CS120: Computer Networks

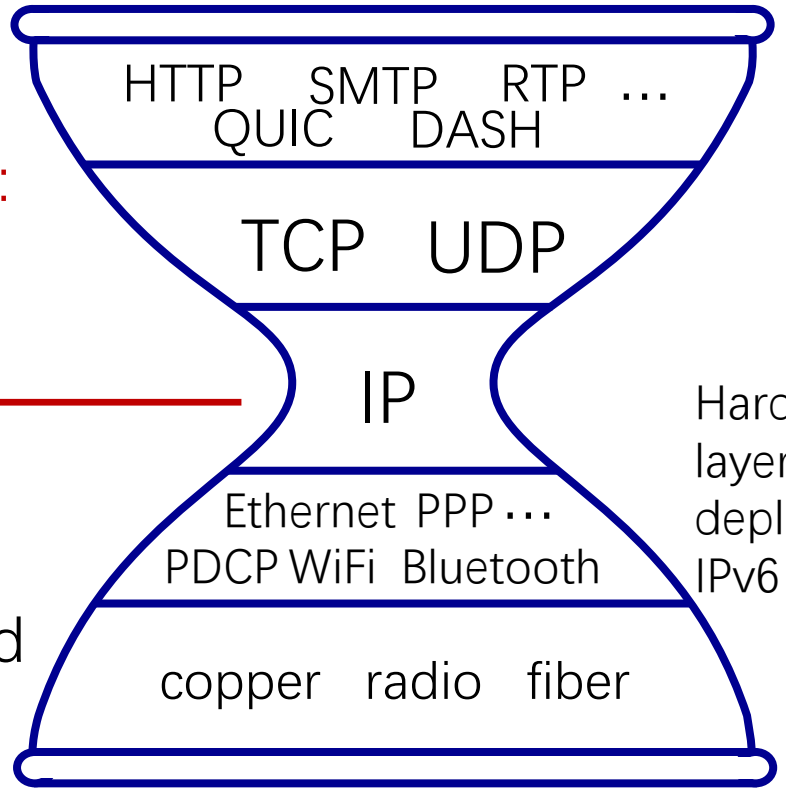
Lecture 13. SDN

Zhice Yang

A Brief History

Internet's "thin waist":

- *one* network layer protocol: IP
- *must* be implemented by every (billions) of Internet-connected devices



Hard for new network layer protocols to deployment. Think about IPv6


OpenFlow: Enabling Innovation in Campus Networks

Nick McKeown, Stanford University
Tom Anderson, University of Washington
Hari Balakrishnan, MIT
Guru Parulkar, Stanford University
Larry Peterson, Princeton University
Jennifer Rexford, Princeton University
Scott Shenker, University of California,
Jonathan Turner, Washington University in

A Brief History

- Internet network layer: historically implemented via distributed, per-router control approach:
  - *monolithic* router contains switching hardware, runs proprietary implementation of Internet standard protocols (IP, RIP, OSPF, BGP) in proprietary router OS (e.g., Cisco IOS)
  - different "middleboxes" for different network layer functions: firewalls, NAT boxes, ..
- ~2005: renewed interest in rethinking the network layer

Generalized Forwarding

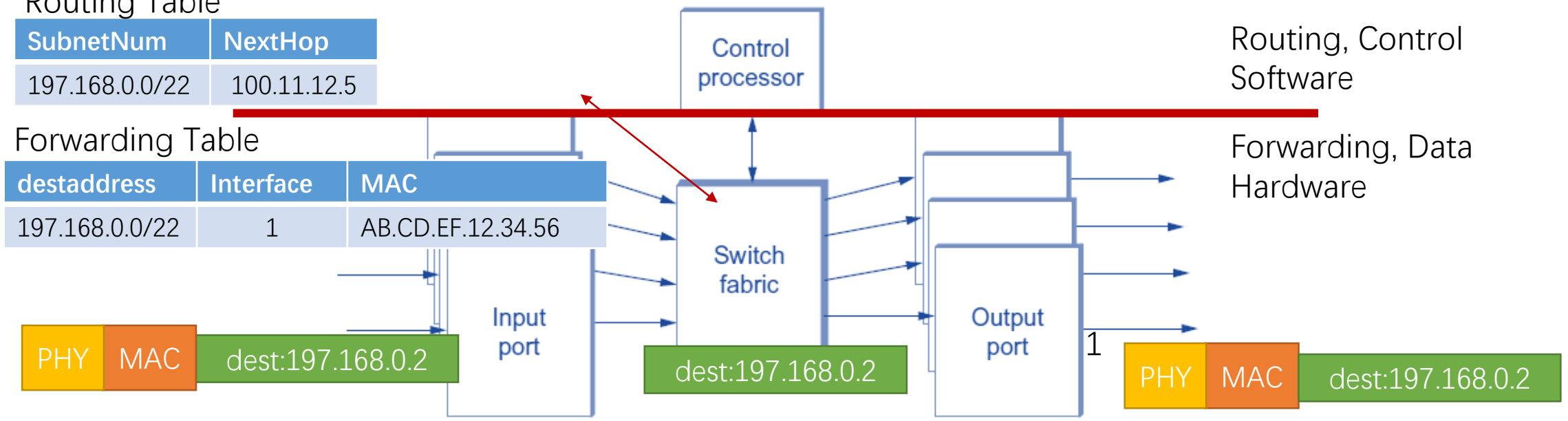
- Destination-based forwarding: forward based on dest. IP address

Routing Table

SubnetNum	NextHop
197.168.0.0/22	100.11.12.5

Forwarding Table

destaddress	Interface	MAC
197.168.0.0/22	1	AB.CD.EF.12.34.56

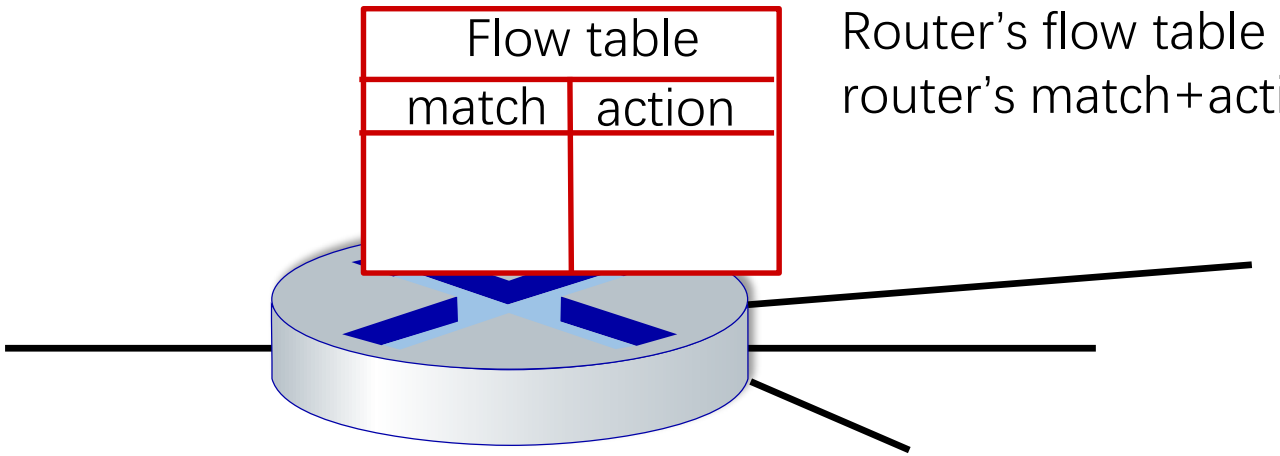


Generalized Forwarding

- Destination-based forwarding: forward based on dest. IP address
- Background: modern switches/routers are programmable
- Generalized forwarding:
  - Many header fields can determine action
  - Many actions possible: forward/drop/copy/modify/log packet

Flow Table Abstraction

- Flow: defined by header field values (in link-, network-, transport-layer fields)
- Generalized forwarding: simple packet-handling rules
  - match: pattern values in packet header fields
  - actions: for matched packet: drop, forward, modify, matched packet or send matched packet to controller
  - priority: disambiguate overlapping patterns
  - counters: #bytes and #packets



Router's flow table define router's match+action rules

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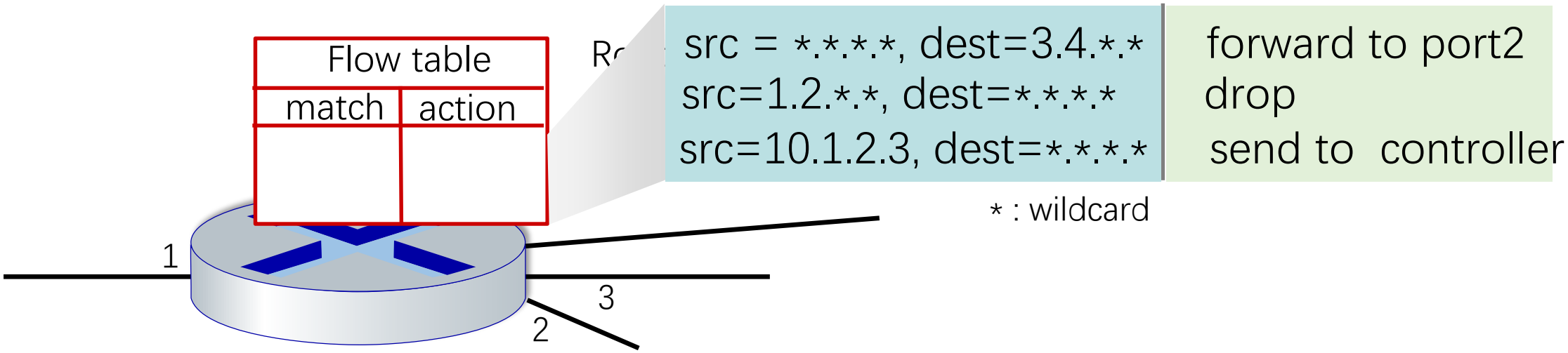
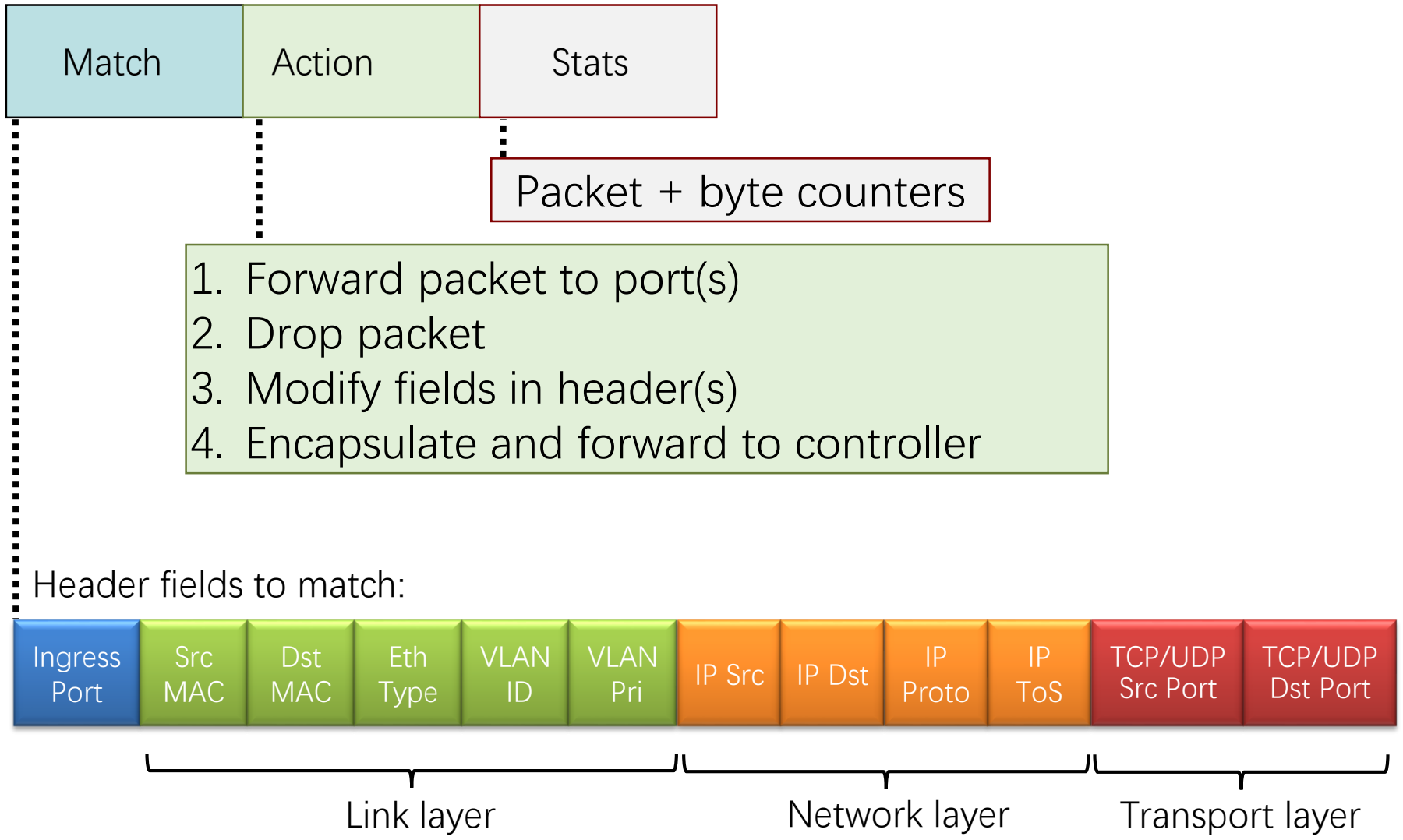


OpenFlow: Flow Table Entries



OpenFlow: Examples

Destination-based forwarding:

Switch Port	MAC src	MAC dst	Eth type	VLAN ID	VLAN Pri	IP Src	IP Dst	IP Prot	IP ToS	TCP s-port	TCP d-port	Action
*	*	*	*	*	*	*	51.6.0.8	*	*	*	*	port6

IP datagrams destined to IP address 51.6.0.8 should be forwarded to router output port 6

Firewall:

Switch Port	MAC src	MAC dst	Eth type	VLAN ID	VLAN Pri	IP Src	IP Dst	IP Prot	IP ToS	TCP s-port	TCP d-port	Action
*	*	*	*	*	*	*	*	*	*	*	22	drop

Block (do not forward) all datagrams destined to TCP port 22 (ssh port #)

Switch Port	MAC src	MAC dst	Eth type	VLAN ID	VLAN Pri	IP Src	IP Dst	IP Prot	IP ToS	TCP s-port	TCP d-port	Action
*	*	*	*	*	*	128.119.1.1	*	*	*	*	*	drop

Block (do not forward) all datagrams sent by host 128.119.1.1

OpenFlow: Examples

Layer 2 destination-based forwarding:

Switch Port	MAC src	MAC dst	Eth type	VLAN ID	VLAN Pri	IP Src	IP Dst	IP Prot	IP ToS	TCP s-port	TCP d-port	Action
*	*	22:A7:23:11:E1:02	*	*	*	*	*	*	*	*	*	port3

layer 2 frames with destination MAC address 22:A7:23:11:E1:02 should be forwarded to output port 3

OpenFlow Abstraction

- match+action: abstraction unifies different kinds of devices

Router

- *match:* longest destination IP prefix
- *action:* forward out a link

Switch

- *match:* destination MAC address
- *action:* forward or flood

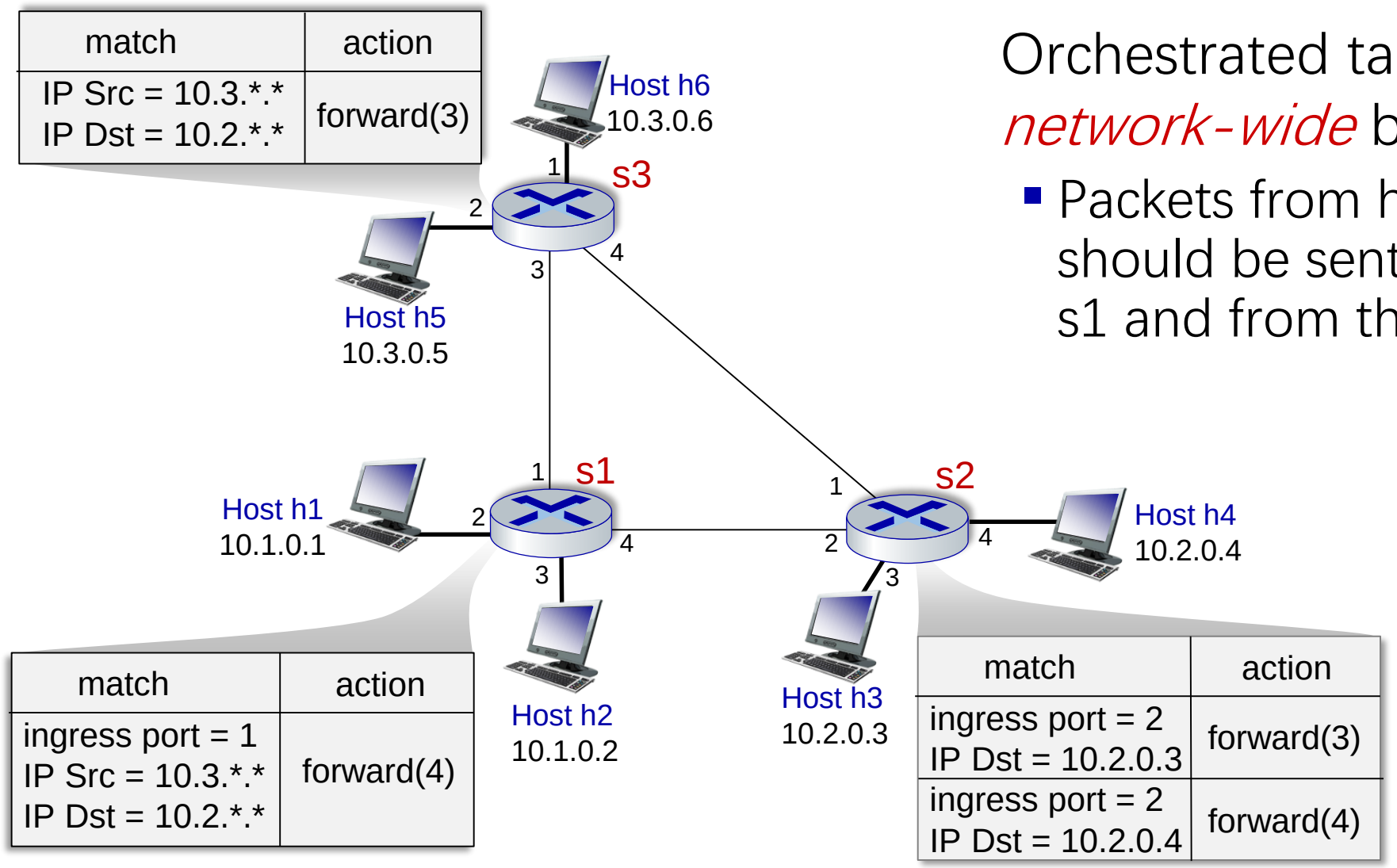
Firewall

- *match*: IP addresses and TCP/UDP port numbers
- *action:* permit or deny

NAT

- *match:* IP address and port
- *action:* rewrite address and port

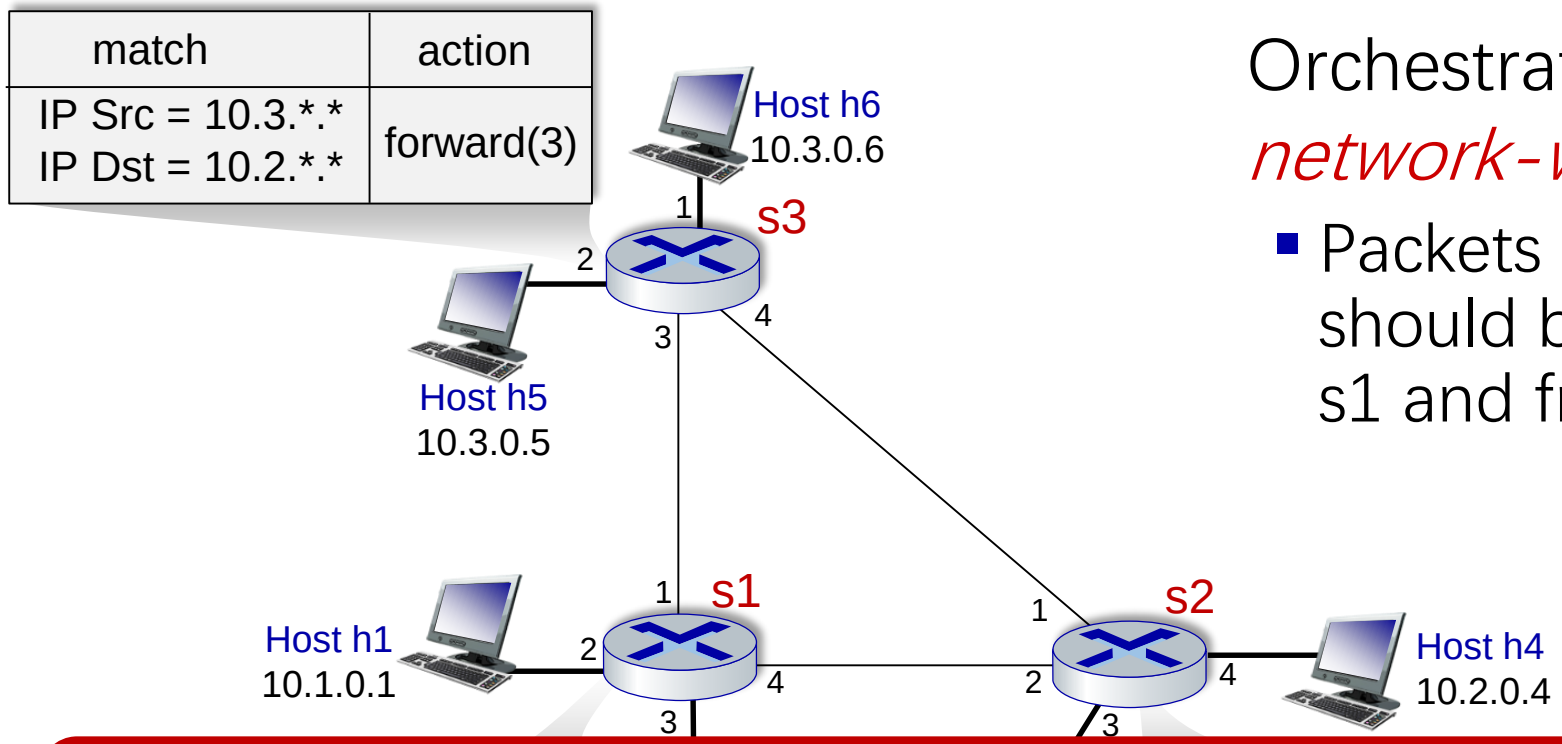
OpenFlow: Fully Flexible Traffic Engineering



Orchestrated tables can create *network-wide* behavior, e.g.,:

- Packets from hosts h5 and h6 should be sent to h3 or h4, via s1 and from there to s2

OpenFlow: Fully Flexible Traffic Engineering

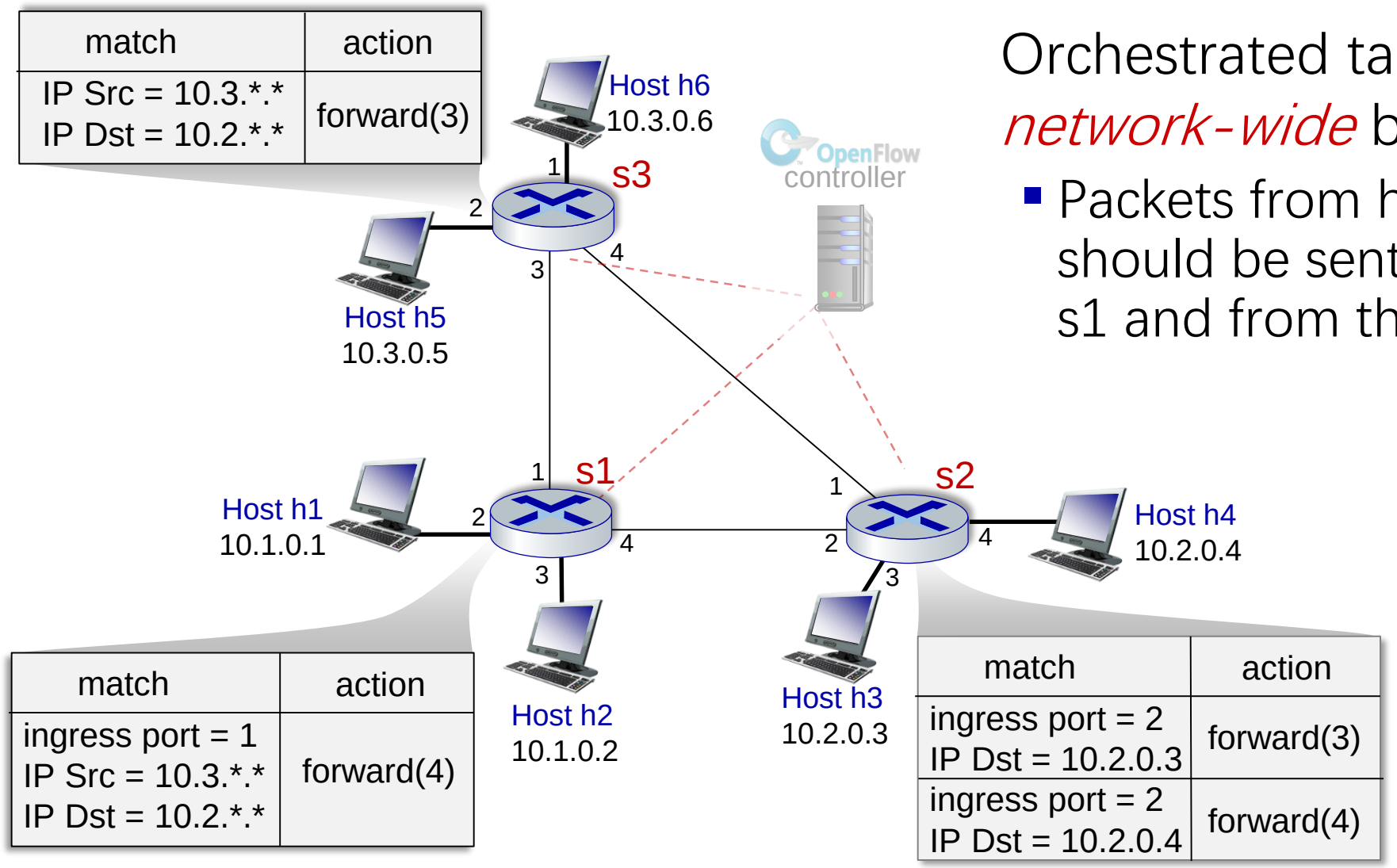


Orchestrated tables can create *network-wide* behavior, e.g.,:

- Packets from hosts h5 and h6 should be sent to h3 or h4, via s1 and from there to s2

Who is responsible for writing these OpenFlow Entries ?

OpenFlow Controller

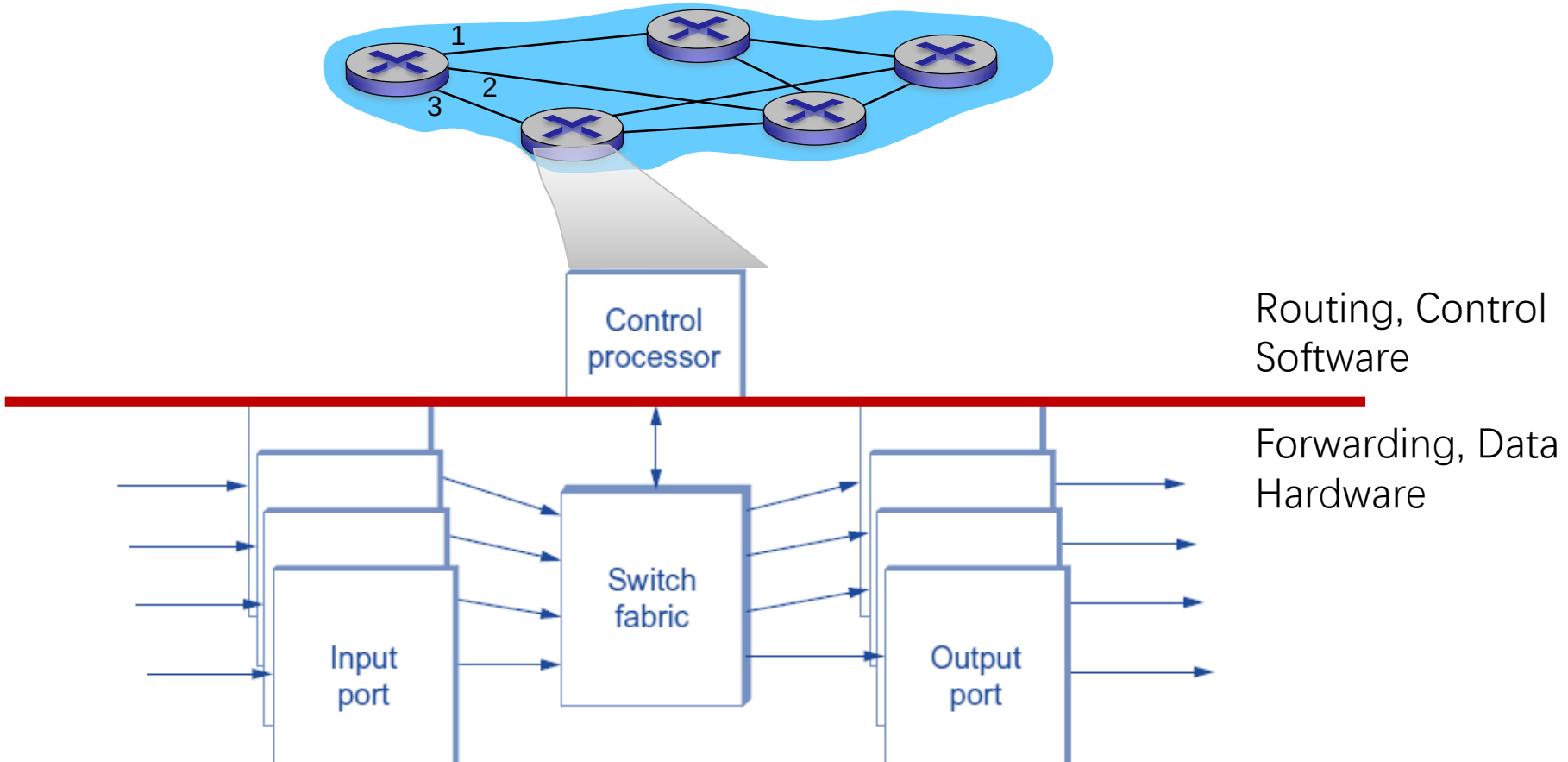


Orchestrated tables can create *network-wide* behavior, e.g.,:

- Packets from hosts h5 and h6 should be sent to h3 or h4, via s1 and from there to s2

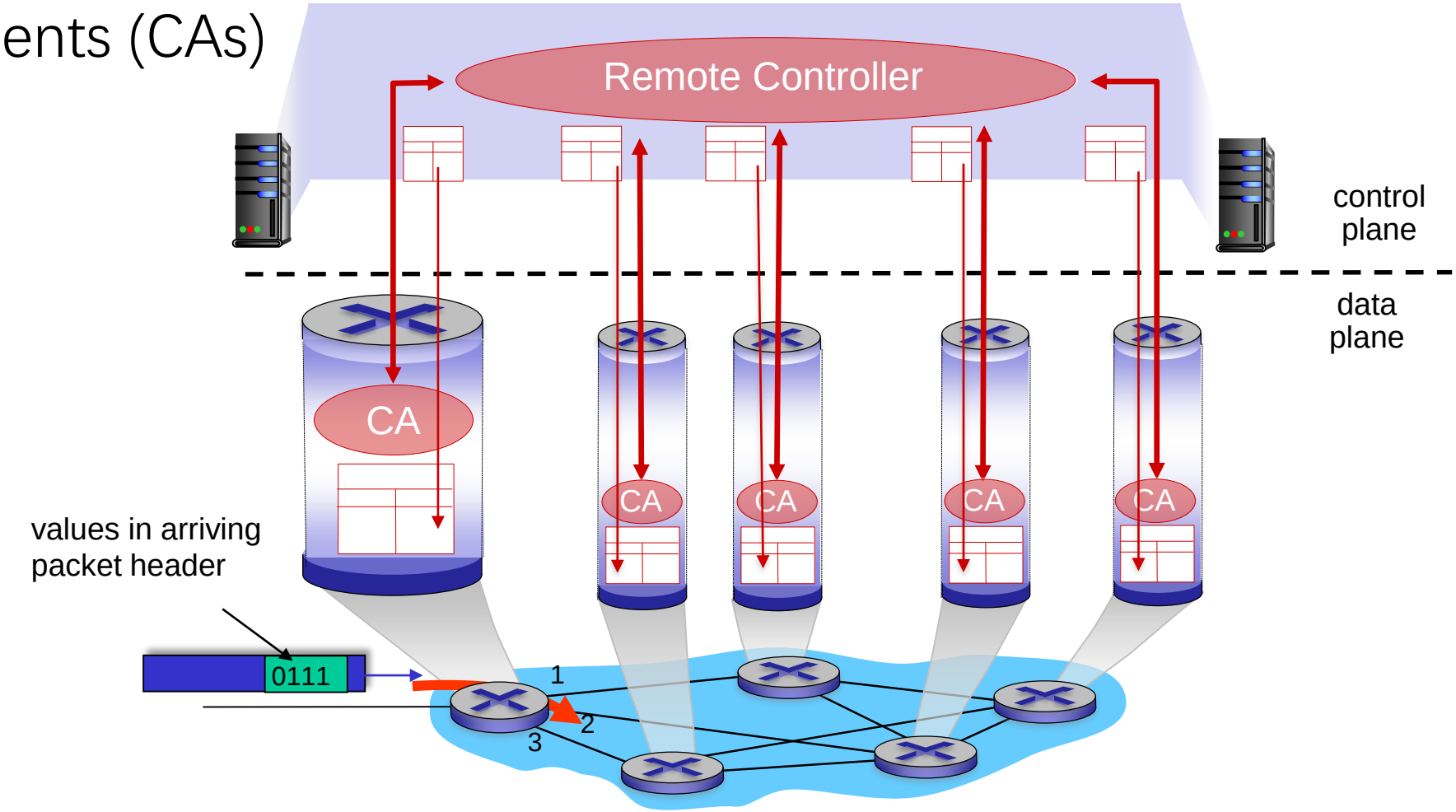
Per-router Control Plane

- Individual routing algorithm components in each and every router compute forwarding tables



SDN Control Plane

Remote controller computes, installs forwarding tables in routers via control agents (CAs)



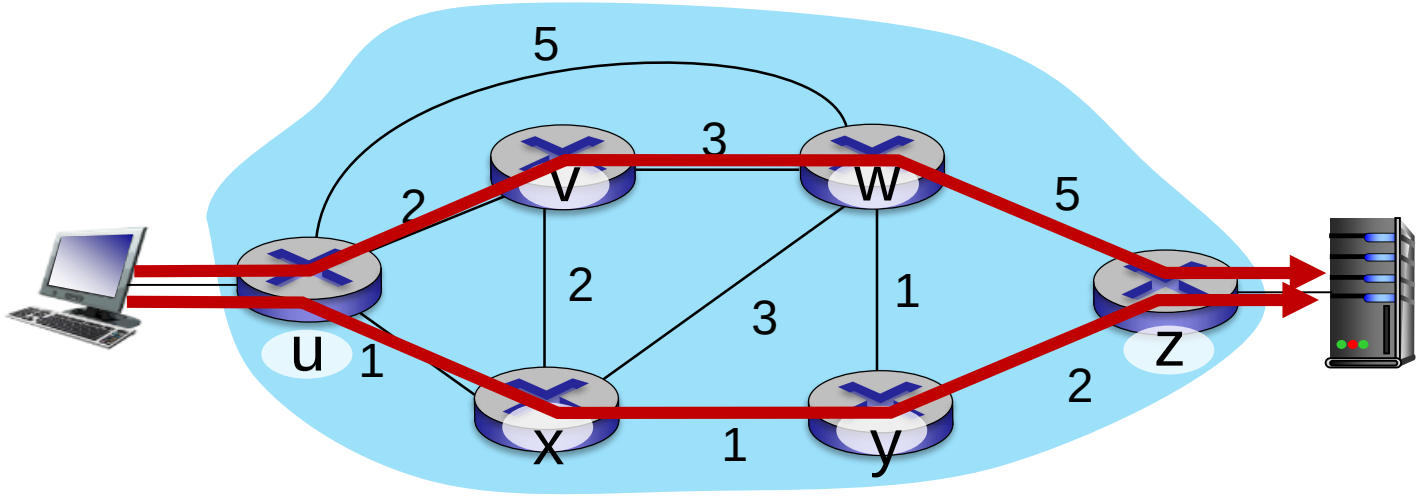
Software defined networking (SDN)

Why a *logically centralized* control plane?

- Easier network management: avoid router misconfigurations, greater flexibility of traffic flows
- Table-based forwarding (OpenFlow API) allows "programming" routers
  - Centralized "programming" easier: compute tables centrally and distribute them
  - Distributed "programming" more difficult: compute tables as result of distributed algorithm (protocol) implemented in each-and-every router
- Open (non-proprietary) implementation of control plane

Example: Traffic Engineering

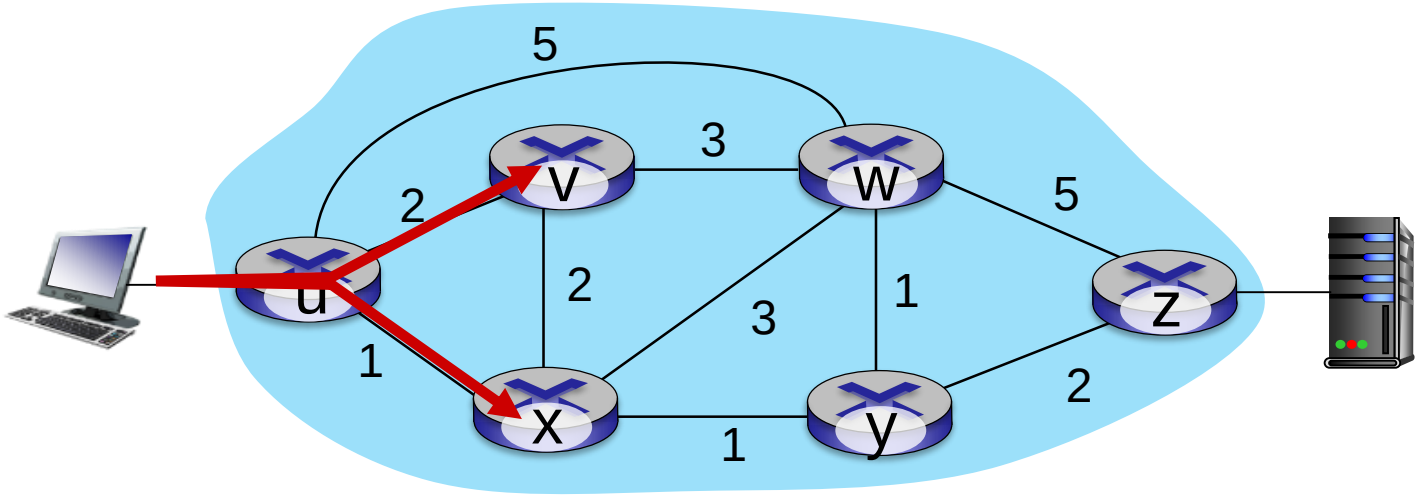
-Difficult with traditional routing



- Want u-to-z traffic to flow along *uvwz*, rather than *uxyz*?
- OSPF: need to re-define link weights so traffic routing algorithm computes routes accordingly (or need a new routing algorithm)!

Example: Traffic Engineering

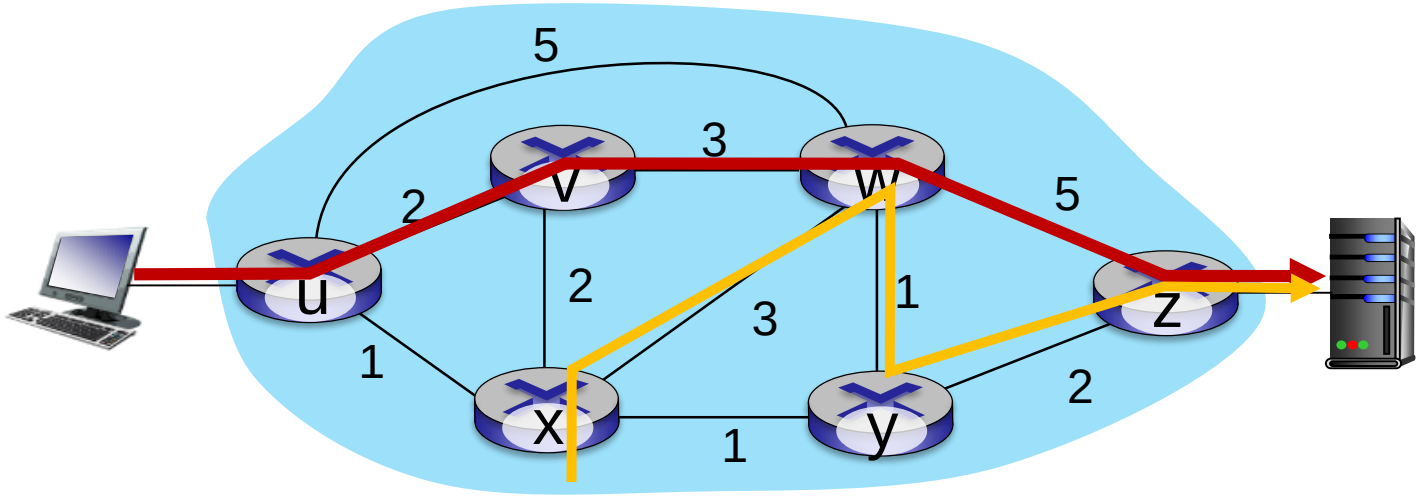
-Difficult with traditional routing



- Split u-to-z traffic along uvwz *and* uxyz (load balancing)?
- Can't do it (or need a new routing algorithm)

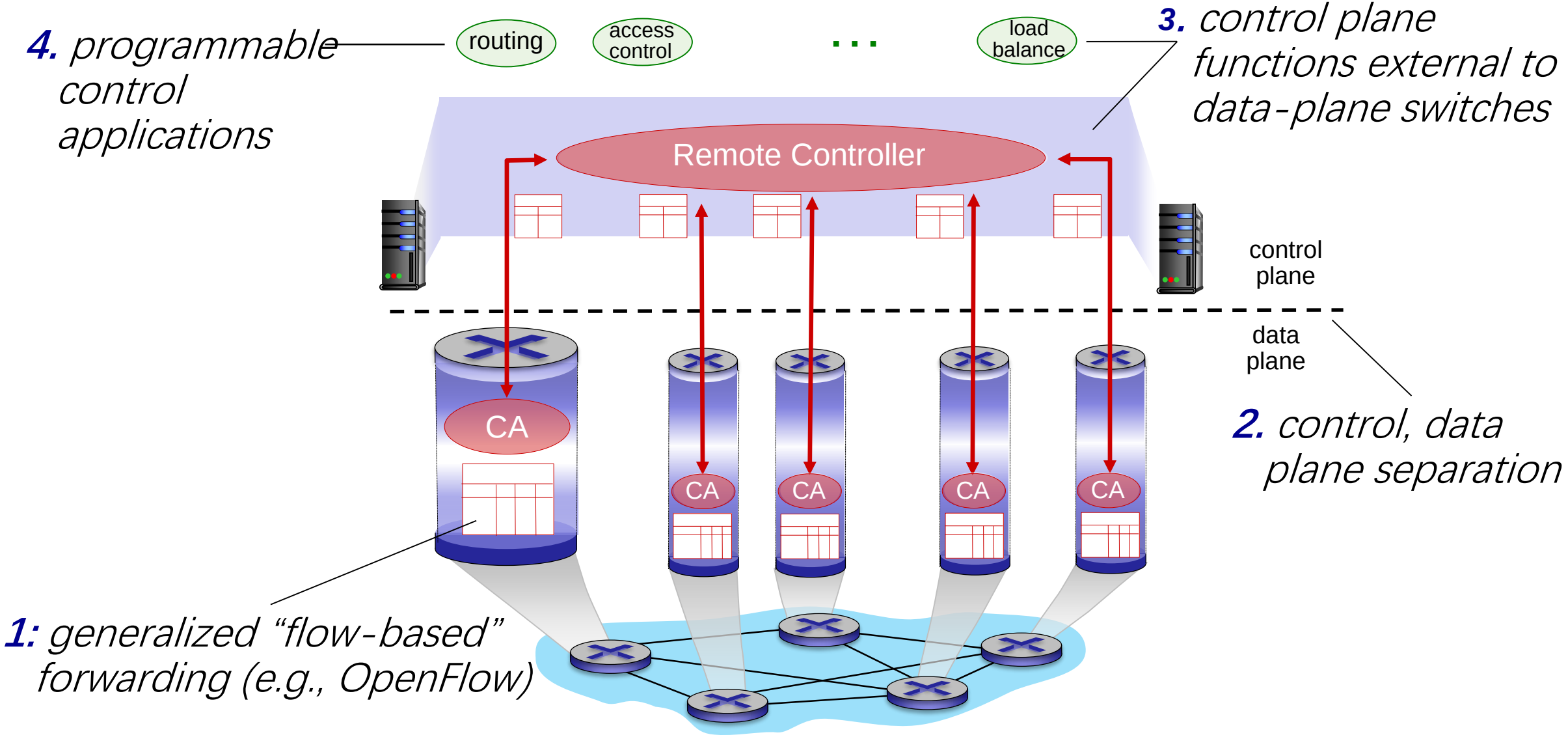
Example: Traffic Engineering

-Difficult with traditional routing



- w wants to route yellow and red traffic differently from w to z?
- Can't do it

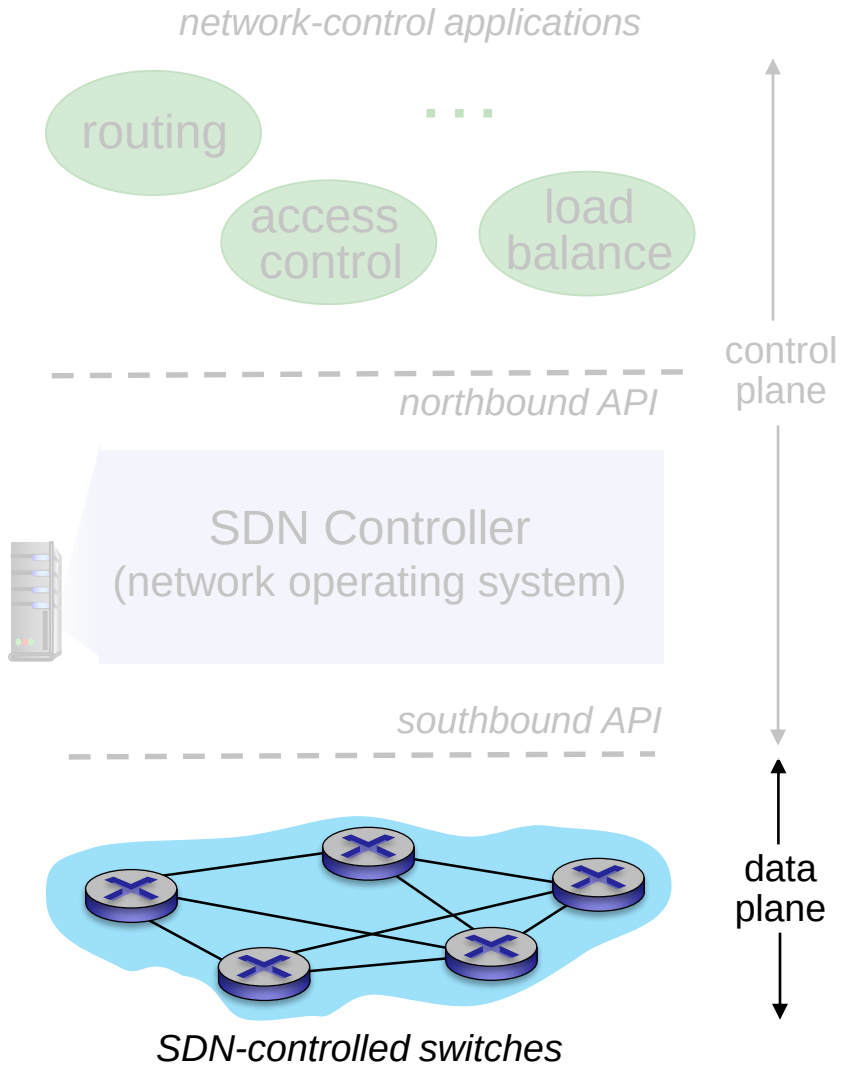
Software Defined Networking (SDN)



SDN Components

Data-plane switches:

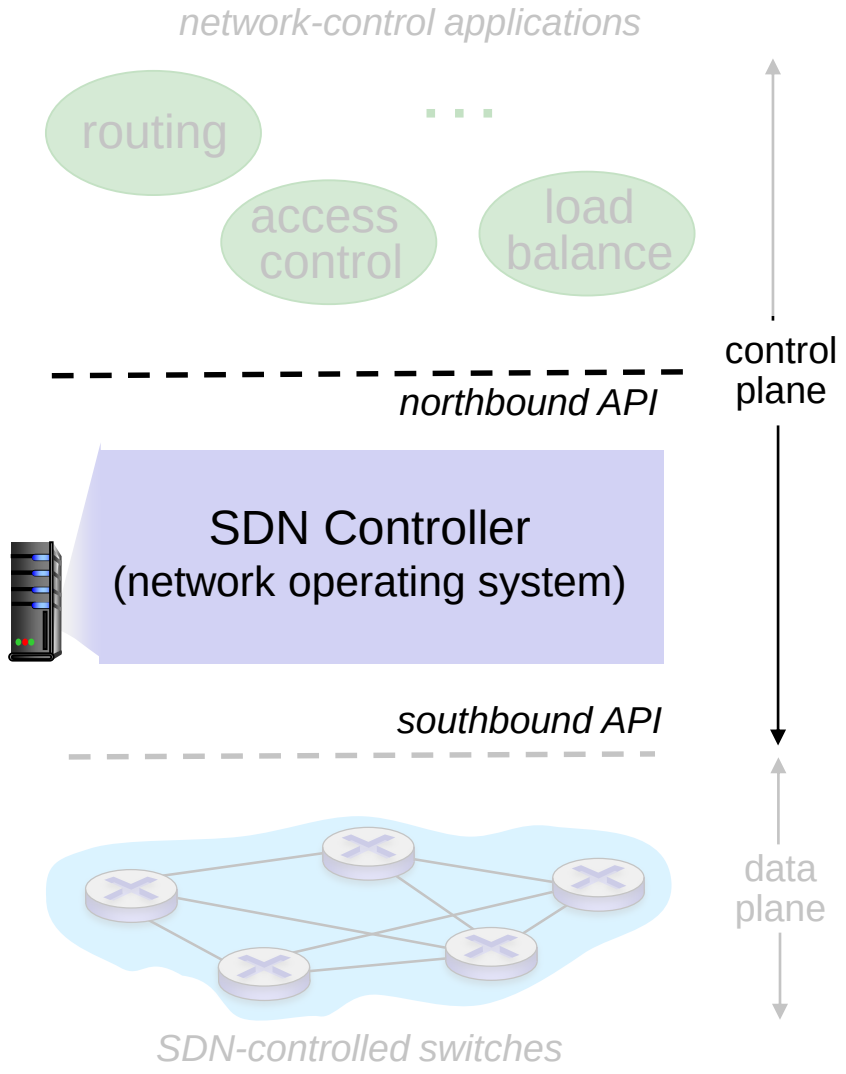
- Fast, simple, commodity switches implementing generalized data-plane forwarding in hardware
- Flow (forwarding) table computed, installed under controller supervision
- API for table-based switch control (e.g., OpenFlow)
  - defines what is controllable, what is not
- Protocol for communicating with controller (e.g., OpenFlow)



SDN Components

SDN controller (network OS):

- Maintain network state information
- Interacts with network control applications “above” via northbound API
- Interacts with network switches “below” via southbound API
- Implemented as distributed system for performance, scalability, fault-tolerance, robustness

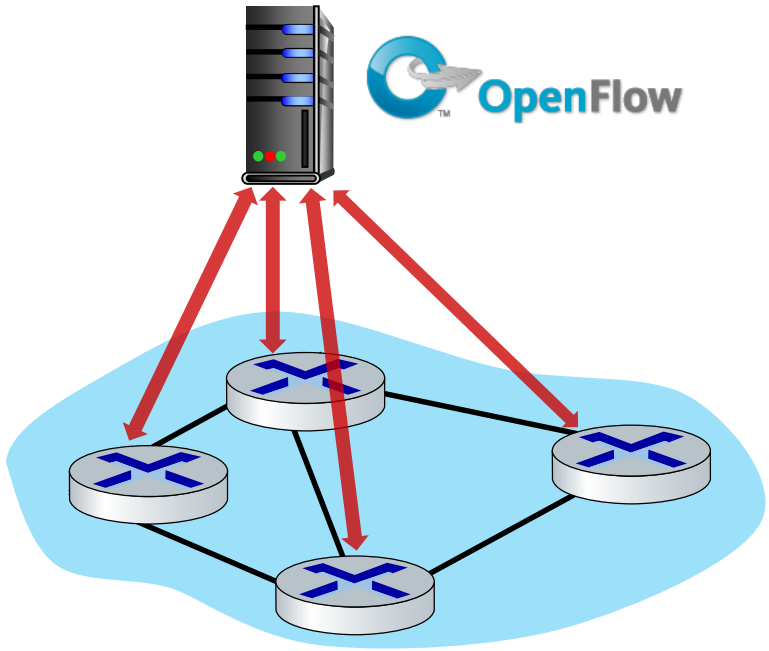


OpenFlow: Controller-to-switch Messages

Key controller-to-switch messages

- *features:* controller queries switch features, switch replies
- *configure:* controller queries/sets switch configuration parameters
- *modify-state:* add, delete, modify flow entries in the OpenFlow tables
- *packet-out:* controller can send this packet out of specific switch port

OpenFlow Controller

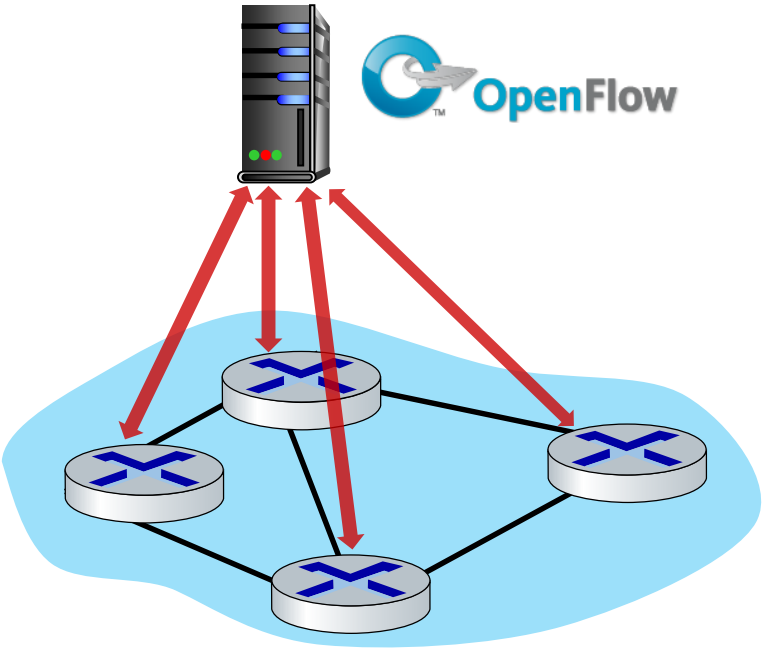


OpenFlow: Switch-to-controller Messages

Key switch-to-controller messages

- *packet-in:* transfer packet (and its control) to controller. See packet-out message from controller
- *flow-removed:* flow table entry deleted at switch
- *port status:* inform controller of a change on a port.

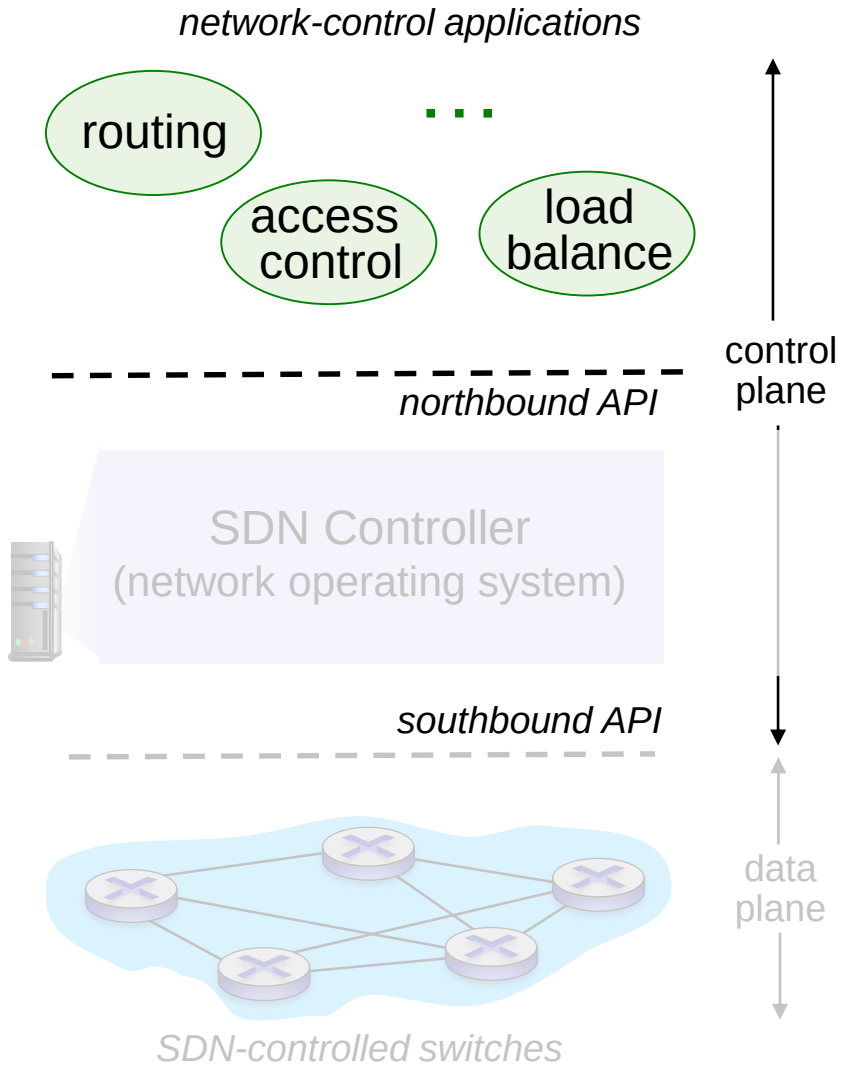
OpenFlow Controller



SDN Components

Network-control apps:

- "brains" of control: implement control functions using lower-level services, API provided by SDN controller
- *unbundled:* can be provided by 3rd party: distinct from routing vendor, or SDN controller



Reference

- Textbook (6th) section 3.5.3
  - https://book.systemsapproach.org/internetworking/impl.html#software-defined-networks
  - https://book.systemsapproach.org/congestion/trend.html
- Most slides are adapted from http://www-net.cs.umass.edu/kurose_ross/ppt.htm by Kurose Ross