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Software-Defined Networking

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Agenda

- What is Software-Defined Networking (SDN)?
- How does SDN work?
  - Infrastructure layer
  - Control layer
  - Application layer
- Research Issues
  - Scalability
  - Consistent network update
  - Flow scheduling
  - Security



What is SDN?



Current Status & Motivation (1/2)

Source: Nick Mckeown, Stanford

- Specialized software
- Specialized firmware
- Specialized hardware
- Specialized interface

Control layer

Vertical-integrated

Horizontal-integrated



Current Status & Motivation (2/2)

- Traditional network is manually configured
  - Operating error may cause network tear down
  - High **CAPEX** and **OPEX**
  - Network equipment is vulnerable to software bugs

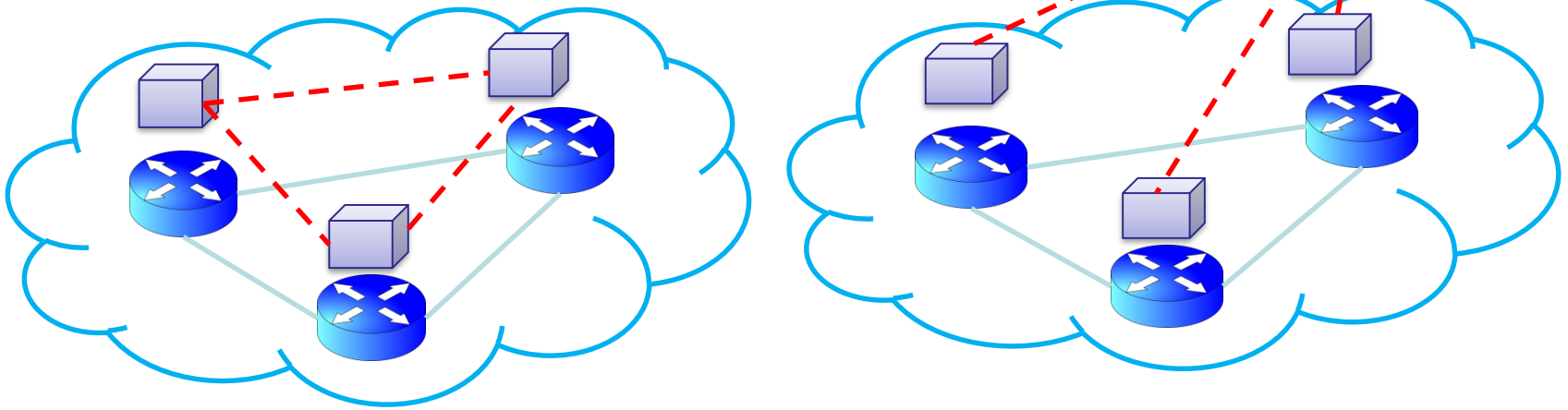
What is SDN?

Source: Shmuel (Mooly) Sagiv, Tel Aviv Univ.

- SDN is an emerging network architecture
  - Decoupling of control and data planes
  - Logically centralizing network intelligence

OPEN NETWORKING FOUNDATION

Control plane: Distributed algorithms
OSPF, BGP, ECMP, etc.
Data plane: Forwarding tables





Goal

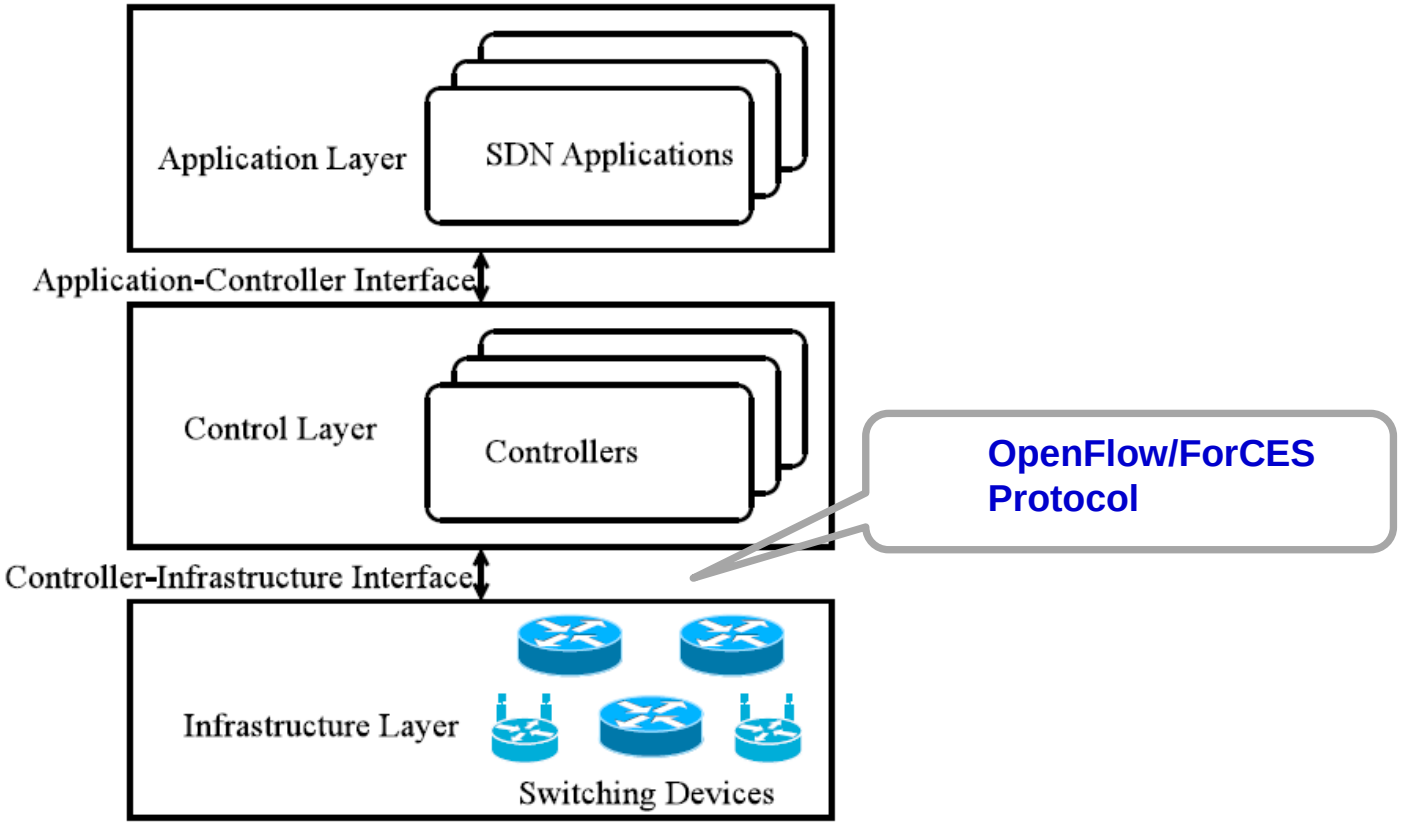
- Simplified and efficient network management
  - Programmable networks
    - Flexible and dynamically customizable networks
  - Network Operating System (NOS)
    - Provide global view
    - Ensure consistent network
  - Standard open interface (Northbound/southbound API)
    - Backward compatibility



How does SDN work?

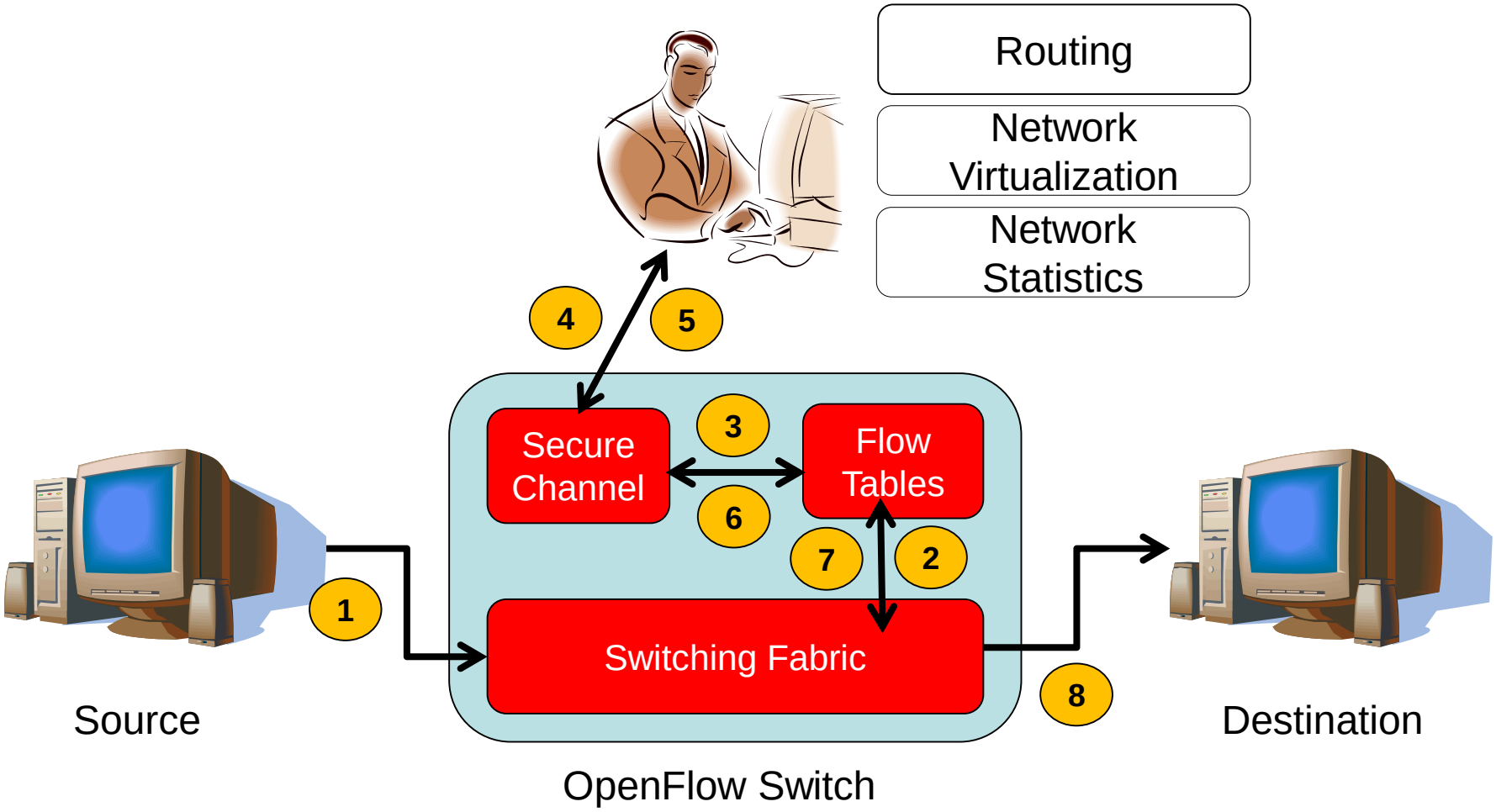
SDN Paradigm

- Reference model[1]



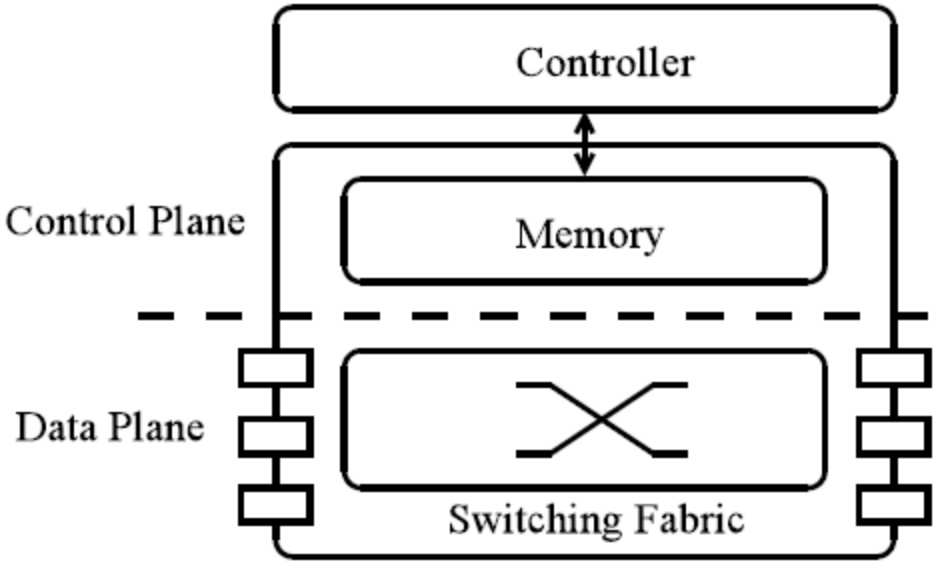


Operation


Routing
Network Virtualization
Network Statistics
4
5
Secure Channel
3
6
Flow Tables
7
2
1
Switching Fabric
8
Source
Destination
OpenFlow Switch

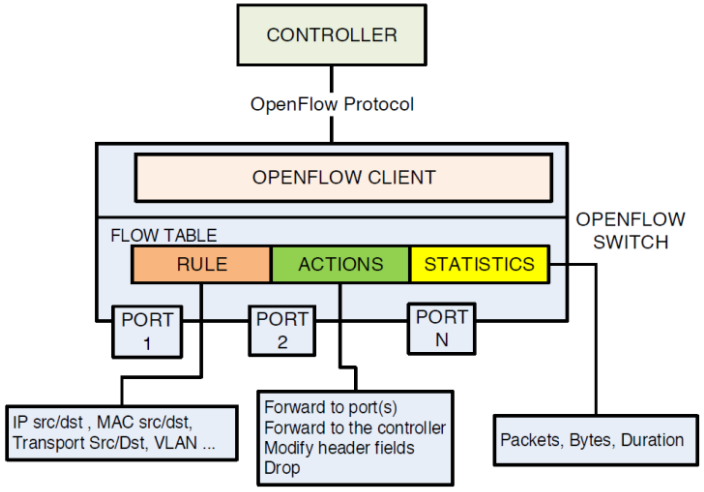
Infrastructure Layer[1]

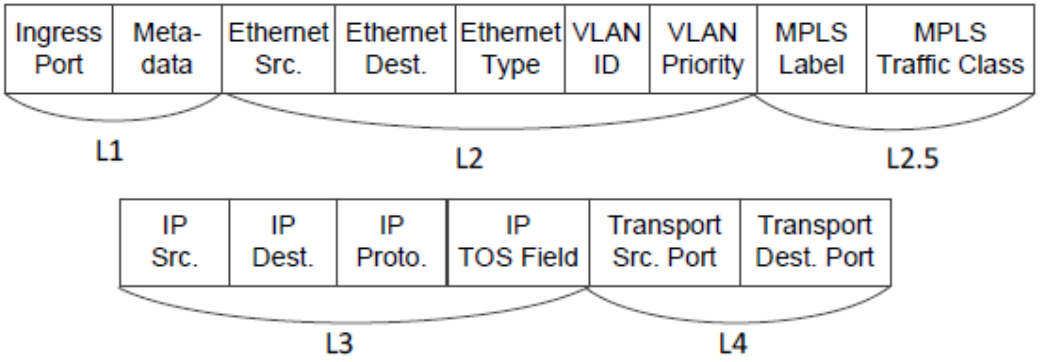
- Network equipment: router, switch, and middlebox
  - Control plane: **flow table** and **secure channel**
  - Data plane: **packet switching/forwarding**



Flow Table in Switch[2-3]

- SDN commonly uses TCAM to store rules in flow tables
  - **Match fields**: Match packets based on packet's header
  - **Action set**: Forward, drop, and modify
  - **Statistics**: Bytes, packets, duration





TCAM (Ternary content-addressable memory)



SDN Switching Devices[1]

OpenFlow Switch	Wireless AP	Network Hardware	Vendor
Representative	OpenWRT	NetFPGA	Pica8
Processing Speed	Low	Middle	High
Flexibility	High	Middle	Low

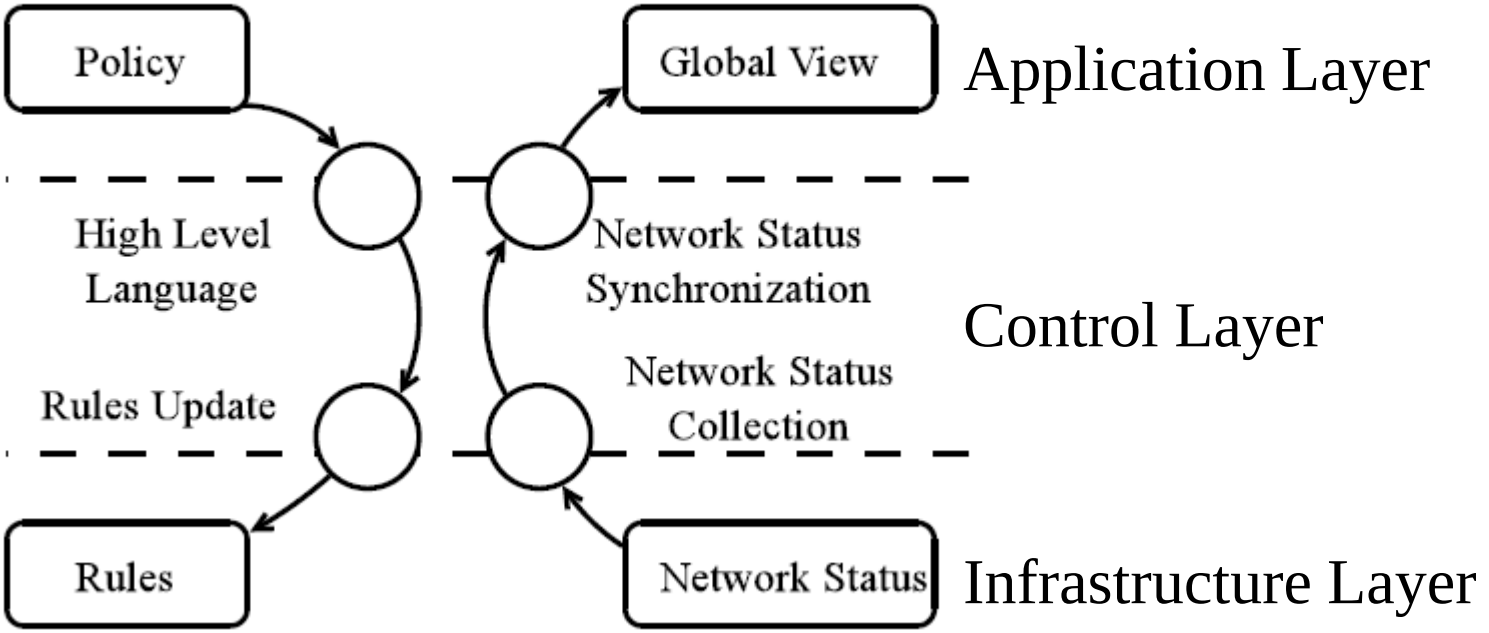
OvS Open vSwitch

OpenFlow



Control Layer

- Software-based SDN controller
  - Provide consolidated control functionality by open interface[1]





OpenFlow Controllers

Controller	Open Source	Language	Multi-threaded	GUI	Origin
NOX [32]	yes	C++/Python	no	yes	Nicira Networks
NOX-MT [46]	yes	C++	yes	no	Nicira Networks and Big Switch Networks
POX [47]	yes	Python	-	yes	Nicira Networks
Maestro [48]	yes	Java	yes	no	Rice University
Beacon [49]	yes	Java	yes	yes	Stanford University
SNAC [50]	no	C++/Python	no	yes	Nicira Networks
RISE [51]	yes	C and Ruby	non-guaranteed	no	NEC
Floodlight [52]	yes	Java	-	yes	Big Switch Networks
McNettle [53]	yes	Nettle/Haskell	no	no	Yale University
MUL [54]	yes	C	yes	yes	KulCloud
RYU [55]	yes	Python	-	-	NTT OSRG and VA Linux
OpenDaylight [56]	yes	Java	yes	yes	Multiple contributors



Application Layer

- Develop SDN applications/policies to manage the network
  - Using high-level API provided by controller
- SDN applications
  - Access control
  - Load balancing
  - Network virtualization
  - Energy efficiency



SDN Research Issues



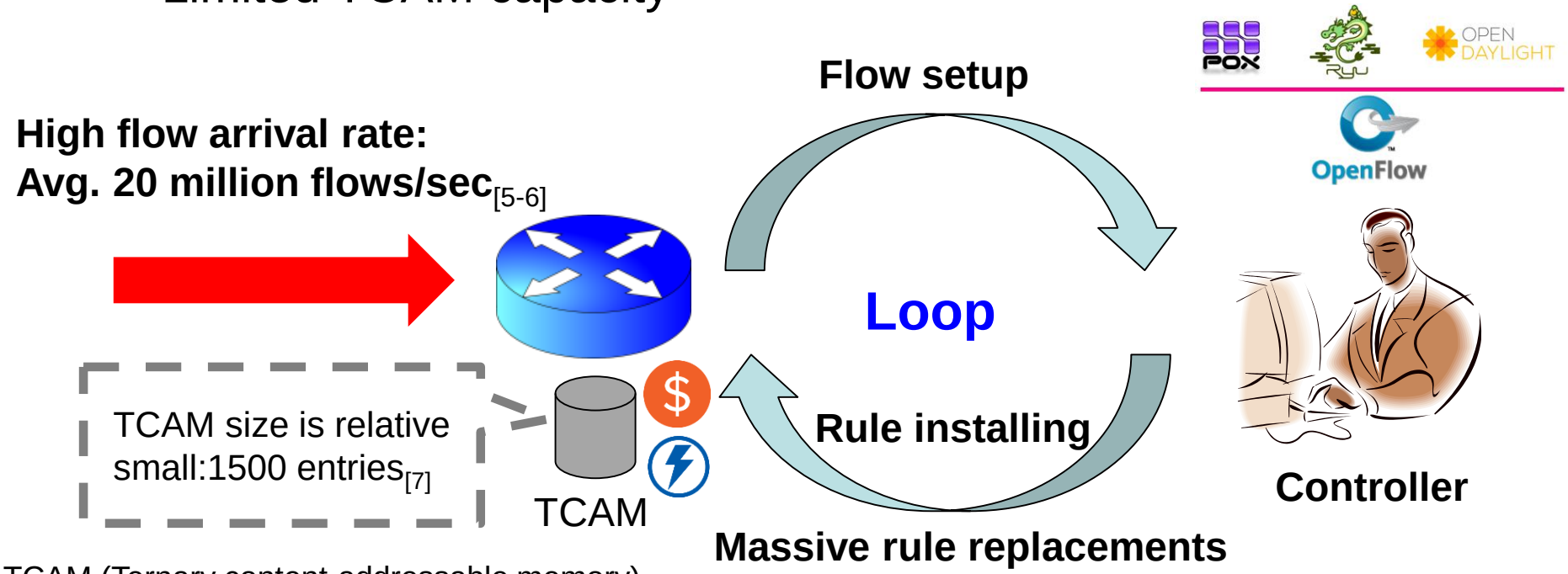
SDN Research Issues

- Controller scalability
- Consistent network update
- Flow scheduling
- Security

Controller Scalability

- Massive flow setups sent to controller
  - High flow arrival rate
  - Fine-grained flow control
  - Limited TCAM capacity

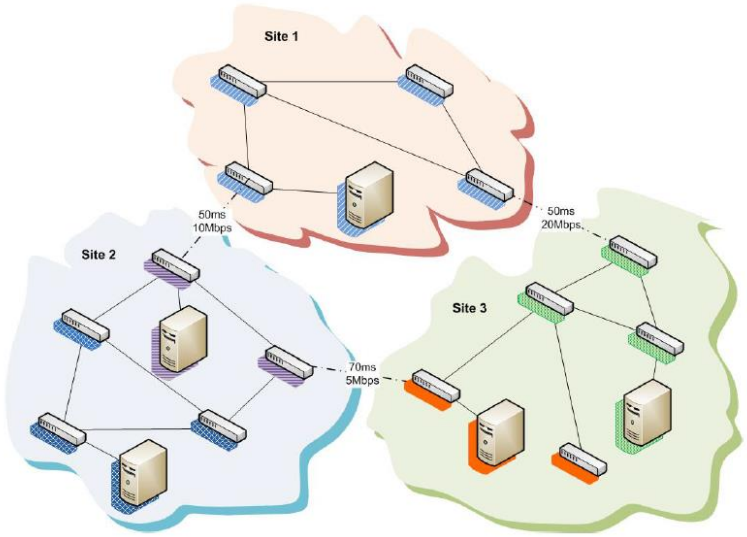
Why?



TCAM (Ternary content-addressable memory)

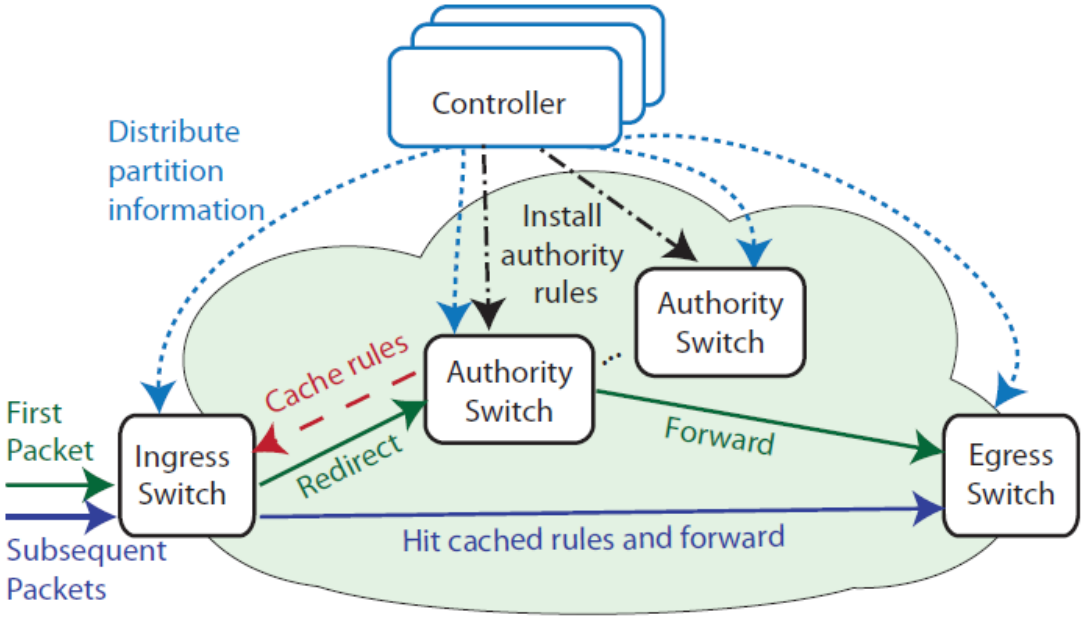
Solutions for Scalability (1/2)

- Capability enhancement for the centralized controller[8]
  - Parallelism mechanisms (Multi-threading and multi-core CPU)
  - I/O batching
- Cooperation among multiple distributed controllers[9-10]
  - Leverage multiple controllers to share the handling of flow setup requests
  - Horizontal/vertical control models



Solutions for Scalability (2/2)

- Switch-assisted[1]
  - Keep flow setups in data plane
    - Redirect flow setup sent to an authority switch





Consistent Network Update (1/2)

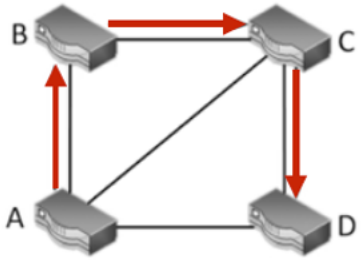
- What is network update?
  - Change network **state** to achieve some **goal**, e.g.,
    - **Goal**: VM migration
    - **State**: Forwarding entries and traffic distribution

- Problem may occur[12]
  - 20% of failures come from careless planned maintenance
    - Forwarding black-hole/forwarding loop
    - Link congestion and policy violation
- Consistent network update
  - **Prevent** specific problems during network update



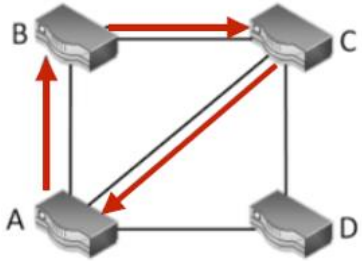
Consistent Network Update (2/2)

- Forwarding loop
  - Reason: **Asynchronous switch update**



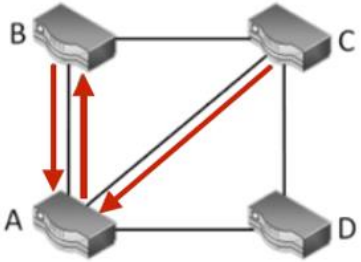
A → B
B → C
C → D

Initial State



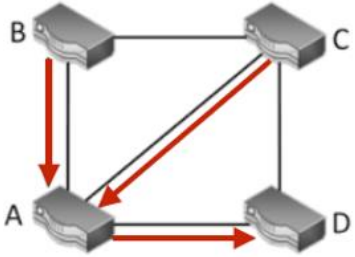
A → B
B → C
C → A

Loop State 1



A → B
B → A
C → A

Loop State 2

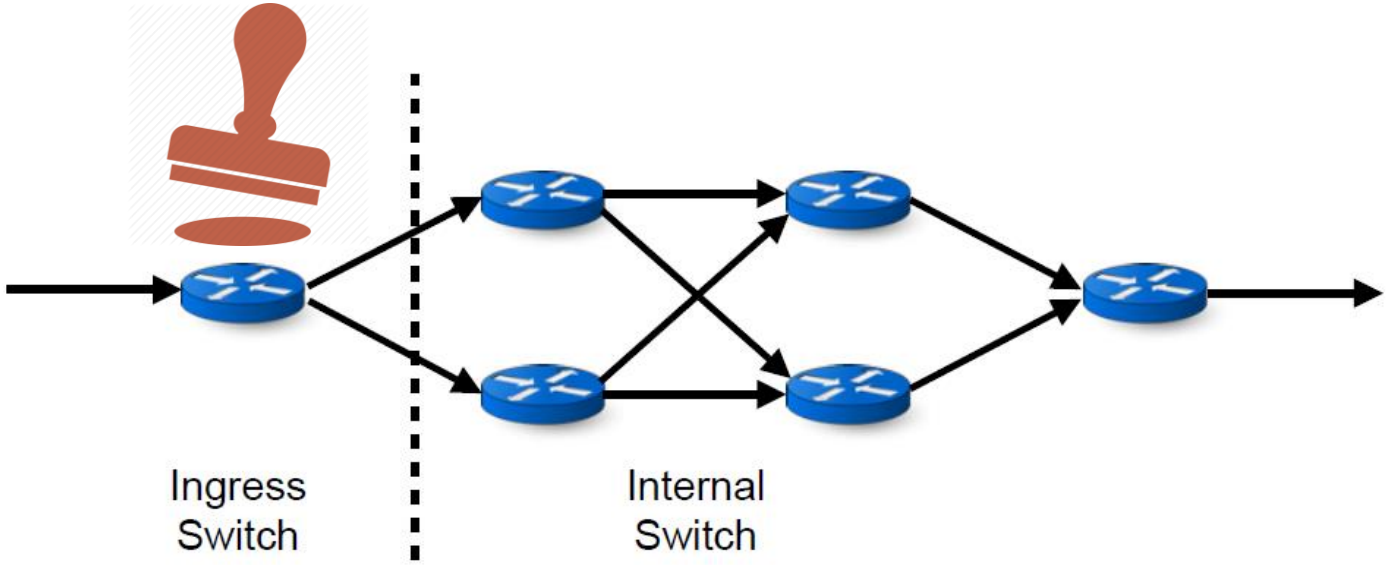


A → D
B → A
C → A

Final State

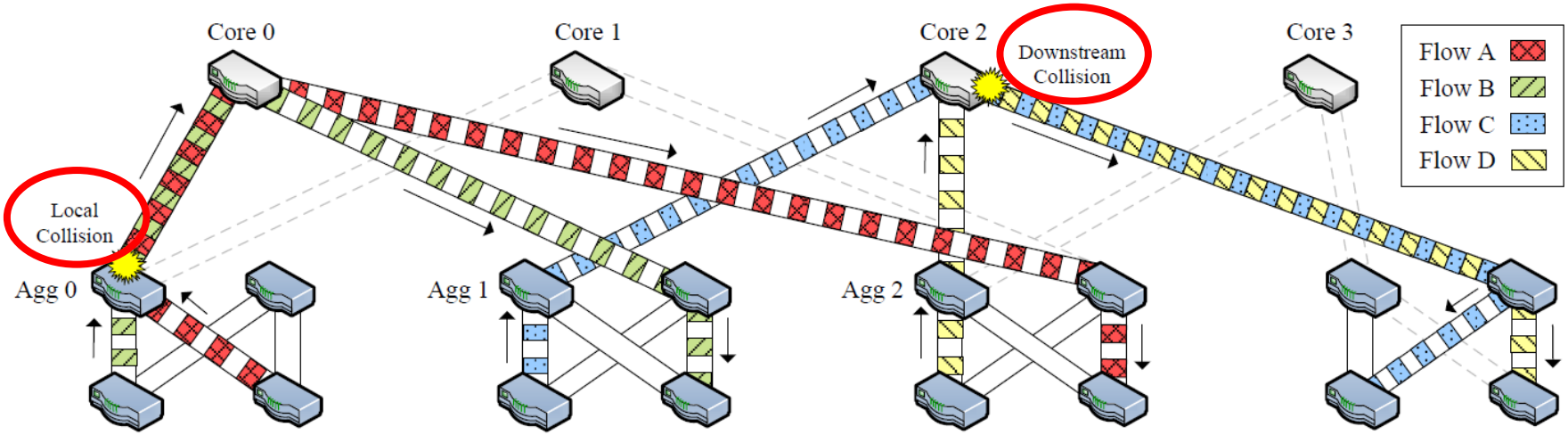
Solutions for Consistent Network Update

- Goal: Ensure common consistent properties
  - Blackhole/loop free, congestion free, and waypoint enforcement
- A simple solution: Two-phase update[13]
  - Add new rules into internal switches and ingress switch
  - Stamp packets with new version tag (VLAN or MPSL labeling)



Flow Scheduling

- Traditional routing protocol may cause substantial bandwidth loss due to long-term collisions
  - Example: ECMP[14]



ECMP (Equal-Cost Multi-Path routing)

Solution for Flow Scheduling

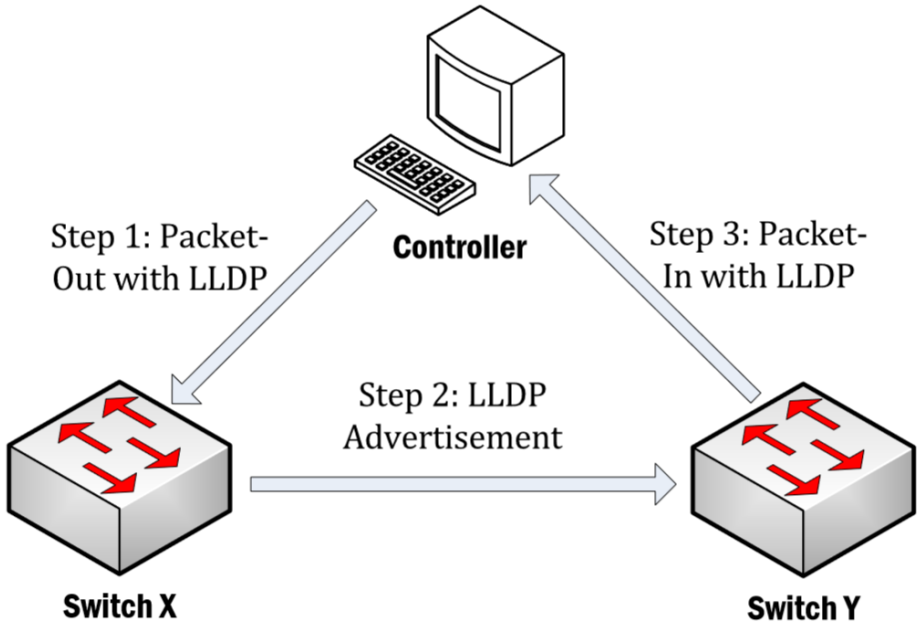
- Observation
  - Network congestions are mainly caused by elephant/large flows
- Hedera[14]: A well-known solution in data center

Security Issues

- SDN enables new opportunities to solve some legacy network security issues, and also faces several new challenges
  - Existing issues
    - DDoS attack
    - Network scanning attack
  - New SDN issues
    - **Link fabrication attack**[15]
    - Policy enforcement attack

Link Fabrication Attack (1/2)

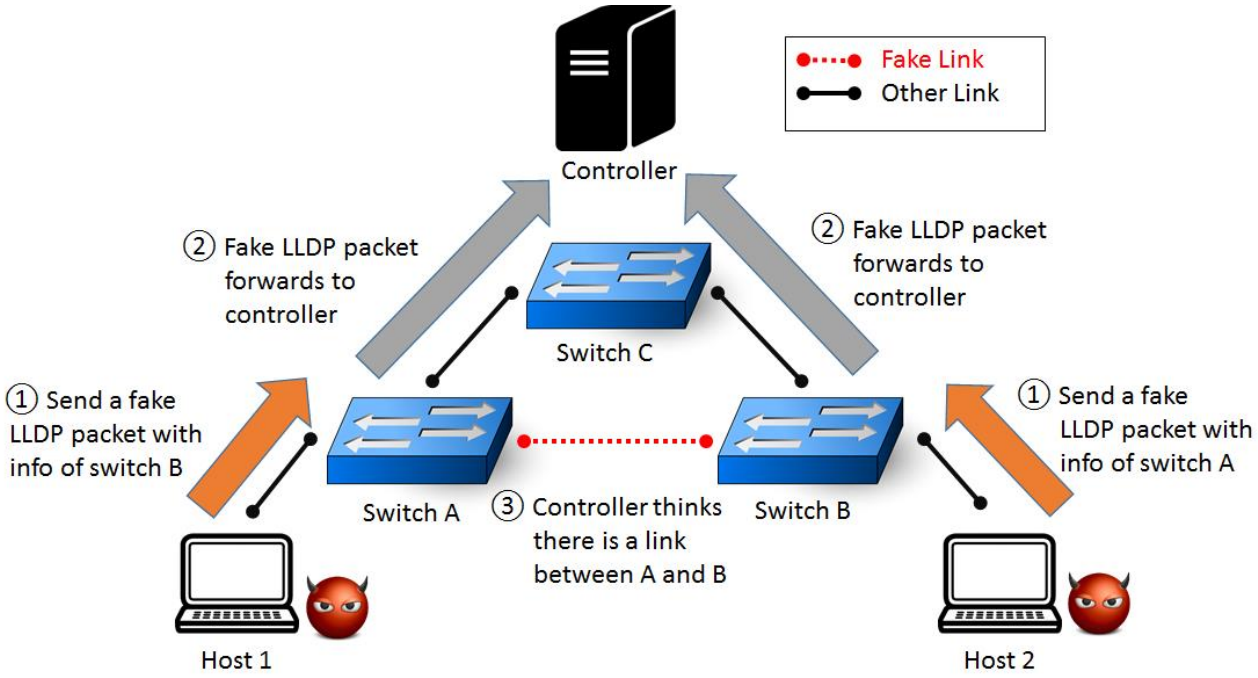
- SDN application requires topology to control the network behavior
- Topology discovery service[15]
  - LLDP packet



LLDP (Link Layer Discovery Protocol)

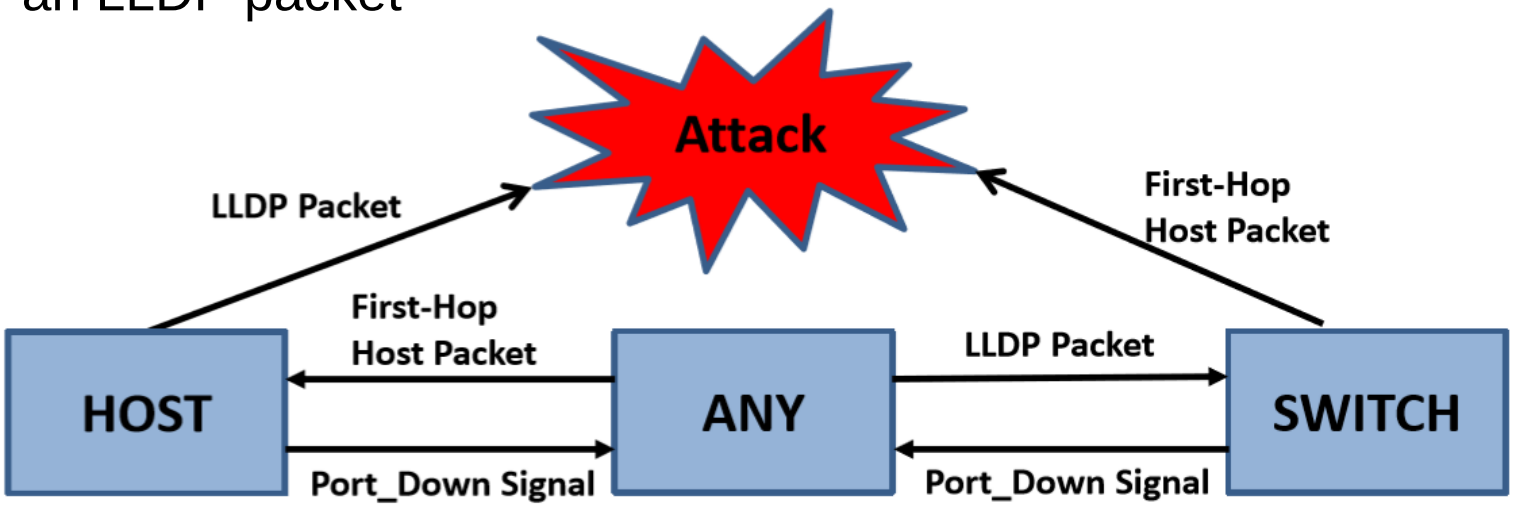
Link Fabrication Attack (2/2)

- However, topology discovery services provided by controllers can be tricked by adversaries
  - **Link fabrication attack**[15]



Solution for Link Fabrication Attack

- Each port of switch has a flag to represent whether the port is connecting to a host/switch
- Controller uses the transition graph to update the flag value and detect the attack
  - For example: An alert is raised if a port connecting to a host receives an LLDP packet





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