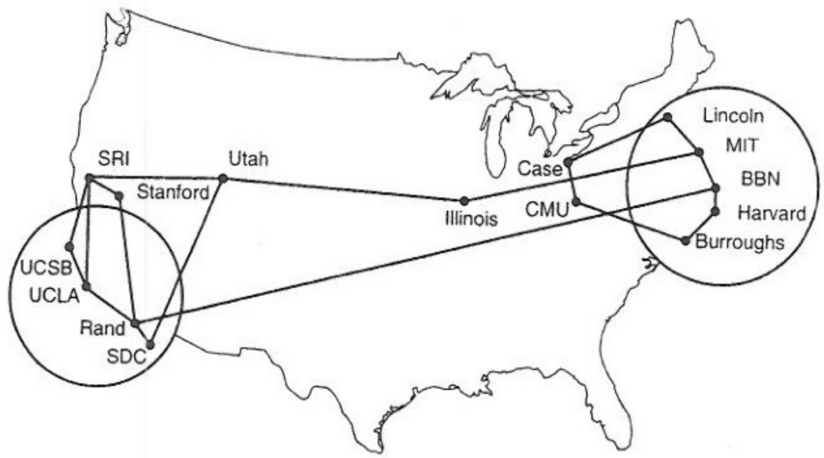


Switching and Forwarding

Reading: Chapter 3

Switching and Forwarding

Next Problem:

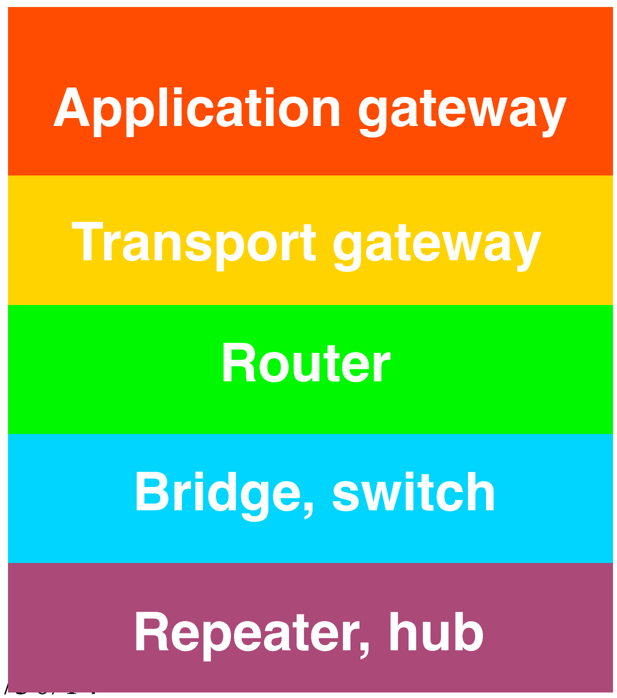
- Enable communication between hosts that are not directly connected…Fundamental Problem of the Internet or any large Network

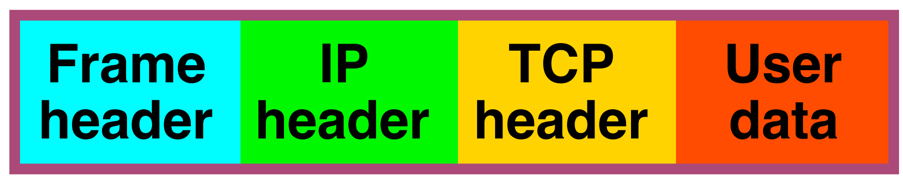
Outline/Goals

- Store-and-Forward Switches
- Bridges and Extended LANs
- Cell Switching
- Segmentation and Reassembly
- Spanning Tree
- Cut-through

Shuttling Data at Different Layers

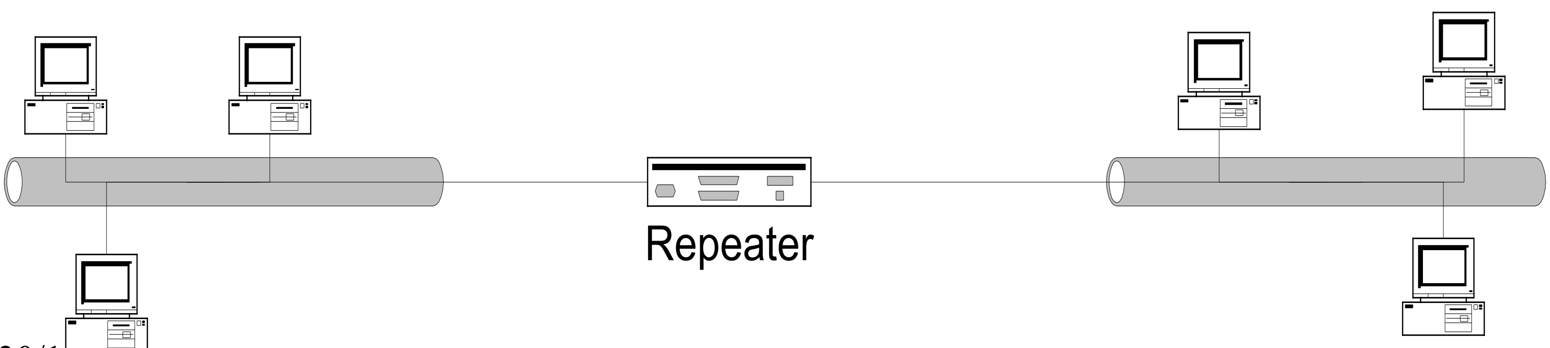
- Different devices switch different things
  - Physical layer: electrical signals (repeaters and hubs)
  - Link layer: frames (bridges and switches)
  - Network layer: packets (routers) – TCP/IP





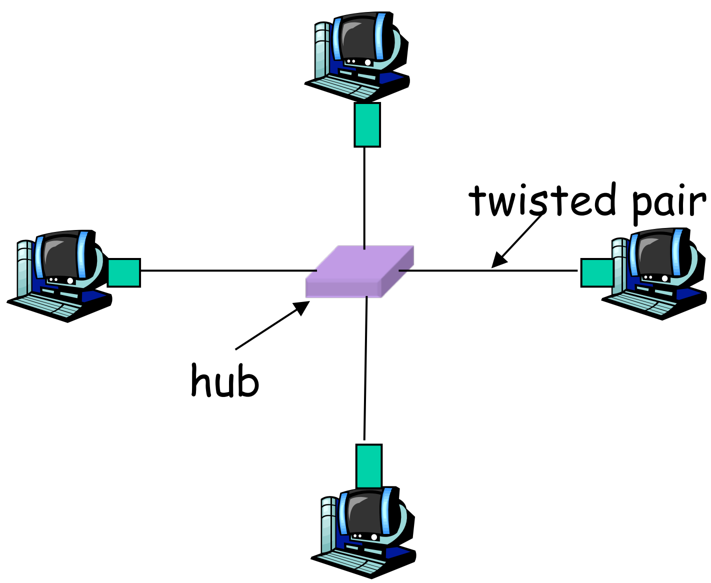
Physical Layer: Repeaters

- 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



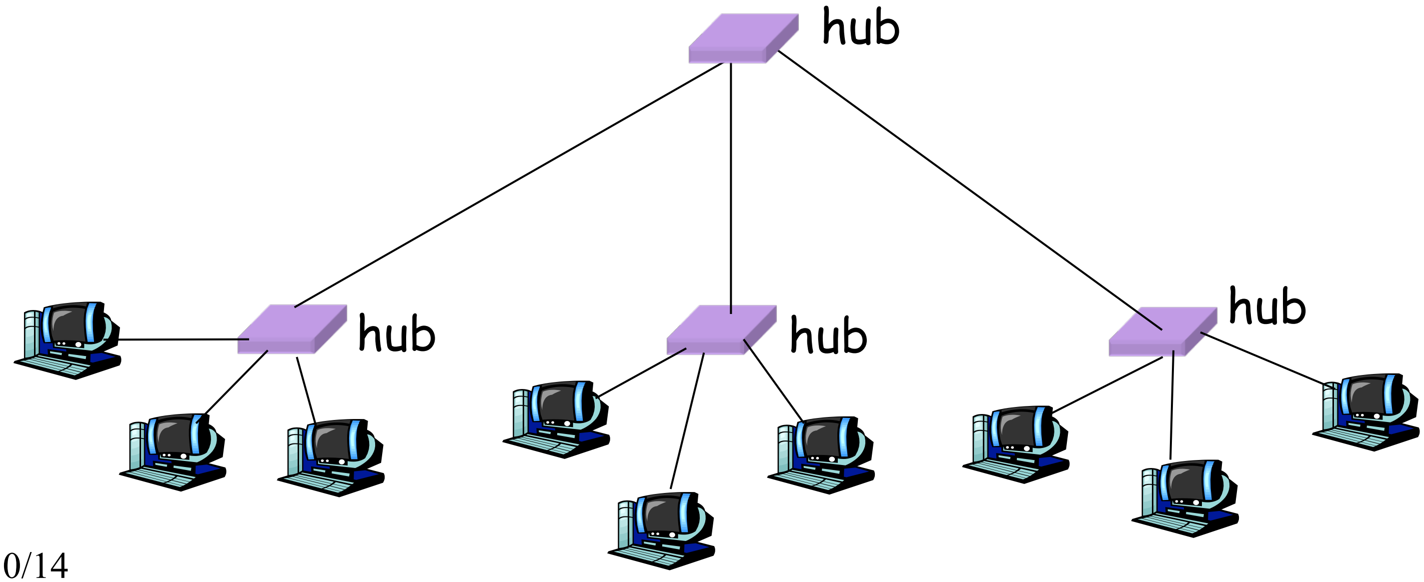
Hubs: Physical-Layer Repeaters

- Hubs are physical-layer repeaters (historical)
  - Bits coming from one link go out all other links
  - At the same rate, with NO frame buffering
  - No CSMA/CD at hub: adapters detect collisions
  - Joins multiple lines electrically – just multi port repeater



Interconnecting with Hubs

- Backbone hub interconnects LAN segments
- All packets seen everywhere, forming one large collision domain
- Can't interconnect Ethernets of different speeds
- Collision Heaven!!!

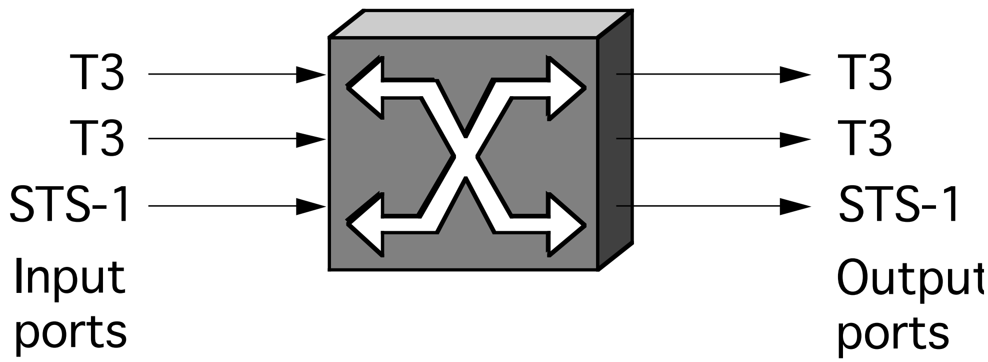


Limitations of Repeaters and Hubs

- 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 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
  - Does not circumvent the limitations of shared media
  - E.g., still cannot go beyond 2500 meters on Ethernet

Link Layer: Scalable Networks

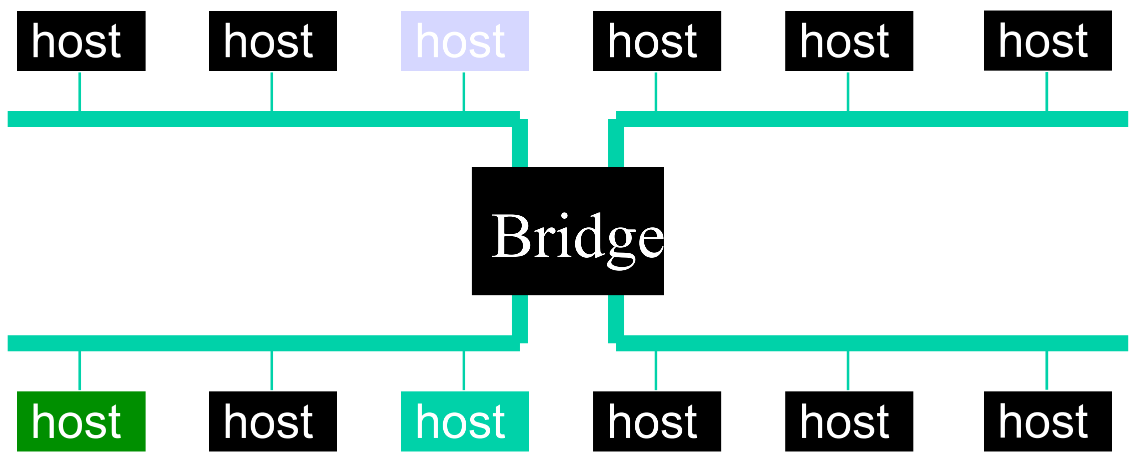
- Switch/Bridge
  - Forwards frames from input port to output port – stores frames, needs memory
  - port selected based on address in frame header



- Advantages
  - cover large geographic area (tolerate latency)
  - support large numbers of hosts (scalable bandwidth)
  - can add hosts without performance penalty vs. shared medium

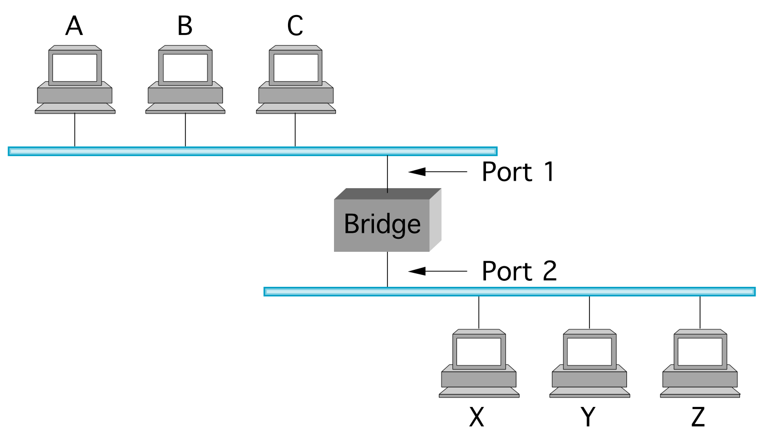
Link Layer: Bridges

- 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 (LAN)



Bridges and Extended LANs

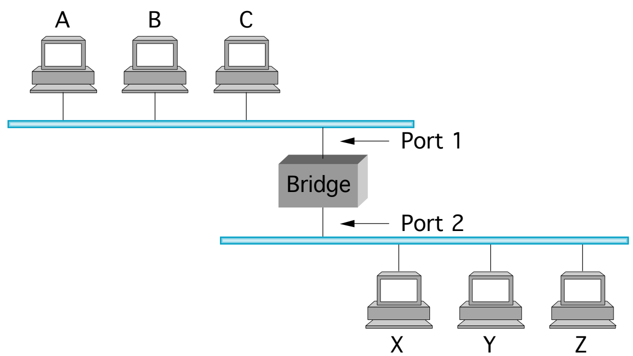
- LANs have physical limitations (e.g., 2500m)
- Connect two or more LANs with a *bridge*
  - accept and forward strategy, forwarding Frames
  - level 2 connection (does not add packet header)



- Ethernet Switch = Bridge on Steroids

Learning Bridges

- Do not forward when unnecessary
- Maintain forwarding table



Host	Port
A	1
B	1
C	1
X	2
Y	2
Z	2

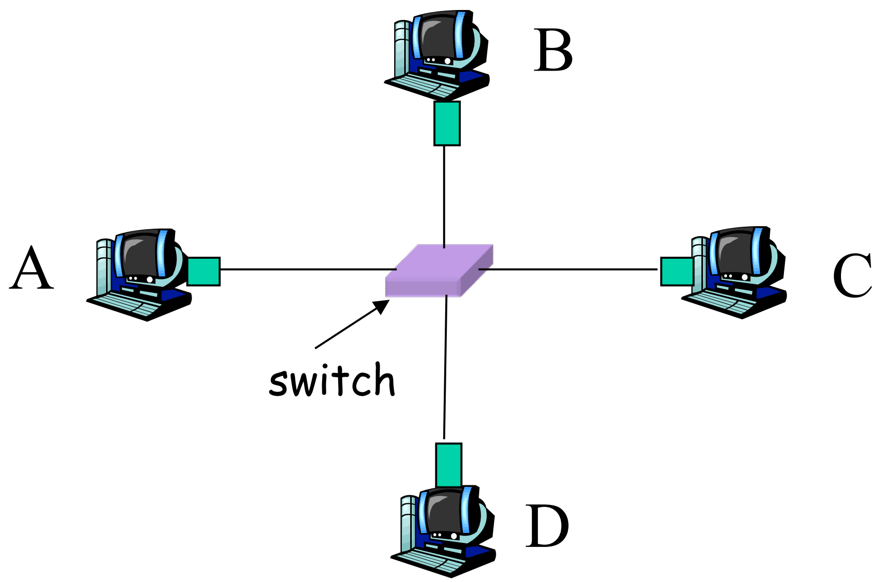
- Learn table entries based on source address of frame
- Table is an optimization; need not be complete
- Always forward broadcast frames
- Timeouts & Aging - Why?

Link Layer: Switches

- Link layer device
  - Stores and forwards (Ethernet) frames
  - Examines frame header and selectively forwards frame based on MAC dest address
  - When frame is to be forwarded on segment, uses CSMA/CD to access segment
- Transparent
  - Hosts are unaware of presence of switches
- Plug-and-play, self-learning
  - Switches do not need to be configured

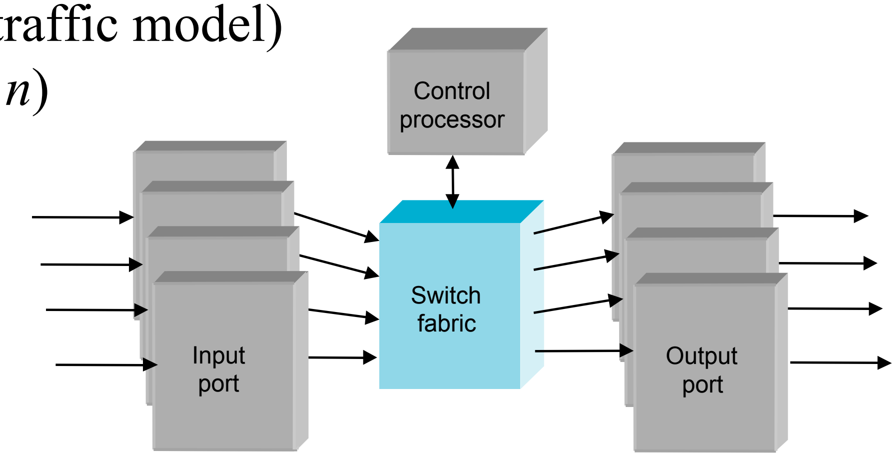
Link Layer: Switches

- Typically connect individual computers
  - A switch is essentially same as a bridge
  - … though typically used to connect hosts, not LANs
  - Collision domain moved into switch
- Like bridges, support concurrent communication
  - Host A can talk to C, while B talks to D
  - Many ports, many simultaneous conversations



Switching Hardware

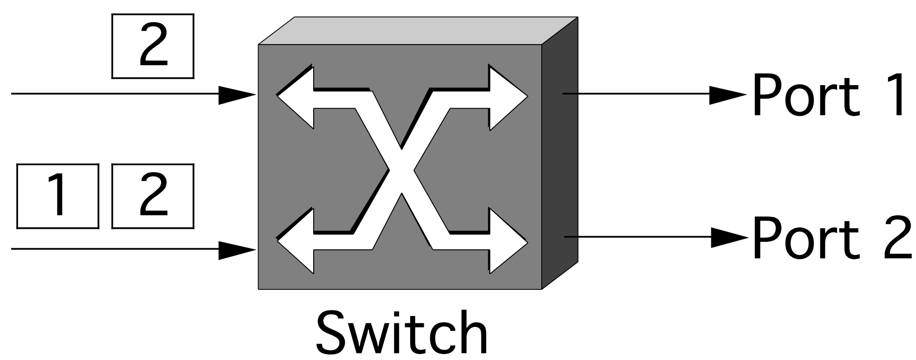
- Design Goals
  - throughput (depends on traffic model)
  - scalability (a function of *n*)



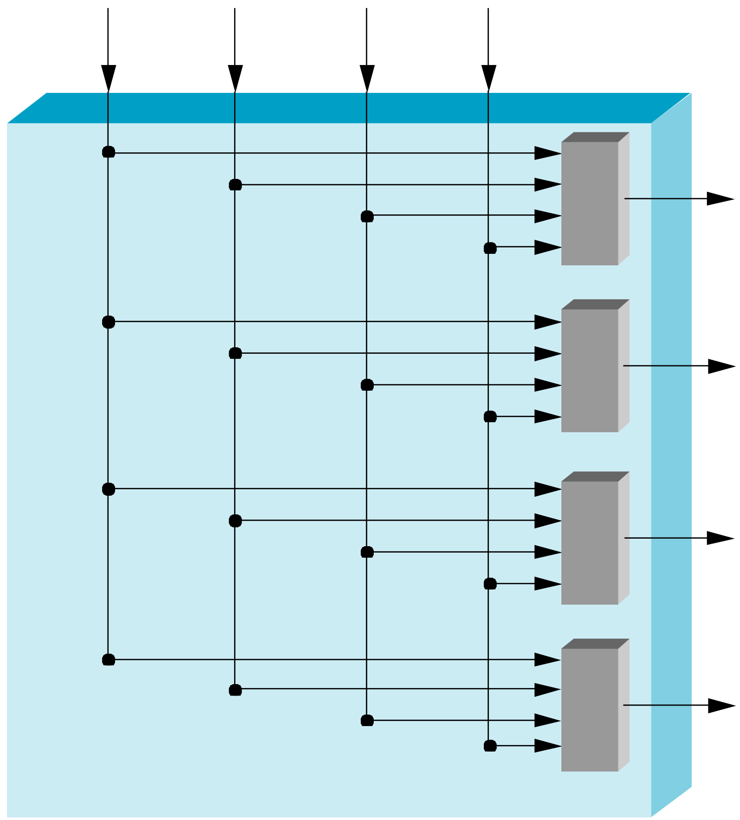
- Ports
  - circuit management (e.g., map VCIs, route datagrams)
  - buffering (input and/or output)
- Fabric
  - as simple as possible
  - sometimes do buffering (internal)

Buffering

- Wherever contention is possible
  - input port (contend for fabric)
  - internal (contend for output port)
  - output port (contend for link)
- Head-of-Line Blocking
  - input buffering

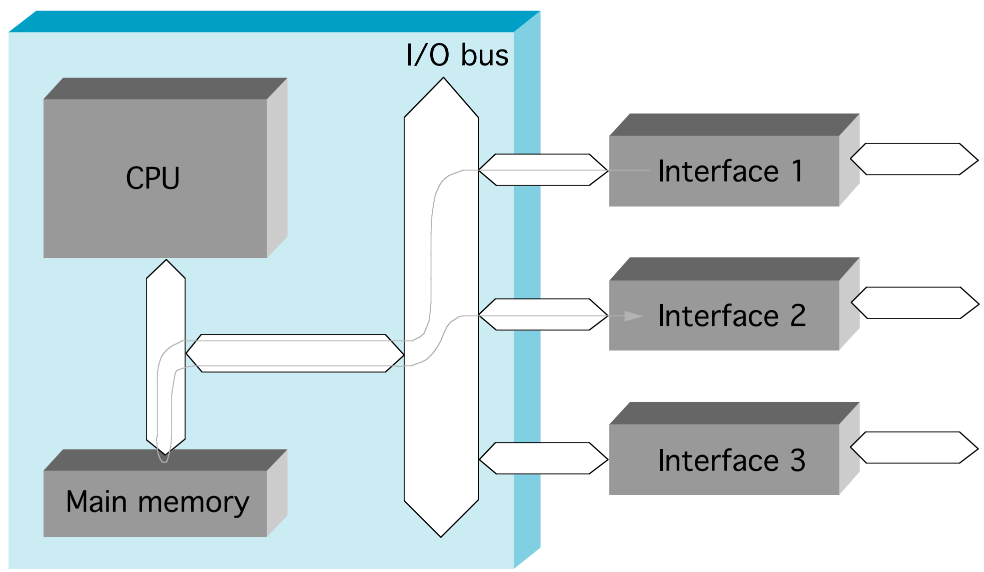


Crossbar Switches



Workstation-Based or Switch Switching

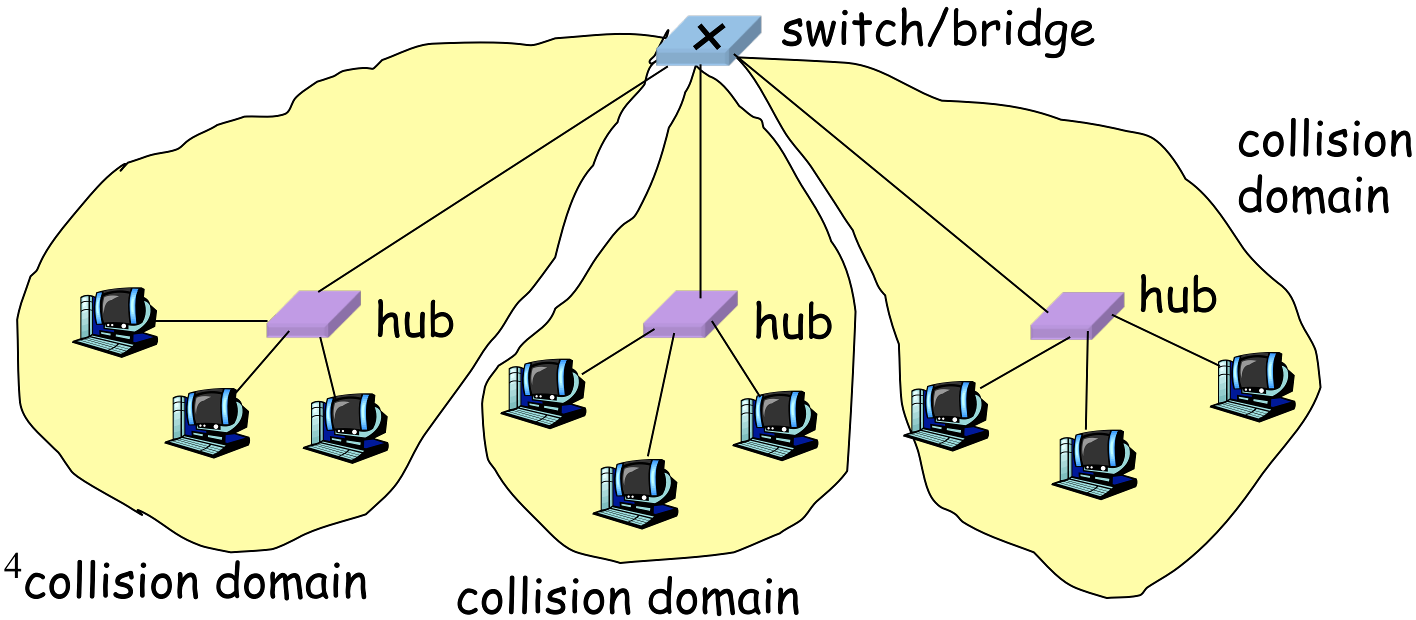
- Aggregate bandwidth
  - 1/2 of the I/O bus bandwidth
  - capacity shared among all hosts connected to switch
  - example: 1Gbps bus can support 5 x 100Mbps ports (in theory)
- Packets-per-second
  - must be able to switch small packets
  - 300,000 packets-per-second is achievable
  - e.g., 64-byte packets implies 155Mbps



Switching Fabric

Bridges/Switches: Traffic Isolation

- Bridge/Switch breaks subnet into LAN segments when multiple nodes per port
- Bridge/Switch filters frames
  - Frame only forwarded to the necessary segments
  - Segments become separate collision domains



Bridge/Switch Advantages Over Hub/Repeater

- 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, less collisions
- Improves privacy by limiting scope of frames
  - Hosts can ONLY “snoop” the traffic traversing their segment
  - … but not all the rest of the traffic
- Applies carrier sense and collision detection
  - Does not transmit when the link is busy
  - Applies exponential back-off after a collision
- Can join segments using different technologies

Bridge/Switch Advantages over Hubs/Repeater

- 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 100BaseT
- Completely avoids collisions
  - Each connection is a bidirectional point-to-point link
  - No need for carrier sense, collision detection, and so on

Bridge/Switch Disadvantages Over Hubs/Repeater

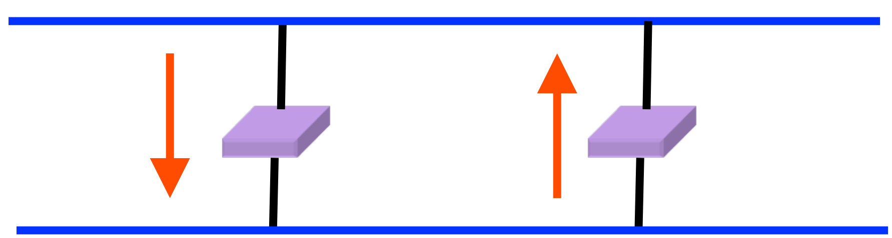
- Delay in forwarding frames
  - Bridge/switch must receive and parse the frame
  - … and perform a look-up to decide where to forward
  - Storing and forwarding the packet introduces delay
  - Solution: cut-through switching ???
- Need to learn where to forward frames
  - Bridge/switch needs to construct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

Bridge/Switch operation: Broadcast and Multicast

- Forward (flood) all broadcast/multicast frames
  - current practice
- Learn when no group members downstream
- Accomplished by having each member of group G send a frame to bridge multicast address with G in source field
- Must maintain many Multicast graphs

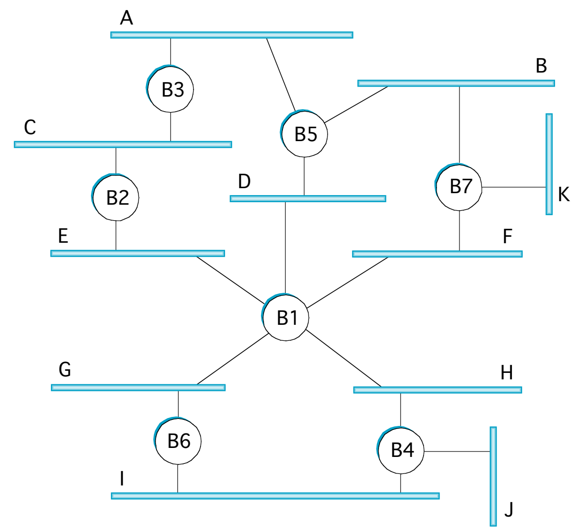
Bridge/Switch: Flooding Can Lead to Loops

- 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

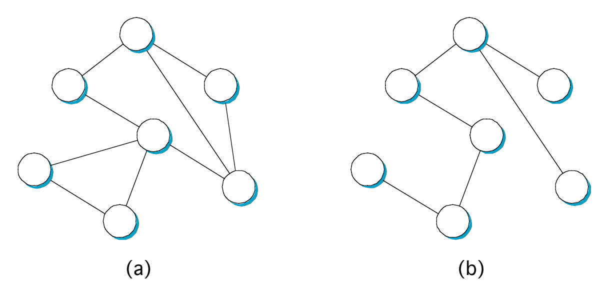


Bridge/Switch: Loop Solution Spanning Tree Algorithm

- Problem: loops



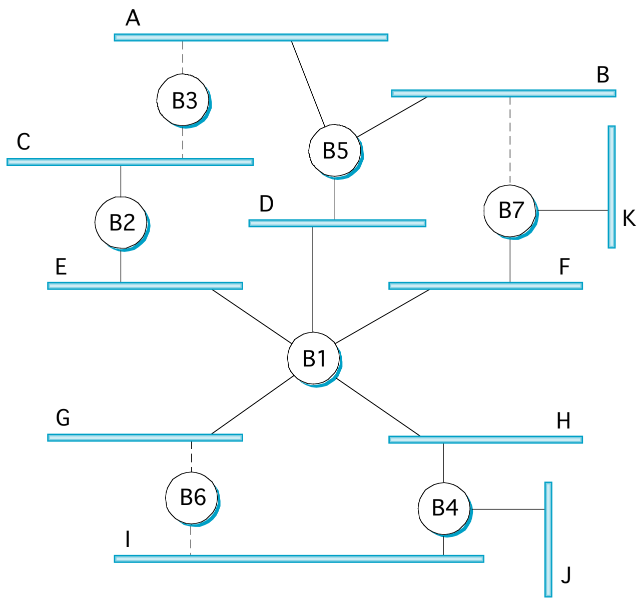
- Bridges run a distributed spanning tree algorithm
  - select which bridges actively forward
  - developed by Radia Perlman
  - now IEEE 802.1 specification
  - Subgraph covers all LANs, no loops



Spanning Tree Algorithm Overview

- Each bridge has unique id (e.g., B1, B2, B3)
- Select bridge with smallest id as root – key point
- Select bridge on each LAN closest to root as designated bridge (use id to break ties)

- Each bridge forwards frames over each LAN for which it is the designated bridge
- A: B5 over B3, hops
- B: B5 over B7, ID
- I: B4 over B6, ID



Spanning Tree Algorithm Details

- Bridges exchange configuration messages
  - id for bridge sending the message
  - id for what the sending bridge believes to be root bridge
  - distance (hops) from sending bridge to root bridge
- Each bridge records current best configuration message for each port
- Initially, each bridge believes it is the root – sends out config info

Spanning Tree Algorithm Details (cont)

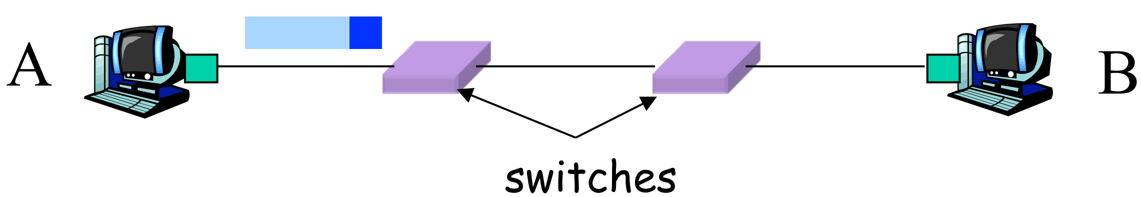
- When learn not root, stop generating config messages
  - in steady state, only root generates configuration messages
- When learn not designated bridge, stop forwarding config messages
  - in steady state, only designated bridges forward config messages
- Root continues to periodically send config messages
- If any bridge does not receive config message after a period of time, it starts generating config messages claiming to be the root

Limitations of Bridges/Switches

- Do not scale
  - spanning tree algorithm does not scale
  - broadcast does not scale
- Do not accommodate heterogeneity
- Not really directly connected:
  - Drops, reorders, no guaranteed delivery

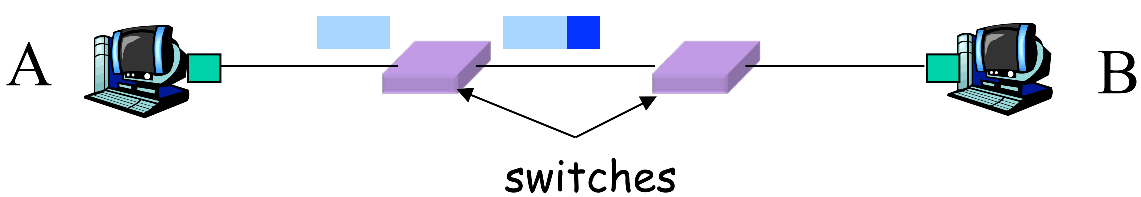
Motivation For Cut-Through Switching

- 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 (possibly) a large fraction of total time



Cut-Through Switching

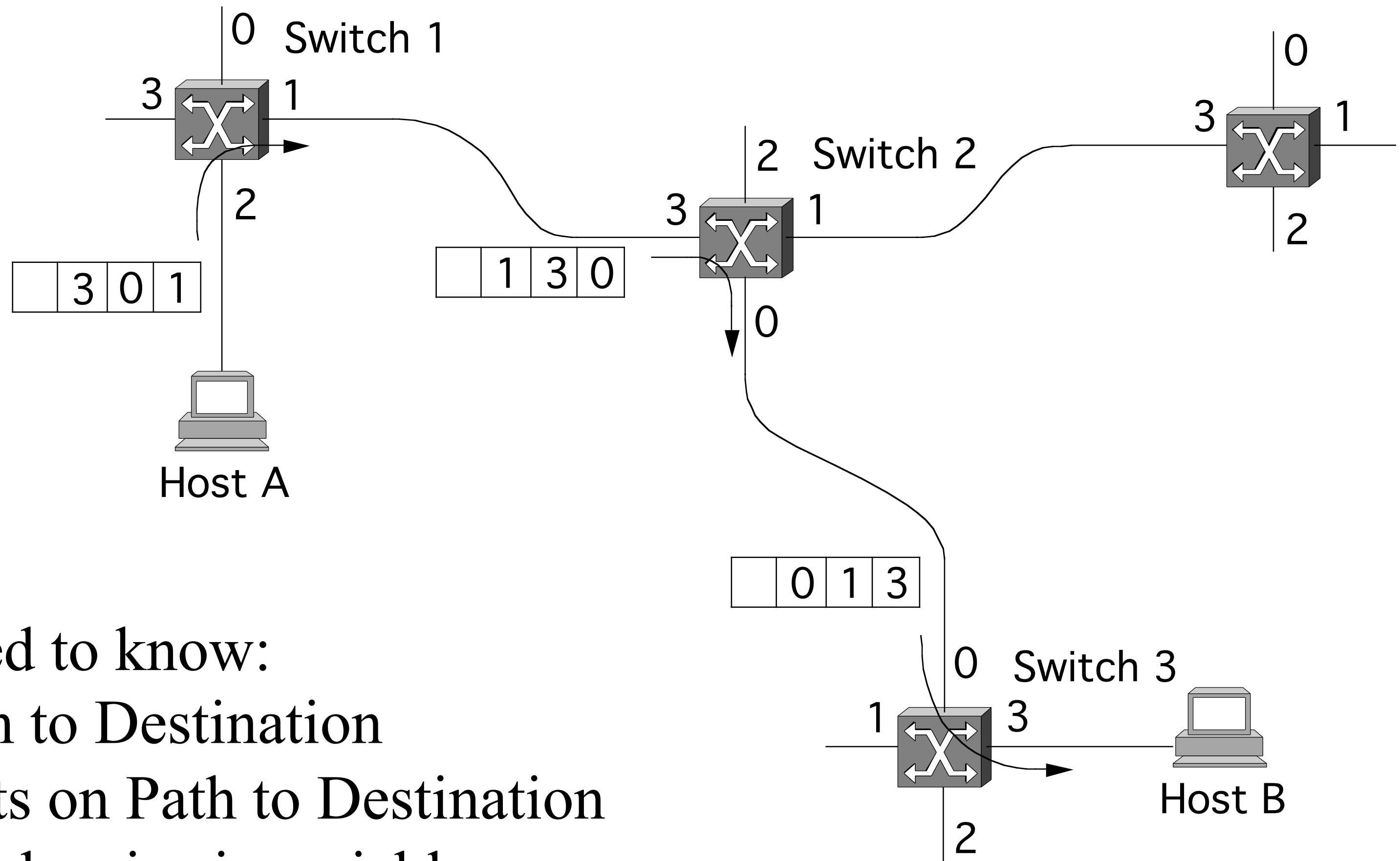
- Start transmitting as soon as possible
  - Inspect the frame header and do the look-up
  - If outgoing link is idle, start forwarding the frame
- Overlapping transmissions
  - Transmit the head of the packet via the outgoing link
  - … while still receiving the tail via the incoming link
  - Sure hope it is a good frame….



Frame Routing
Knowing and Traveling the Path

- Problem: Choose output port
  - Source Routing
  - Virtual Circuits
  - Datagrams
- Problem: Name receiving host:
  - Addresses

Approach 1: Source Routing



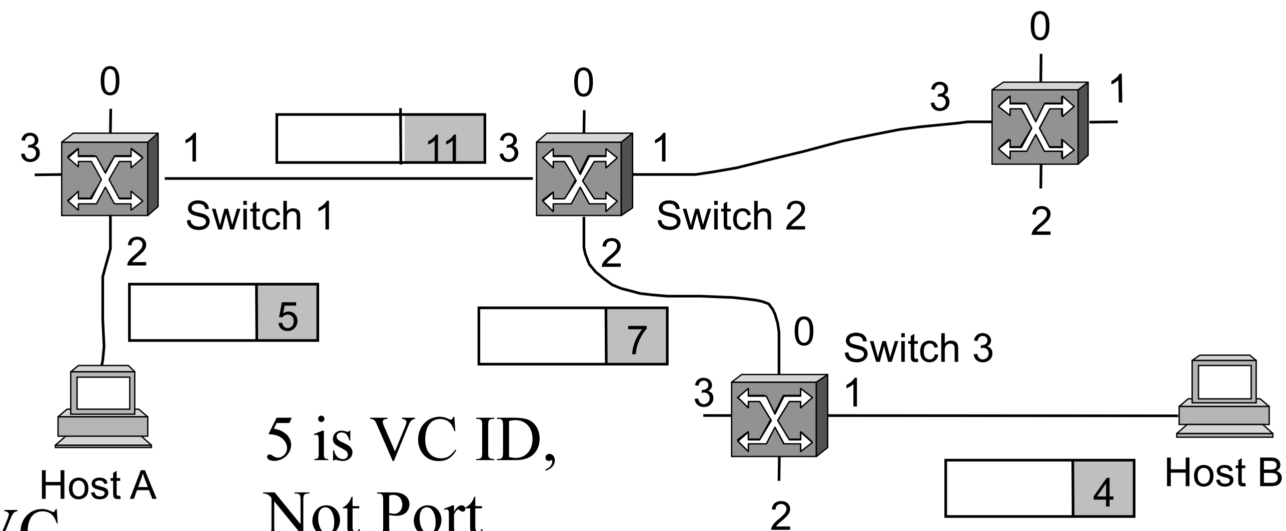
Need to know:
Path to Destination
Ports on Path to Destination
Header size is variable
Header rotation – checksum issues

Approach 2: Virtual Circuit Switching

- Explicit connection setup (and tear-down) phase
- Subsequence packets follow same circuit
- Sometimes called *connection-oriented* model

- Analogy: phone call

- Each switch maintains a VC table



5 is VC ID, Not Port

Notes: Virtual Circuit Model

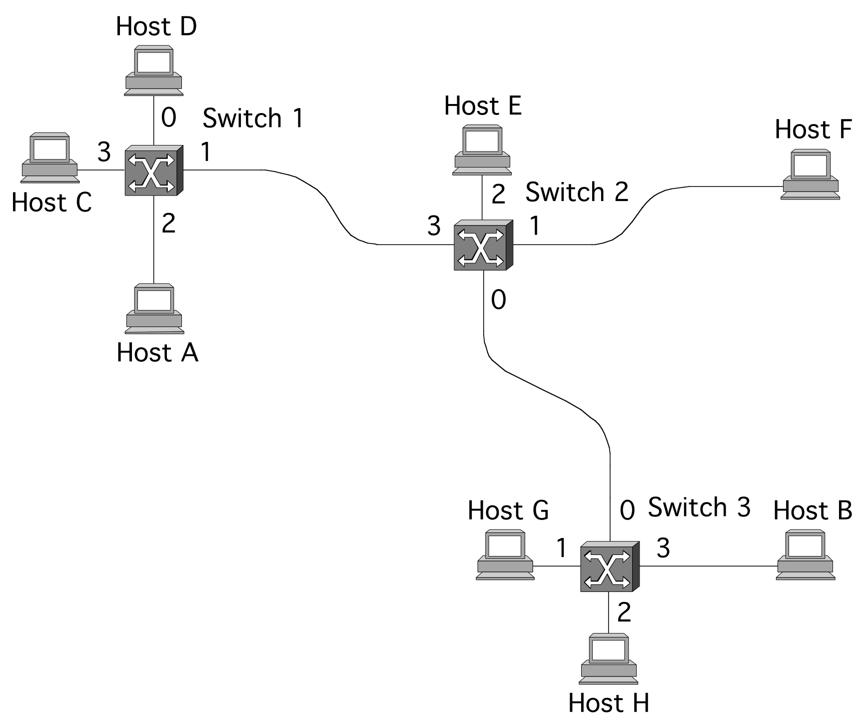
- Typically wait full RTT for connection setup before sending first data packet.
- While the connection request contains the full address for destination, each data packet contains only a small identifier, making the per-packet header overhead small.
- If a switch or a link in a connection fails, the connection is broken and a new one needs to be established.
- Connection setup provides an opportunity to reserve resources.

Approach 3: Datagram Switching

- No connection setup phase
- Each packet forwarded independently
- Sometimes called *connectionless* model

- Analogy: postal system

- Each switch maintains a forwarding (routing) table



Notes: Datagram Model

- There is no round trip delay waiting for connection setup; a host can send data as soon as it is ready.
- Source host has no way of knowing if the network is capable of delivering a packet or if the destination host is even up.
- Since packets are treated independently, it is possible to route around link and node failures.
- Since every packet must carry the full address of the destination, the overhead per packet is higher than for the connection-oriented model.
- Someone must build the tables in each switch…

Example Tables

- Circuit Table
  (switch 1, port 2)

VC In	VC Out	Port Out
5	11	1
6	8	1
…	…	…

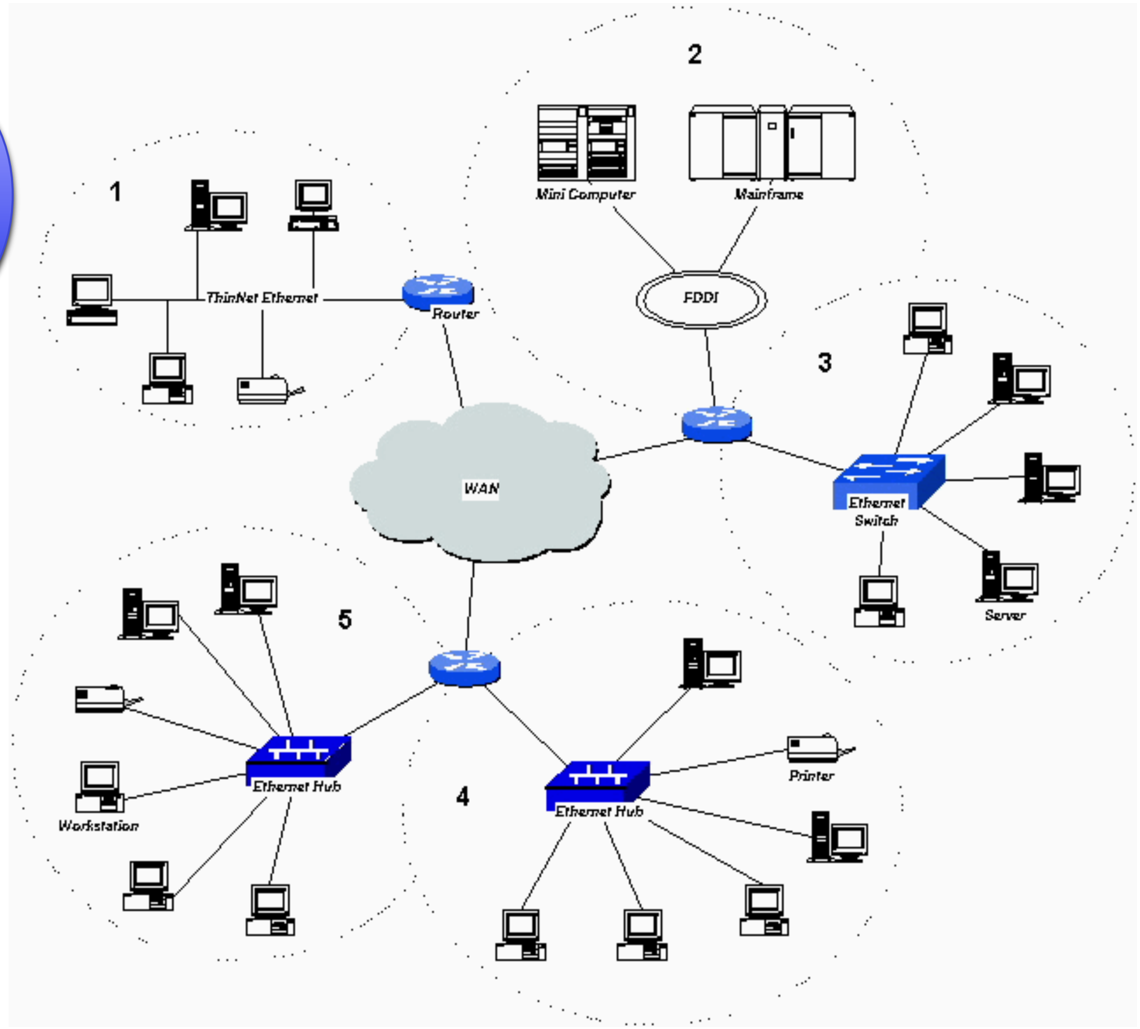
- Forwarding Table
  (switch 1)

Address	Port
A	2
C	3
F	1
G	1
…	…

Typical Network

- Individual broadcast and collision domains
- Connected by routers
- Routers add latency to packet transmission

Typical network with Switches and Routers



LAN == Collision Domain

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
  - Want flexibility in mapping offices to different LANs
  - Routers add some delay

VLAN allows Grouping users based on organizational structure, rather than the physical layout of the building.

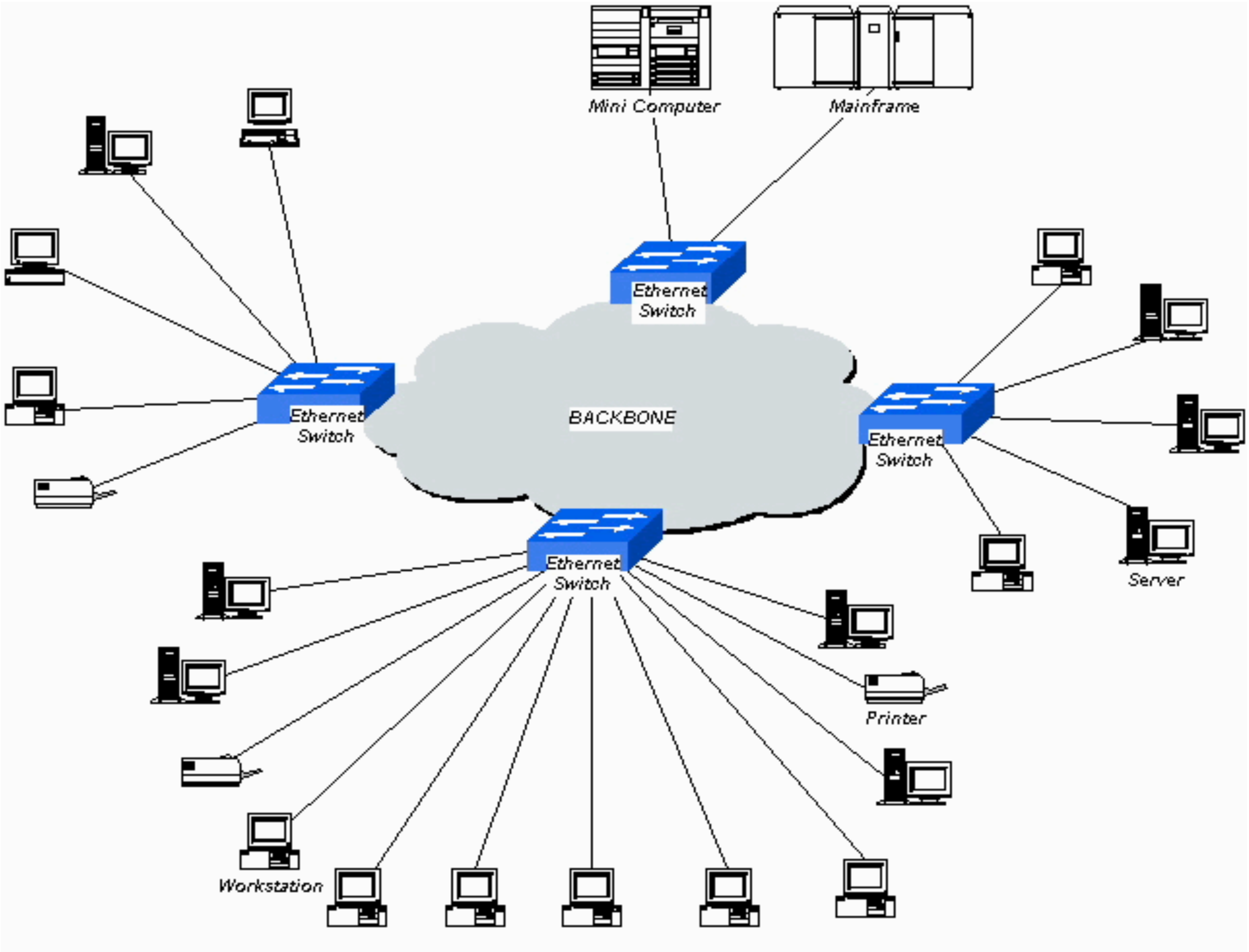
Why Organize LAN by Organizational Structure?

- 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
  - Reduce router traffic by keeping on common collision domain

LAN Reality: People Move, and Roles Change

- Organizational changes are frequent
  - E.g., faculty office becomes a grad-student office
- Physical rewiring is a major pain
  - Requires unplugging the cable from one port
  - … and plugging it into another
  - … and hoping you don't make a mistake
- Would like to "rewire" the building in software
  - The resulting concept is a Virtual LAN (VLAN)
- VLAN – Virtual LAN
  - Group devices on different physical LANs as if on same physical LAN
  - Shared Collision Domain

VLAN Grouping



Making VLANs Work

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

- Changing the Ethernet header
  – Adding a field for a VLAN tag
  – Implemented on the bridges/switches – key point
  – … but can still interoperate with old Ethernet cards
  – Devices (nodes) do not care, only switches need to understand.

VLAN Benefits

- Increased performance
  - Organized collision domains – workgroups with different private services
  - Group users into logical networks with smaller collision and broadcast domains –
  - Reduce routed traffic
- Improved manageability
  - Allow centralized configuration of devices located in diverse locations
  - Easier to add/subtract nonlocal users
  - Configure LANs without moving hosts

VLAN Benefits

- Network Tuning
  - Group users and software configurations
  - IP addresses, subnet masks, etc.
  - Bootp and DHCP easier to manage

- Increased Security
  - sensitive material
  - isolate testing

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

Comparing Hubs, Switches, & Routers

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

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)