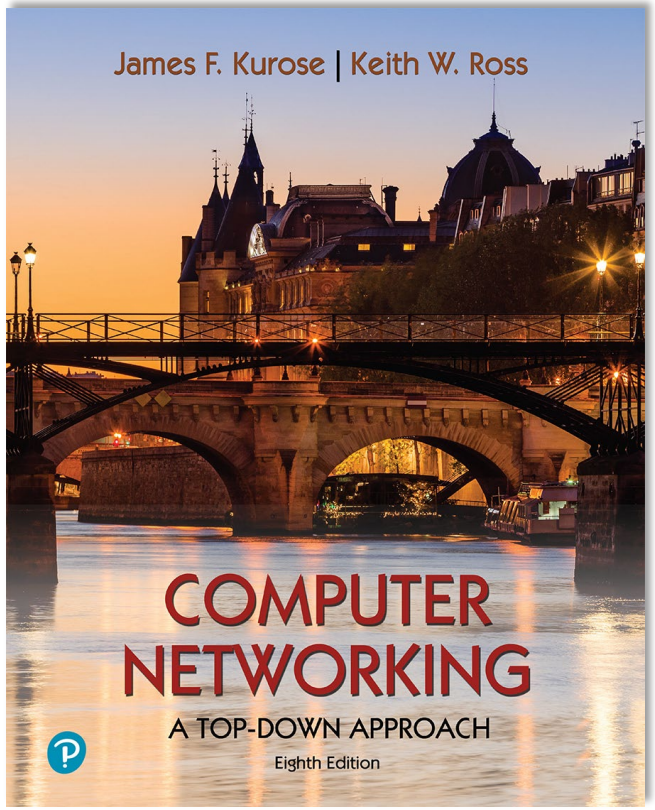
Packet Switched Networks



Computer Networking: A Top-Down Approach
8th edition
Jim Kurose, Keith Ross
Pearson, 2020

Acknowledgements
These Slides have been adapted from the originals made available by J. Kurose and K. Ross

Goals

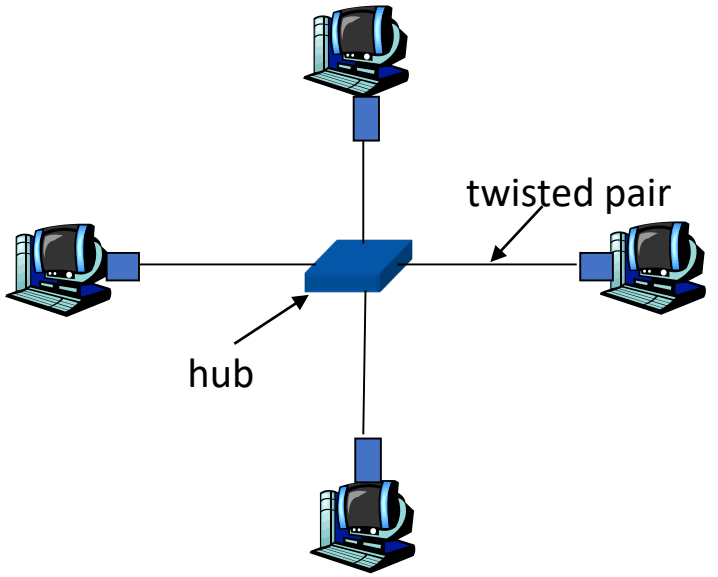
- Understanding principles behind packet switched networks
- Introducing some examples of packed switched networks

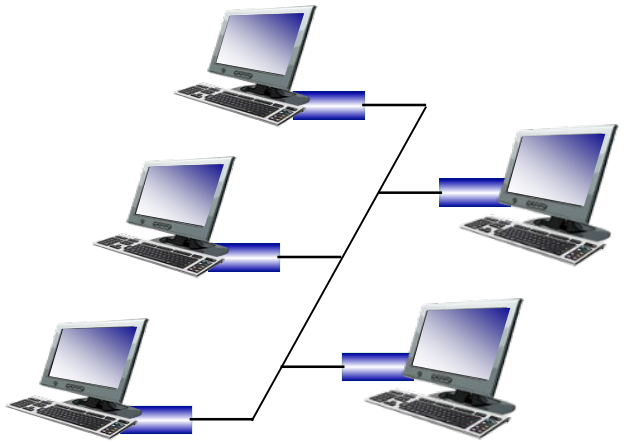
Roadmap

- Link-layer switches
- Switched Ethernet
- Virtual LANs
- Wide-Area Packet Switched Networks
- Link virtualization

Ethernet Hubs

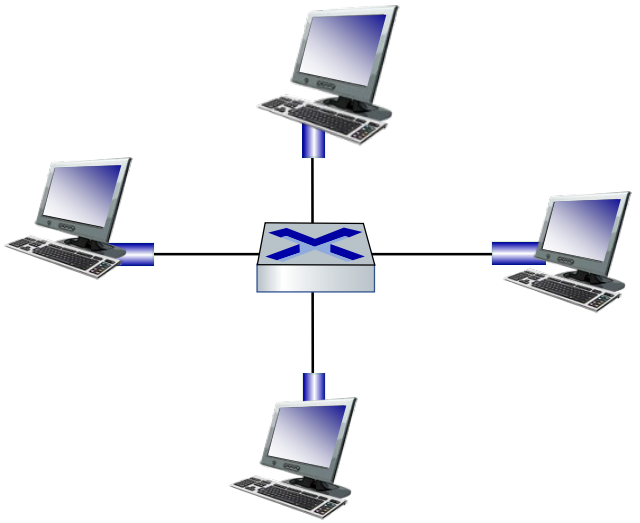
- Physical-layer ("dumb") repeater
  - bits coming in one link go out *all* other links at same rate
  - all nodes connected to hub can collide with one another
  - no frame buffering
  - no CSMA/CD at hub: host NICs detect collisions





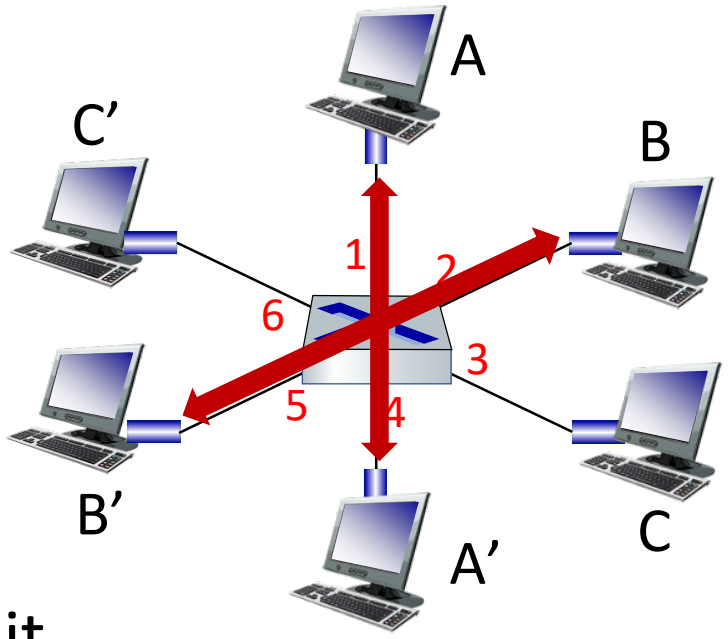
Ethernet switch

- Switch is a link-layer device: takes an *active* role
  - store, forward Ethernet frames
    - examine incoming frame's MAC address
    - *selectively* forward frame to one-or-more outgoing links when frame is to be forwarded on segment
    - uses CSMA/CD to access segment
- transparent: hosts *unaware* of presence of switches
- plug-and-play, self-learning
  - switches do not need to be configured



Switch: multiple simultaneous transmissions

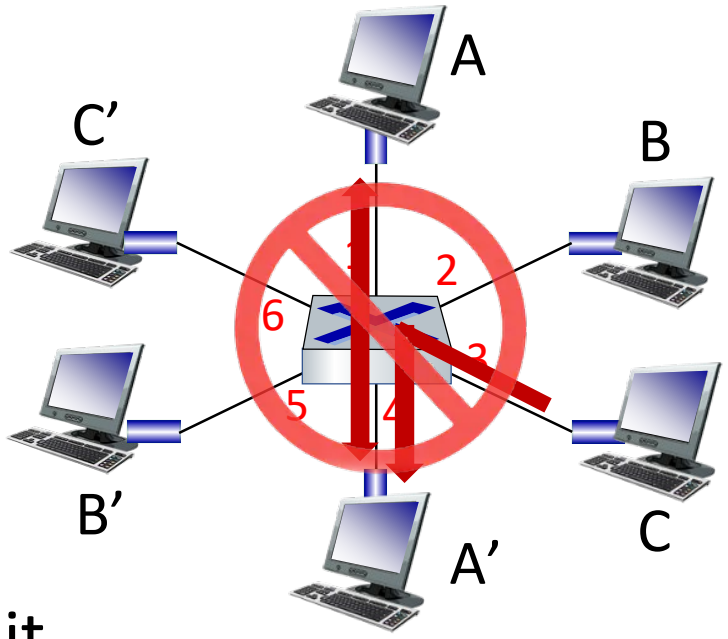
- hosts have dedicated, direct connection to switch
- switches buffer packets
- Ethernet protocol used on *each* incoming link, so:
  - no collisions; full duplex
  - each link is its own collision domain
- switching: A-to-A' and B-to-B' can transmit simultaneously, without collisions



switch with six interfaces (1,2,3,4,5,6)

Switch: multiple simultaneous transmissions

- hosts have dedicated, direct connection to switch
- switches buffer packets
- Ethernet protocol used on *each* incoming link, so:
  - no collisions; full duplex
  - each link is its own collision domain
- switching: A-to-A' and B-to-B' can transmit simultaneously, without collisions
  - but A-to-A' and C to A' can *not* happen simultaneously



switch with six interfaces (1,2,3,4,5,6)

Switch forwarding table

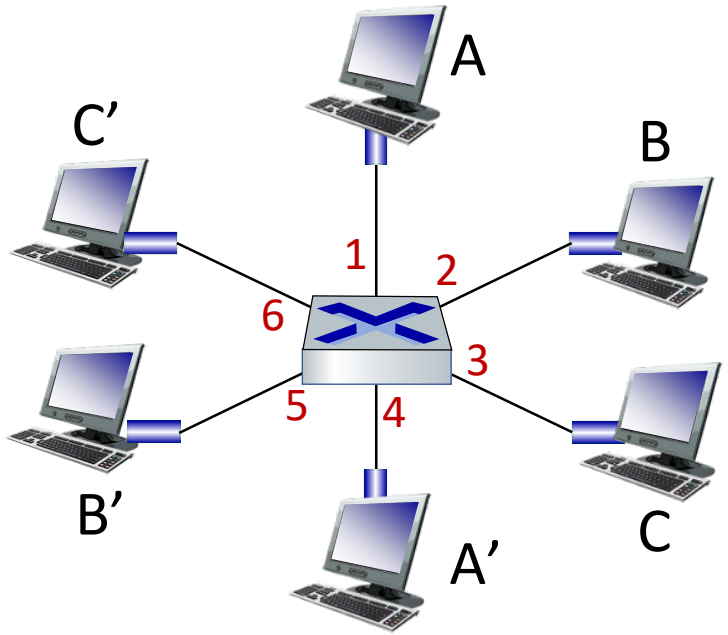
Q: how does switch know A' reachable via interface 4, B' reachable via interface 5?

A: each switch has a switch table, each entry:

- (MAC address of host, interface to reach host, time stamp)
- looks like a routing table!

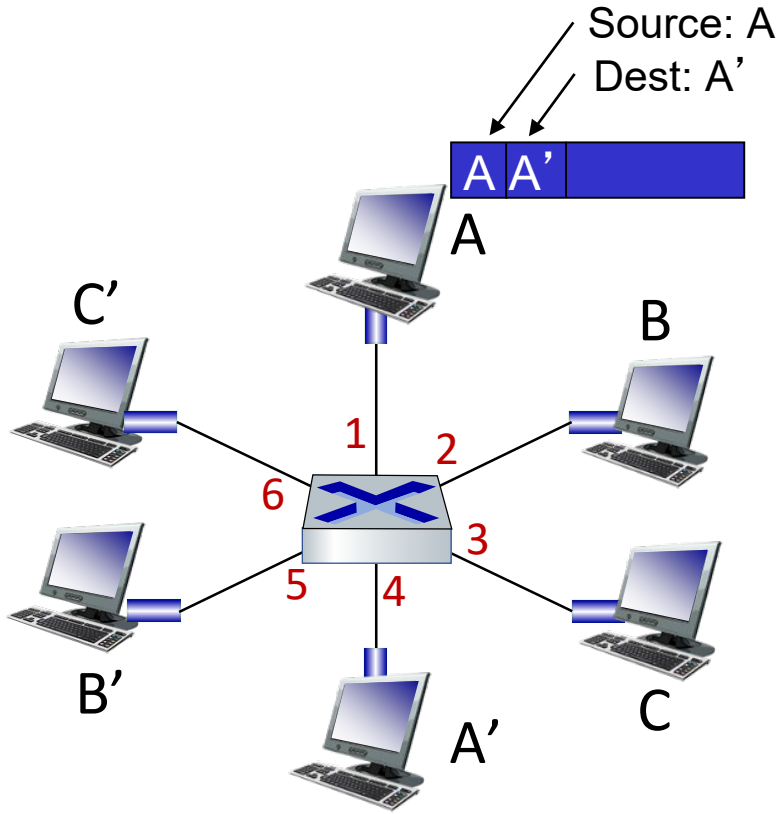
Q: how are entries created, maintained in switch table?

- something like a routing protocol?



Switch: self-learning

- switch *learns* which hosts can be reached through which interfaces
  - when frame received, switch "learns" location of sender: incoming LAN segment
  - records sender/location pair in switch table



MAC addr	interface	TTL
A	*1*	*60*

Switch table (initially empty)

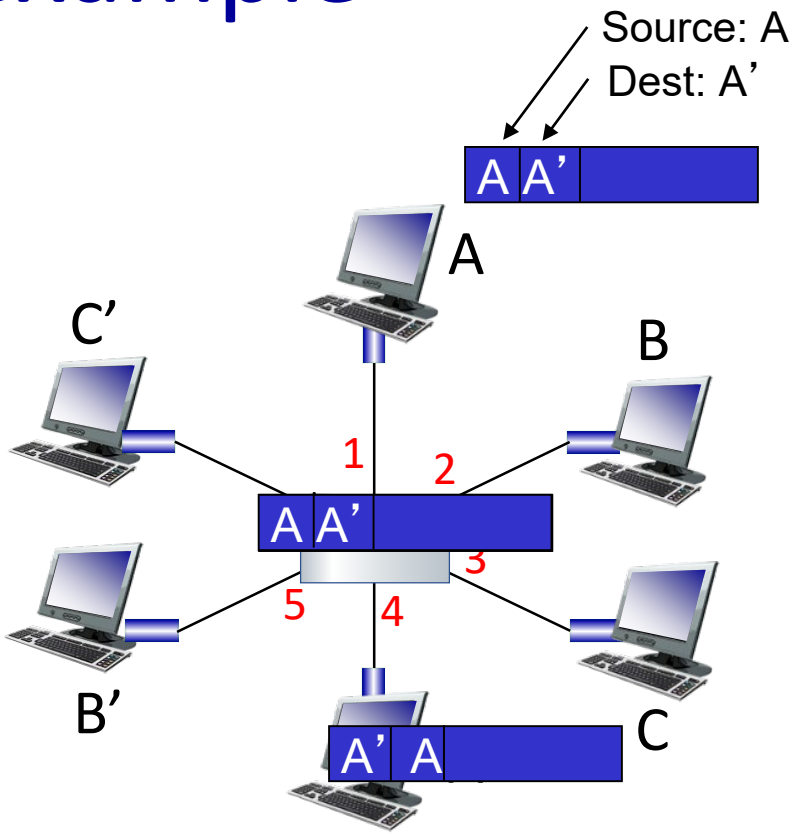
Switch: frame filtering/forwarding

when frame received at switch:

1. record incoming link, MAC address of sending host
2. index switch table using MAC destination address
3. if entry found for destination
   then {
   if destination on segment from which frame arrived
      then drop frame
       else forward frame on interface indicated by entry
    }
   else flood /* forward on all interfaces except arriving interface */

Self-learning, forwarding: example

- frame destination, A', location unknown: flood
- destination A location known: selectively send on just one link



MAC addr	interface	TTL
A	1	60
A'	4	60

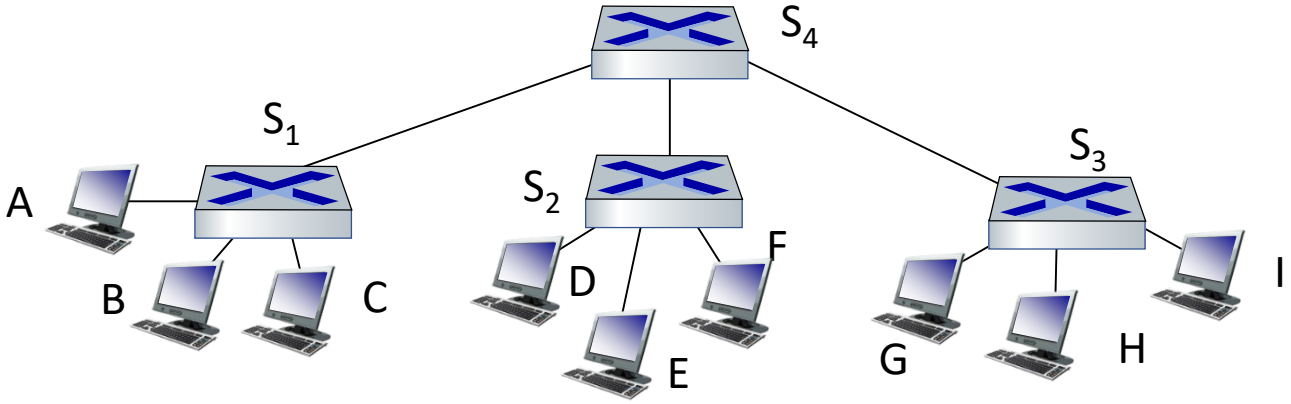
switch table (initially empty)

Roadmap

- Link-layer switches
- Switched Ethernet
- Virtual LANs
- Wide-Area Packet Switched Networks
- Link virtualization

Interconnecting switches

self-learning switches can be connected together:

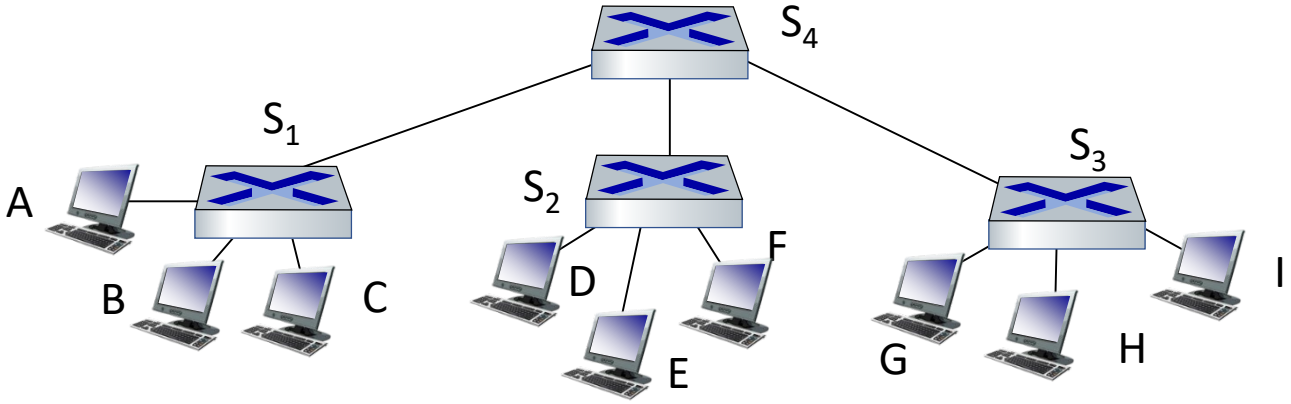


Q: sending from A to G - how does S_1 know to forward frame destined to G via S_4 and S_3?

- *A:* self learning! (works exactly the same as in single-switch case!)

Self-learning multi-switch example

Suppose C sends frame to I, I responds to C



Q: show switch tables and packet forwarding in S_1, S_2, S_3, S_4

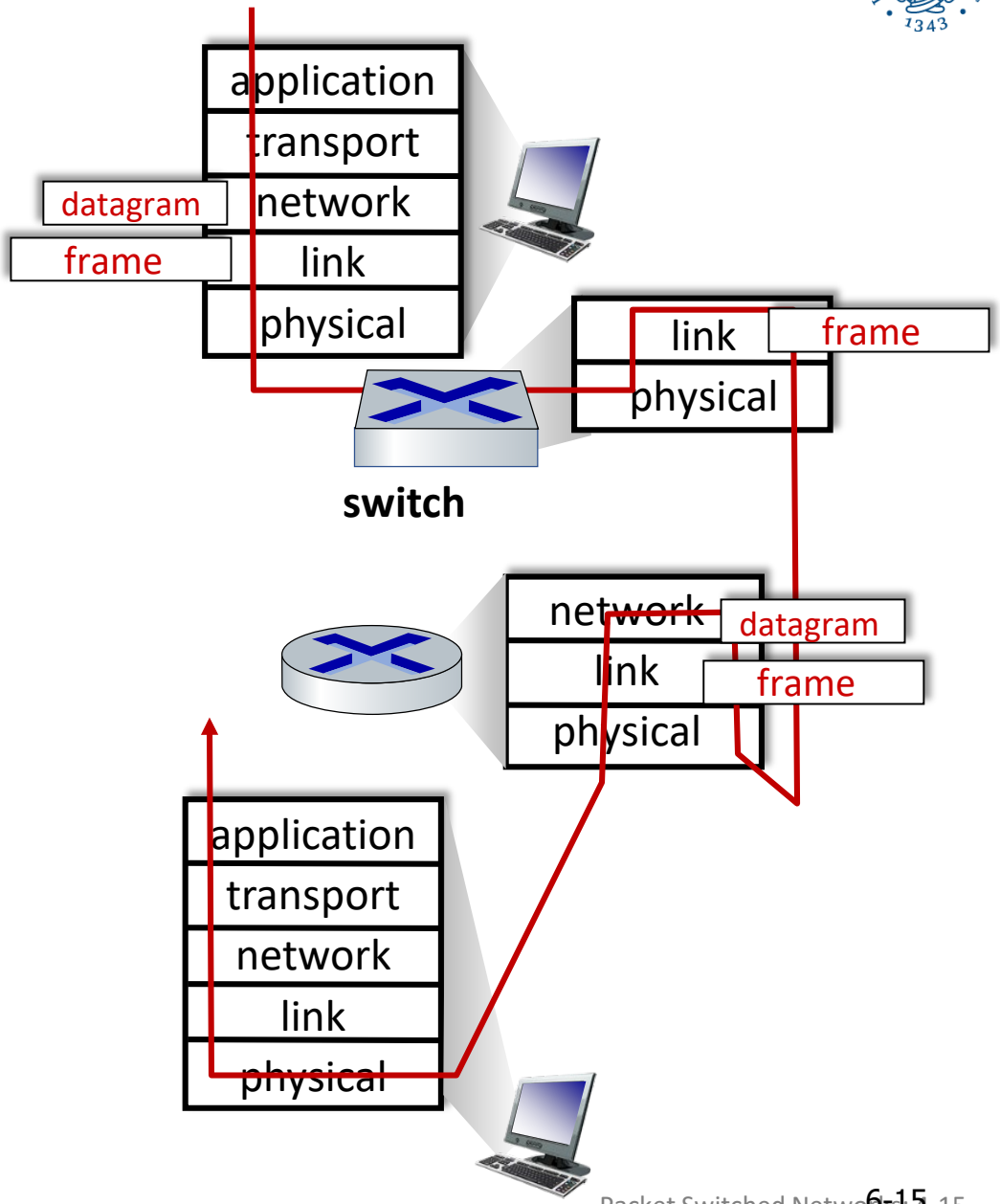
Switches vs. routers

both are store-and-forward:

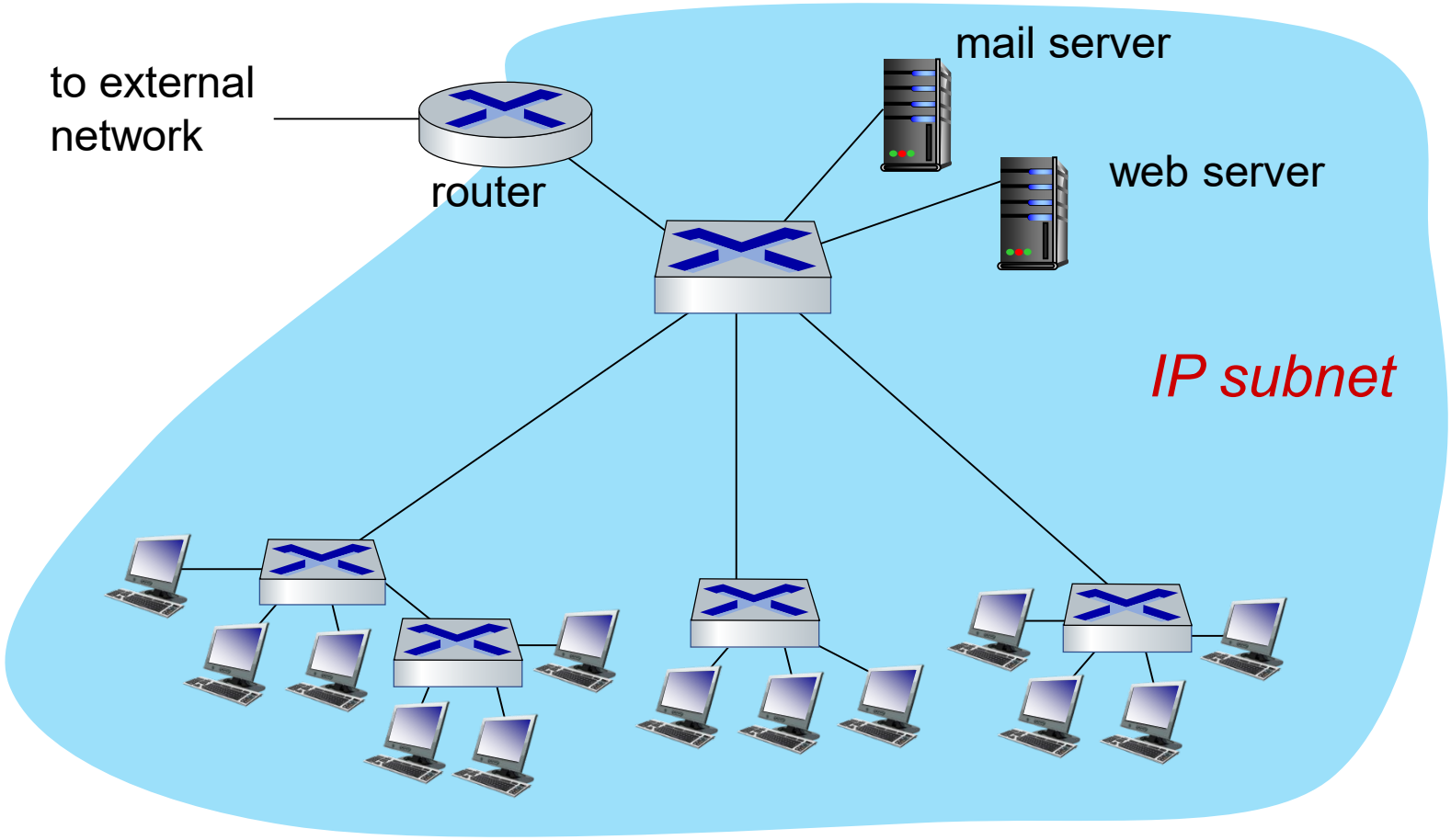
- *routers*: network-layer devices (examine network-layer headers)
- *switches:* link-layer devices (examine link-layer headers)

both have forwarding tables:

- *routers:* compute tables using routing algorithms, IP addresses
- *switches:* learn forwarding table using flooding, learning, MAC addresses



Small institutional network



Datacenter networks

10’s to 100’s of thousands of hosts, often closely coupled, in close proximity:

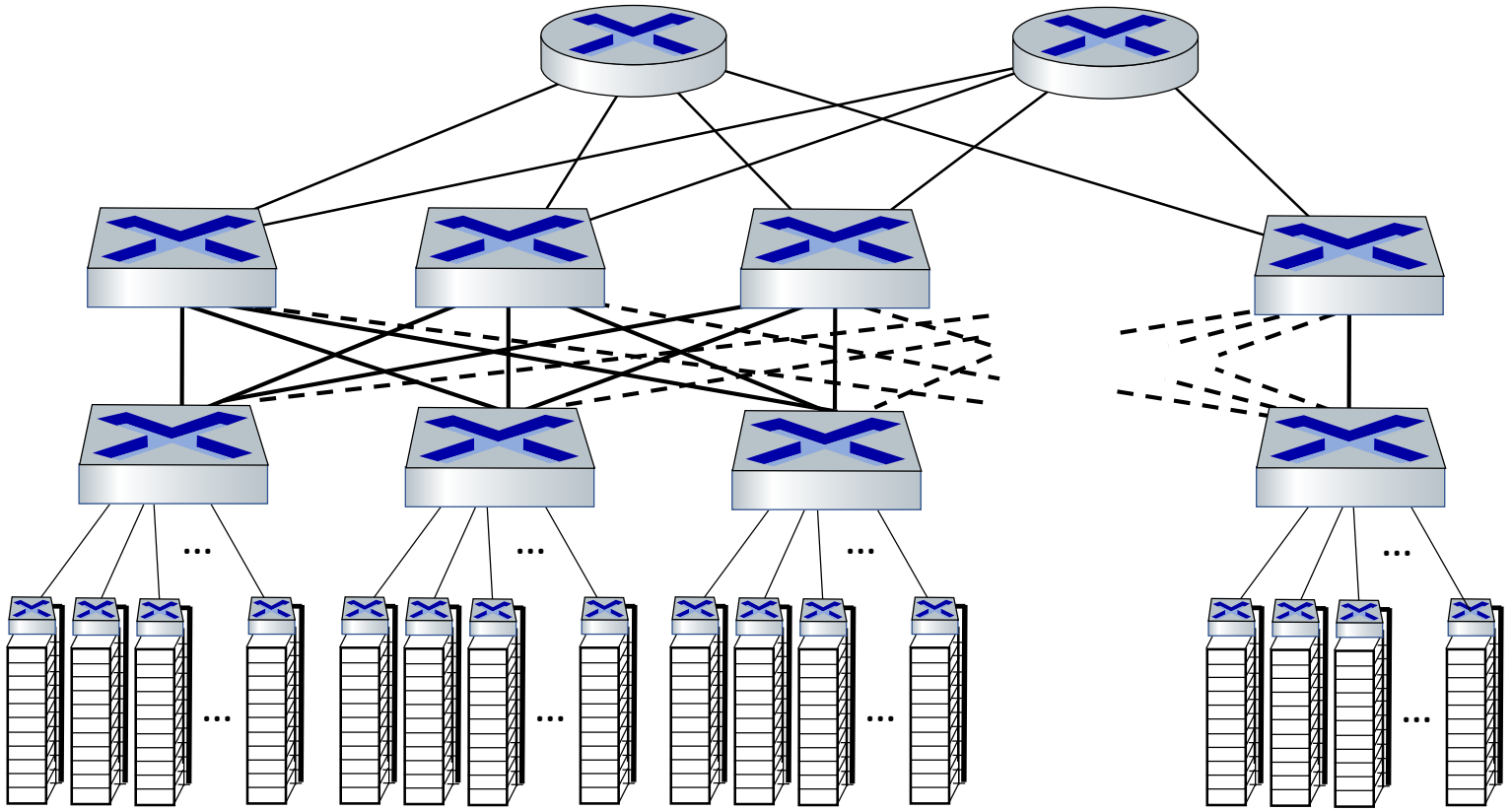
- e-business (e.g. Amazon)
- content-servers (e.g., YouTube, Akamai, Apple, Microsoft)
- search engines, data mining (e.g., Google)

challenges:

- multiple applications, each serving massive numbers of clients
- reliability
- managing/balancing load
- avoiding (processing, networking, data) bottlenecks

Inside a 40-ft Microsoft container, Chicago data center

Datacenter networks



Border routers

- connections outside datacenter

Tier-1 switches

- connecting to ~16 T-2s below

Tier-2 switches

- connecting to ~16 TORs below

Top of Rack (TOR) switch

- one per rack
- 40-100Gbps Ethernet to blades

Server racks

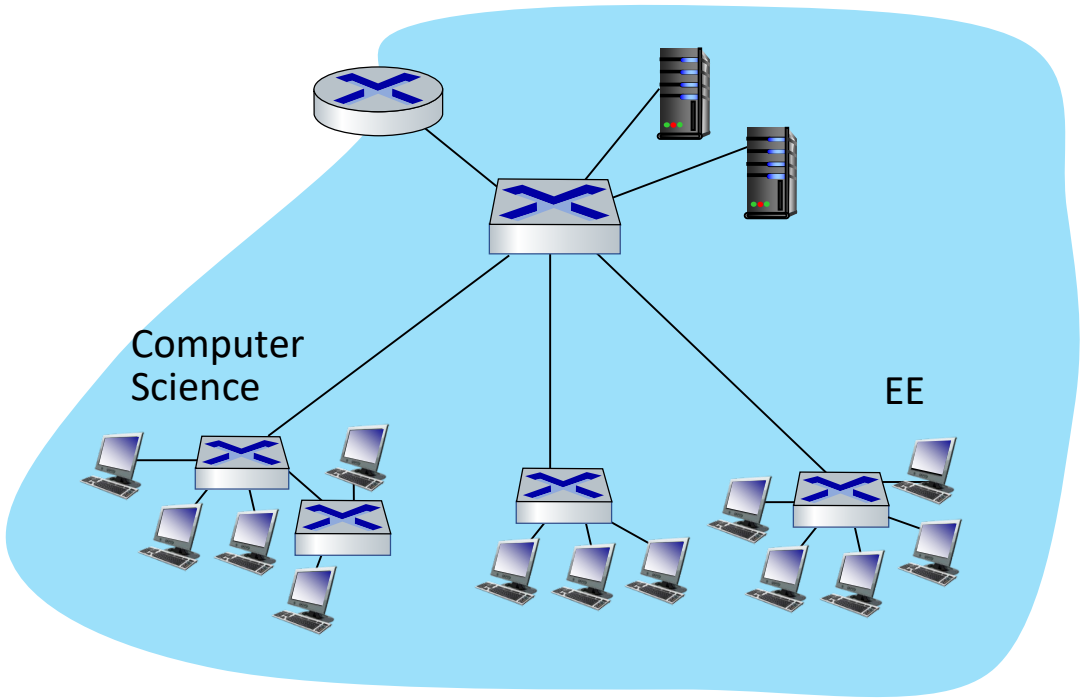
- 20- 40 server blades: hosts

Roadmap

- Link-layer switches
- Switched Ethernet
- Virtual LANs
- Wide-Area Packet Switched Networks
- Link virtualization

Virtual LANs (VLANs): motivation

Q: what happens as LAN sizes scale, users change point of attachment?

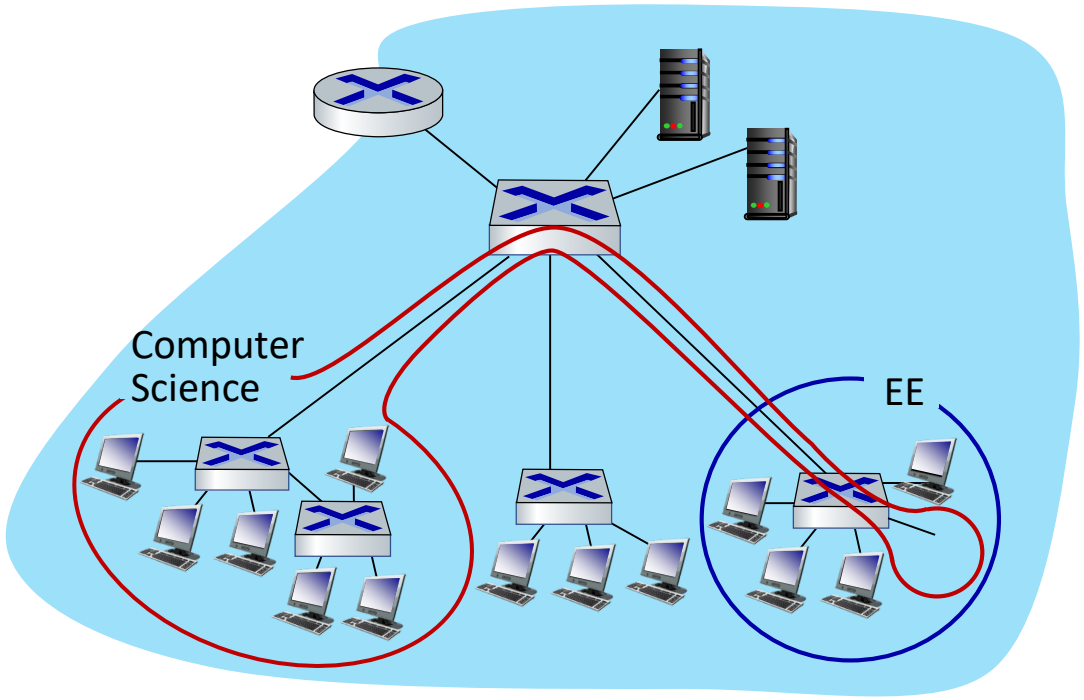


single broadcast domain:

- *scaling:* all layer-2 broadcast traffic (ARP, DHCP, unknown MAC) must cross entire LAN
- efficiency, security, privacy issues

Virtual LANs (VLANs): motivation

Q: what happens as LAN sizes scale, users change point of attachment?



single broadcast domain:

- *scaling:* all layer-2 broadcast traffic (ARP, DHCP, unknown MAC) must cross entire LAN
- efficiency, security, privacy, efficiency issues

administrative issues:

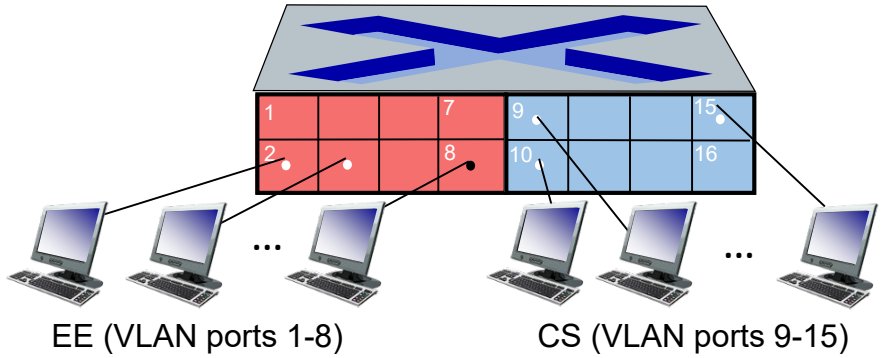
- CS user moves office to EE - *physically* attached to EE switch, but wants to remain *logically* attached to CS switch

Port-based VLANs

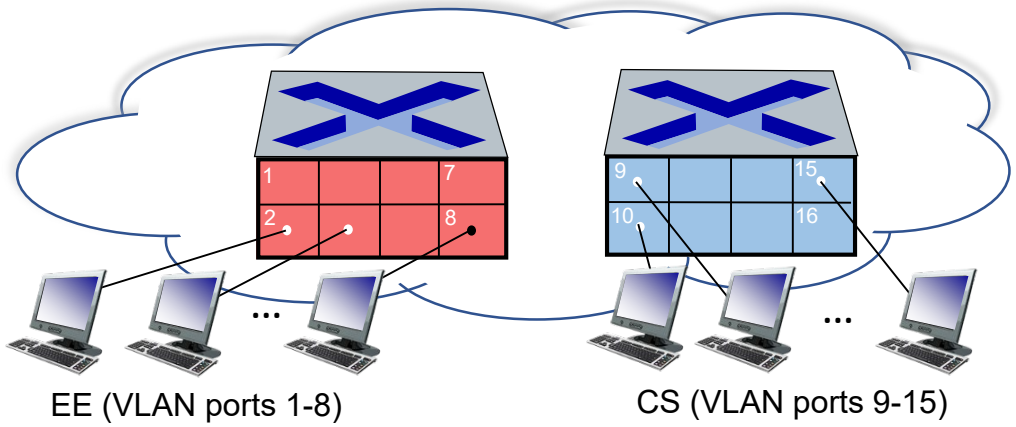
Virtual Local Area Network (VLAN)

switch(es) supporting VLAN capabilities can be configured to define multiple *virtual* LANS over single physical LAN infrastructure.

port-based VLAN: switch ports grouped (by switch management software) so that *single* physical switch ……

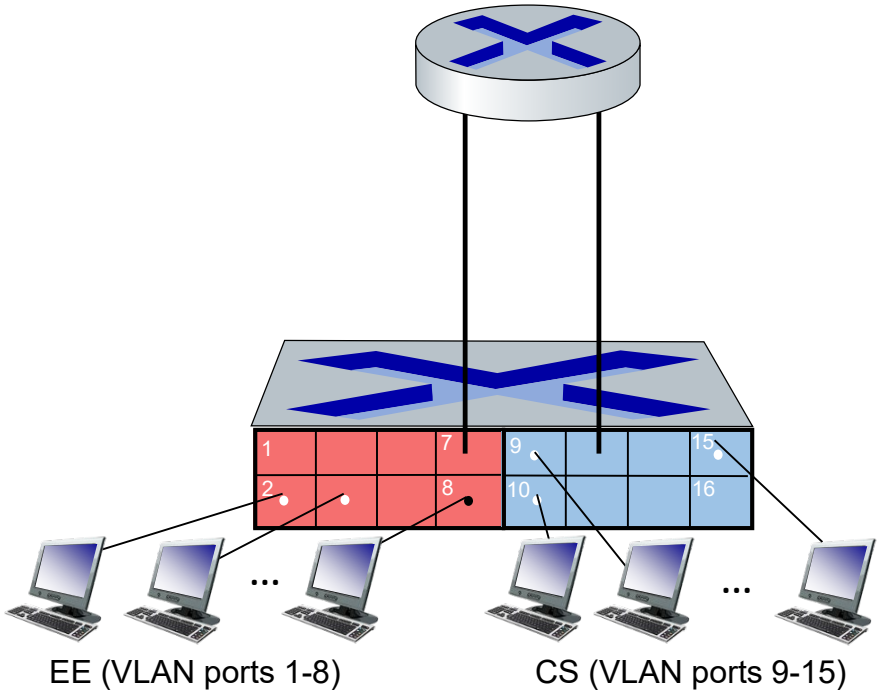


… operates as multiple virtual switches

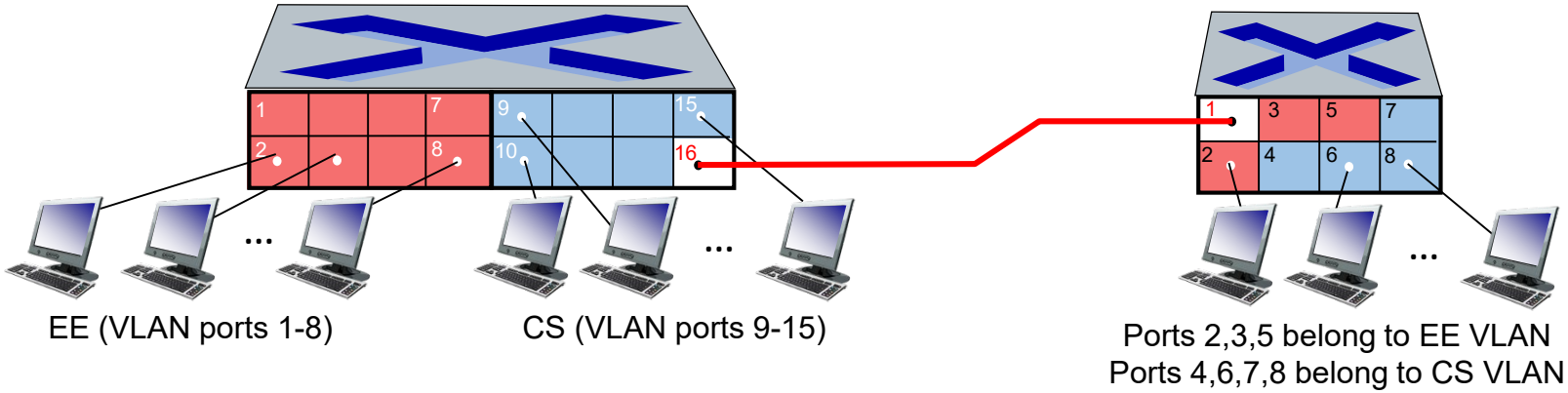


Port-based VLANs

- traffic isolation: frames to/from ports 1-8 can *only* reach ports 1-8
  - can also define VLAN based on MAC addresses of endpoints, rather than switch port
- dynamic membership: ports can be dynamically assigned among VLANs
- forwarding between VLANS: done via routing (just as with separate switches)
  - in practice vendors sell combined switches plus routers



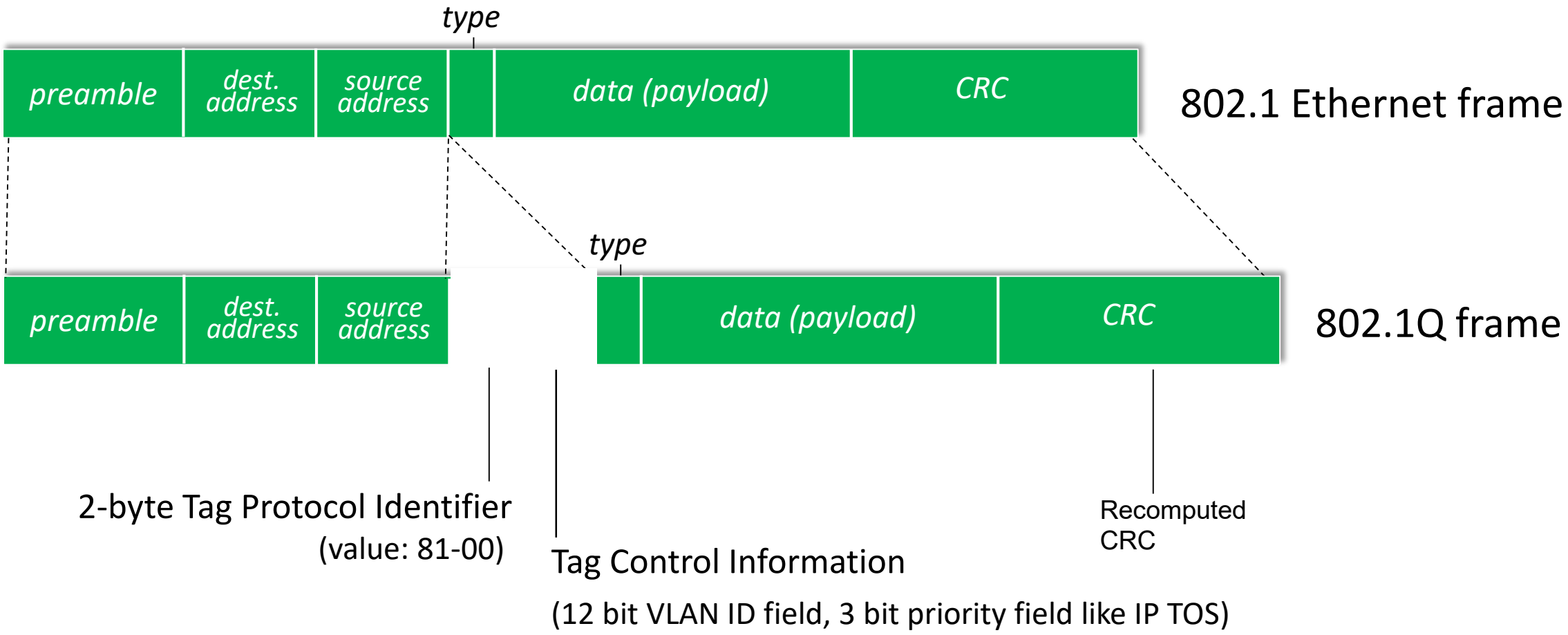
VLANS spanning multiple switches



trunk port: carries frames between VLANS defined over multiple physical switches

- frames forwarded within VLAN between switches can't be vanilla 802.1 frames (must carry VLAN ID info)
- 802.1q protocol adds/removed additional header fields for frames forwarded between trunk ports

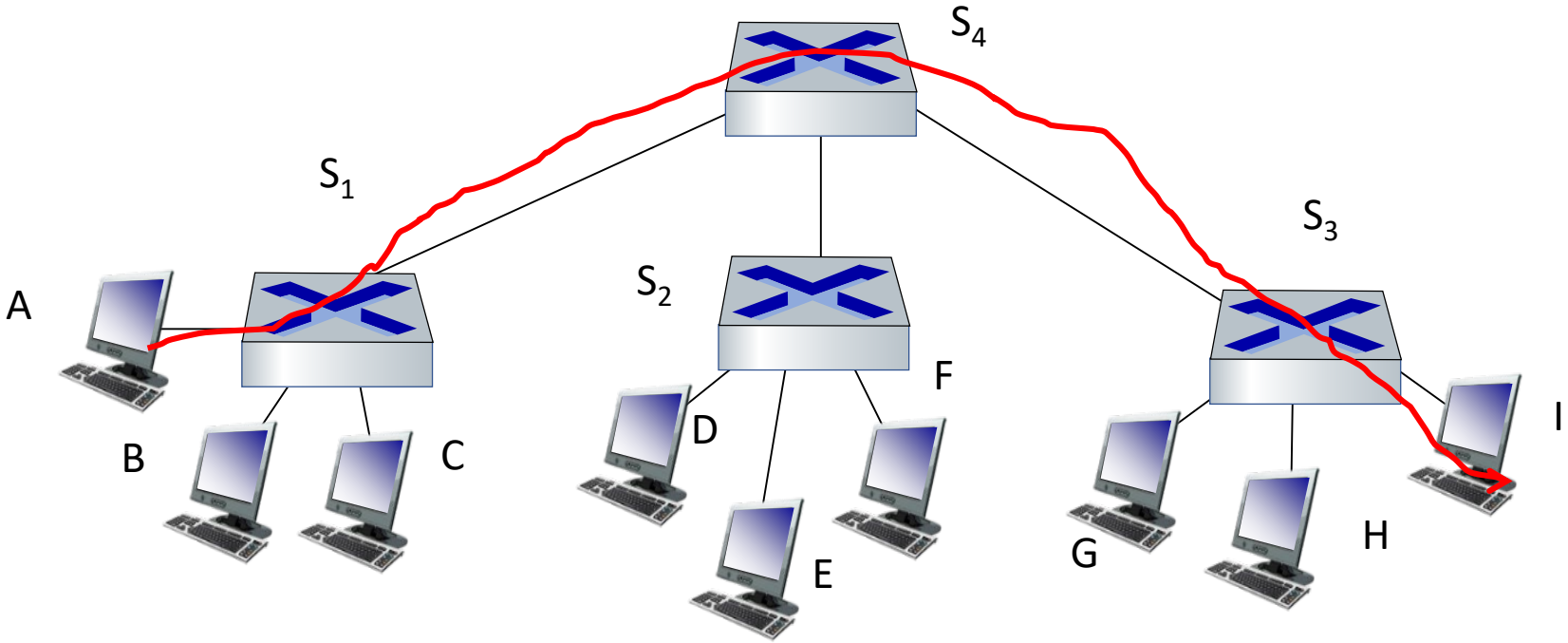
802.1Q VLAN frame format



Roadmap

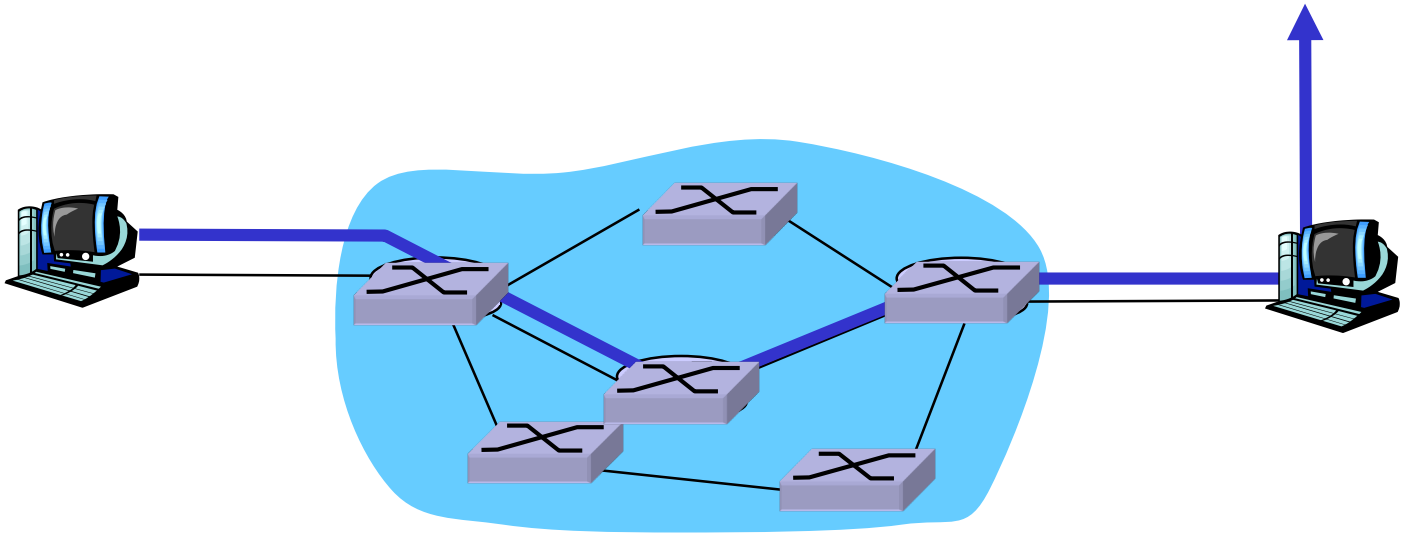
- Link-layer switches
- Switched Ethernet
- Virtual LANs
- Wide-Area Packet Switched Networks
- Link virtualization

Switched Ethernet



Packet-Switched Wide-Area Networks (WANs)

- Nodes identified through a unique address
  - Similar to the Ethernet MAC address



Type of Service

- Connectionless
- Each packet is managed on an individual basis
- Also known as datagram service

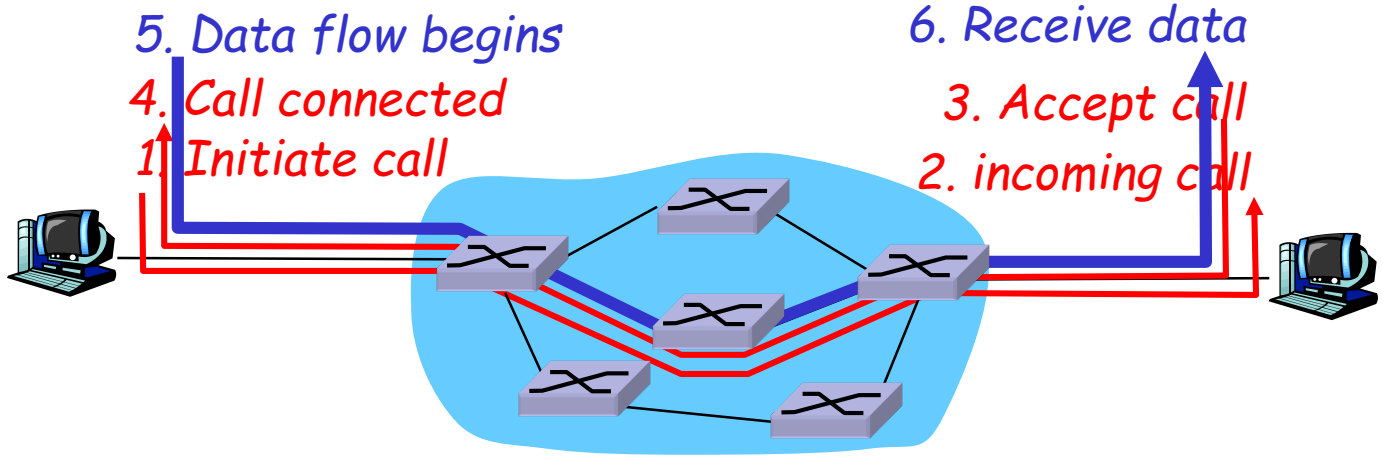
- Connection
  - A Virtual Circuit is preliminary established
  - All packets follow the same path

Virtual Circuit

Source-to-destination path

- behaves much like telephone circuit
- performance-wise
- network actions along source-to-dest path

- call setup, teardown for each call *before* data can flow



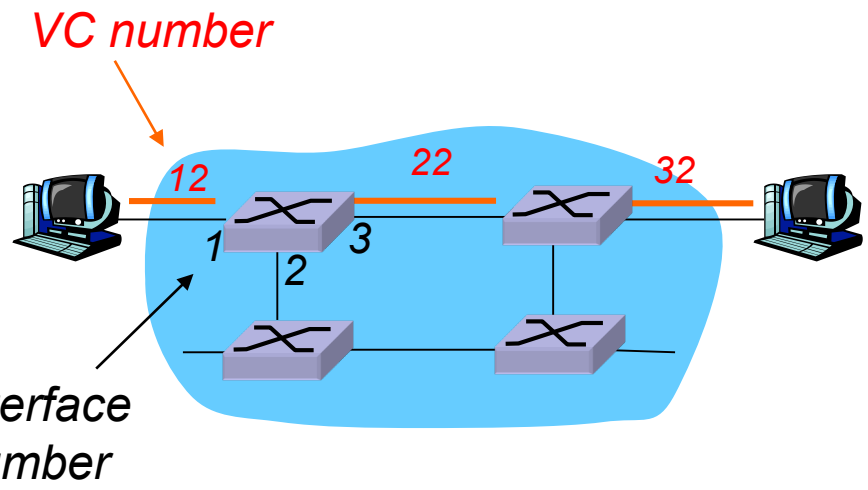
VC Implementation

A VC consists of:

1. path from source to destination
2. VC numbers, one number for each link along path
3. entries in forwarding tables in routers along path

- A packet belonging to VC carries VC number
  - rather than dest address
- VC number can be changed on each link
  - New VC number comes from forwarding table

Forwarding Table



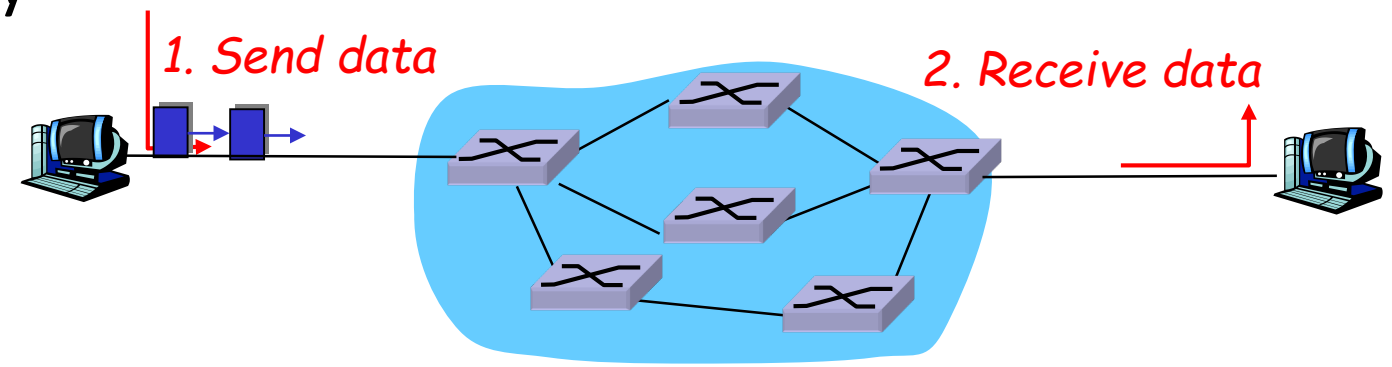
Forwarding table in
A switch

Incoming interface	Incoming VC #	Outgoing interface	Outgoing VC #
1	12	3	22
2	63	1	18
3	7	2	17
1	97	3	87
…	…	…	…

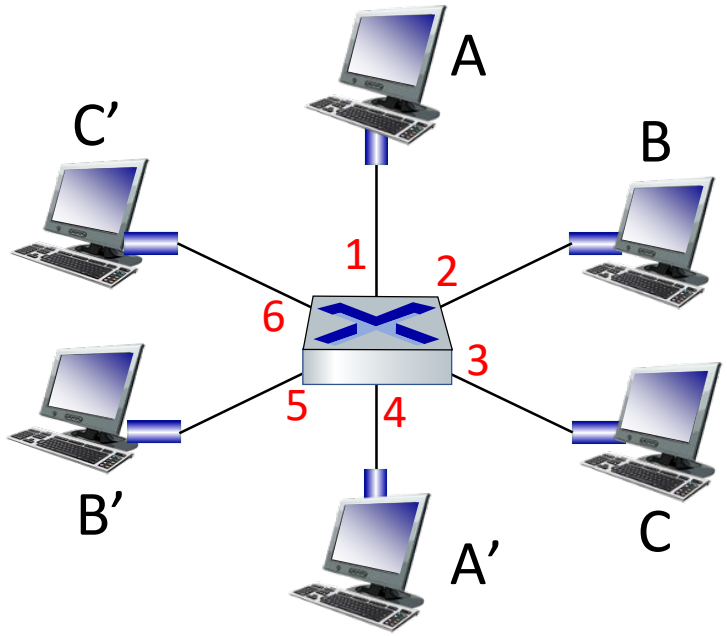
Switches maintain connection state information!

Datagram service

- no call setup
- switches: no state about end-to-end connections
  - no concept of “connection”
- packets between the same source-destination pair may take different paths
- packets forwarded using destination host address



Forwarding Table



MAC address	Interface	TTL
A	*1*	*60*
A'	*4*	*60*

Forwarding Table

forwarding table

Destination Address Range	Link Interface
11001000 00010111 00010000 00000000 through 11001000 00010111 00010111 11111111	0
11001000 00010111 00011000 00000000 through 11001000 00010111 00011000 11111111	1
11001000 00010111 00011001 00000000 through 11001000 00010111 00011111 11111111	2
otherwise	3

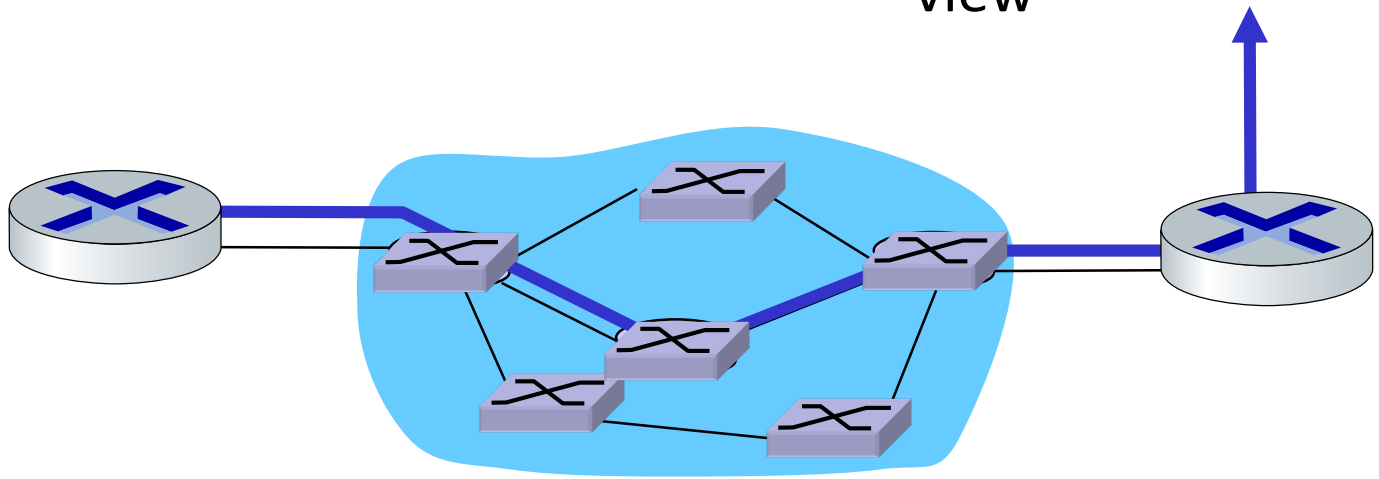
Roadmap

- Link-layer switches
- Switched Ethernet
- Virtual LANs
- Wide-Area Packet Switched Networks
- Link virtualization

Virtual Links

- Virtualization of resources: powerful abstraction in systems engineering:
  - virtual memory
  - virtual devices
  - virtual machines: e.g., java

- Virtual Link:
  - The path from S to D is regarded as a point-to-point virtual link
  - Just like a physical point-to-point link
  - The service type is thus not relevant from the Internet point of view



Summary

- Principles behind packet switched networks
- Switched LANS, VLANs
- Wide-Area Packet-Switched Networks
- Virtualized networks as a point-to point link