LAN switching and Bridges

CS491G: Computer Networking Lab

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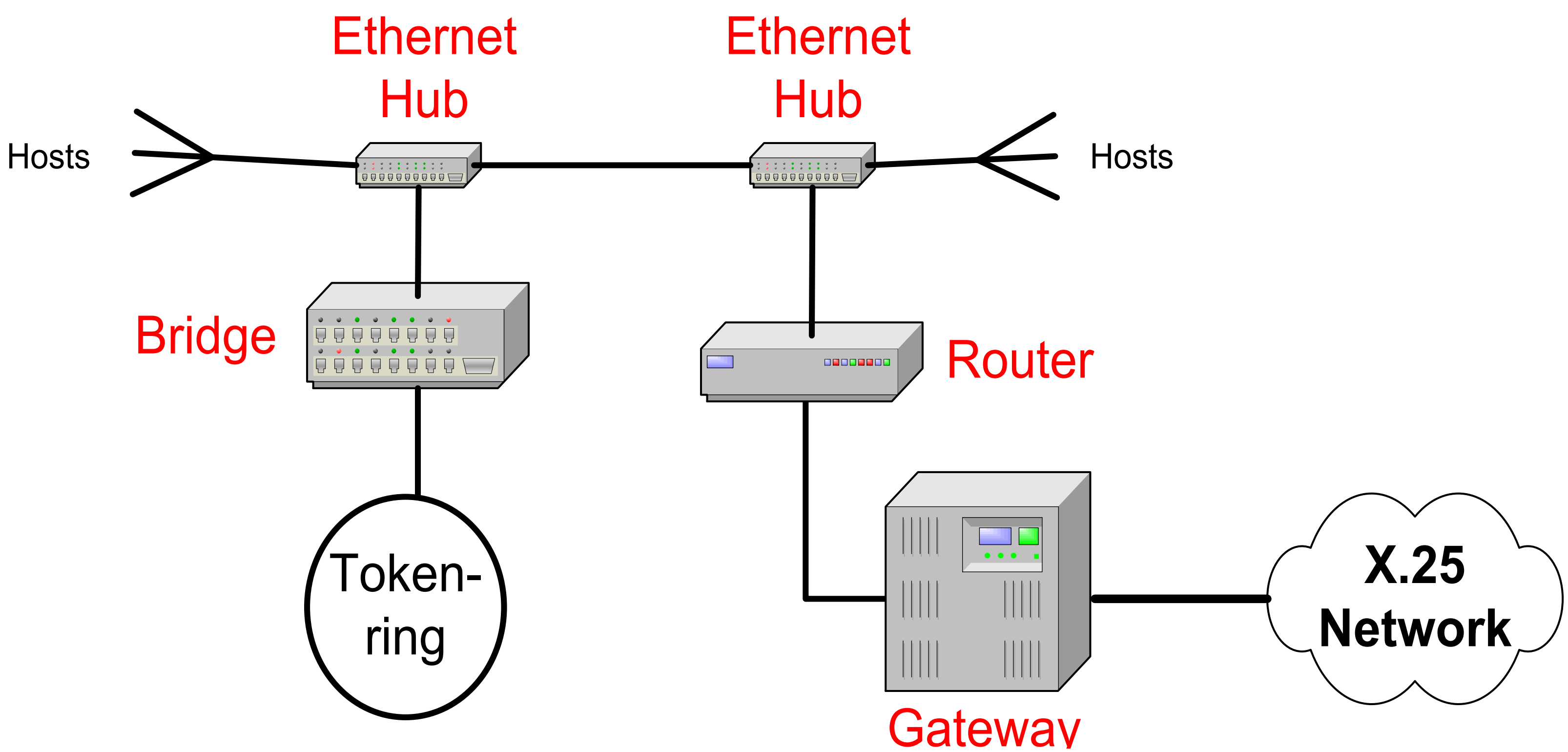
Slides adapted from Liebeherr and El Zarki, and Kurose and Ross

Outline

- Interconnection devices
- Bridges/LAN switches vs. Routers
- Learning Bridges
- Transparent bridges

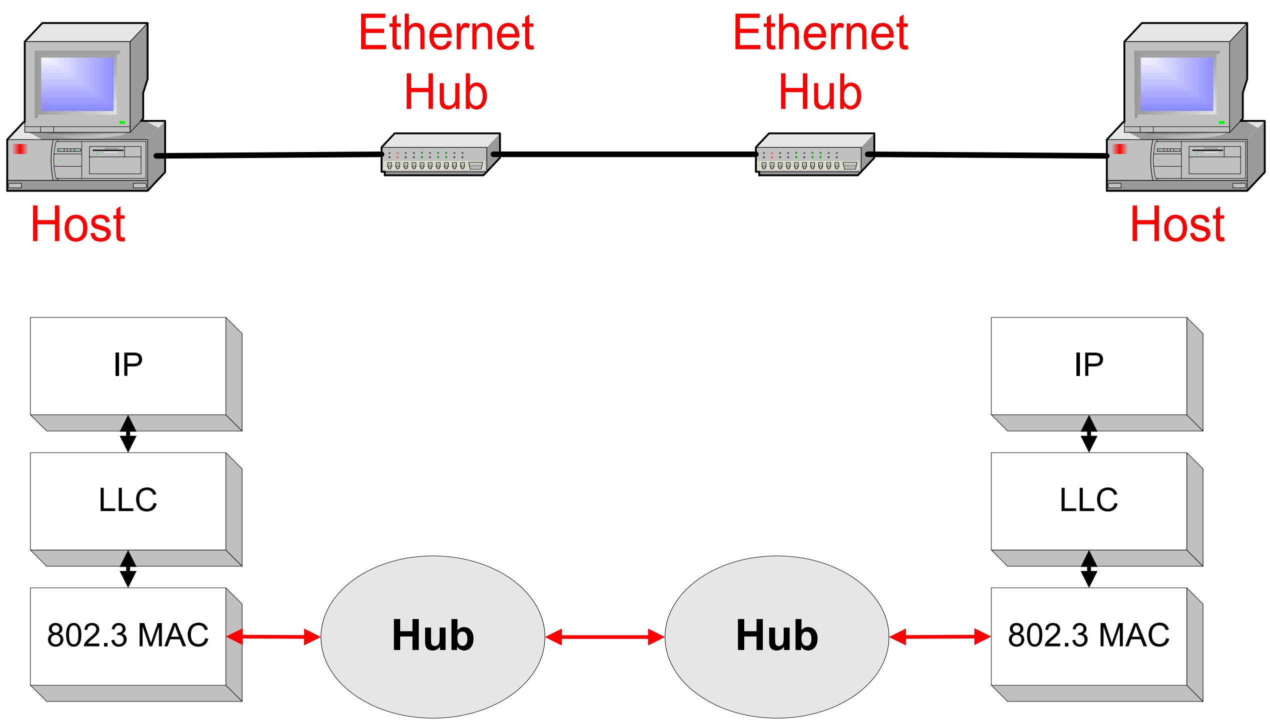
Introduction

- Several different devices for interconnecting networks



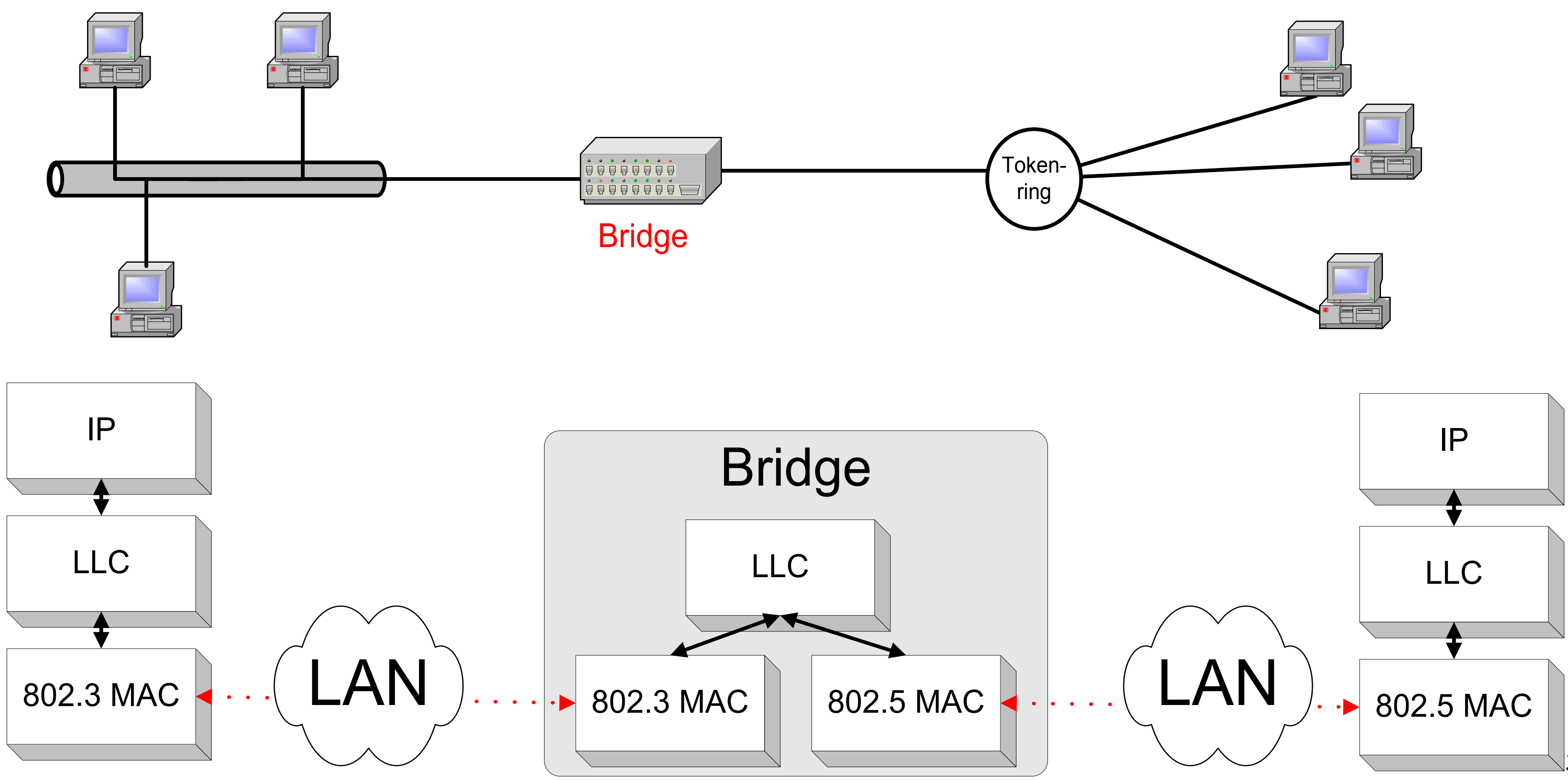
Ethernet Hub

- Connects hosts to Ethernet LAN and connects multiple Ethernet LANs
- Collisions are propagated



Bridges/LAN switches

- A *bridge or LAN switch* is a device that interconnects two or more *Local Area Networks* (*LANs)* and forwards packets between these networks.
- Bridges/*LAN switches* operate at the Data Link Layer (Layer 2)



Terminology: Bridge, LAN switch, Ethernet switch

There are different terms to refer to a data-link layer interconnection device:

- The term **bridge** was coined in the early 1980s.
- Today, the terms **LAN switch** or (in the context of Ethernet) **Ethernet switch** are used.

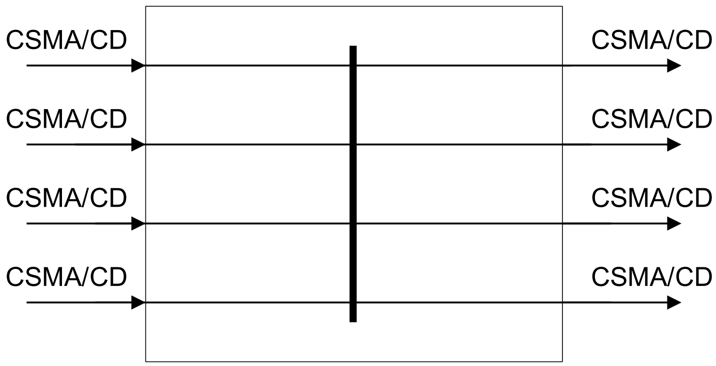
Convention:

- We will use the three terms interchangeably.

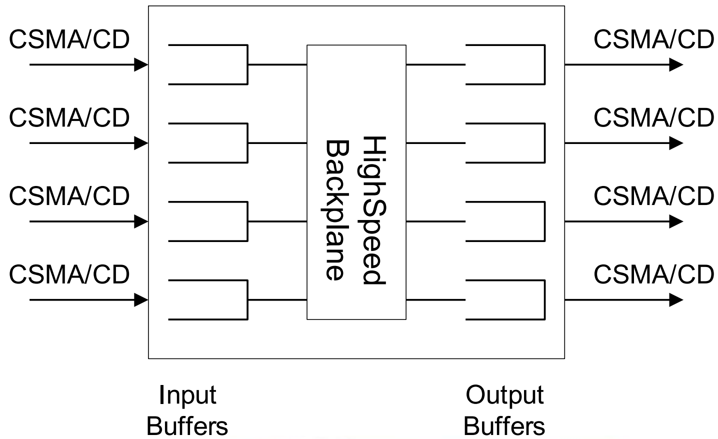
Ethernet Hubs vs. Ethernet Switches

- An **Ethernet switch** is a packet switch for Ethernet frames
    - Buffering of frames prevents collisions.
    - Each port is isolated and builds its own collision domain
- An **Ethernet Hub** does not perform buffering:
    - Collisions occur if two frames arrive at the same time.

Hub

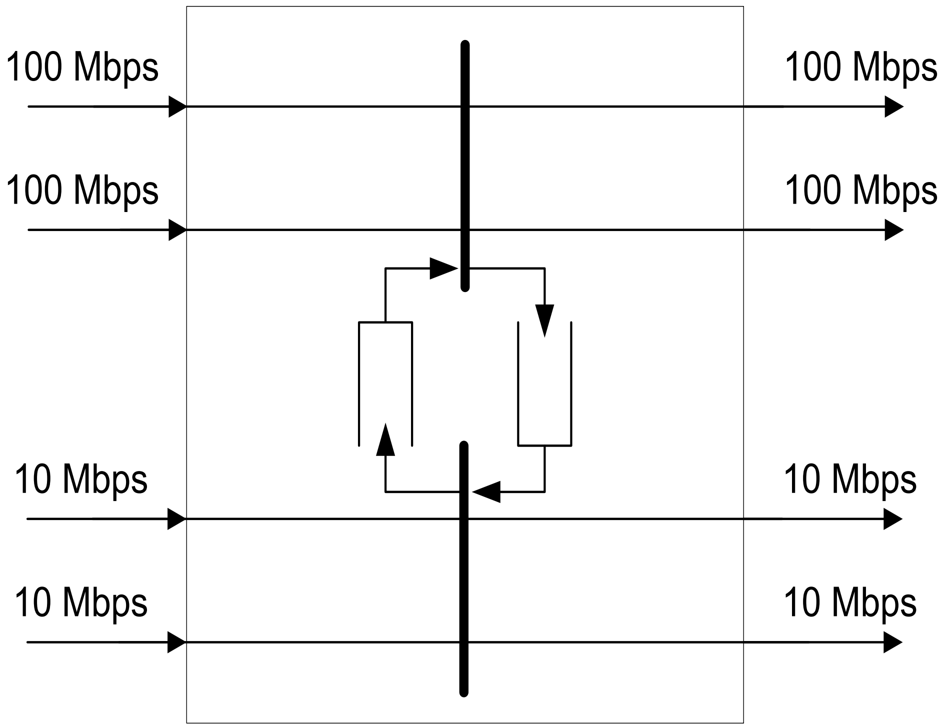


Switch



Dual Speed Ethernet hub

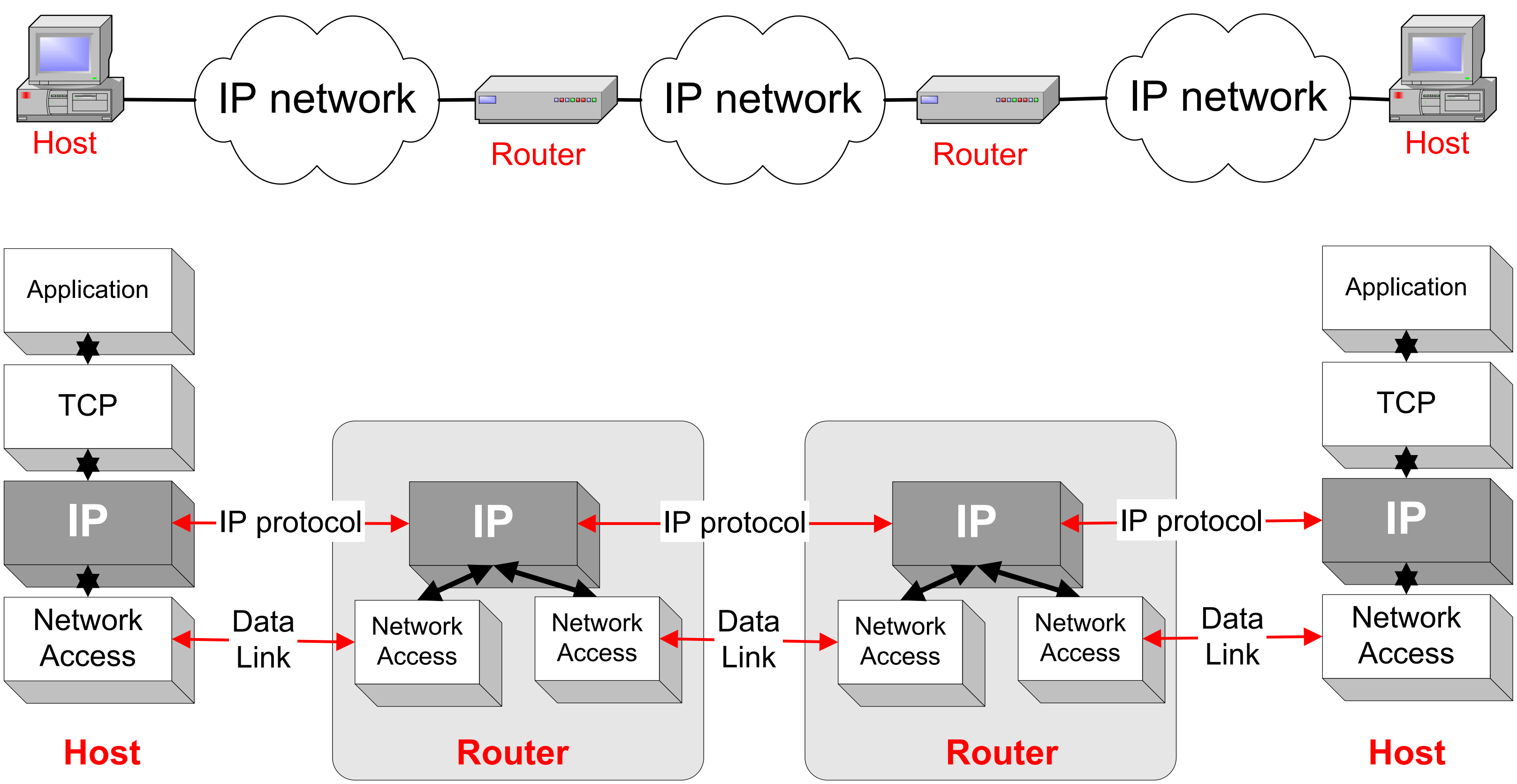
- Dual-speed hubs operate at 10 Mbps and 100 Mbps per second
- Conceptually these hubs operate like two Ethernet hubs separated by a bridge



Dual-Speed Ethernet Hub

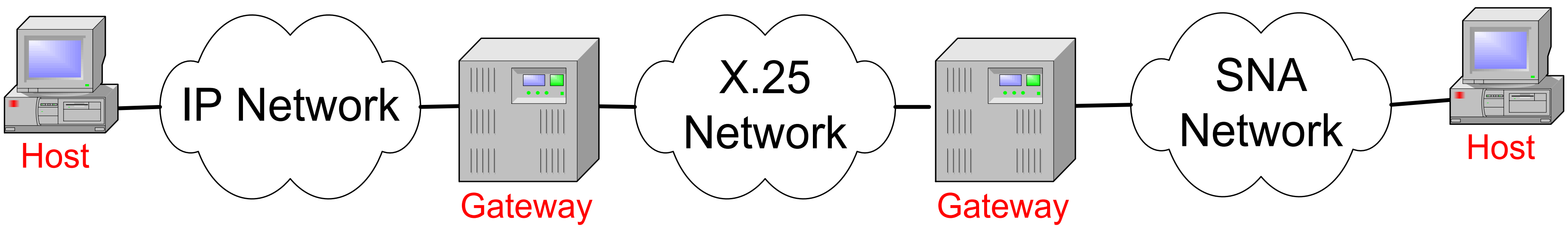
Routers

- Routers operate at the Network Layer (Layer 3)
- Interconnect IP networks



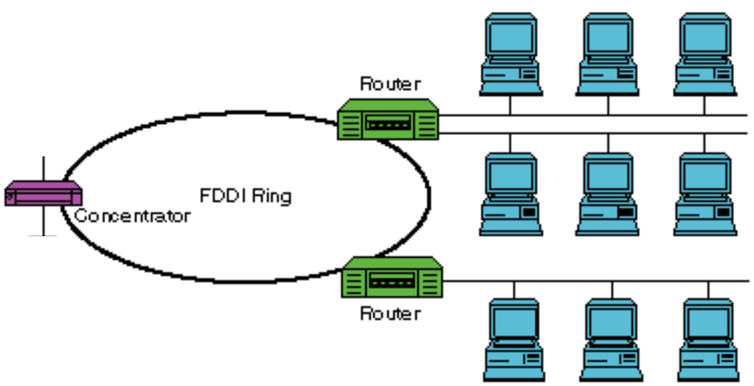
Gateways

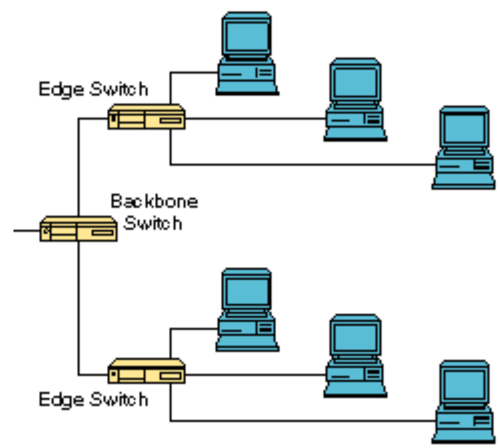
- The term "Gateway" is used with different meanings in different contexts
- "Gateway" is a generic term for routers (Level 3)
- "Gateway" is also used for a device that interconnects different Layer 3 networks and which performs translation of protocols ("Multi-protocol router")



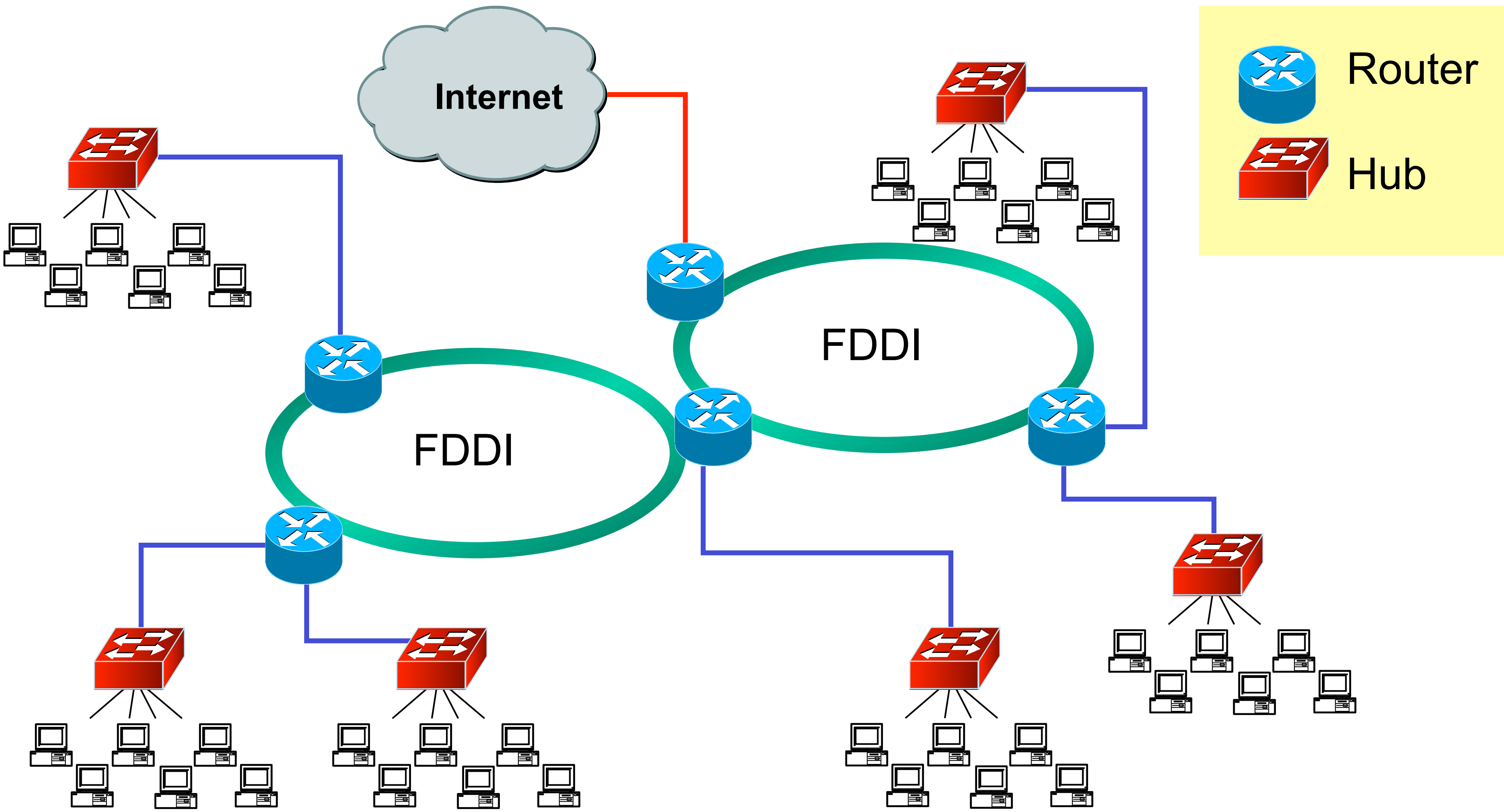
Bridges versus Routers

- An enterprise network (e.g., university) with a large number of local area networks (LANs) can use routers or bridges
  - 1980s: LANs interconnection via bridges
  - Late 1980s and early 1990s: increasingly use of routers
  - Since mid1990s: LAN switches replace most routers
  - Late 2000s: Switches and SDN

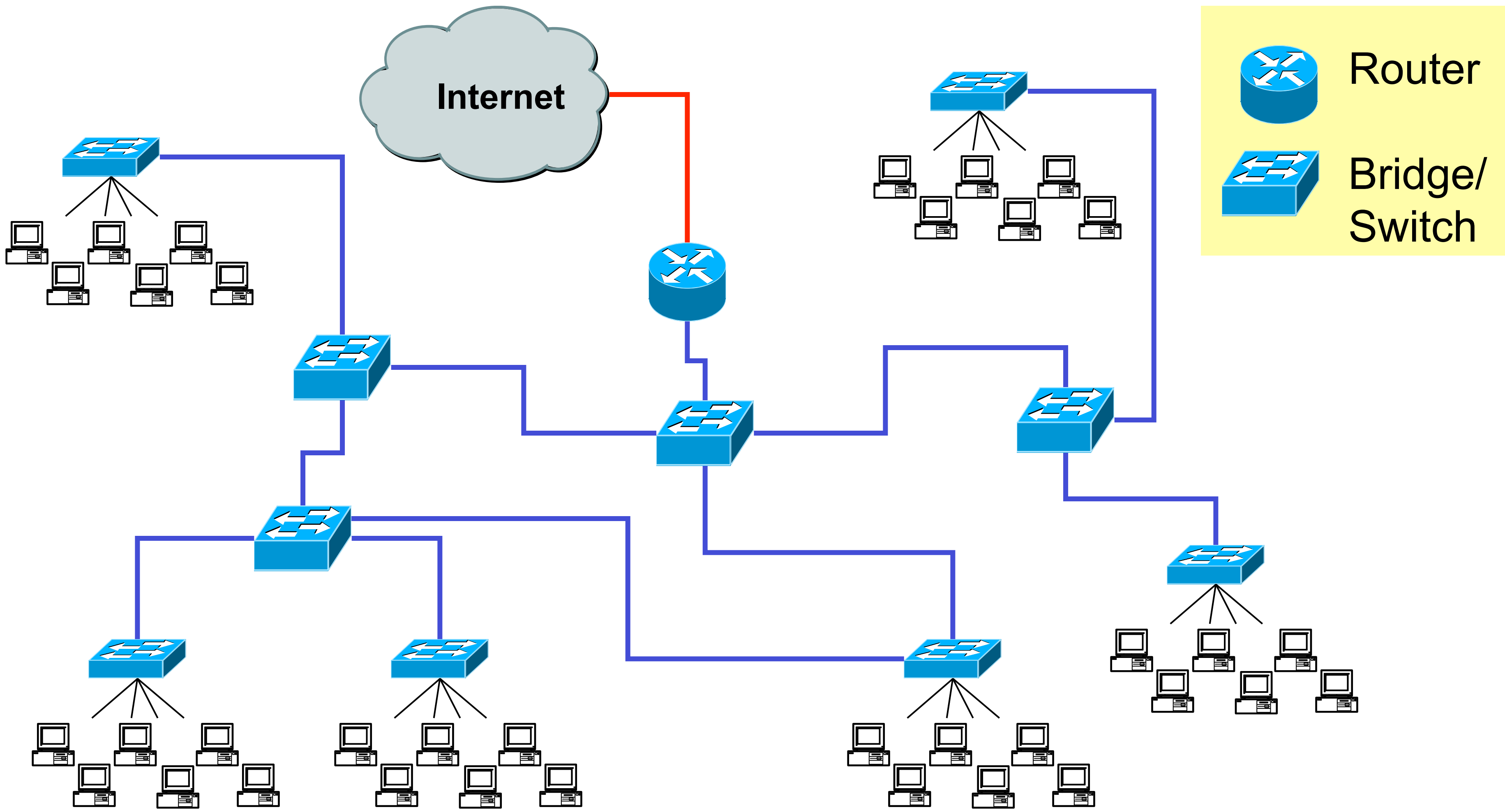




A Routed Enterprise Network



A Switched Enterprise Network



Interconnecting networks: Bridges versus Routers

Routers

- Each host’s IP address must be configured
- If network is reconfigured, IP addresses may need to be reassigned
- Routing done via RIP or OSPF
- Each router manipulates packet header (e.g., reduces TTL field)

Bridges/LAN switches

- MAC addresses of hosts are hardwired
- No network configuration needed
- Routing done by
  - **learning bridge algorithm**
  - **spanning tree algorithm**
- Bridges do not manipulate frames

Bridges

Overall design goal: **Complete transparency**

"Plug-and-play"

Self-configuring without hardware or software changes

Bridges should not impact operation of existing LANs

Three parts to understanding bridges:

(1) Forwarding of Frames

(2) Learning of Addresses

(3) Spanning Tree Algorithm

(1) Frame Forwarding

- Each bridge maintains a **MAC forwarding table**
- Forwarding table plays the same role as the routing table of an IP router
- Entries have the form (MAC address, port, age), where

MAC address:	host name or group address
port:	port number of bridge
age:	aging time of entry (in seconds)

with interpretation:

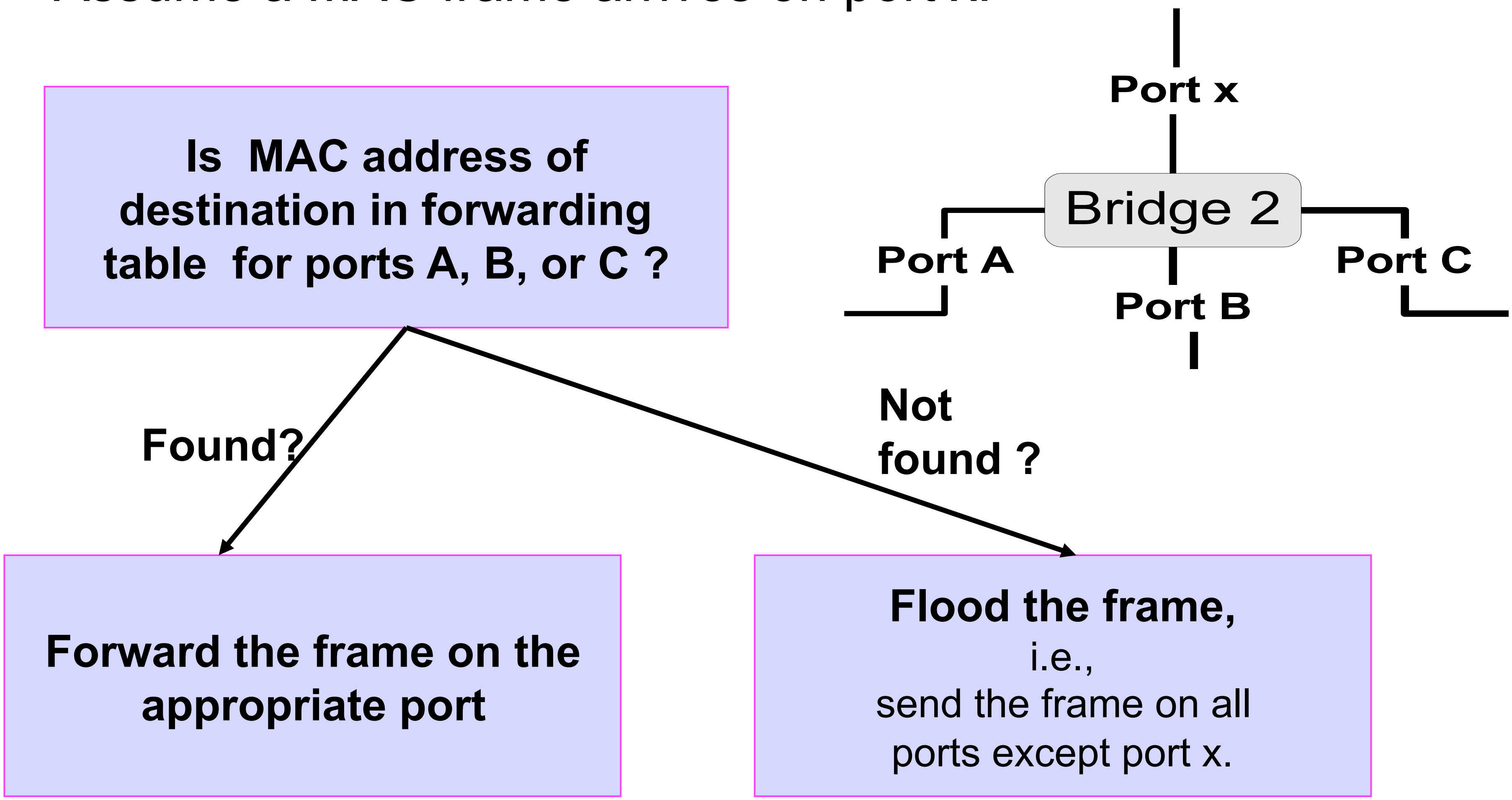
a machine with **MAC address** lies in direction of the **port** number from the bridge. The entry is **age** time units old.

MAC forwarding table →

MAC address	port	age
a0:e1:34:82:ca:34	1	10
45:6d:20:23:fe:2e	2	20

(1) Frame Forwarding

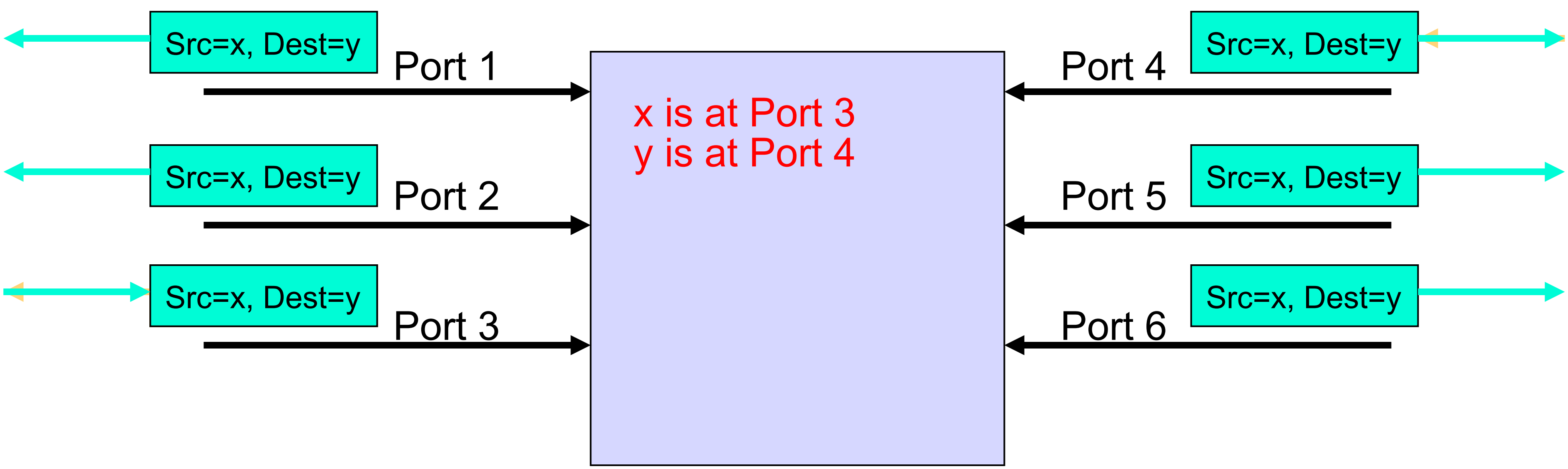
- Assume a MAC frame arrives on port x.



(2) Address Learning (Learning Bridges)

- Routing entries set automatically with a simple heuristic:

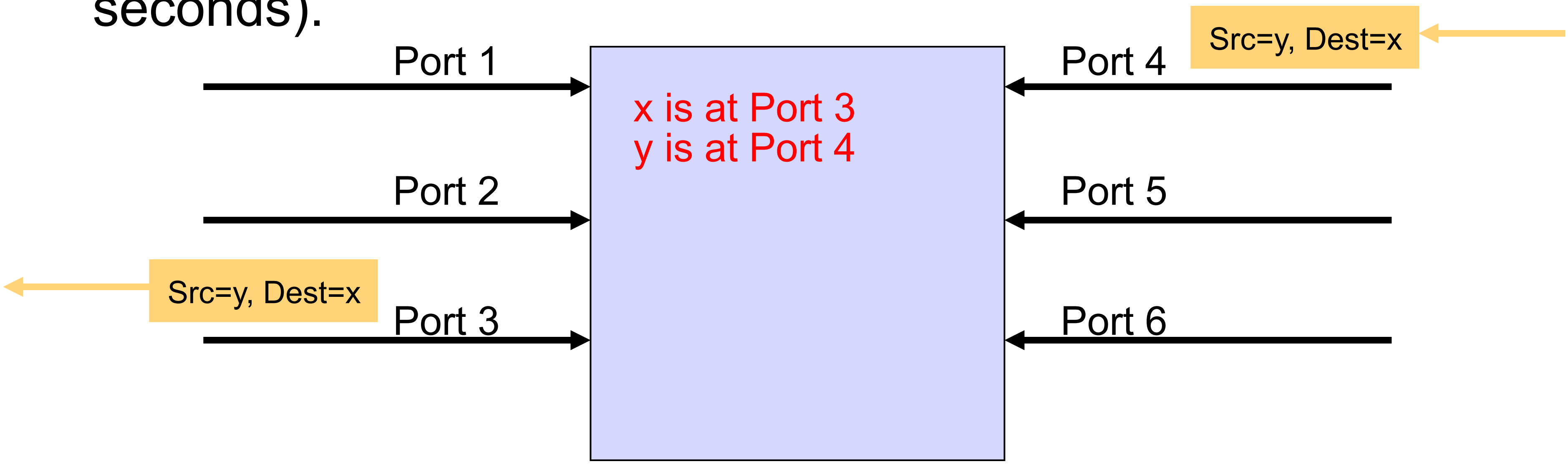
  Source field of a frame that arrives on a port tells which hosts are reachable from this port.



(2) Address Learning (Learning Bridges)

Learning Algorithm:

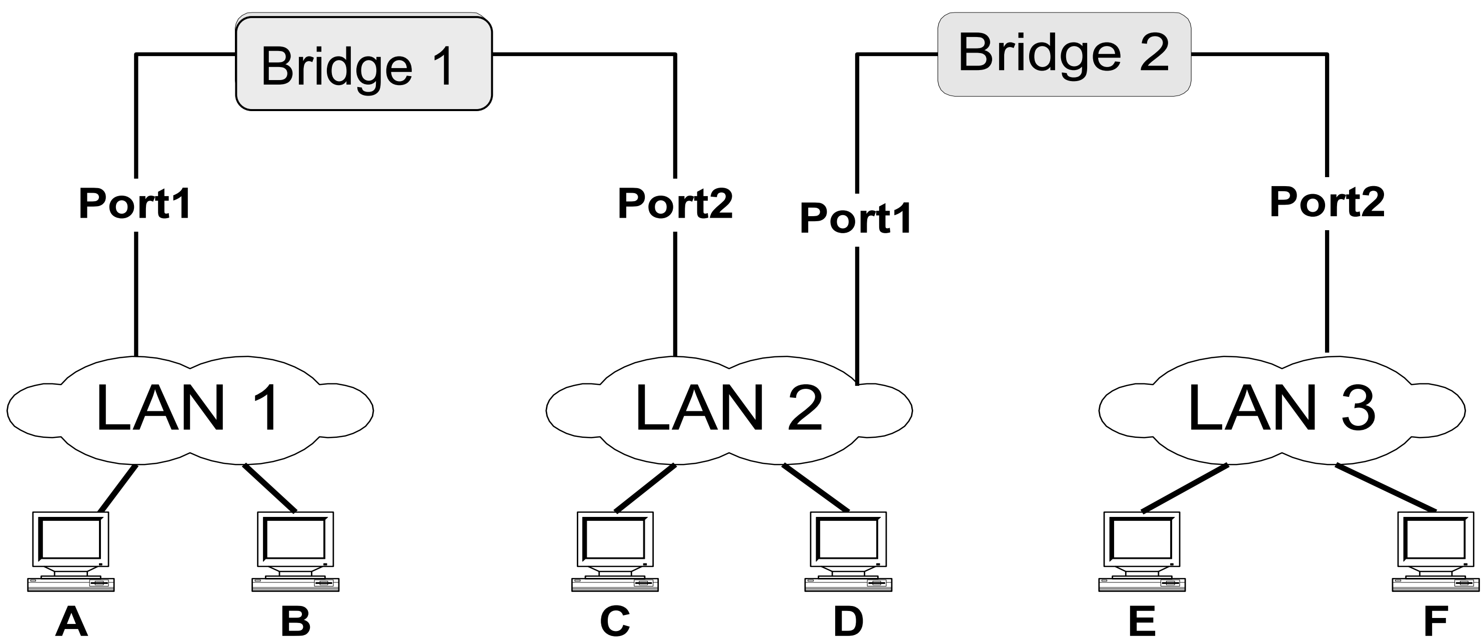
- For each frame received, the source stores the source field in the forwarding database together with the port where the frame was received.
- All entries are deleted after some time (default is 15 seconds).



Example

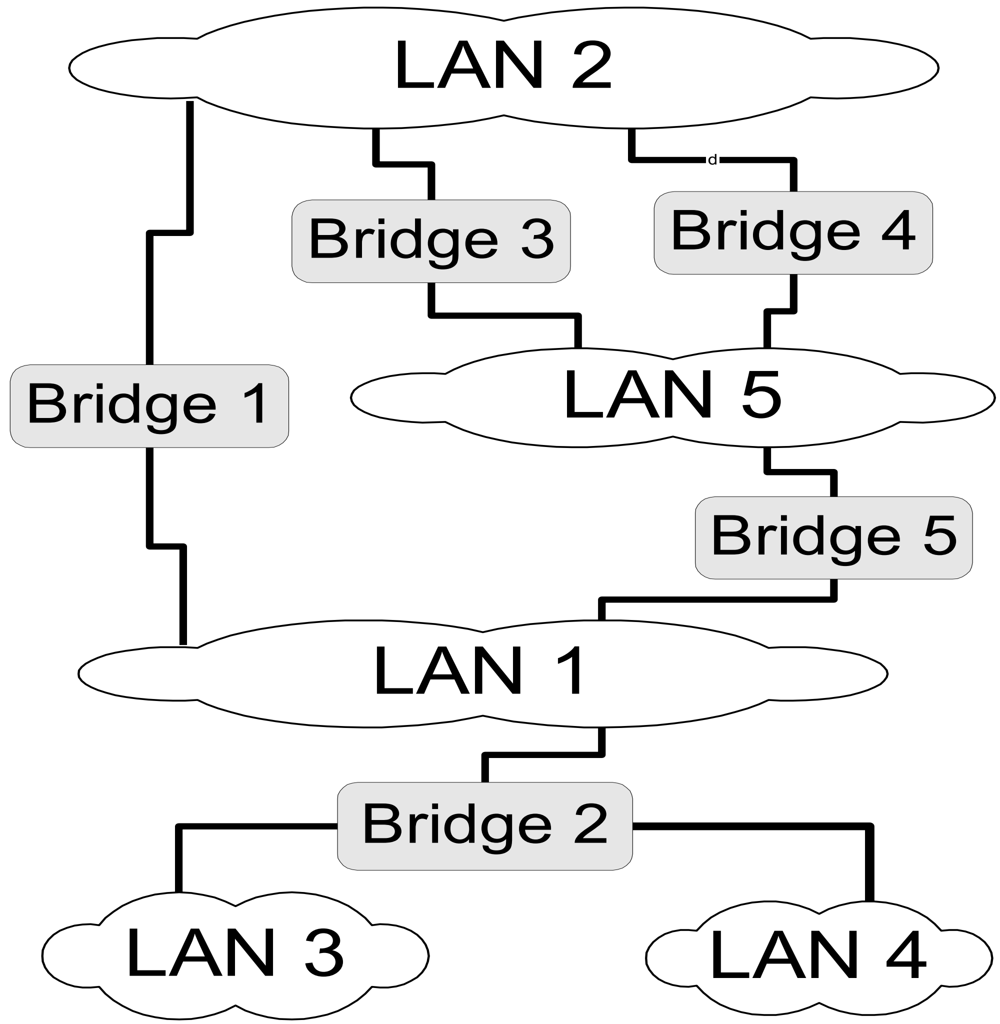
•Consider the following packets:
(Src=A, Dest=F), (Src=C, Dest=A), (Src=E, Dest=C)

•What have the bridges learned?



Need for a forwarding between networks

- What do bridges do if some LANs are reachable only in multiple hops ?
- What do bridges do if the path between two LANs is not unique ?



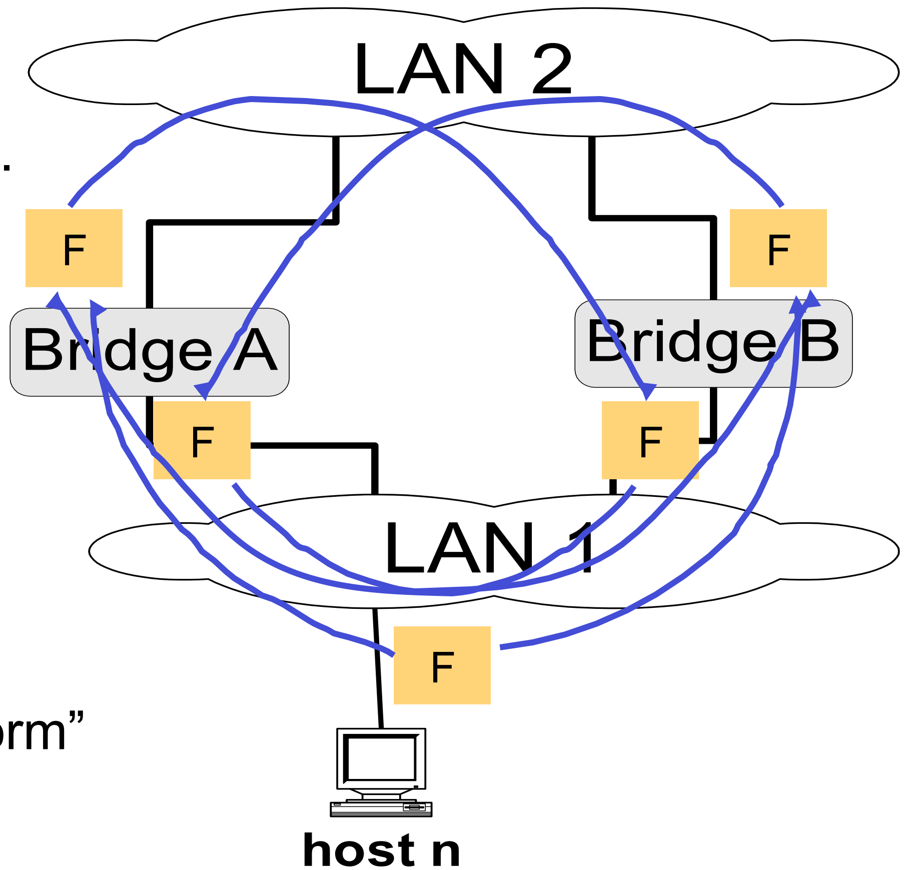
Problems with network of bridges

- Consider the two LANs that are connected by two bridges.
- Assume *host n* is transmitting a frame F with unknown destination.

What is happening?

- Bridges A and B flood the frame to LAN 2.
- Bridge B sees F on LAN 2 (with unknown destination), and copies the frame back to LAN 1
- Bridge A does the same.
- Duplication causes “broadcast storm”

Where’s the problem? What’s the solution ?



Transparent Bridges

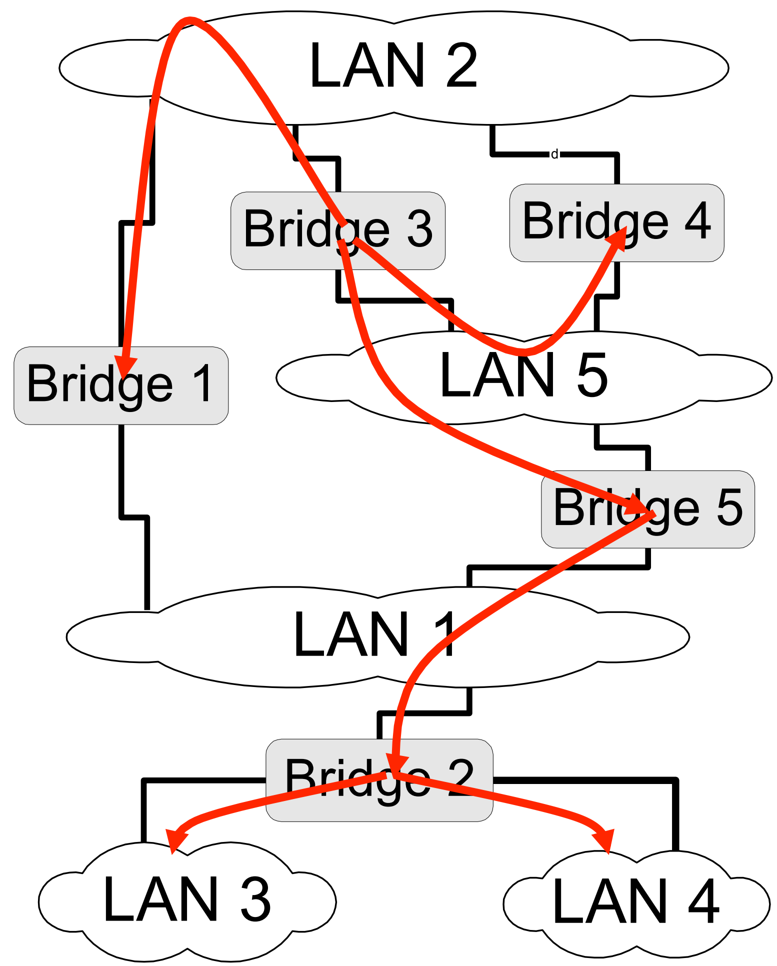
- Three principal approaches can be found:
  - **Fixed Routing**
  - **Source Routing**
  - **Spanning Tree Routing** (IEEE 802.1d)

- We only discuss the last one

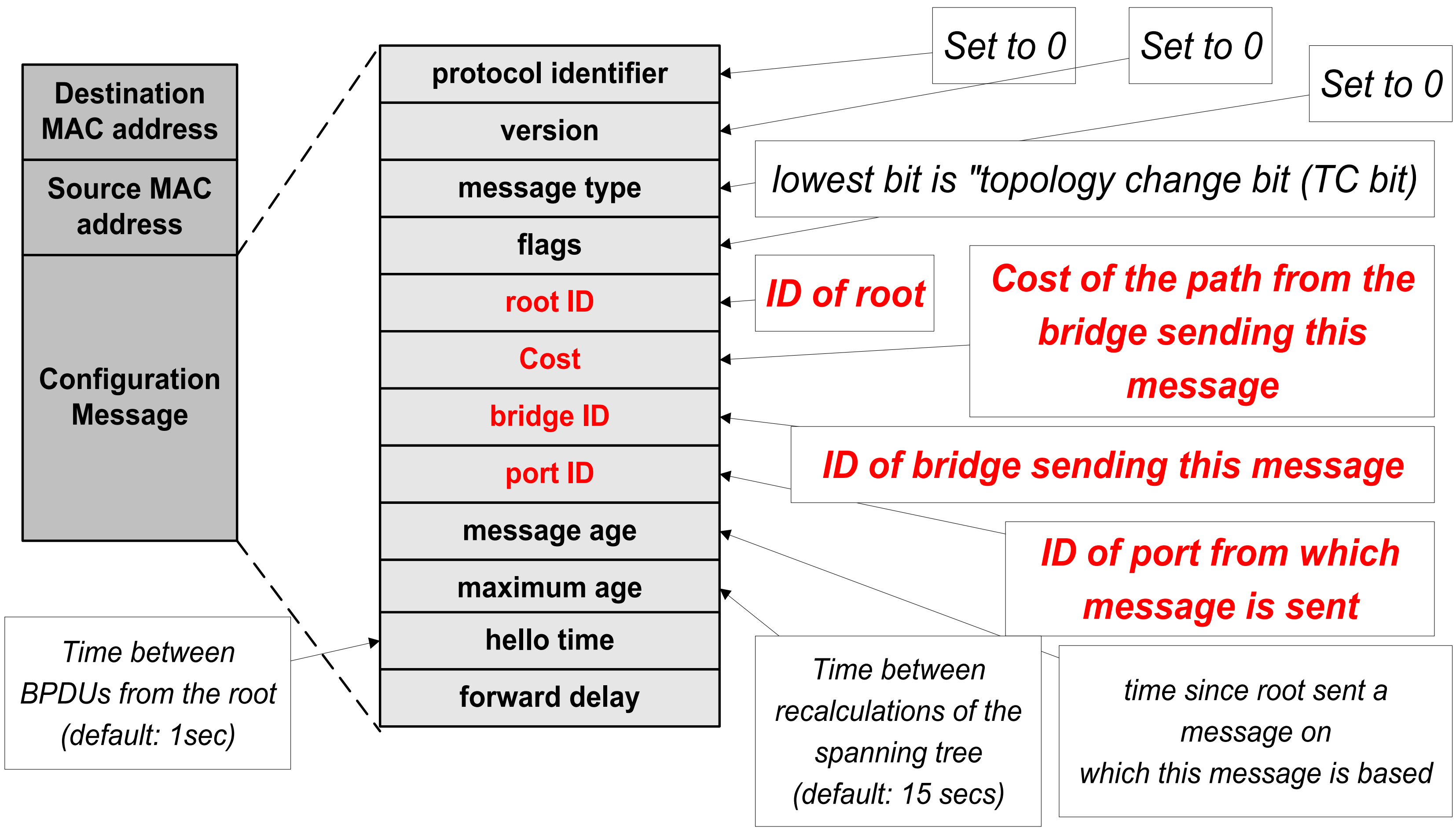
- Bridges that execute the spanning tree algorithm are called **transparent bridges**

Spanning Tree Protocol (IEEE 802.1d)

- Spanning Tree Protocol (SPT) is a solution to prevent loops when forwarding frames between LANs
  – Standardized as IEEE 802.1d
- SPT organizes bridges and LANs as spanning tree in a dynamic environment
  – Frames are forwarded only along the branches of the spanning tree
  – Trees don't have loops
- Bridges exchange messages to configure the bridge (Bridge Protocol Data Unit or BPDUs) to build tree.



Configuration BPDUs



What do the BPDUs do?

With the help of the BPDUs, bridges can:

- Elect a single bridge as the **root bridge**.
- Calculate the distance of the shortest path to the root bridge
- Each LAN can determine a **designated bridge**, which is the bridge closest to the root. The designated bridge will forward packets towards the root bridge.
- Each bridge can determine a **root port**, the port that gives the best path to the root.
- Select ports to be included in the spanning tree.

Concepts

- Each bridge as a unique identifier: Bridge ID

  Bridge ID = Priority : 2 bytes
  Bridge MAC address: 6 bytes

  - Priority is configured
  - Bridge MAC address is lowest MAC addresses of all ports

- Each port of a bridge has a unique identifier (port ID).

- **Root Bridge:** The bridge with the lowest identifier is the root of the spanning tree.
- **Root Port**: Each bridge has a root port which identifies the next hop from a bridge to the root.

Concepts

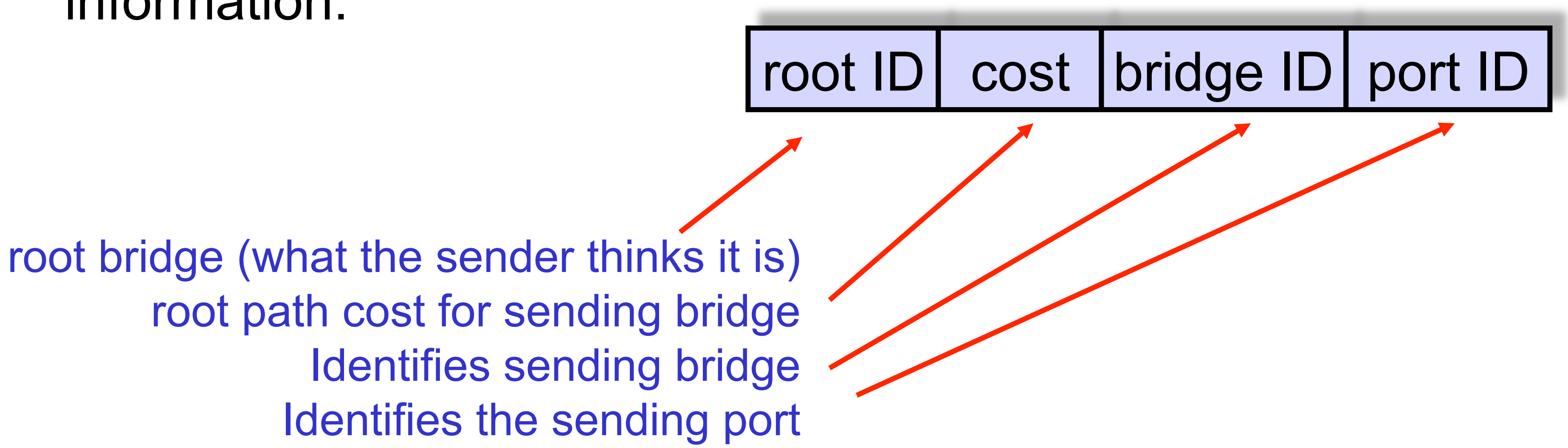
- **Root Path Cost:** For each bridge, the cost of the min-cost path to the root.

- **Designated Bridge, Designated Port:** Single bridge on a LAN that provides the minimal cost path to the root for this LAN:
  - if two bridges have the same cost, select one with highest priority
  - if min-cost bridge has two or more ports on the LAN, select port with lowest ID

- **Note:** We assume that "cost" of a path is the number of "hops".

Steps of Spanning Tree Algorithm

- Each bridge is sending out BPDUs that contain the following information:



- Transmission of BPDUs results in the distributed computation of a spanning tree
- Convergence of the algorithm is very quick

Ordering of Messages

- We define an ordering of BPDU messages

ID R1	C1	ID B1	ID P1

M1

ID R2	C2	ID B2	ID P2

M2

We say M1 **advertises a better path** than M2 ("**M1<<M2**") if
(R1 < R2),
Or (R1 == R2) and (C1 < C2),
Or (R1 == R2) and (C1 == C2) and (B1 < B2),
Or (R1 == R2) and (C1 == C2) and (B1 == B2) and (P1 < P2)

Initializing the Spanning Tree Protocol

- Initially, all bridges assume they are the root bridge.
- Each bridge B sends BPDUs of this form on its LANs from each port P:

B	0	B	P

- Each bridge looks at the BPDUs received on all its ports and its own transmitted BPDUs.
- Root bridge updated to the smallest received root ID that has been received so far

Operations of Spanning Tree Protocol

- Each bridge B looks on all its ports for BPDUs that are better than its own BPDUs
- Suppose a bridge with BPDU:

M1	R1	C1	B1	P1

receives a “better” BPDU:

M2	R2	C2	B2	P2

Then it will update the BPDU to:

R2	C2+1	B1	P1

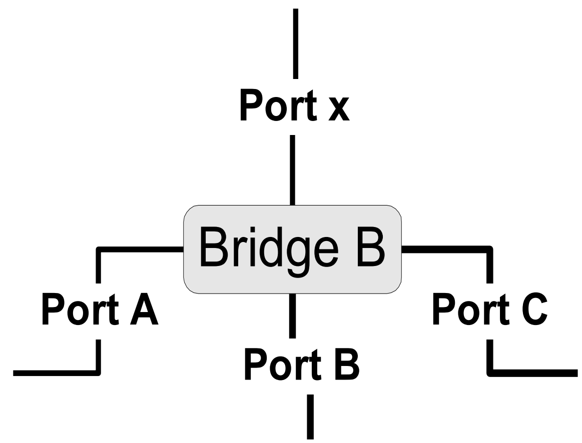
- However, the new BPDU is not necessarily sent out
- On each bridge, the port where the “best BPDU” (via relation “**<<**“) was received is the **root port of the bridge**.

When to send a BPDU

- Say, B has generated a BPDU for each port x

R	Cost	B	x

- B will send this BPDU on port x only if its BPDU is better (via relation "**<<**") than any BPDU that B received from port x.



- In this case, B also assumes that it is the **designated bridge** for the LAN to which the port connects
- And port x is the **designated port** of that LAN

Selecting the Ports for the Spanning Tree

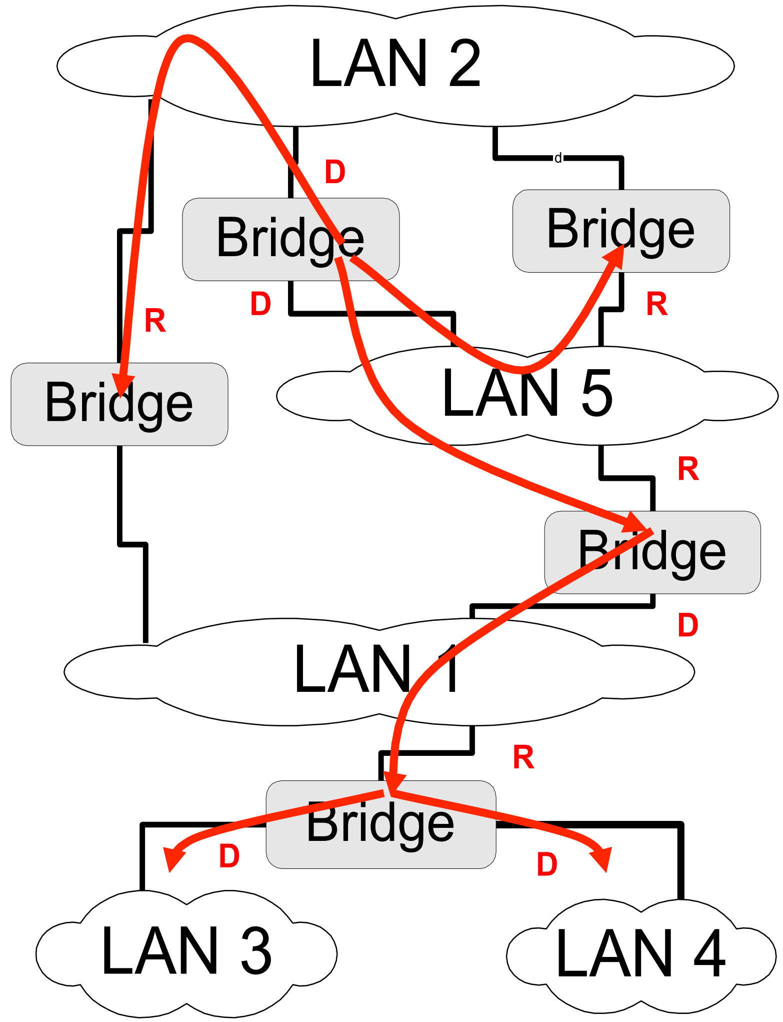
- Each bridges makes a local decision which of its ports are part of the spanning tree
- Now **B can decide which ports are in the spanning tree:**
    - B's root port is part of the spanning tree
    - All designated ports are part of the spanning tree
    - All other ports are not part of the spanning tree

- B's ports that are in the spanning tree will forward packets (=forwarding state)
- B's ports that are not in the spanning tree will not forward packets (=blocking state)

Building the Spanning Tree

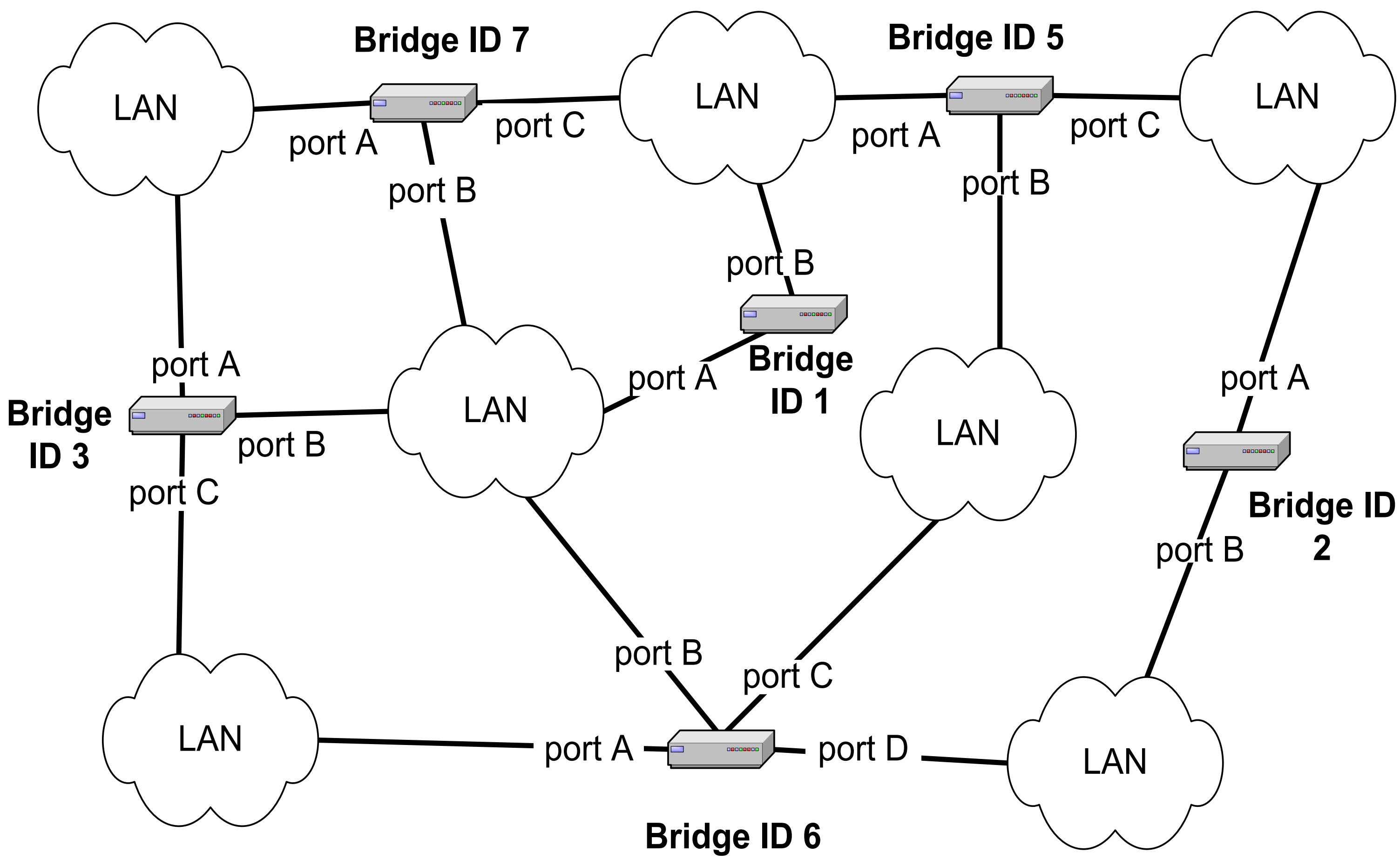
- Consider the network on the right.
- Assume that the bridges have calculated the designated ports (D) and the root ports (R) as indicated.

- What is the spanning tree?
  – On each LAN, connect R ports to the D ports on this LAN



Example

- Assume that all bridges send out their BPDU's once per second, and assume that all bridges send their BPDUs at the same time
- Assume that all bridges are turned on simultaneously at time T=0 sec.



Example: BPDU's sent by the bridges

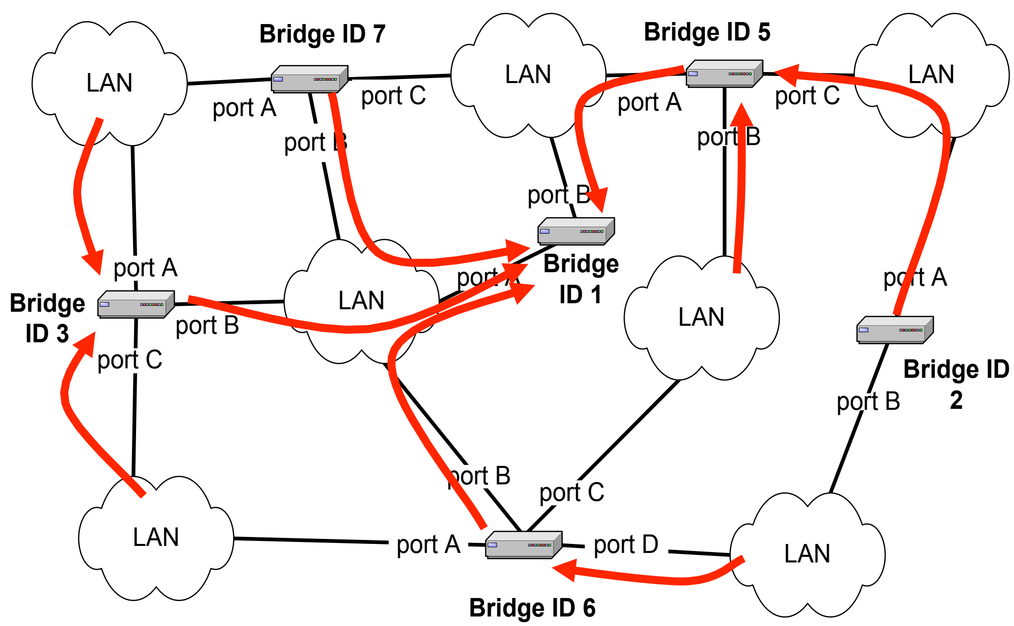
	Bridge 1	Bridge 2	Bridge 3	Bridge 5	Bridge 6	Bridge 7
T=0sec	(1,0,1,port) sent on ports: A,B	(2,0,2,port) ports A,B	(3,0,3,port) ports A,B,C	(5,0,5,port) ports A,B,C	(6,0,6,port) ports A,B,C,D	(7,0,7,port) ports A,B,C
T=1sec	(1,0,1,port) A,B	(2,0,2,port) A,B	(1,1,3,port) A,C	(1,1,5,port) B,C	(1,1,6,port) A,C,D	(1,1,7,port) A
T=2sec	(1,0,1,port) A,B	(1,2,2,port) none	(1,1,3,port) A,C	(1,1,5,port) B,C	(1,1,6,port) D	(1,1,7,port) none

- In the table (1,0,1,port) means that the BPDU is (1,0,1,A) if the BPDU is sent on port A and (1,0,1,B) if it is sent on port B.
- At T=1, Bridge 7 receives two BPDUs from Bridge 1: (1,0,1,A) and (1,0,1,B). We assume that A is numerically smaller than B. If not, then the root port of Bridge 7 changes.

Example: Settings after convergence

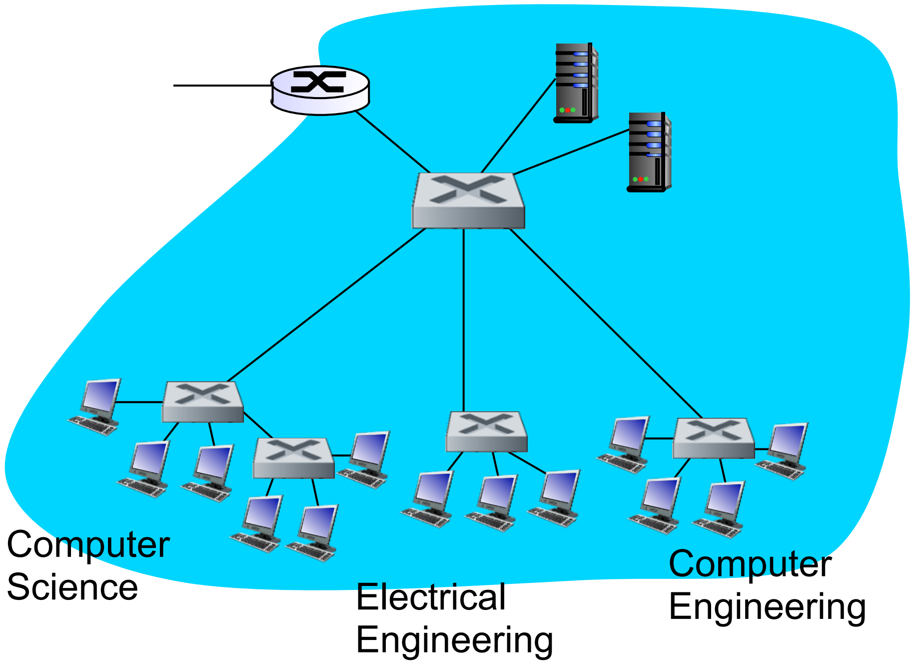
	Bridge 1	Bridge 2	Bridge 3	Bridge 5	Bridge 6	Bridge 7
Root Port	-	A	B	A	B	B
Designated Ports	A,B	-	A,C	B,C	D	-
Blocked ports	-	B	-	-	A,C	A,C

Resulting tree:



VLANS

VLANs: motivation



consider:

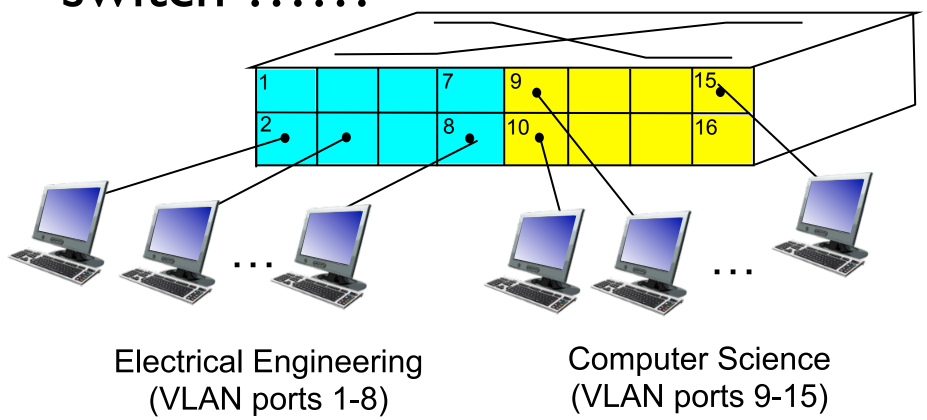
- CS user moves office to EE, but wants connect to CS switch?
- single broadcast domain:
  - all layer-2 broadcast traffic (ARP, DHCP, unknown location of destination MAC address) must cross entire LAN
  - security/privacy, efficiency issues

VLANs

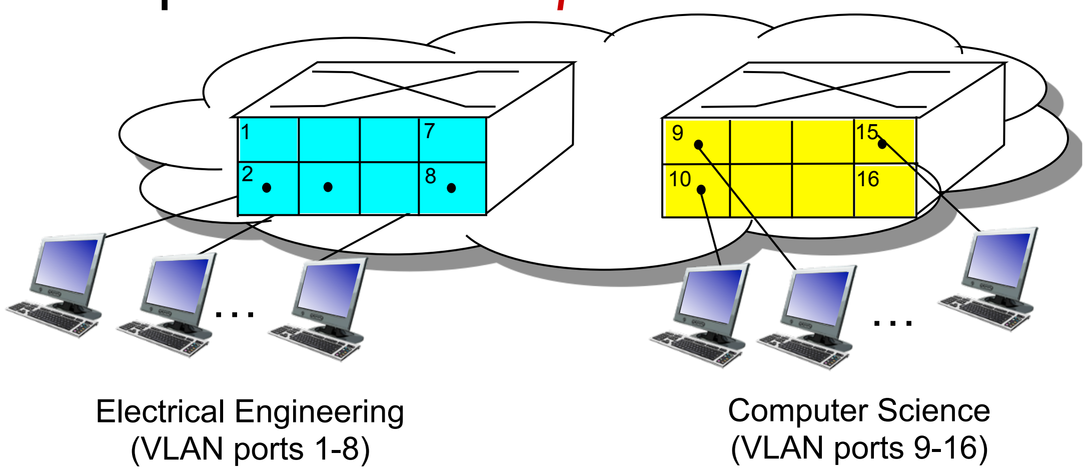
Virtual Local Area Network

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 ……

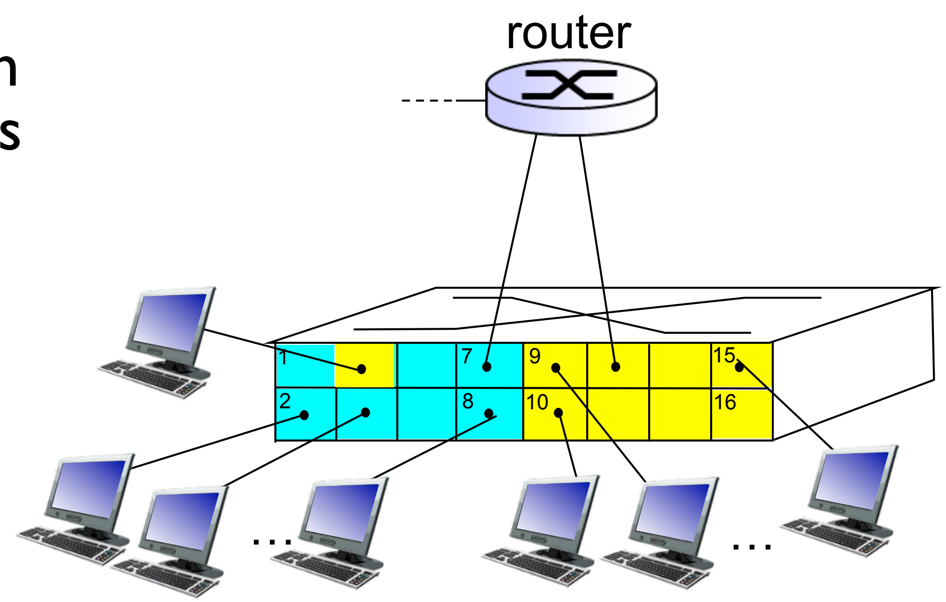


… operates as *multiple* virtual switches

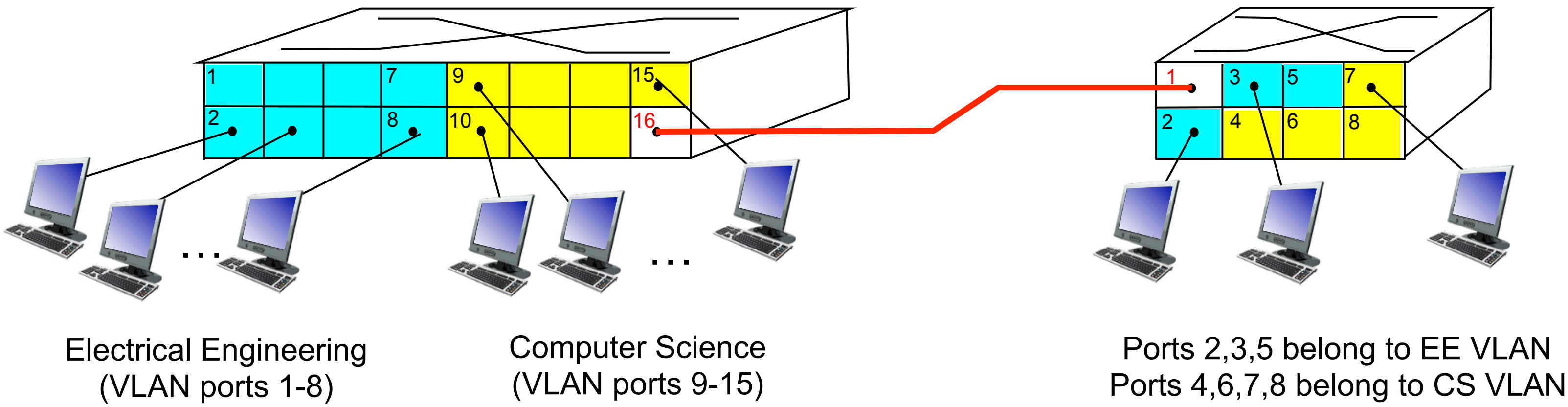


Port-based VLAN

- *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