CSCI-1680
Link Layer Wrap-Up

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Based partly on lecture notes by David Mazières, Phil Levis, John Jannotti

Administrivia

- **Homework I out later today, due next Friday, Feb 17th**

Today: Link Layer (cont.)

- Framing
- Reliability
  - Error correction
  - Sliding window
- **Medium Access Control**
- **Case study: Ethernet**
- **Link Layer Switching**

Media Access Control

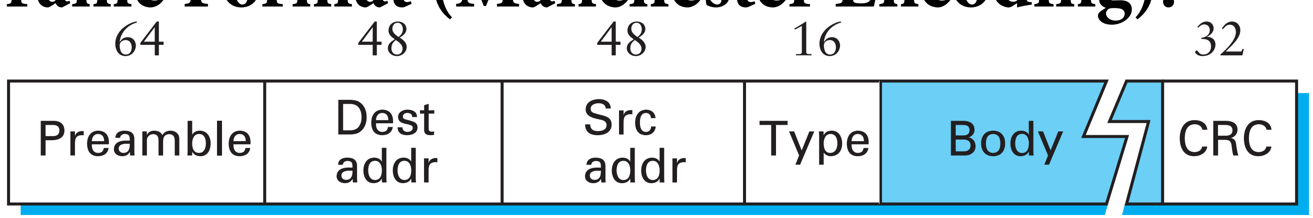
- **Control access to shared physical medium**
  - E.g., who can talk when?
  - If everyone talks at once, no one hears anything
  - Job of the Link Layer
- **Two conflicting goals**
  - Maximize utilization when one node sending
  - Approach 1/N allocation when N nodes sending

Different Approaches

- **Partitioned Access**
  - Time Division Multiple Access (TDMA)
  - Frequency Division Multiple Access (FDMA)
  - Code Division Multiple Access (CDMA)
- **Random Access**
  - ALOHA/ Slotted ALOHA
  - Carrier Sense Multiple Access / Collision Detection (CSMA/CD)
  - Carrier Sense Multiple Access / Collision Avoidance (CSMA/CA)
  - RTS/CTS (Request to Send/Clear to Send)
  - Token-based

Case Study: Ethernet (802.3)

- **Dominant wired LAN technology**
  - 10BASE2, 10BASE5 (Vampire Taps)
  - 10BASET, 100BASE-TX, 1000BASE-T, 10GBASE-T,…
- **Both Physical and Link Layer specification**
- **CSMA/CD**
  - Carrier Sense / Multiple Access / Collision Detection
- **Frame Format (Manchester Encoding):**



Ethernet Addressing

- **Globally unique, 48-bit unicast address per adapter**
  - Example: 00:1c:43:00:3d:09 (Samsung adapter)
  - 24 msb: organization
  - http://standards.ieee.org/develop/regauth/oui/oui.txt
- **Broadcast address: all 1s**
- **Multicast address: first bit 1**
- **Adapter can work in *promiscuous* mode**

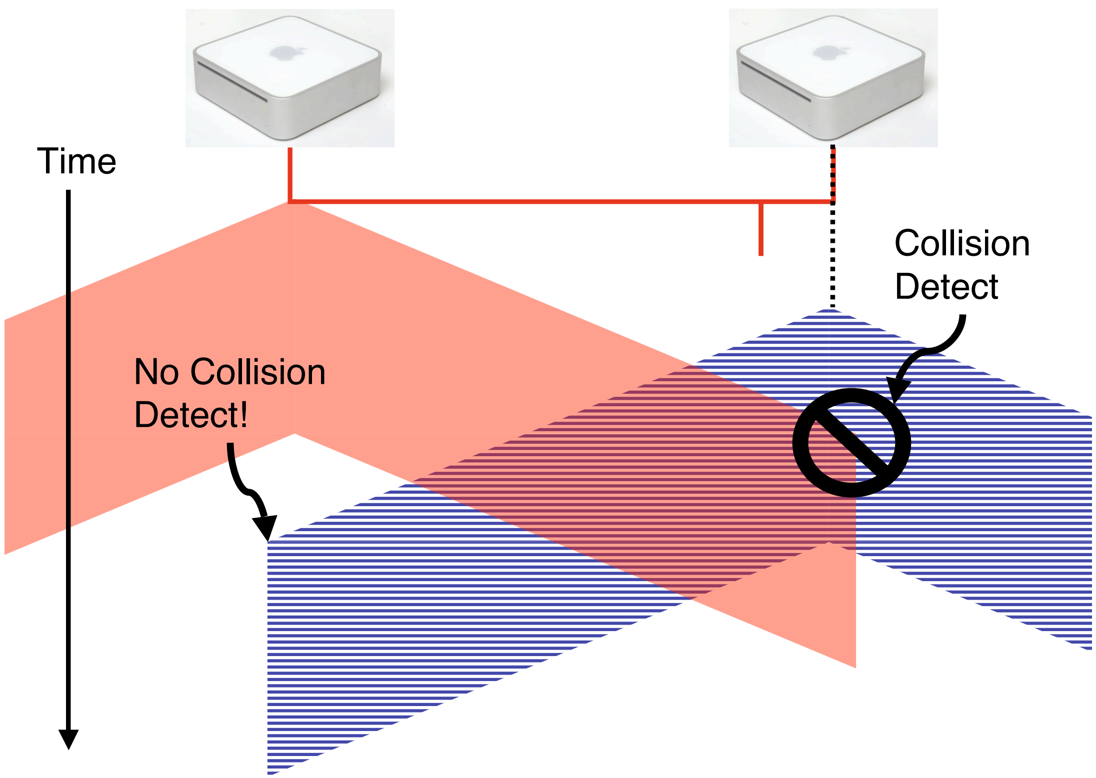
Ethernet MAC: CSMA/CD

- **Problem: shared medium**
  - 10Mbps: 2500m, with 4 repeaters at 500m
- **Transmit algorithm**
  - If line is idle, transmit immediately
  - Upper bound message size of 1500 bytes
  - Must wait 9.6μs (96-bit time) between back to back frames
    - (Old limit) To give time to switch from tx to rx mode
  - If line is busy: wait until idle and transmit immediately

Handling Collisions

- **Collision detection (10Base2 Ethernet)**
  - Uses Manchester encoding. Why does that help?
  - Constant average voltage unless multiple transmitters
- **If collision**
  - Jam for 32 bits, then stop transmitting frame
- **Collision detection constrains protocol**
  - Imposes min. packet size (64 bytes or 512 bits)
  - Imposes maximum network diameter (2500m)
  - Ensure transmission time ≥ 2x propagation delay (why?)

Collision Detection



- **Without minimum frame length, might not detect collision**

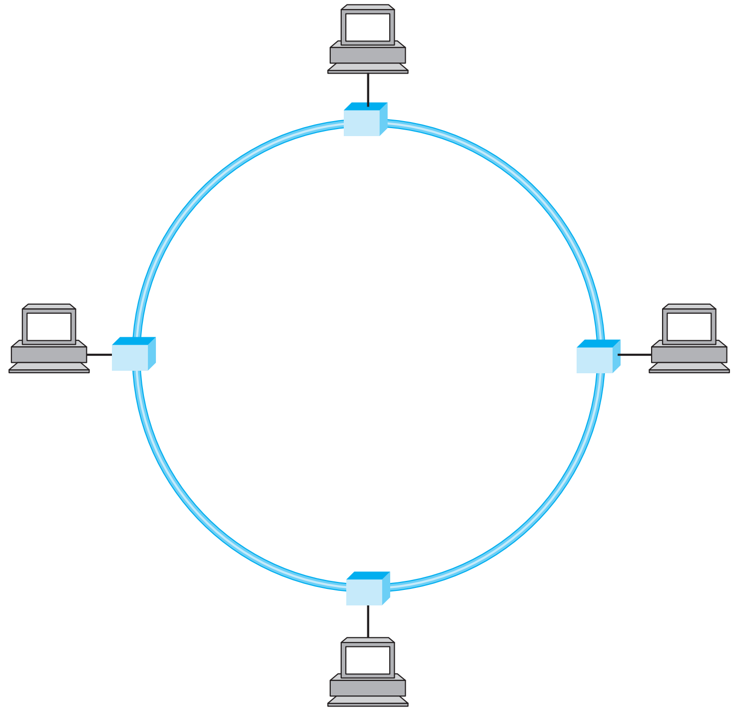
When to transmit again?

- **Delay and try again: exponential backoff**
- ***n*th time: $k \times 51.2\mu s$, for $k = U\{0..2^{\min(n,10)}-1\}$**
  - 1^{st} time: 0 or 51.2μs
  - 2^{nd} time: 0, 51.2, 102.4, or 153.6μs
- **Give up after several times (usually 16)**

Capture Effect

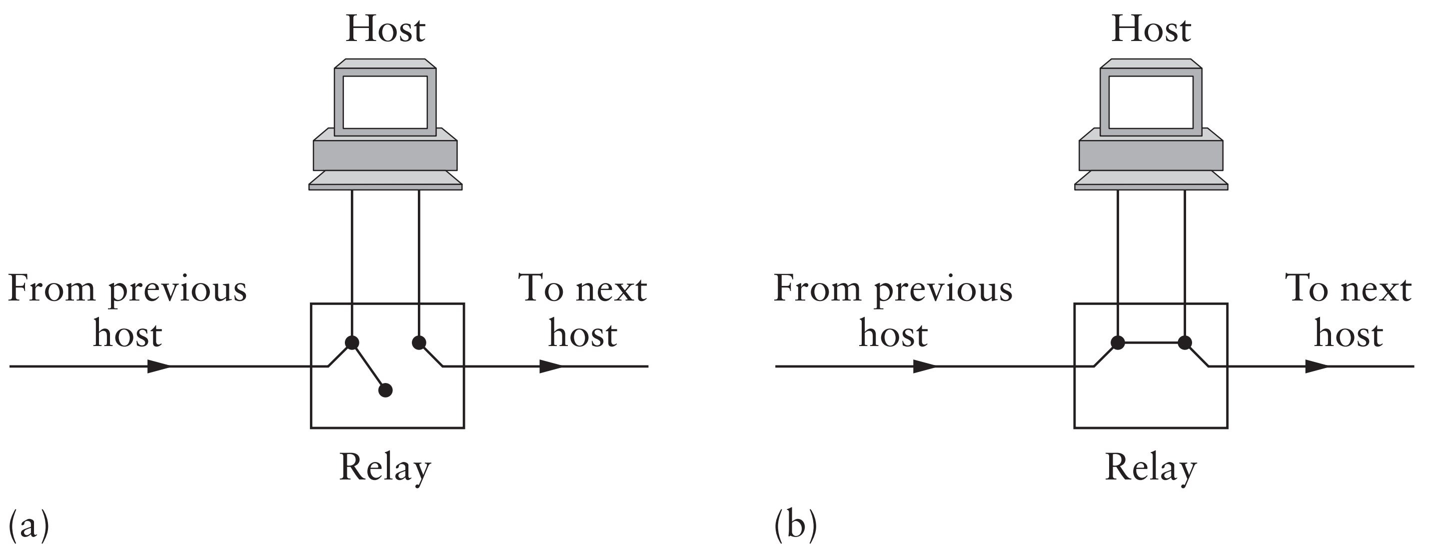
- **Exponential backoff leads to self-adaptive use of channel**
- **A and B are trying to transmit, and collide**
- **Both will back off either 0 or 51.2μs**
- **Say A wins.**
- **Next time, collide again.**
  - A will wait between 0 or 1 slots
  - B will wait between 0, 1, 2, or 3 slots
- **…**

Token Ring



- Idea: frames flow around ring
- Capture special "token" bit pattern to transmit
- Variation used today in Metropolitan Area Networks, with fiber

Interface Cards



- **Problem: if host dies, can break the network**
- **Hardware typically has relays**

Token Ring Frames

- **Frame format (Differential Manchester)**

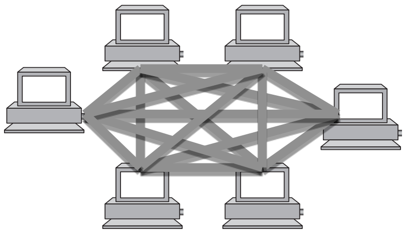
8	8	8	48	48	Variable	32	8	8
Start delimiter	Access control	Frame control	Dest addr	Src addr	Body	Checksum	End delimiter	Frame status

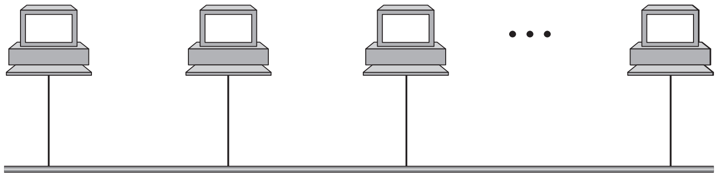
- **Sender grabs token, sends message(s)**
- **Recipient checks address**
- **Sender removes frame from ring after lap**
- **Maximum holding time: avoid capture**
- **Monitor node reestablishes lost token**

Switching

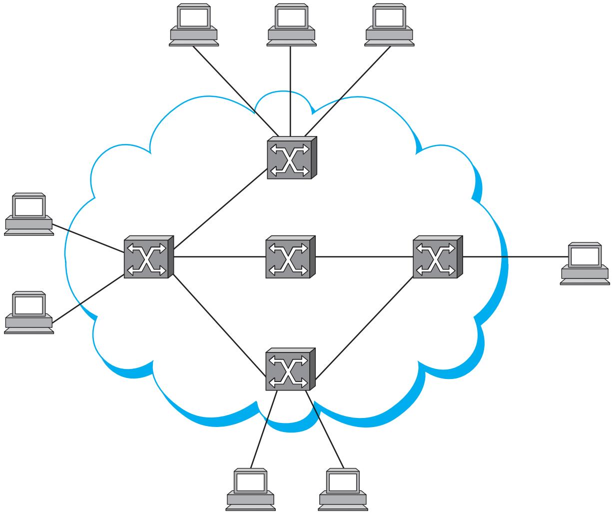
Basic Problem

- Direct-link networks don't scale

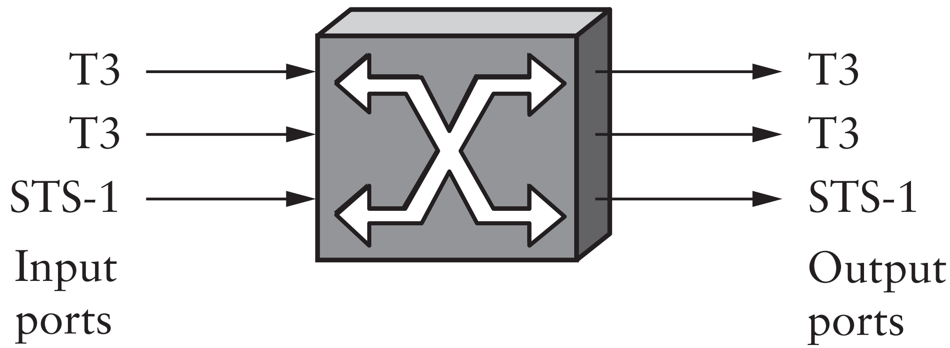




- Solution: use *switches* to connect network segments

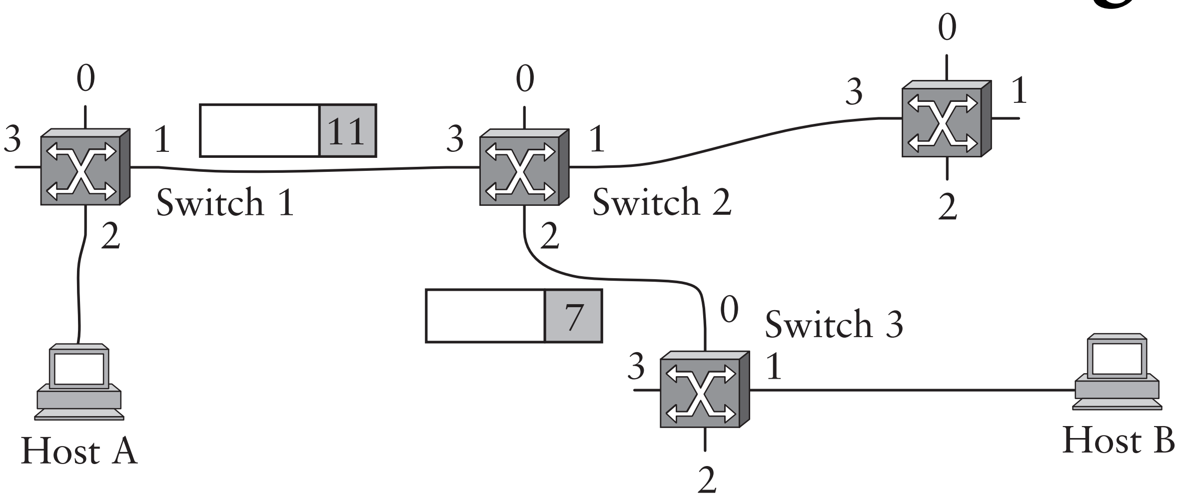


Switching



- **Switches must be able to, given a packet, determine the outgoing port**
- **3 ways to do this:**
  - Virtual Circuit Switching
  - Datagram Switching
  - Source Routing

Virtual Circuit Switching

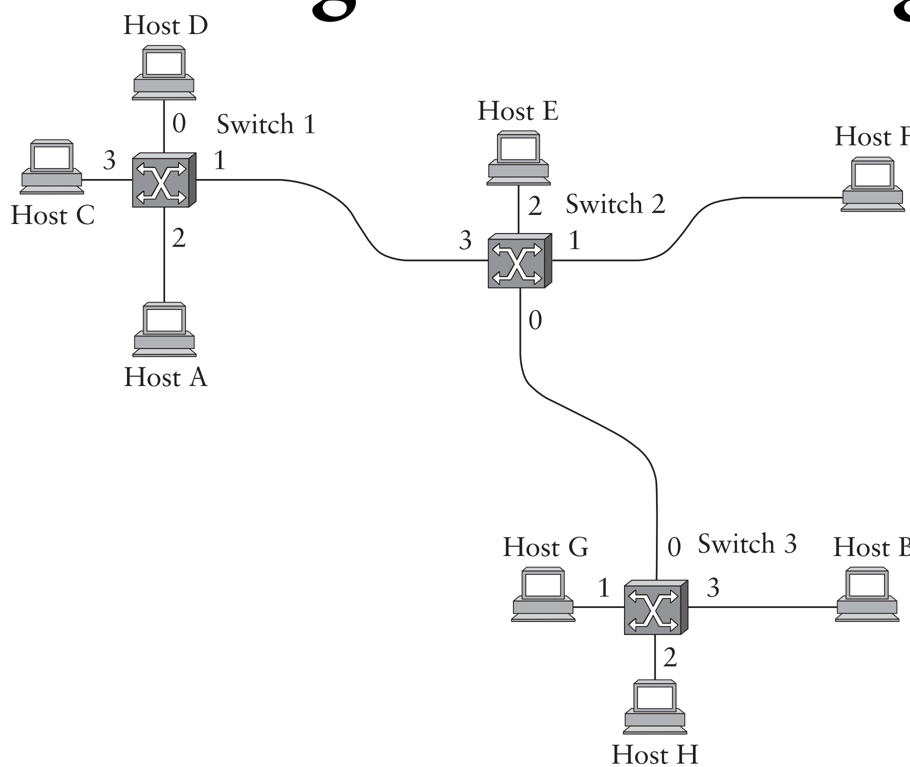


- **Explicit set-up and tear down phases**
  - Establishes Virtual Circuit Identifier on each link
  - Each switch stores VC table
- **Subsequent packets follow same path**
  - Switches map [in-port, in-VCI] : [out-port, out-VCI]
- **Also called *connection-oriented* model**

Virtual Circuit Model

- **Requires one RTT before sending first packet**
- **Connection request contain full destination address, subsequent packets only small VCI**
- **Setup phase allows reservation of resources, such as bandwidth or buffer-space**
  - Any problems here?
- **If a link or switch fails, must re-establish whole circuit**
- **Example: ATM**

Datagram Switching



Switch 2

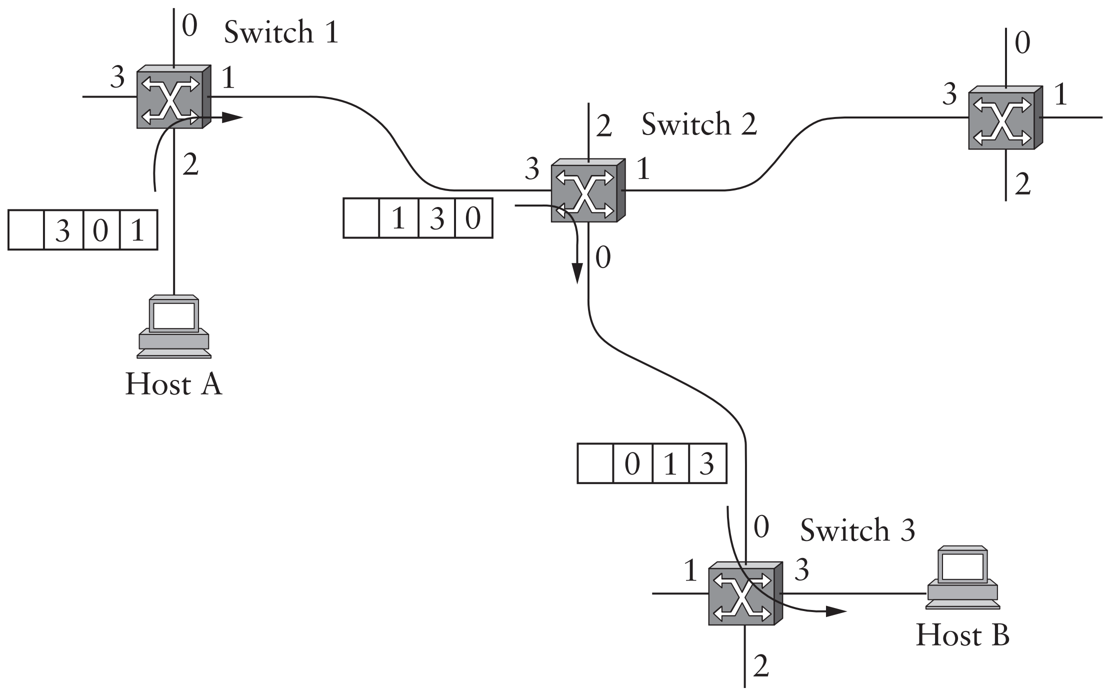
Addr	Port
A	3
B	0
C	3
D	3
E	2
F	1
G	0
H	0

- **Each packet carries destination address**
- **Switches maintain address-based tables**
  - Maps [destination address]:[out-port]
- **Also called *connectionless* model**

Datagram Switching

- No delay for connection setup
- Source can't know if network can deliver a packet
- Possible to route around failures
- Higher overhead per-packet
- Potentially larger tables at switches

Source Routing

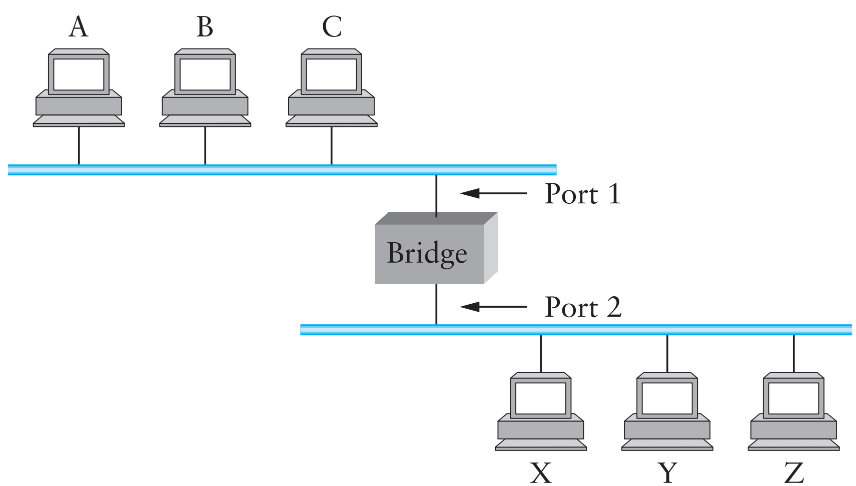


- **Packets carry entire route: ports**
- **Switches need no tables!**
  - But end hosts must obtain the path information
- **Variable packet header**

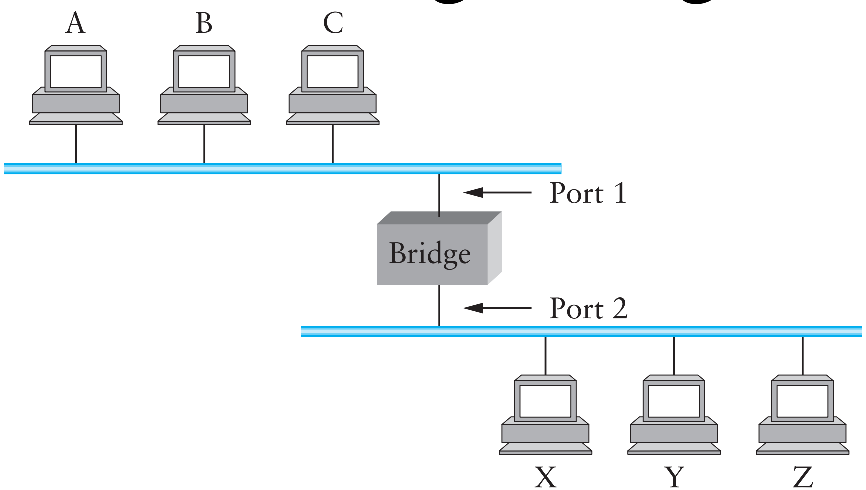
Bridging

Bridges and Extended LANs

- **LANs have limitations**
  - E.g. Ethernet < 1024 hosts, < 2500m
- **Connect two or more LANs with a *bridge***
  - Operates on Ethernet addresses
  - Forwards packets from one LAN to the other(s)
- **Ethernet *switch* is just a multi-way bridge**



Learning Bridges



- **Idea: don't forward a packet where it isn't needed**
  - If you know recipient is not on that port
- **Learn hosts' locations based on source addresses**
  - Build a table as you receive packets
  - Table is a *cache*: if full, evict old entries. Why is this fine?
- **Table says when *not* to forward a packet**
  - Doesn't need to be complete for *correctness*

Attack on a Learning Switch

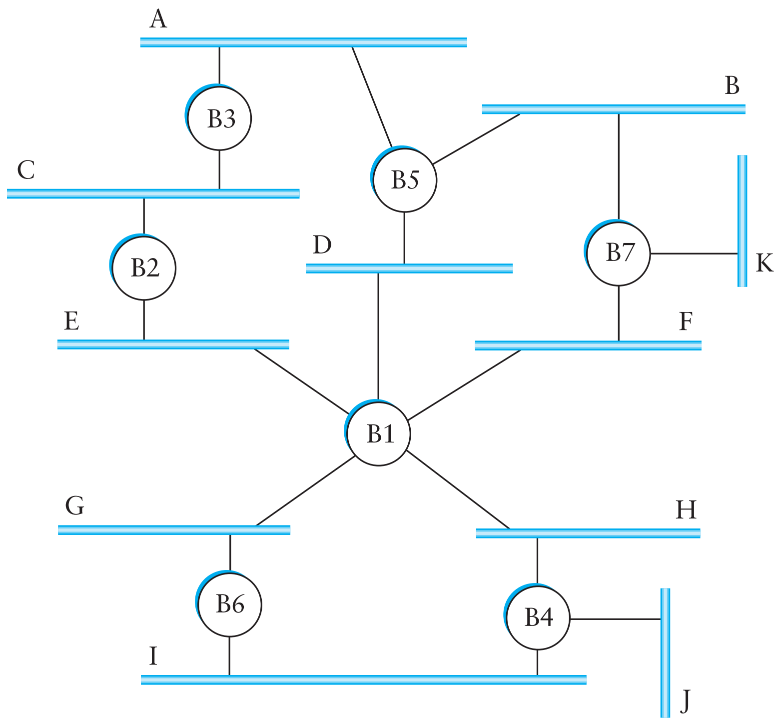
- **Eve: wants to sniff all packets sent to Bob**
- **Same segment: easy (shared medium)**
- **Different segment on a learning bridge: hard**
  - Once bridge learns Bob's port, stop broadcasting
- **How can Eve force the bridge to keep broadcasting?**
  - Flood the network with frames with spoofed src addr!

Bridges

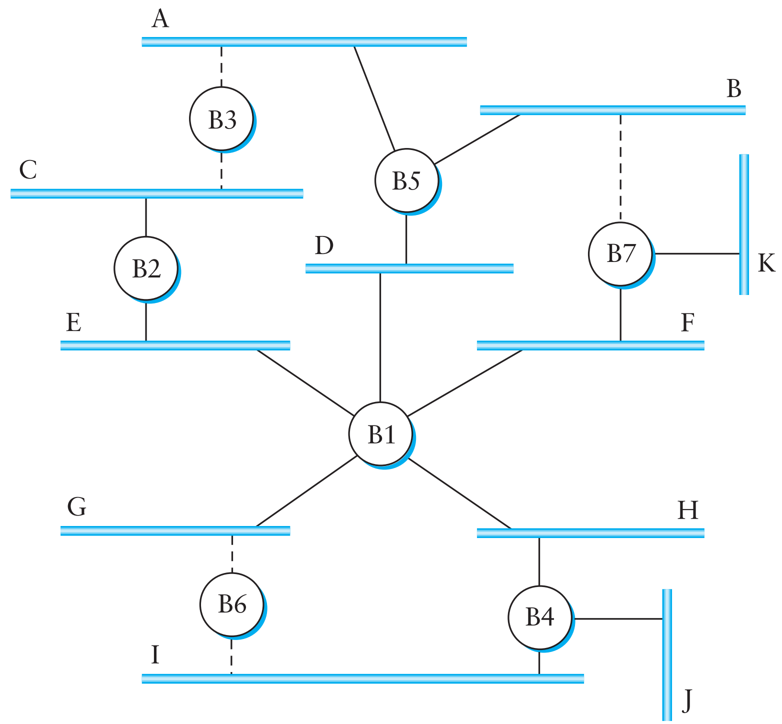
- **Unicast: forward with filtering**
- **Broadcast: always forward**
- **Multicast: always forward or learn groups**
- **Difference between bridges and repeaters?**
  - Bridges: same broadcast domain; copy *frames*
  - Repeaters: same broadcast and *collision domain*; copy *signals*

Dealing with Loops

- **Problem: people may create loops in LAN!**
  - Accidentally, or to provide redundancy
  - Don't want to forward packets indefinitely



Spanning Tree



- **Need to disable ports, so that no loops in network**
- **Like creating a spanning tree in a graph**
  - View switches and networks as nodes, ports as edges

Distributed Spanning Tree Algorithm

- **Every bridge has a unique ID (Ethernet address)**
- **Goal:**
  - Bridge with the smallest ID is the root
  - Each segment has one designated bridge, responsible for forwarding its packets towards the root
    - Bridge closest to root is designated bridge
    - If there is a tie, bridge with lowest ID wins

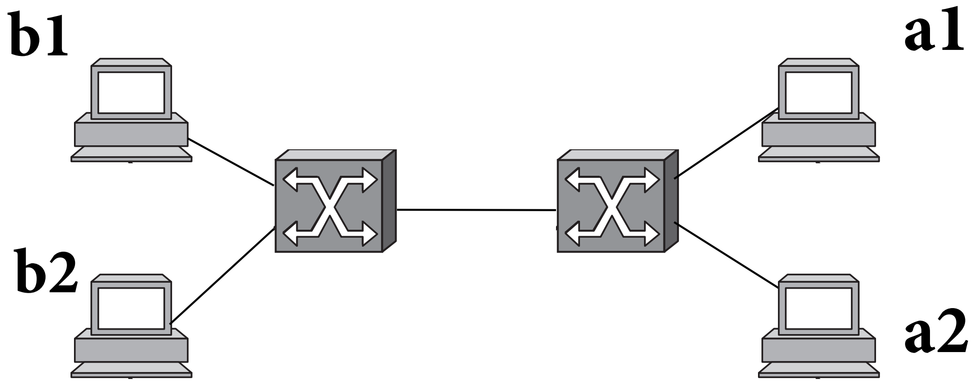
Spanning Tree Protocol

- **Spanning Tree messages contain:**
  - ID of bridge sending the message
  - ID sender believes to be the root
  - Distance (in hops) from sender to root
- **Bridges remember best config msg on each port**
- **Send message when you think you are the root**
- **Otherwise, forward messages from best known root**
  - Add one to distance before forwarding
  - Don't forward if you know you aren't dedicated bridge
- **In the end, only root is generating messages**

Limitations of Bridges

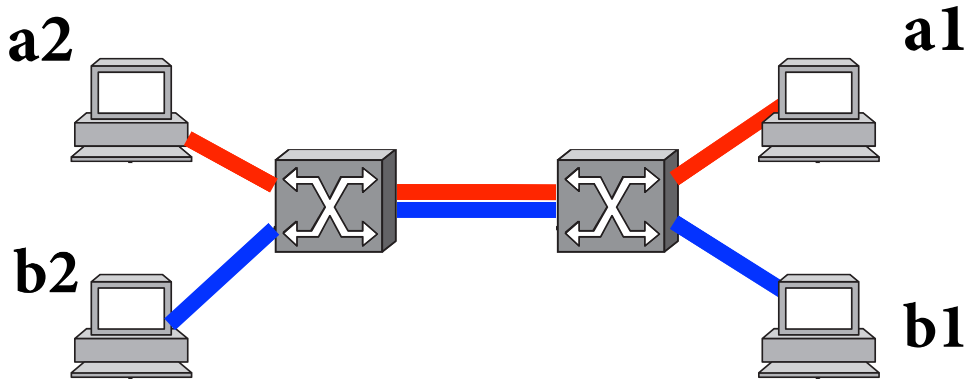
- **Scaling**
  – Spanning tree algorithm doesn't scale
  – Broadcast does not scale
  – No way to route around congested links, *even if path exists*
- **May violate assumptions**
  – Could confuse some applications that assume single segment
  – Much more likely to drop packets
  – Makes latency between nodes non-uniform
  – Beware of transparency

VLANs



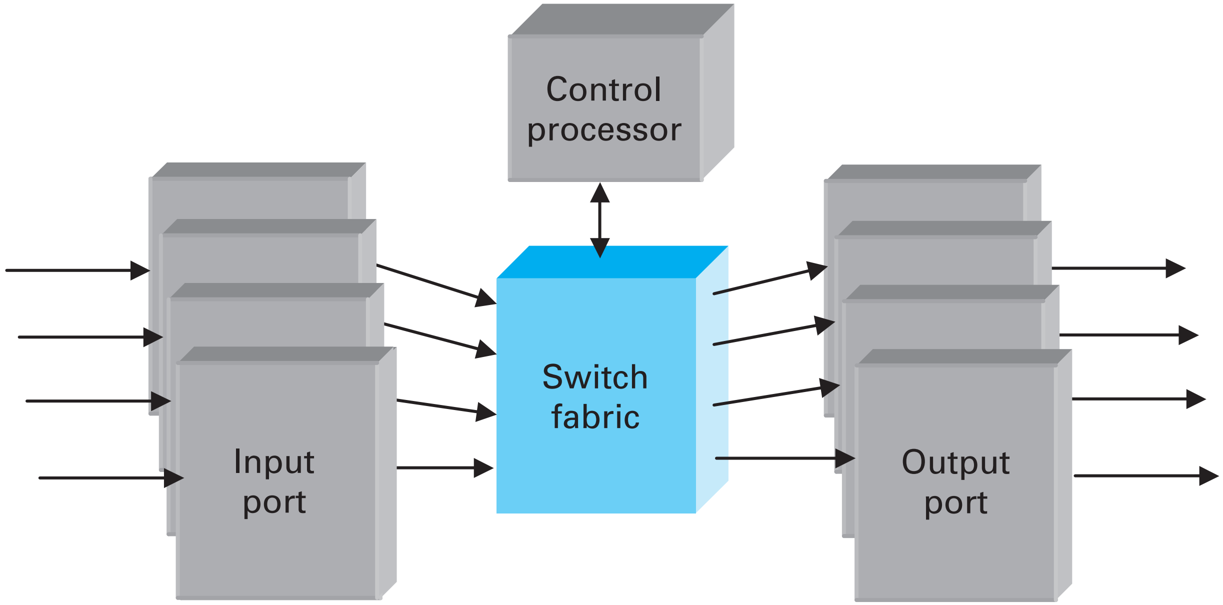
- **Company network, A and B departments**
  - Broadcast traffic does not scale
  - May not *want* traffic between the two departments
  - Topology has to mirror physical locations
  - What if employees move between offices?

VLANs



- **Solution: Virtual LANs**
  - Assign switch ports to a VLAN ID (color)
  - Isolate traffic: only same color
  - Trunk links may belong to multiple VLANs
  - Encapsulate packets: add 12-bit VLAN ID
- **Easy to change, no need to rewire**

Generic Switch Architecture



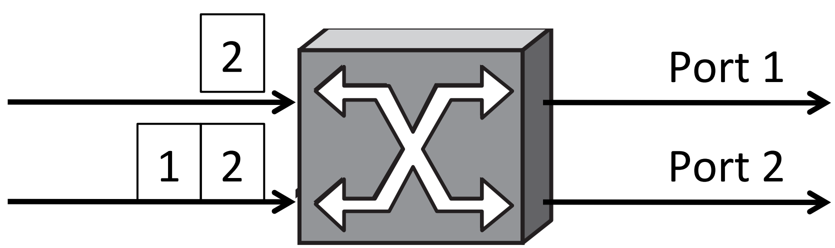
- **Goal: deliver packets from input to output ports**
- **Three potential performance concerns:**
  - Throughput in bytes/second
  - Throughput in packets/second
  - Latency

Cut through vs. Store and Forward

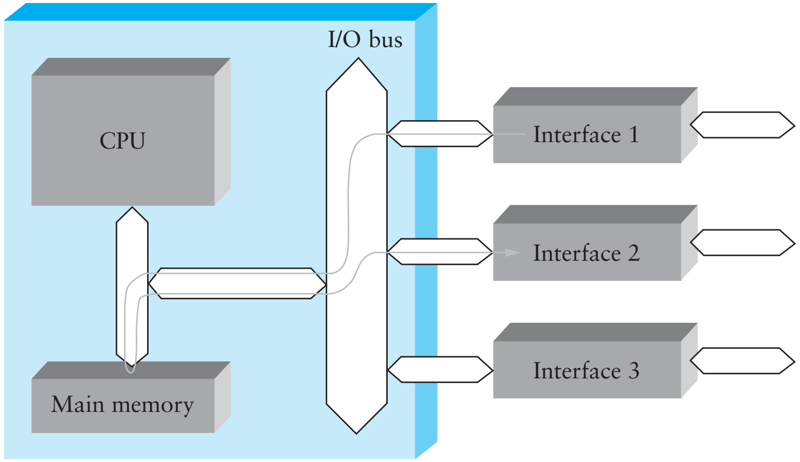
- **Two approaches to forwarding a packet**
  - Receive a full packet, then send to output port
  - Start retransmitting as soon as you know output port, before full packet
- **Cut-through routing can greatly decrease latency**
- **Disadvantage**
  - Can waste transmission (classic *optimistic* approach)
  - CRC may be bad
  - If Ethernet collision, may have to send runt packet on output link

Buffering

- **Buffering of packets can happen at input ports, fabric, and/or output ports**
- **Queuing discipline is very important**
- **Consider FIFO + input port buffering**
  - Only one packet per output port at any time
  - If multiple packets arrive for port 2, they may block packets to other ports that are free
  - *Head-of-line blocking*

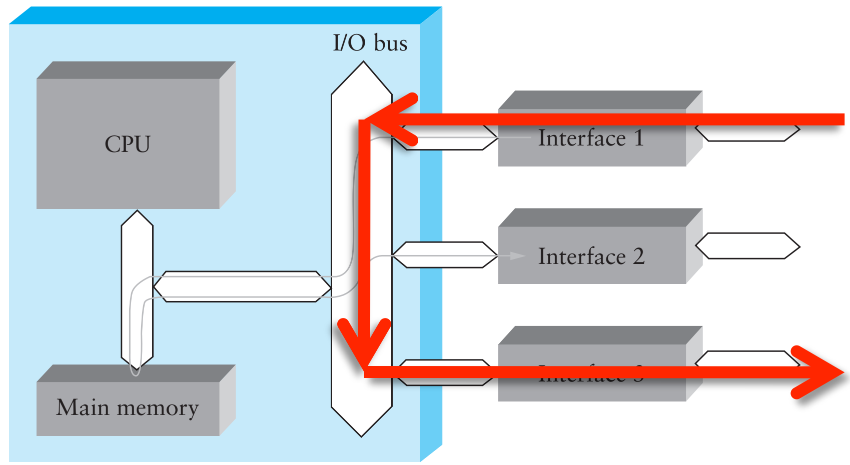


Shared Memory Switch



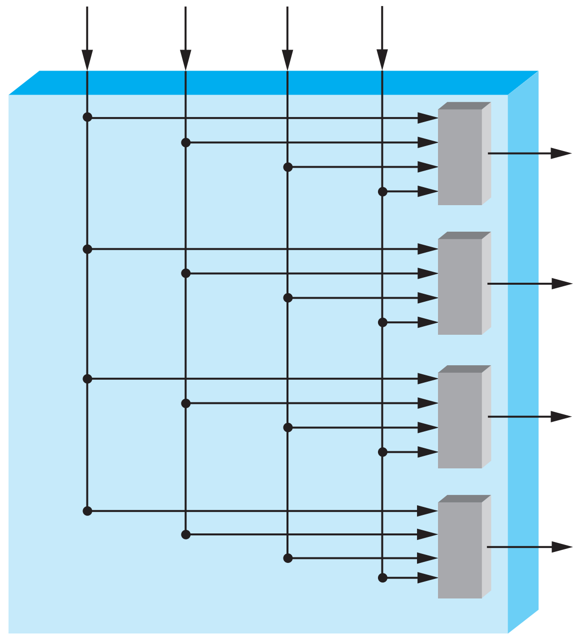
- **1st Generation – like a regular PC**
  - NIC DMAs packet to memory over I/O bus
  - CPU examines header, sends to destination NIC
  - I/O bus is serious bottleneck
  - For small packets, CPU may be limited too
  - Typically < 0.5 Gbps

Shared Bus Switch



- **2st Generation**
  - NIC has own processor, cache of forwarding table
  - Shared bus, doesn't have to go to main memory
  - Typically limited to bus bandwidth
    - (Cisco 5600 has a 32Gbps bus)

Point to Point Switch



- **3rd Generation: overcomes single-bus bottleneck**
- **Example: Cross-bar switch**
  - Any input-output permutation
  - Multiple inputs to same output requires trickery
  - Cisco 12000 series: 60Gbps

Coming Up

- Connecting multiple networks: IP and the Network Layer
- Remember: no class on Tuesday!