Switches
Reading: Section 3.2

CS 375: Computer Networks

Thomas Bressoud

Goals of Today's Lecture

- Devices that shuttle data at different layers
  - Repeaters and hubs
  - Bridges and switches
  - Routers

- Switch protocols and mechanisms
  - Dedicated access and full-duplex transfers
  - Cut-through switching
  - Self learning of the switch table
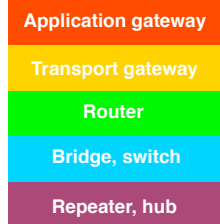 - Spanning trees

- Virtual LANs (VLANs)

Message, Segment, Packet, and Frame
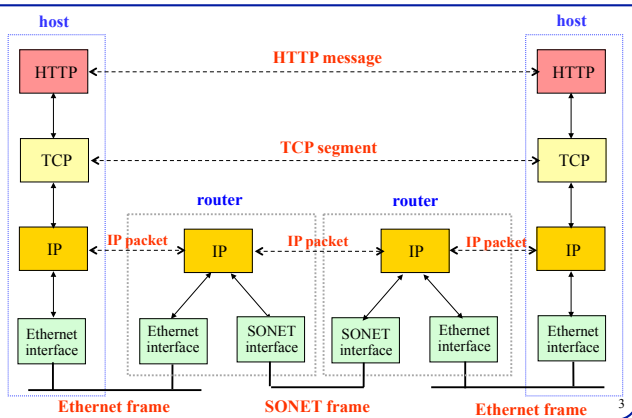
Shuttling Data at Different Layers

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

Application gateway
Transport gateway
Router
Bridge, switch
Repeater, hub

Frame header	Packet header	TCP header	User data

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## 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

- Repeaters join LANs together
  - Analog electronic device
  - Continuously monitors electrical signals on each LAN
  - Transmits an amplified copy
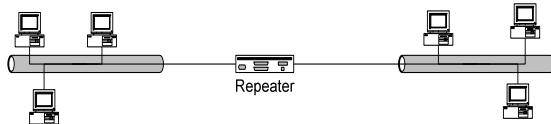
Repeater

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Physical Layer: Hubs

- Joins multiple input lines electrically
  - Designed to hold multiple line cards
  - Do not necessarily amplify the signal

- Very similar to repeaters
 - Also operates at the physical layer

hub

hub   hub   hub
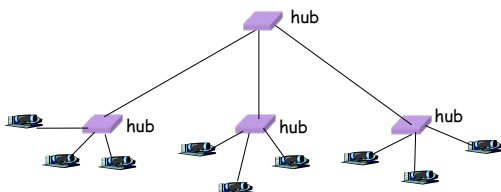
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Limitations of Repeaters and Hubs

• One large shared link
  – Each bit is sent everywhere
  – So, aggregate throughput is limited
  – E.g., three departments each get 10 Mbps independently
  – … and then connect via a hub and must share 10 Mbps

• Cannot support multiple LAN technologies
  – Does not buffer or interpret frames
  – So, can't interconnect between different rates or formats
  – E.g., 10 Mbps Ethernet and 100 Mbps Ethernet

• Limitations on maximum nodes and distances
  – Shared medium imposes length limits (see next lecture)
  – E.g., cannot go beyond 2500 meters on Ethernet   7

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 can carry its own traffic

| host | host | host | host | host | host |

Bridge

| host | host | host | host | host | host |
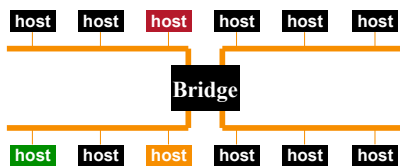
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Link Layer: Switches

• Typically connects individual computers
  – A switch is essentially the same as a bridge
  – … though typically used to connect hosts, not LANs

• Like bridges, support concurrent communication
  – Host A can talk to C, while B talks to D

B

A   C
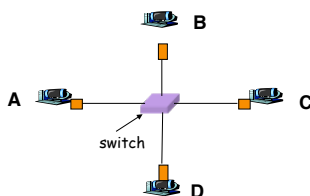
switch

D   9

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
  - Host sending to switch, and host receiving from switch
  - E.g., in 10BaseT and 100Base T

- Completely supports concurrent transmissions
  - Each connection is a bidirectional point-to-point link

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Bridges/Switches: Traffic Isolation

- Switch breaks subnet into LAN segments

- Switch filters packets
  - Frame only forwarded to the necessary segments
  - Segments can support separate transmissions

switch/bridge

segment

hub

hub

hub
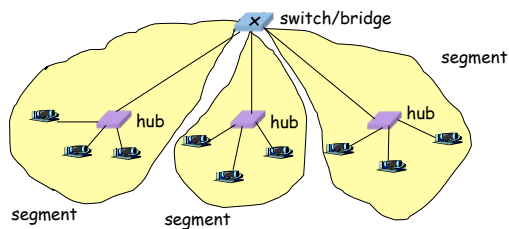
segment

segment

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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 segments 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

- Can join 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
  - Storing and forwarding the packet introduces 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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Motivation For Cut-Through Switching

- Buffering a frame takes time
  - Suppose L is the length of the frame
  - And R is the transmission rate of the links
  - Then, receiving the frame takes L/R time units

- Buffering delay can be a high fraction of total delay
  - Propagation delay is small over short distances
  - Making buffering delay a large fraction of total
  - Analogy: large group walking through NYC

A ——————— B
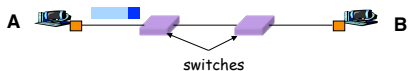
switches

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Cut-Through Switching

- Start transmitting as soon as possible
  - Inspect the frame header and do the look-up
  - If outgoing link is idle, start forwarding the frame

- Overlapping transmissions
  - Transmit the head of the packet via the outgoing link
  - … while still receiving the tail via the incoming link
  - Analogy: different folks crossing different intersections

A ——————— B
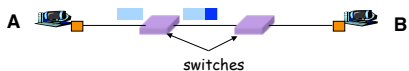
switches

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Motivation For Self Learning

- Switches forward frames selectively
  - Forward frames only on segments that need them

- Switch table
  - Maps destination MAC address to outgoing interface
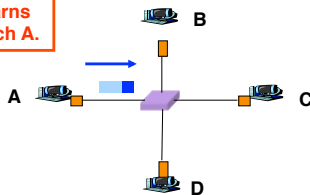 - Goal: construct the switch table automatically

B

A   C

switch

D
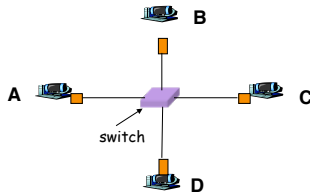
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Self Learning: Building the Table

- When a frame arrives
  - Inspect the *source* MAC address
  - Associate the address with the *incoming* interface
  - Store the mapping in the switch table
  - Use a time-to-live field to eventually forget the mapping
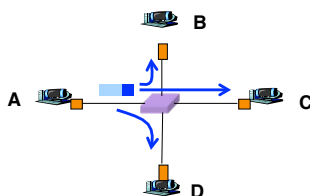
Switch learns
how to reach A.

B

A   C

D

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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!

B

A   C

D

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Switch Filtering/Forwarding

When switch receives a frame:

index switch table using MAC dest address

if entry found for destination
  then{
    if dest on segment from which frame arrived
      then drop the frame

       else forward the frame on interface indicated

  }
  else flood

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

- Broadcasting is implemented by flooding
  - Transmitting frame out every interface
  - … except the one where the frame arrived

- 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 topology has no loops
  - Avoid using some of the links when flooding
  - … to avoid forming a loop

- Spanning tree
  - Sub-graph that covers all vertices but contains no cycles
 - Links not in the spanning tree do not forward frames
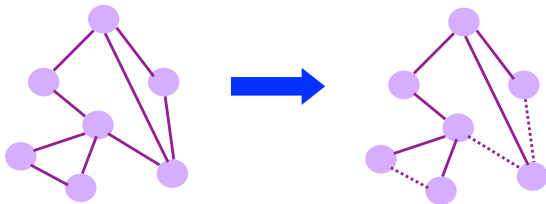
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Constructing a Spanning Tree

- 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 with the smallest identifier
  - Each switch identifies if its interface is on the shortest path from the root
    - And it exclude from the tree if not
  - Messages (Y, d, X)
    - From node X
    - Claiming Y is the root
   - And the distance is d

root

One hop

Three hops

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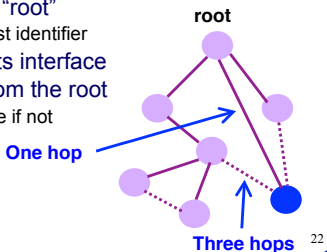
Steps in Spanning Tree Algorithm

- Initially, each switch thinks it is the root
  - Switch sends a message out every interface
  - … identifying itself as the root with distance 0
  - Example: switch X announces (X, 0, X)

- Switches update their view of the root
  - Upon receiving a message, check the root id
  - If the new id is 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 a shortest path to the root
  - … and exclude them from the spanning tree

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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
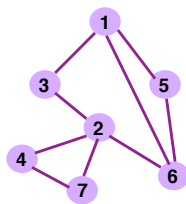
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Example From Switch #4's Viewpoint

- 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
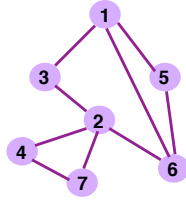
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Robust Spanning Tree Algorithm

- 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 26

Evolution Toward Virtual LANs

- In the olden days…
  - Thick cables snaked through cable ducts in buildings
  - Every computer they passed was plugged in
  - All people in adjacent offices were put on the same LAN
  - Independent of whether they belonged together or not

- More recently…
  - Hubs and switches changed all that
  - Every office connected to central wiring closets
  - Often multiple LANs (*k* hubs) connected by switches
  - Flexibility in mapping offices to different LANs

Group users based on organizational structure, rather than the physical layout of the building.

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Why Group by Organizational Structure?

- Security
  - Ethernet is a shared media
  - Any interface card can be put into "promiscuous" mode
  - … and get a copy of all of the traffic (e.g., midterm exam)
  - So, isolating traffic on separate LANs improves security

- Load
  - Some LAN segments are more heavily used than others
  - E.g., researchers running experiments get out of hand
  - … can saturate their own segment and not the others
  - Plus, there may be natural locality of communication
 - E.g., traffic between people in the same research group

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People Move, and Roles Change

- Organizational changes are frequent
  - E.g., faculty office becomes a grad-student office
  - E.g., graduate student becomes a faculty member

- Physical rewiring is a major pain
  - Requires unplugging the cable from one port
  - … and plugging it into another
  - … and hoping the cable is long enough to reach
  - … and hoping you don't make a mistake

- Would like to "rewire" the building in software
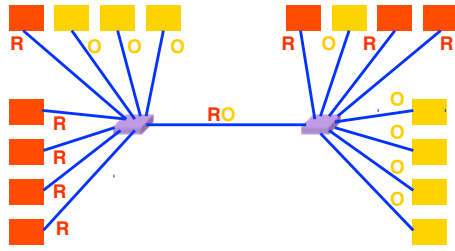 - The resulting concept is a Virtual LAN (VLAN)

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Example: Two Virtual LANs
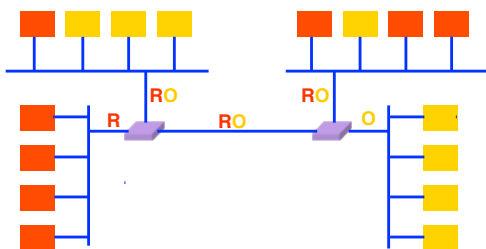
Red VLAN and **Orange VLAN**
Bridges forward traffic as needed

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Example: Two Virtual LANs

Red VLAN and **Orange VLAN**
Switches forward traffic as needed

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Making VLANs Work

• Bridges/switches need configuration tables
  – Saying which VLANs are accessible via which interfaces

• Approaches to mapping to VLANs
  – Each interface has a VLAN color
    • Only works if all hosts on same segment belong to same VLAN
  – Each MAC address has a VLAN color
    • Useful when hosts on same segment belong to different VLANs
    • Useful when hosts move from one physical location to another

• Changing the Ethernet header
  – Adding a field for a VLAN tag
  – Implemented on the bridges/switches
  – … but can still interoperate with old Ethernet cards

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Moving From Switches to Routers

• Advantages of switches over routers
  – Plug-and-play
  – Fast filtering and forwarding of frames
  – No pronunciation ambiguity (e.g., "rooter" vs. "rowter")

• Disadvantages of switches over routers
  – Topology is restricted to a spanning tree
  – Large networks require large ARP tables
  – Broadcast storms can cause the network to collapse

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Comparing Hubs, Switches, Routers

	Hub/ Repeater	Bridge/ Switch	Router
Traffic isolation	no	yes	yes
Plug and Play	yes	yes	no
Efficient routing	no	no	yes
Cut through	yes	yes	no

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Conclusion

• Shuttling data from one link to another
  – Bits, frames, packets, …
  – Repeaters/hubs, bridges/switches, routers, …

• Key ideas in switches
  – Cut-through switching
  – Self learning of the switch table
  – Spanning trees
  – Virtual LANs (VLANs)

• Next week
  – Monday: Links
  – Wednesday: Midterm exam

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