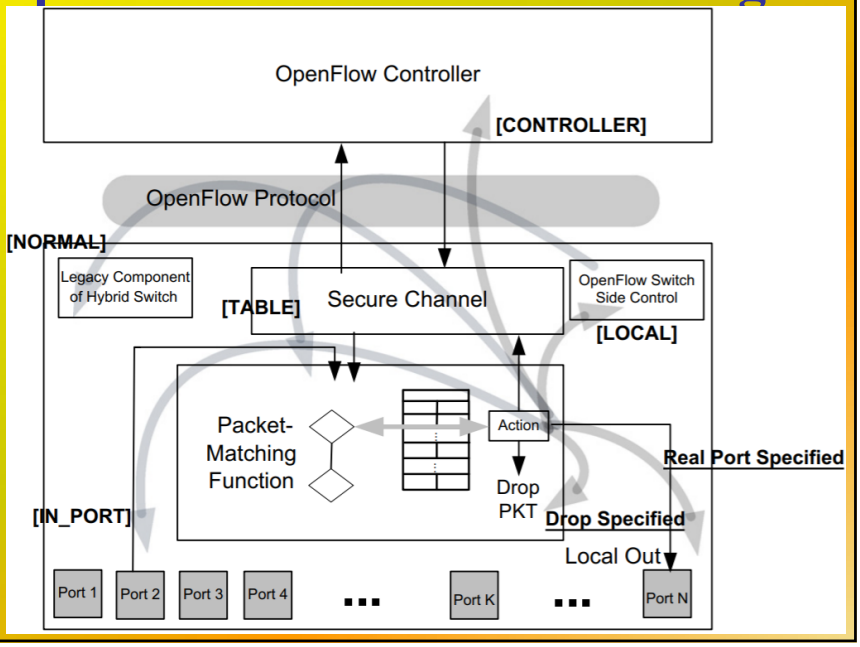
OpenFlow: Flow Tables

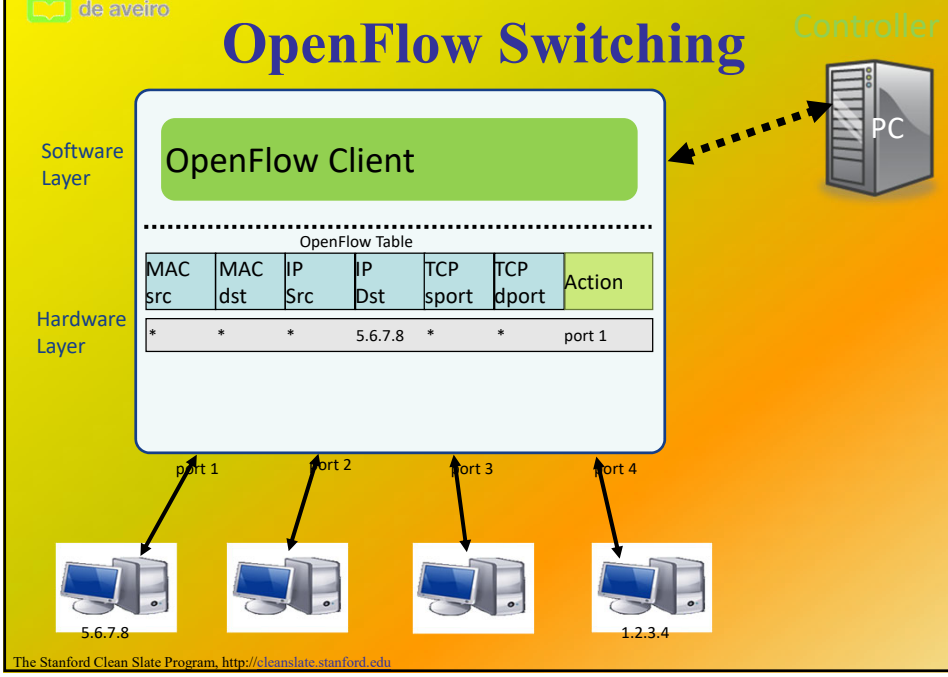
- Header fields: match criteria to determine whether an incoming packet matches this entry
- Counters: track statistics relative to this flow, such as how many packets have been forwarded or dropped for this flow
- Actions fields prescribe what the switch should do with a packet matching this entry

Flow Entry 0		Flow Entry 1		...	Flow Entry F		...	Flow Entry M	
Header Fields	Inport 12 192.32.10.1, Port 1012	Header Fields	Inport * 209.*.*.*, Port *		Header Fields	Inport 2 192.32.20.1, Port 995		Header Fields	Inport 2 192.32.30.1, Port 995
Counters	val	Counters	val		Counters	val		Counters	val
Actions	val	Actions	val		Actions	val		Actions	val

OpenFlow: Packet Forwarding



OpenFlow Switching



The Stanford Clean Slate Program, http://cleanslate.stanford.edu

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OpenFlow: MPLS