Ethernet: Links, Hubs, Switches

EE 122: Intro to Communication Networks

Fall 2006 (MW 4-5:30 in Donner 155)

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Materials with thanks to Jennifer Rexford, Ion Stoica, and colleagues at Princeton and UC Berkeley

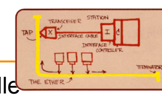
Announcements

- Office hours (329 Soda)
  - Regular slot moving to Weds 3-4PM (half hour later)
  - Extra office hours: Monday Oct 16 1:30-3:30PM
  - Also by appointment, but not this Thursday/Friday

Goals of Today's Lecture

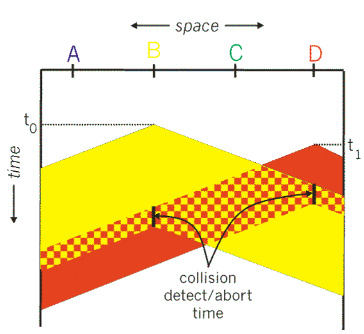
- Ethernet: single segment
  - Carrier sense, collision detection, and random access
  - Frame structure
- Ethernet: spanning multiple segments
  - Repeaters and hubs
  - Bridges and switches
  - Cut-through switching
  - Self-learning *(plug-and-play)*
  - Spanning trees
  - Virtual LANs (VLANs)
- The spectrum of interconnections
  - Hubs vs. switches vs. routers

Ethernet: CSMA/CD Protocol

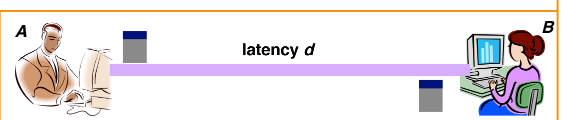


- **Carrier sense**: wait for link to be idle
- **Collision detection**: listen while transmitting
  - No collision: transmission is complete
  - Collision: abort transmission & send **jam** signal
- **Random access**: exponential back-off
  - After collision, wait a random time before trying again
  - After m^{th} collision, choose K randomly from $\{0, \ldots, 2^m-1\}$
  - … and wait for K*512 bit times before trying again
- **The** wired LAN technology
  - **Hugely** successful: 3/10/100/1000/10000 Mbps

CSMA/CD Collision Detection

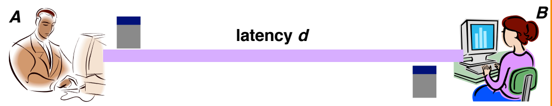


Limitations on Ethernet Length



- Latency depends on physical length of link
  - Time to propagate a packet from one end to the other
- Suppose *A* sends a packet at time ***t***
  - And *B* sees an idle line at a time just before ***t+d***
  - … so *B* happily starts transmitting a packet
- *B* detects a collision, and sends jamming signal
  - But *A* can't see collision until ***t+2d***

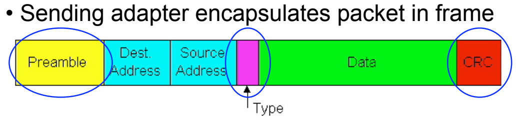
Limitations on Ethernet Length



- *A* needs to wait for time ***2d*** to detect collision
  - So, *A* should keep transmitting during this period
  - … and keep an eye out for a possible collision
- Imposes restrictions on Ethernet. For 10 Mbps:
  - Maximum length of the wire: 2,500 meters
  - Minimum length of the packet: 512 bits (64 bytes)
    - 512 bits = 51.2 μsec (at 10 Mbit/sec)
    - For light in vacuum, 51.2 μsec ≈ 15,000 meters vs. 5,000 meters "round trip" to wait for collision

Ethernet Frame Structure

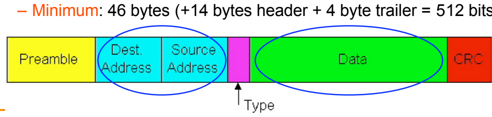
- Sending adapter encapsulates packet in frame



- Preamble: synchronization
  - Seven bytes with pattern **10101010**, followed by one byte with pattern **10101011**
  - Used to synchronize receiver & sender clock rates
- Type: indicates the higher layer protocol
  - Usually IP (but also Novell IPX, AppleTalk, …)
- CRC: cyclic redundancy check
  - Receiver checks & simply drops frames with errors

Ethernet Frame Structure (Continued)

- Addresses: 48-bit source and destination MAC addresses
  - Receiver's adaptor passes frame to network-level protocol
    - If destination address matches the adaptor's
    - Or the destination address is the broadcast address (**ff:ff:ff:ff:ff:ff**)
    - Or the destination address is a multicast group receiver belongs to
    - Or the adaptor is in promiscuous mode
  - Addresses are **globally unique**
    - Assigned by NIC vendors (top three octets specify vendor)
      - During any given week, > 500 vendor codes seen at LBNL
- Data:
  - Maximum: 1,500 bytes
  - Minimum: 46 bytes (+14 bytes header + 4 byte trailer = 512 bits)



Unreliable, Connectionless Service

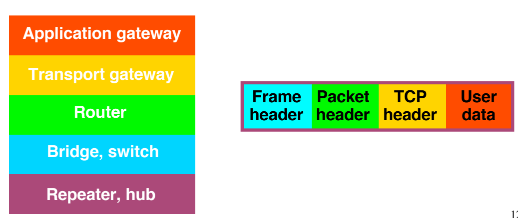
- Connectionless
  - No handshaking between sending and receiving adapter
- Unreliable
  - Receiving adapter doesn't send ACKs or NACKs
  - Packets passed to network layer can have gaps
  - Gaps will be filled if application is using TCP
  - Otherwise, application will see the gaps

Benefits of Ethernet

- Easy to administer and maintain
- Inexpensive
- Increasingly higher speed
- Evolved from shared media to switches
  - Changes everything except the frame format
  - A good general lesson for evolving the Internet:
    - The right interface (service model) can often accommodate unanticipated changes
  - In fact, Ethernet **framing** used for wildly different technologies, e.g., 802.11 wireless

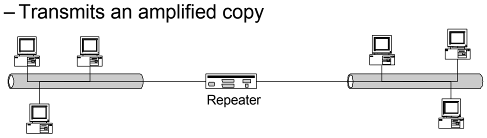
Shuttling Data at Different Layers

- Different devices switch different things
  - Physical layer: electrical signals (repeaters and hubs)
  - Link layer: frames (bridges and switches)
  - Network layer: packets (routers)



Physical Layer: Repeaters

- Distance limitation in local-area networks
  - Electrical signal becomes weaker as it travels
  - Imposes a limit on the length of a LAN
    - In addition to limit imposed by collision detection
- Repeaters join LANs together
  - Analog electronic device
  - Continuously monitors electrical signals on each LAN
  - Transmits an amplified copy



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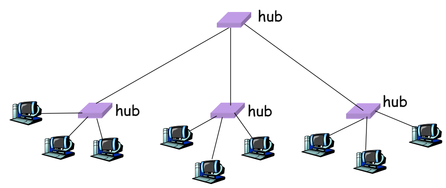
Physical Layer: Hubs

- Joins multiple input lines electrically
  - Do not necessarily amplify the signal
- Very similar to repeaters
  - Also operates at the physical layer



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Limitations of Repeaters and Hubs

- One large collision domain
  - Every bit is sent everywhere
  - So, aggregate throughput is limited
  - E.g., three departments each get 10 Mbps independently
  - … and then if connect via a hub must share 10 Mbps
- Cannot support multiple LAN technologies
  - Repeaters/hubs do not buffer or interpret frames
  - So, can't interconnect between different rates or formats
  - E.g., no mixing 10 Mbps Ethernet & 100 Mbps Ethernet
- Limitations on maximum nodes and distances
  - Does not circumvent limitations of shared media
  - E.g., still cannot go beyond 2500 meters on Ethernet

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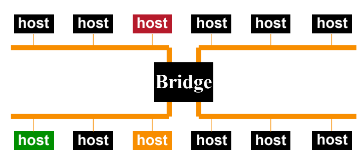
Link Layer: Bridges

- Connects two or more LANs at the link layer
  - Extracts destination address from the frame
  - Looks up the destination in a table
  - Forwards the frame to the appropriate LAN segment
- Each segment is its own collision domain



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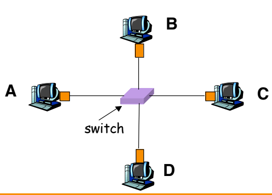
Link Layer: Switches

- Typically connects individual computers
  - Essentially the same as a bridge
  - … though connecting hosts, not LANs
    - In a point-to-point fashion
- Like bridges, support concurrent communication
  - Host A can talk to C, while B talks to D



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Dedicated Access and Full Duplex

- Dedicated access
  - Host has direct connection to the switch
  - … rather than a shared LAN connection
- Full duplex
  - Each connection can send in both directions
    - At the same time (otherwise, "half duplex")
  - Host sending to switch, and host receiving from switch
- Completely avoids collisions
  - Each connection is a bidirectional point-to-point link
  - No need for carrier sense, collision detection, and so on

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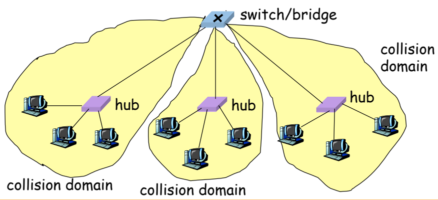
Bridges/Switches: Traffic Isolation

- Breaks subnet into LAN segments
- Filters packets
  - Frame only forwarded to the necessary segments
  - Segments become separate collision domains



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5 Minute Break

Questions Before We Proceed?

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Advantages Over Hubs/Repeaters

- Only forwards frames as needed
  - Filters frames to avoid unnecessary load on segments
  - Sends frames only to segments that need to see them
- Extends the geographic span of the network
  - Separate collision domains allow longer distances
- Improves privacy by limiting scope of frames
  - Hosts can “snoop” the traffic traversing their segment
  - … but not all the rest of the traffic
- If needed, applies carrier sense & collision detection
  - Does not transmit when the link is busy
  - Applies exponential back-off after a collision
- Joins segments using different technologies

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Disadvantages Over Hubs/Repeaters

- Delay in forwarding frames
  - Bridge/switch must receive and parse the frame
  - … and perform a look-up to decide where to forward
  - Introduces store-and-forward delay
  - Solution: cut-through switching
- Need to learn where to forward frames
  - Bridge/switch needs to construct a forwarding table
  - Ideally, without intervention from network administrators
  - Solution: self-learning
- Higher cost
  - More complicated devices that cost more money

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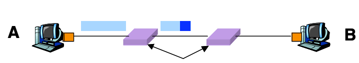
Cut-Through Switching

- Buffering a frame takes time
  - If **L** is length of the frame, **R** is the transmission rate …
  - … then receiving the frame takes **L/R** time units
  - When will this be significant?
- Cut-Through: Begin sending as soon as possible
  - Inspect frame header & look-up destination
  - If outgoing link idle, start forwarding
  - Can transmit head of packet while still receiving tail



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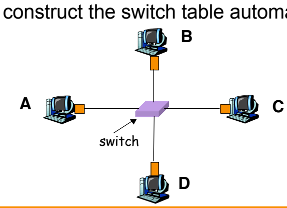
Motivation For Self Learning

- Large benefit if switch/bridge forward frames only on segments that need them
  - Allows concurrent use of other links
- Switch table
  - Maps destination MAC address to outgoing interface
  - Goal: construct the switch table automatically



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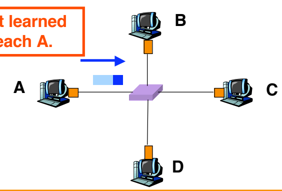
Self Learning: Building the Table

- When a frame arrives
  - Inspect *source* MAC address
  - Associate address with the *incoming* interface
  - Store mapping in the switch table
  - Use time-to-live field to eventually forget the mapping
    - ***Soft state***

Switch just learned how to reach A.



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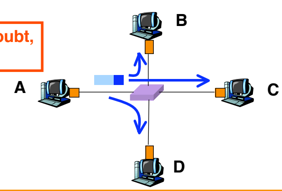
Self Learning: Handling Misses

- When frame arrives with unfamiliar destination
  - Forward the frame out all of the interfaces
  - … except for the one where the frame arrived
  - Hopefully, this case won't happen very often

When in doubt, shout!



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Switch Filtering/Forwarding

When switch receives a frame:

index the switch table using MAC dest address

if entry found for destination **{**

if dest on segment from which frame arrived
then drop frame

else forward frame on interface indicated

}

else flood

Problems?

forward on all but the interface on which the frame arrived

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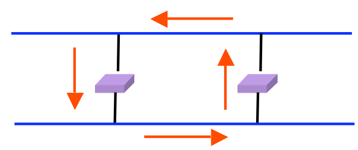
Flooding Can Lead to Loops

- Switches sometimes need to broadcast frames
  - Upon receiving a frame with an unfamiliar destination
  - Upon receiving a frame sent to the broadcast address
  - Implemented by flooding
- Flooding can lead to forwarding loops
  - E.g., if the network contains a cycle of switches
  - Either accidentally, or by design for higher reliability



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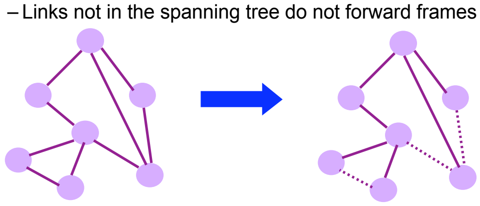
Solution: Spanning Trees

- Ensure the forwarding topology has no loops
  - Avoid using some of the links when flooding
  - … to prevent loop from forming
- Spanning tree
  - Sub-graph that covers all vertices but contains no cycles
  - Links not in the spanning tree do not forward frames



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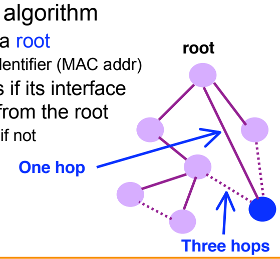
Constructing a Spanning Tree

- Need a distributed algorithm
  - Switches cooperate to build the spanning tree
  - … and adapt automatically when failures occur
- Key ingredients of the algorithm
  - Switches need to elect a root
    - The switch w/ smallest identifier (MAC addr)
  - Each switch determines if its interface is on the shortest path from the root
    - Excludes it from the tree if not
  - Messages (Y, d, X)
    - From node X
    - Proposing Y as the root
    - And the distance is d



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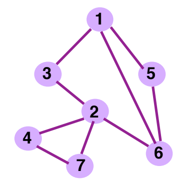
Steps in Spanning Tree Algorithm

- Initially, each switch proposes itself as the root
  - Switch sends a message out every interface
  - … proposing itself as the root with distance 0
  - Example: switch X announces (X, 0, X)
- Switches update their view of the root
  - Upon receiving message (Y, d, Z) from Z, check Y's id
  - If new id smaller, start viewing that switch as root
- Switches compute their distance from the root
  - Add 1 to the distance received from a neighbor
  - Identify interfaces not on shortest path to the root
  - … and exclude them from the spanning tree
- If root or shortest distance to it changed, flood updated message (Y, d+1, X)

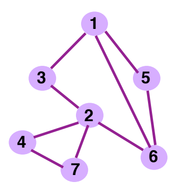
Example From Switch #4's Viewpoint

- Switch #4 thinks it is the root
  - Sends (4, 0, 4) message to 2 and 7
- Then, switch #4 hears from #2
  - Receives (2, 0, 2) message from 2
  - … and thinks that #2 is the root
  - And realizes it is just one hop away
- Then, switch #4 hears from #7
  - Receives (2, 1, 7) from 7
  - And realizes this is a longer path
  - So, prefers its own one-hop path
  - And removes 4-7 link from the tree



Example From Switch #4's Viewpoint

- Switch #2 hears about switch #1
  - Switch 2 hears (1, 1, 3) from 3
  - Switch 2 starts treating 1 as root
  - And sends (1, 2, 2) to neighbors
- Switch #4 hears from switch #2
  - Switch 4 starts treating 1 as root
  - And sends (1, 3, 4) to neighbors
- Switch #4 hears from switch #7
  - Switch 4 receives (1, 3, 7) from 7
  - And realizes this is a longer path
  - So, prefers its own three-hop path
  - And removes 4-7 link from the tree



Robust Spanning Tree Algorithm

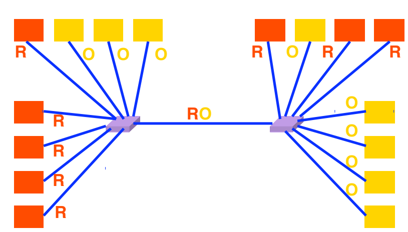
- Algorithm must react to failures
  - Failure of the root node
    - Need to elect a new root, with the next lowest identifier
  - Failure of other switches and links
    - Need to recompute the spanning tree
- Root switch continues sending messages
  - Periodically reannouncing itself as the root (1, 0, 1)
  - Other switches continue forwarding messages
- Detecting failures through timeout (soft state)
  - Switch waits to hear from others
  - Eventually times out and claims to be the root

See Section 3.2.2 in the textbook for details and another example

Virtual LANs

- Once we have switches, we can enforce policies regarding isolation
  - Group users based on organizational structure rather than physical layout of building
- Implemented as "virtual LANs" or VLANs
  - Associate a "color" (tag) with either each switch interface
    - Assuming entire segment it serves on same VLAN
  - … or with each MAC address
    - Also allows hosts to move from one physical location to another
- Security:
  - Prevents nodes from seeing traffic not meant for them
  - Can force traffic leaving the VLAN to transit control point
    - E.g., firewall or Intrusion Detection System (IDS)

Example: Two Virtual LANs



Red VLAN and Orange VLAN
Switches forward traffic as needed

Moving From Switches to Routers

- Advantages of switches over routers
  - Plug-and-play
  - Fast filtering and forwarding of frames
- Disadvantages of switches over routers
  - Topology restricted to a spanning tree
  - Large networks require large ARP tables
  - Broadcast storms can cause the network to collapse
  - Can't accommodate non-Ethernet segments (why not?)

Comparing Hubs, Switches & Routers

	hubs	switches	routers
traffic isolation	no	yes	yes
plug & play	yes	yes	no
optimized routing	no	no	yes
cut-through	yes	yes	no

Summary

- Ethernet as an exemplar of link-layer technology
- Simplest form, single segment:
  - Carrier sense, collision detection, and random access
- Extended to span multiple segments:
  - Hubs: physical-layer interconnects
  - Bridges & switches: link-layer interconnects
- Key ideas in switches
  - Cut-through switching
  - Self learning of the switch table
  - Spanning trees
  - Virtual LANs (VLANs)
- Next time: midterm review