Data link layer

Goals:

- Principles behind data link layer services
  - Error detection, correction
  - Sharing a broadcast channel: Multiple access
  - Link layer addressing
  - Reliable data transfer, flow control: optional
- Example link layer technology: Ethernet

Link layer services

Framing and link access

- Encapsulate datagram: Frame adds header, trailer
- Channel access – if shared medium
- Frame headers use 'physical addresses' = "MAC" to identify source and destination
  - Different from IP address!

Reliable delivery (between adjacent nodes)

- Seldom used on low bit error links (fiber optic, co-axial cable and some twisted pairs)
- Sometimes used on high error rate links (e.g., wireless links)

Link layer services (2.)

Flow Control

- Pacing between sending and receiving nodes

Error Detection

- Errors are caused by signal attenuation and noise.
- Receiver detects presence of errors
  signals sender for retrans. or drops frame

Error Correction

- Receiver identifies and corrects bit error(s) without resorting to retransmission

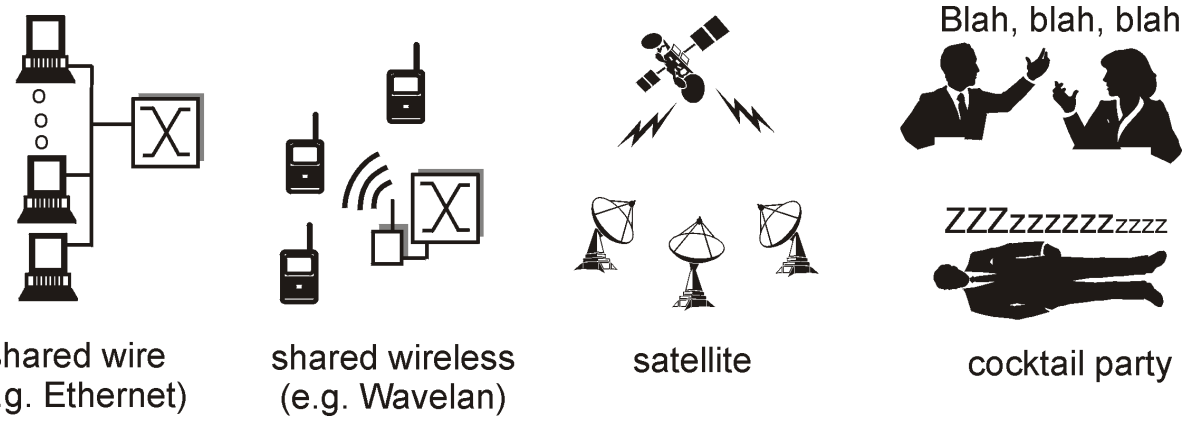
Half-duplex and full-duplex

- With half duplex, nodes at both ends of link can transmit, but not at same time

Multiple access links / protocols

Two types of “links”:

- Point-to-point
  - PPP for dial-up access
  - Point-to-point link between Ethernet switch and host
- Broadcast (shared wire or medium)
  - Traditional Ethernet
  - Upstream HFC
  - 802.11 wireless LAN



MAC protocols: Three broad classes

- Channel Partitioning
  - Divide channel into smaller “pieces” (time slots, frequency)
  - Allocate piece to node for exclusive use
- Random Access
  - Allow collisions
  - “Recover” from collisions
- “Taking turns”
  - Tightly coordinate shared access to avoid collisions

Goal: Efficient, fair, simple, decentralized

Addresses

IP address:

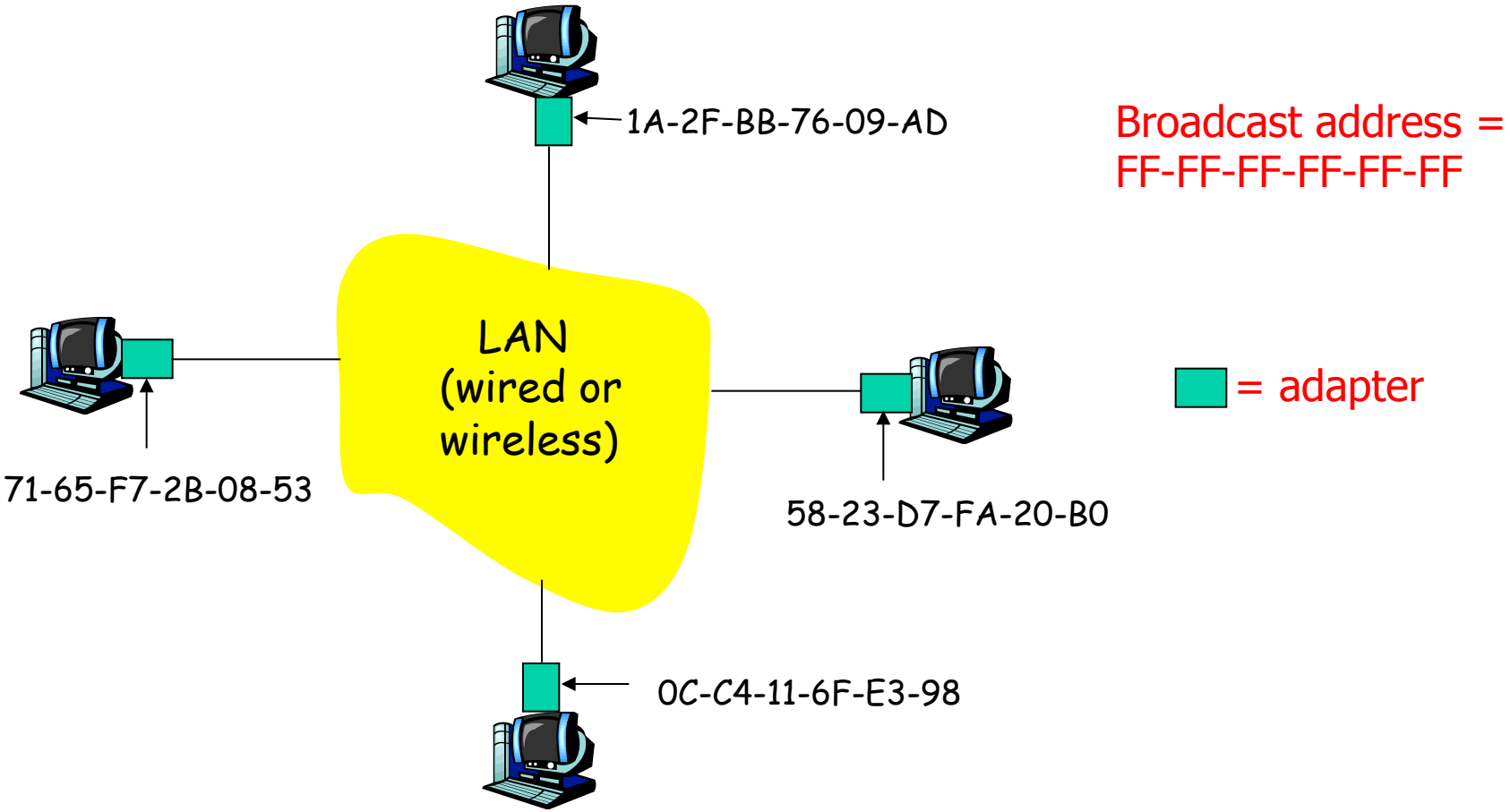
- Network-layer address
- Used to get datagram to destination network (recall IP network definition)

MAC (or LAN or physical or Ethernet) address:

- Data link-layer address
- Used to get datagram from one interface to another physically-connected interface (same network)
- 48 bit MAC address (for most LANs) burned in the adapter ROM

Addresses (2.)

Each adapter on LAN has unique LAN address



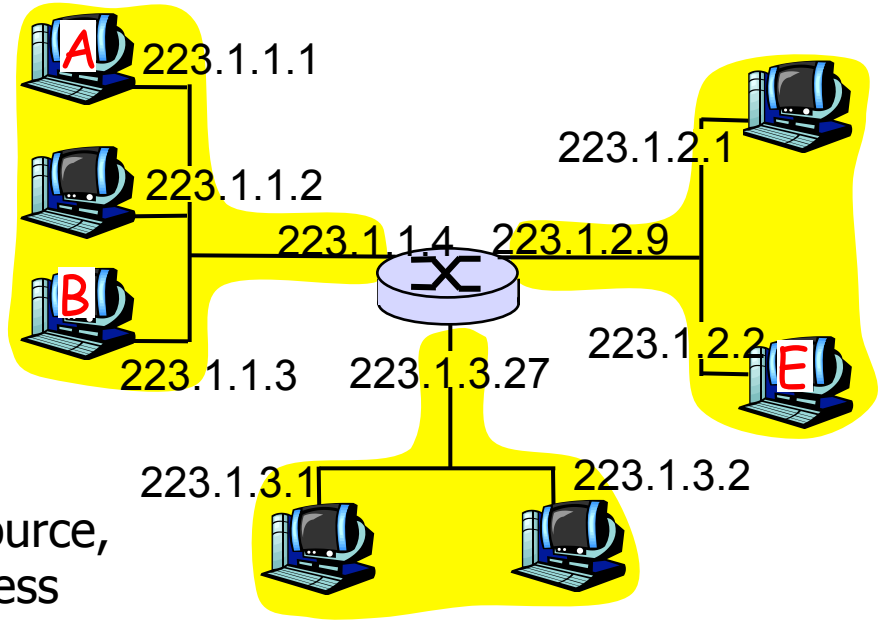
Addresses (3.)

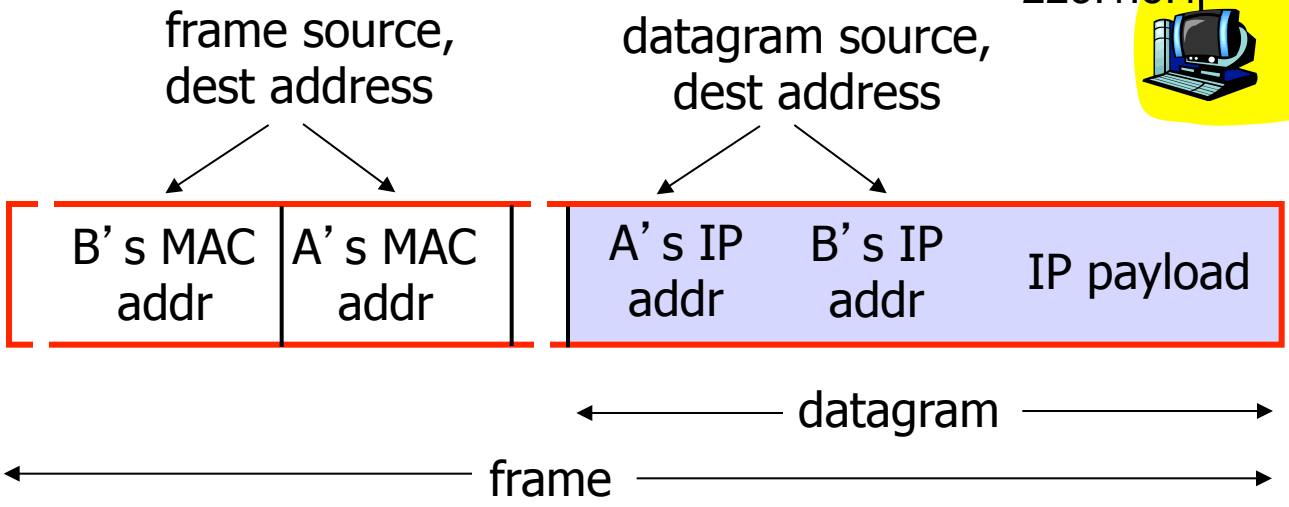
- MAC address allocation administered by IEEE
- Manufacturer buys portion of MAC address space (to assure uniqueness)
- Analogy:
  - MAC address: Like Social Security Number
  - IP address: Like postal address
- MAC flat address ⇨ portability
  - Can move LAN card from one LAN to another
- IP hierarchical address NOT portable
  - Depends on network to which one attaches

Example

Starting at A, given IPv4 datagram addressed to B:

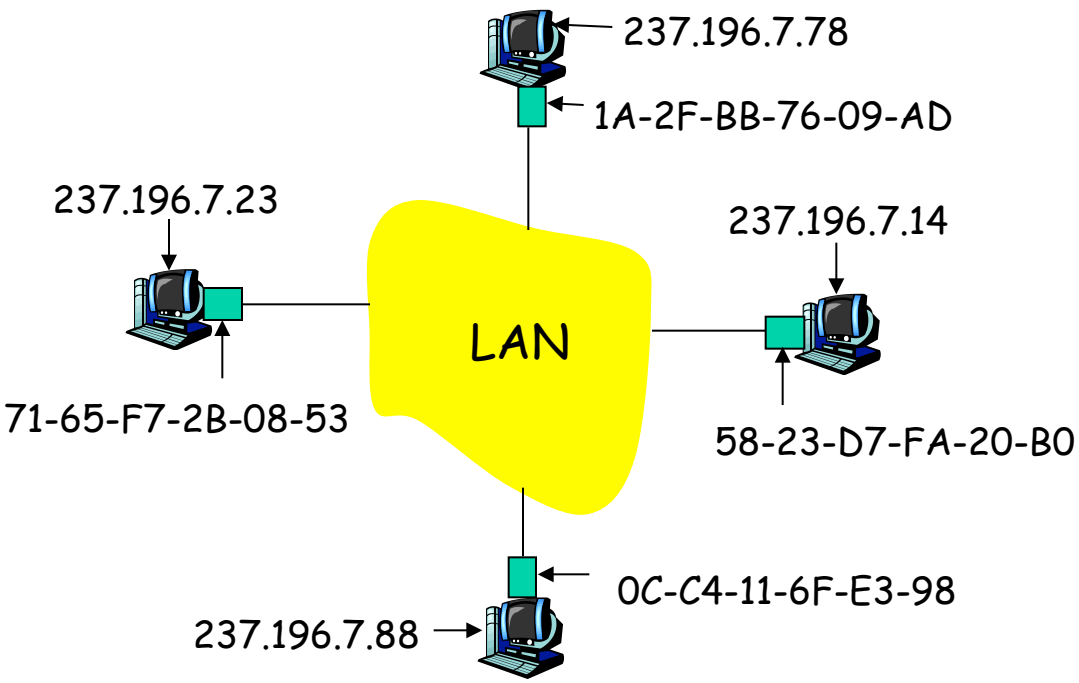
- Look up net. address of B, find B on same net. as A
- Link layer send datagram to B inside link-layer frame





ARP: Address Resolution Protocol

Question: how to determine the MAC address of B knowing B's IP address?



- Each IPv4 node on LAN has an ARP table containing the mapping IP to MAC address for some LAN nodes

  < IP address; MAC address; TTL>

  - TTL (Time To Live): time after which address mapping will be forgotten (typically 20 min)

ARP Protocol: Same LAN (Network)

Question: How is the ARP Table populated?

① A wants to send datagram to B, and B's MAC address not in A's ARP table.

② A broadcasts ARP query packet, containing B's IP address
- Dest MAC address = FF-FF-FF-FF-FF-FF
- All machines on LAN (incl. B) receive ARP query

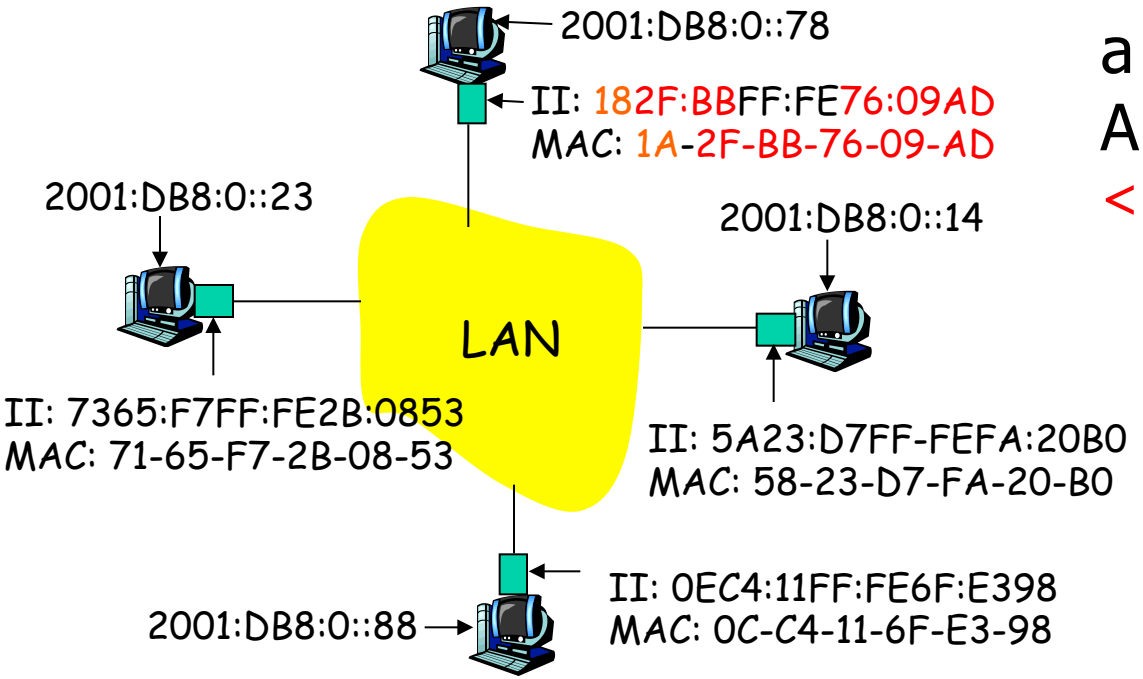
③ B replies to A with its (B's) MAC address
- Frame sent to A's MAC address (unicast)

④ A caches (saves) IP-to-MAC address pair in its ARP table until information becomes old (times out)
  ① Soft state: information that times out (goes away) unless refreshed

- ARP uses its own Ethernet protocol
- Nodes create their ARP tables without intervention from net administrator

IPv6 Neighbor Discovery

Question: How to determine MAC address of B knowing B's IPv6 address?



- Each IP node on a LAN has a Neighbor Table a IPv6 equivalent of the ARP Table:
  < IPv6 address; Interface Identifyer; TTL>
- The Interface Identifier is a generalization of the MAC address to support other link protocols

IPv6 Neighbor Discovery (2)

Question: How is the Neighbor Table populated?

① A wants to send datagram to B, and B's II is not in A's Neighbor table.

② A sends a ICMP neighbor solicitation
Source: A's link-local IPv6 address
Dest: solicited node multicast address
ff02::1:ff +[last 24 bits of B's IPv6 address]

③ Only machines on LAN that share last 24 bits of the IPv6 address receive the message (incl. B)

④ B replies to A neighbor advertisement with its (B's) II using A's link local address

④ A caches (saves) IPv6-to-II address pair in its neighbor table until information becomes old (times out)

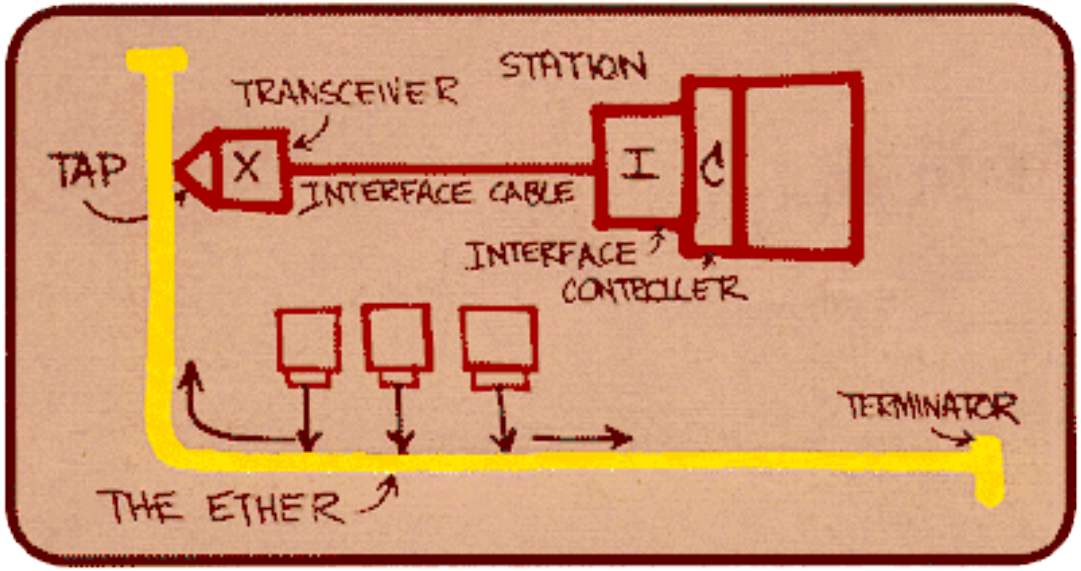
- Soft state: information that times out (goes away) unless refreshed

- Neighbor discovery is based on ICMP
- Nodes create their neighbor tables without intervention from net administrator

Ethernet

"Dominant" LAN technology:

- Cheap $20 for 100Mbs!
- First widely used LAN technology
- Simpler, cheaper than token LANs and ATM
- Kept up with speed race: 10 Mbps – 10 Gbps
- Shared medium



Metcalfe's Etheret sketch

Unreliable, connectionless service

- Connectionless:
  No handshaking between sending and receiving adapter.
- Unreliable:
  Receiving adapter does not send ACKs or NACKs to sending adapter
  - Stream of datagrams passed to network layer can have gaps
  - Gaps will be filled if app is using TCP
  - Otherwise, app will see the gaps

Ethernet uses CSMA/CD

- No slots
- Adapter does not transmit if it senses that some other adapter is transmitting, that is: carrier sense
- Transmitting adapter aborts when it senses that another adapter is transmitting, that is: collision detection
- Before attempting a retransmission, adapter waits a random time, that is: random access

Ethernet CSMA/CD algorithm

1. Adaptor receives datagram from net layer & creates frame
2. If adapter senses channel idle, it starts to transmit frame. If it senses channel busy, waits until channel idle and then transmits
3. If adapter transmits entire frame without detecting another transmission, the adapter is done with frame!
4. If adapter detects another transmission while transmitting, aborts and sends jam signal
5. After aborting, adapter enters **exponential backoff**: After the *m*-th collision, adapter chooses *a* *K* at random from $\{0,1,2,\ldots,2^{m}-1\}$. Adapter waits $K \cdot 512$ bit times and returns to Step 2

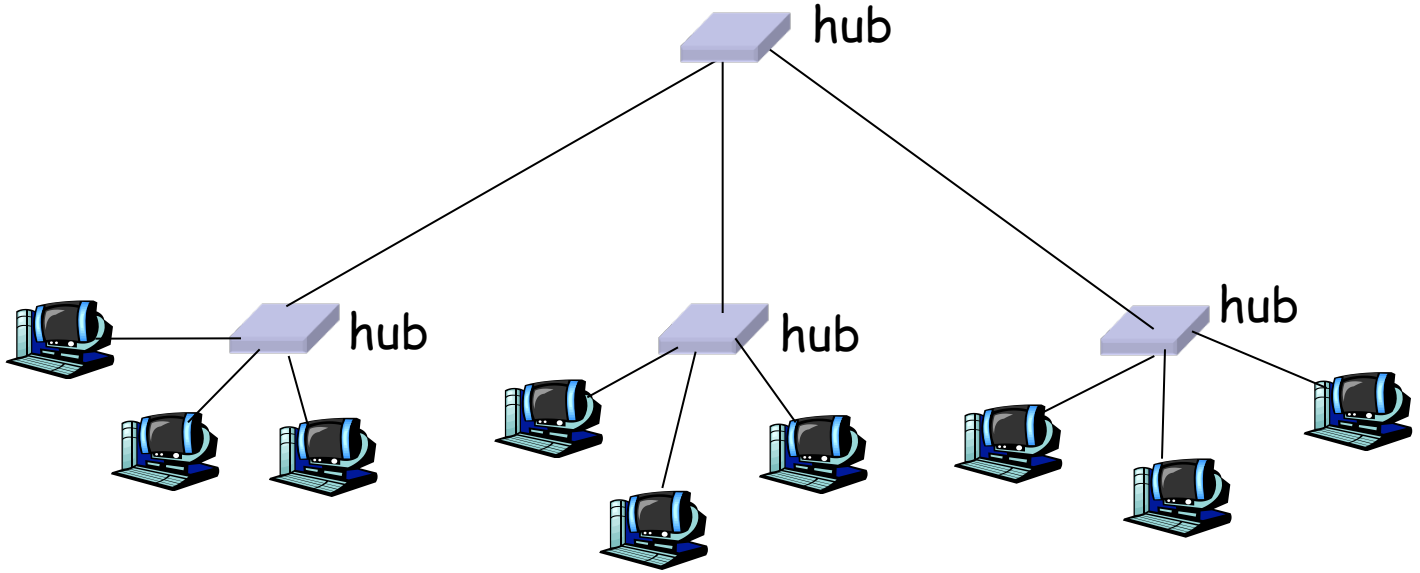
Interconnecting LANs

Q: Why not just one big LAN?

- All stations must share bandwidth
- Limited cable length
- Large “collision domain” (can collide with many stations)
- Limited number of stations

Interconnecting with hubs

- Physical Layer devices:
  Essentially repeaters operating at bit levels:
  Repeat received bits on one interface to all other interfaces
- Hubs can be arranged in a hierarchy (or multi-tier design), with backbone hub at its top



Hubs (2.)

- Each connected LAN referred to as LAN segment
- Hubs do not isolate collision domains: Node may collide with any node residing at any segment in LAN
- Hub Advantages
  - Simple, inexpensive device
  - Multi-tier provides graceful degradation: portions of the LAN continue to operate if one hub malfunctions
  - Extends maximum distance between node pairs (100m per Hub)

Bridges (switches)

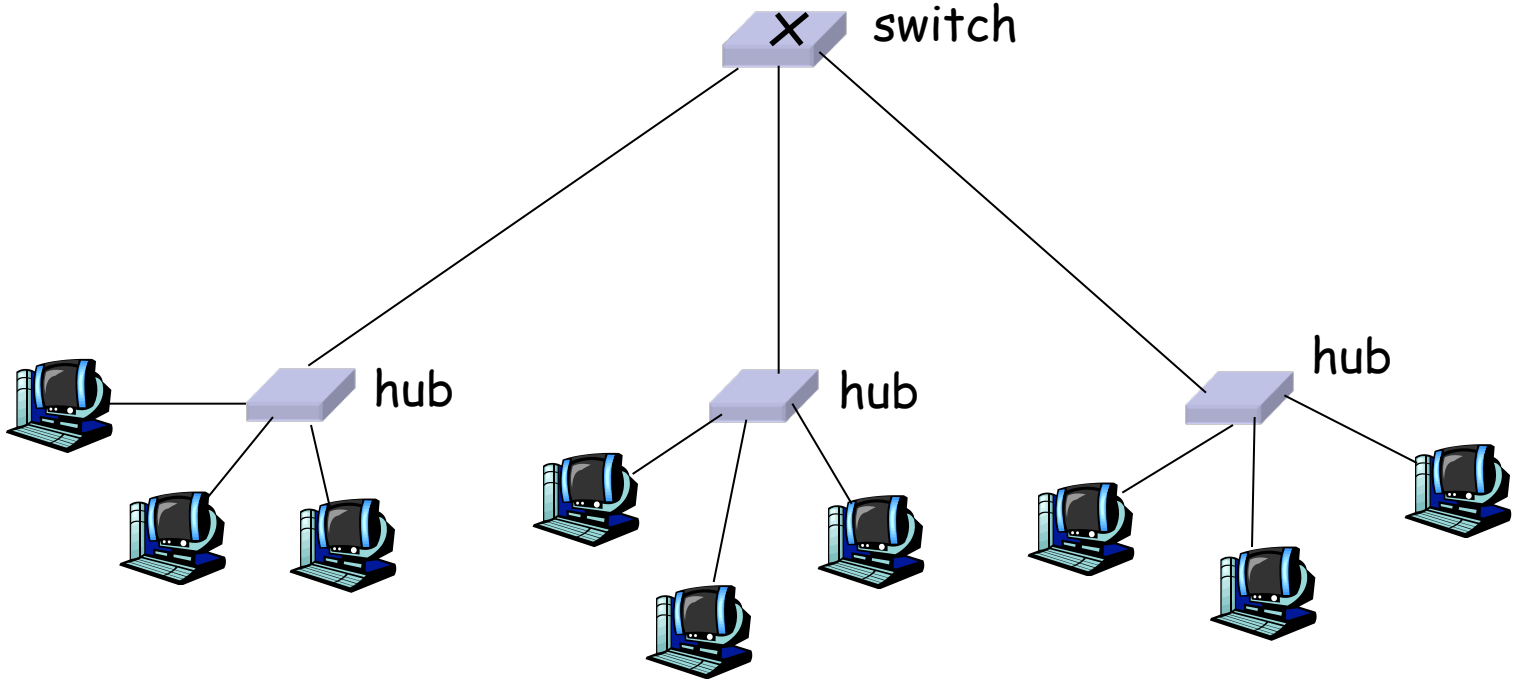
- Link Layer devices
  - Stores and forwards Ethernet frames
  - Examines frame header and selectively forwards frame based on MAC dst address
  - When frame is to be forwarded on segment, uses CSMA/CD to access segment
  - ⇨ Bridge isolates collision domains: It buffers frames

Bridges/switch: Advantages

- Higher total max throughput
- No limit on number of nodes
- No limit on geographical coverage
- Can connect different Ethernet types (store and forward)
- Transparent: Hosts do not need to change LAN adapters
- Plug-and-play, self-learning
  - Switches do not need to be configured

Bridges/switch: Forwarding

- Forwarding:
  - To which LAN segment should a frame be forwarded?
  - Looks like a routing problem



Bridges/switch: Self learning

- A bridge/switch has a bridge/switch table
- Entry in table
  - (MAC Address, Interface, Time Stamp)
  - Stale entries in table dropped (TTL can be 60 min)
- Bridge *learns* which hosts can be reached through which interfaces
  - When frame received, switch "learns" location of sender: Incoming LAN segment
  - Records sender/location pair in bridge table

Bridges/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

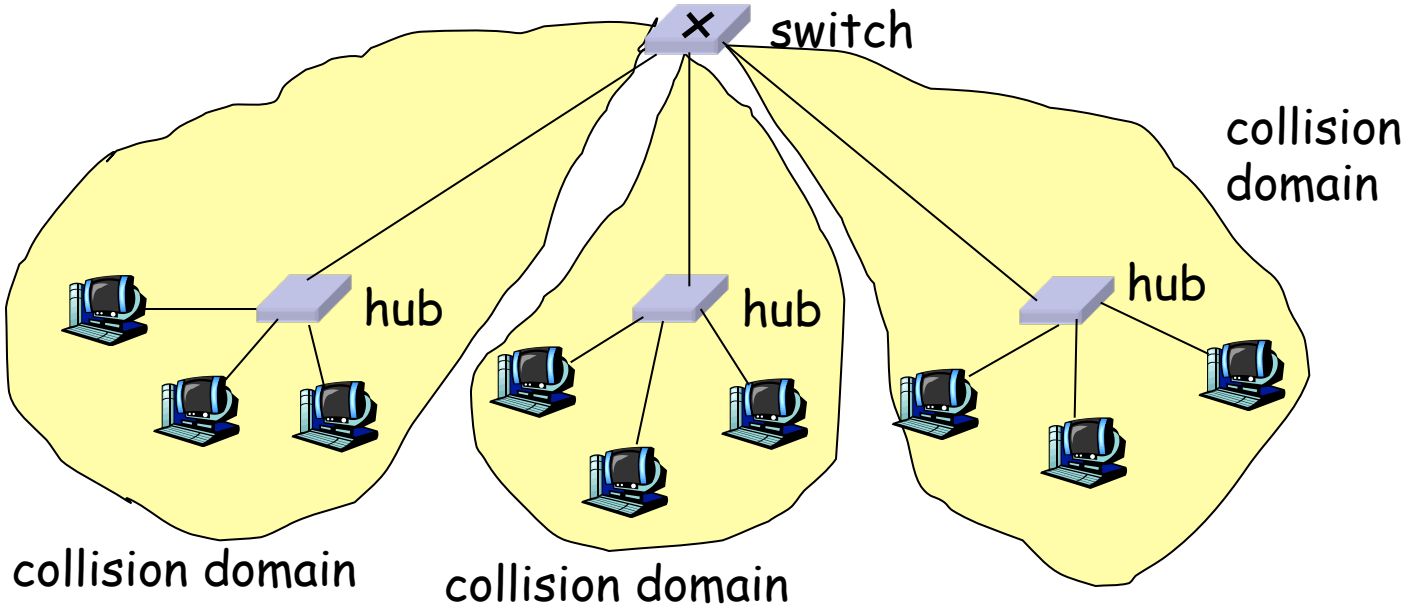
}

else flood

forward on all but the interface on which the frame arrived

Switch: Traffic isolation

- Switch installation breaks subnet into LAN segments
- Switch filters packets:
  - Same-LAN-segment frames not usually forwarded onto other LAN segments
  - Segments become separate collision domains

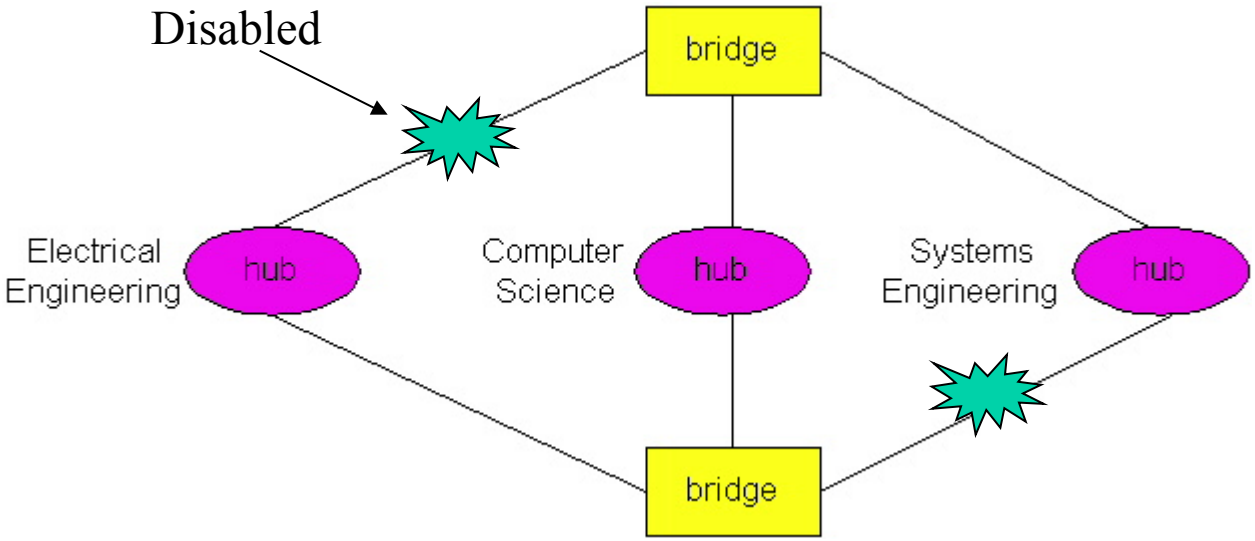


Redundant networks

- Network with multiple paths
  - Alternate path for each source, destination pair
- Advantage
  - Increased reliability
  - Single network failure OK
  - More opportunities for load distribution
- Disadvantage
  - Added complexity

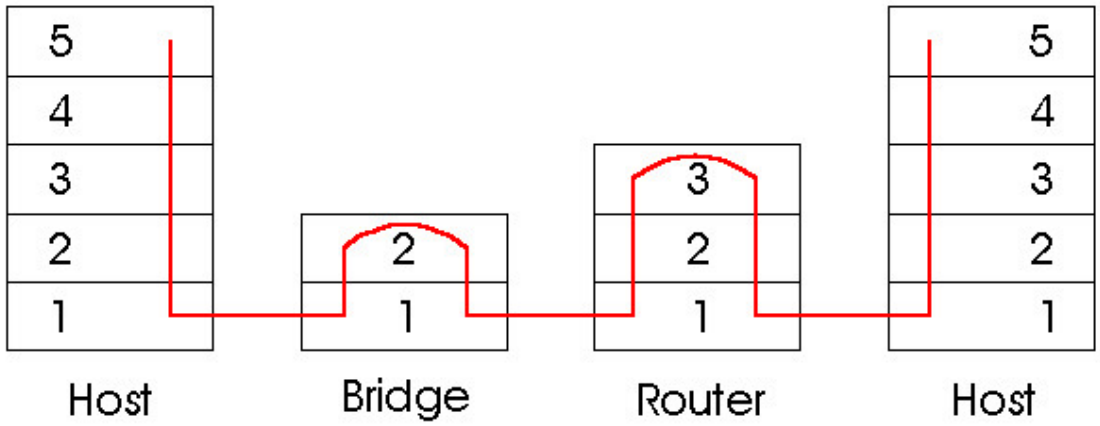
Bridges spanning tree

- Avoid cycles
  - Frames may multiply and forwarded forever
- Organize bridges into spanning tree
  - Disable a subset of interfaces



Bridges vs. Routers

- Both store-and-forward devices
  - Routers: Network layer devices (examine network layer headers)
  - Bridges/switches: Link layer devices
- Use tables
  - Routers: Routing tables via routing algorithms
  - Bridges: Filtering tables via filtering, learning, spanning tree algorithm



Bridges + and -

+ Simple operation
  - Low processing bandwidth
- Restricted topologies:
  - Spanning tree to avoid cycles
- Single broadcast domain
  - No protection from broadcast storms (broadcasts will be forwarded by bridge)

Routers + and -

+ Arbitrary topologies
  - Limited cycling (TTL and good routing protocols)
+ Firewalls protection
  - Against broadcast storms
- Complex operation
  - Require IP address configuration (not plug and play)
  - Require higher processing bandwidth

Routers vs. Bridges

- Bridges
  - Good in small networks (few hundred hosts)
- Routers
  - Good in large networks (thousands of hosts)

- Layer 3 switch
  - Bridge + router (but usually limited routing table!)

Summary/comparison

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