# 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
- **Example link layer technology**
  - Ethernet
- **Bridges vs. routers**

# 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!

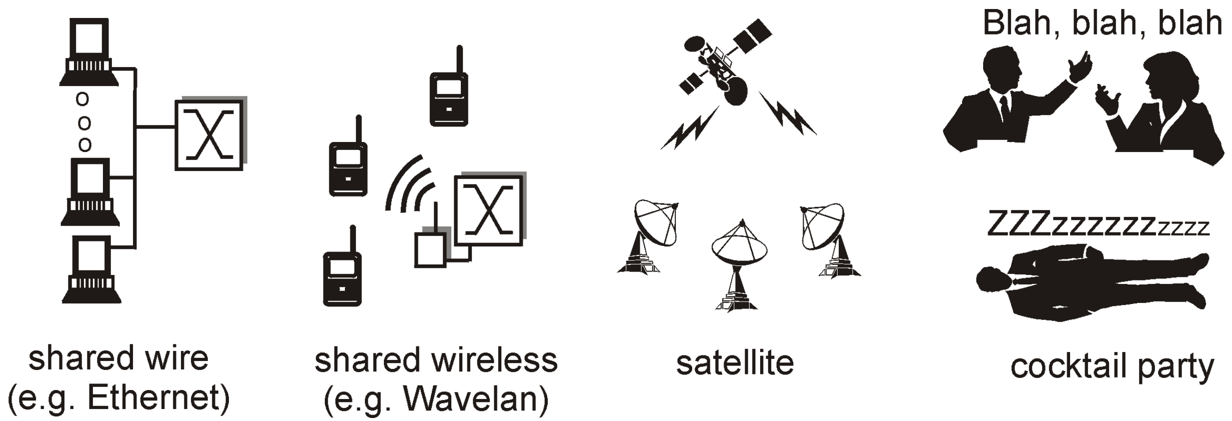
**Reliable delivery (between adjacent nodes)**

- 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)

# Multiple access links

**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 categories

- **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 (32-bit IPv4 / 128-bit IPv6)*:**

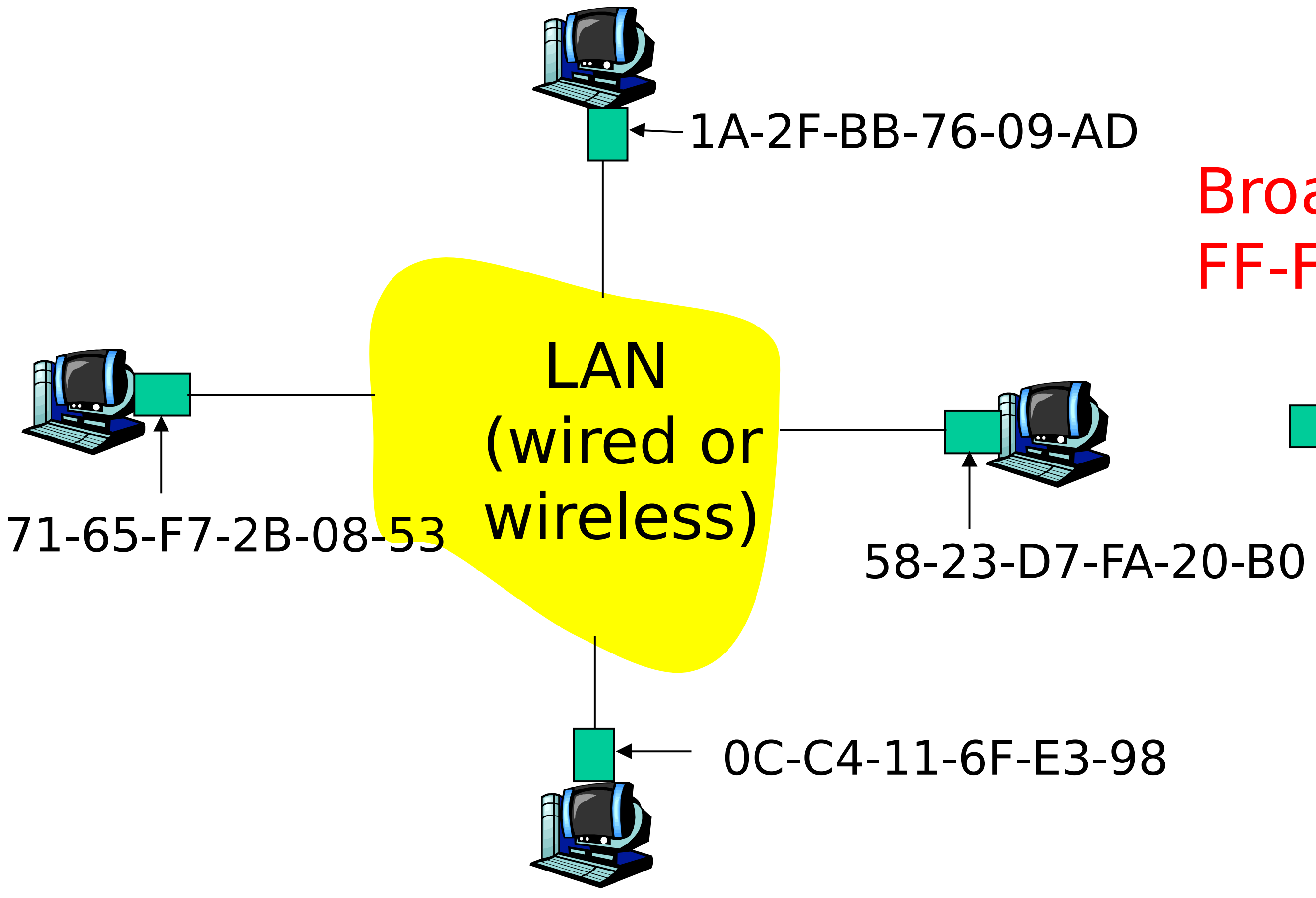
- **Network-layer address**
- **Used to get datagram to destination network (recall IP network definition)**

**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




Broadcast address =
FF-FF-FF-FF-FF-FF

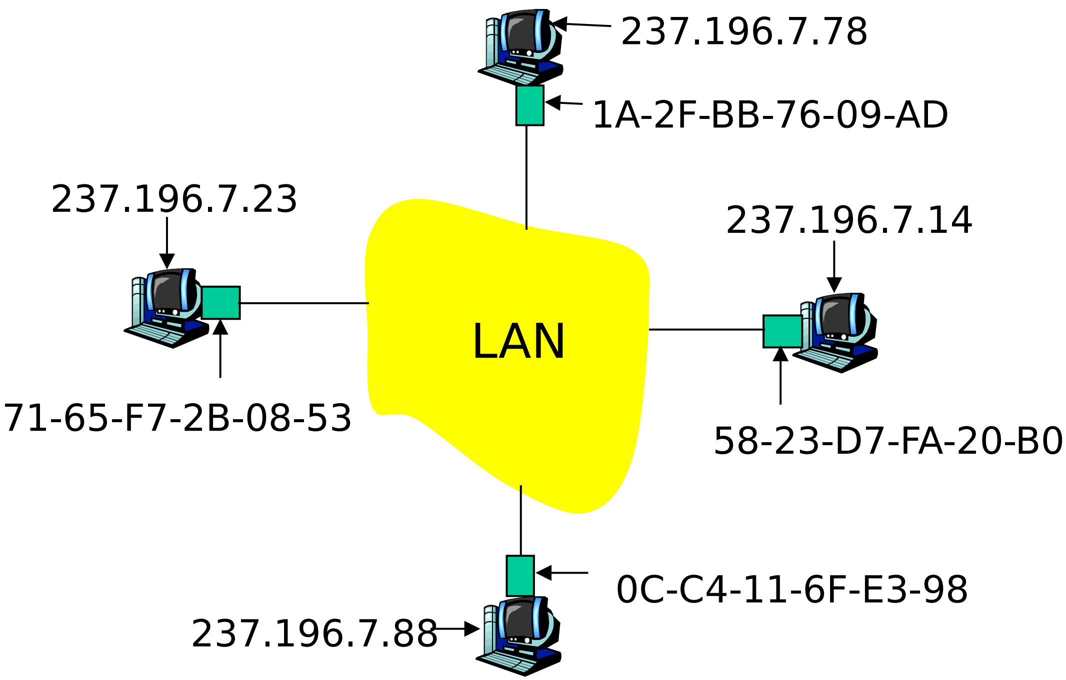
= adapter

# 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

# ARP: Address Resolution Protocol

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




- **Each IP node (Host, Router) on LAN has ARP table**
- **ARP Table: IP/MAC address mappings for some LAN nodes**

  **< IP address; MAC address; TTL>**

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

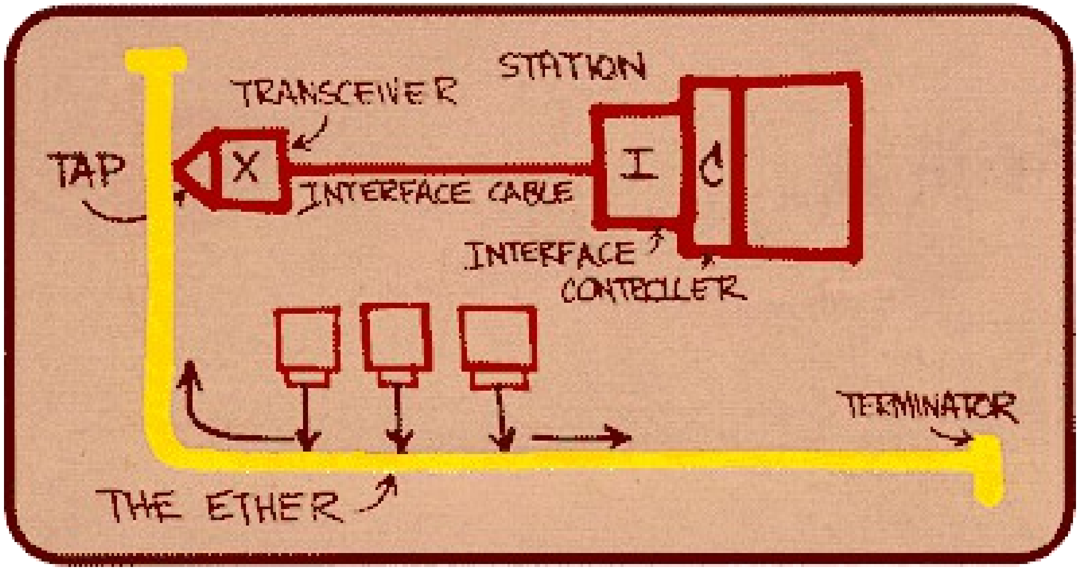
# ARP protocol: Same LAN (Network)

- **A wants to send datagram to B, and B’s MAC address not in A’s ARP table.**
- **A broadcasts ARP query packet, containing B's IP address**
  - Dest MAC address = FF-FF-FF-FF-FF-FF
  - All machines on LAN receive ARP query
- **B receives ARP packet, replies to A with its (B's) MAC address**
  - Frame sent to A’s MAC address (unicast)
- **A caches (saves) IP-to-MAC address pair in its ARP table until information becomes old (times out)**
  - Soft state: information that times out (goes away) unless refreshed
- **ARP is “plug-and-play”:**
  - Nodes create their ARP tables without intervention from net administrator

# Ethernet

**"Dominant" LAN technology:**

- **Cheap!**
- **First widely used LAN technology**
- **Simpler, cheaper than token LANs and ATM**
- **Kept up with speed race: 10 Mbps – 10 Gbps**
- **Full duplex via switches**




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**

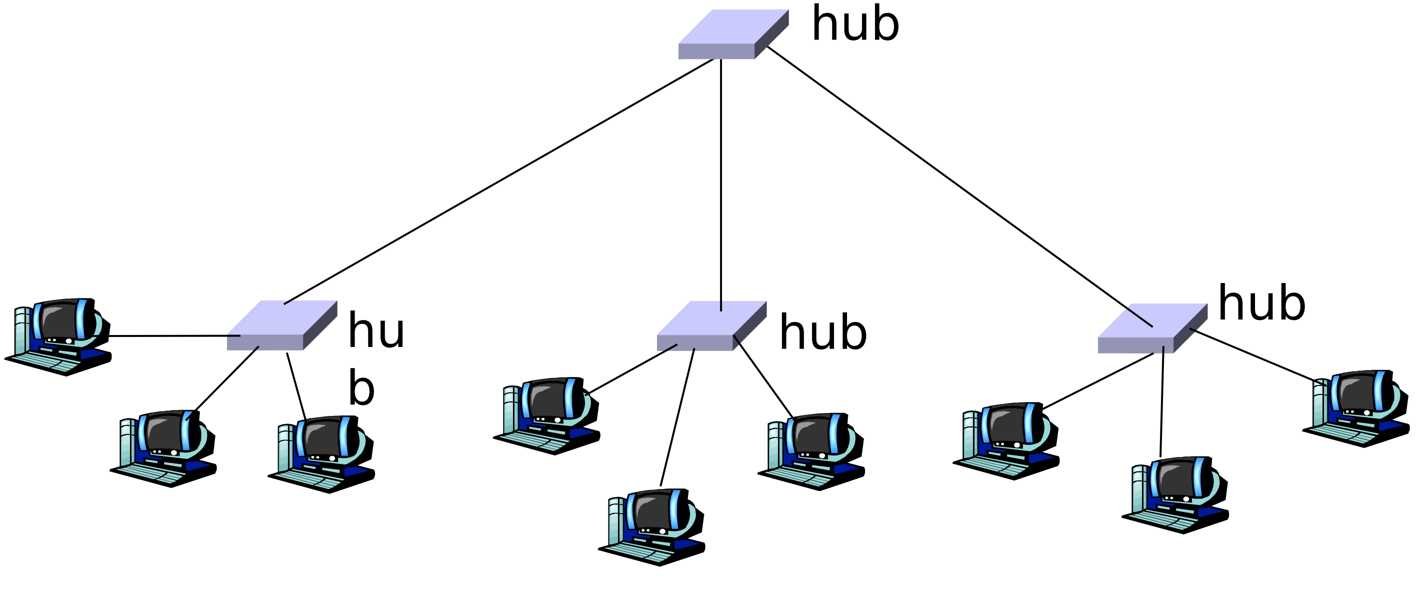
# Interconnecting LANs

**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 (more)

- **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)

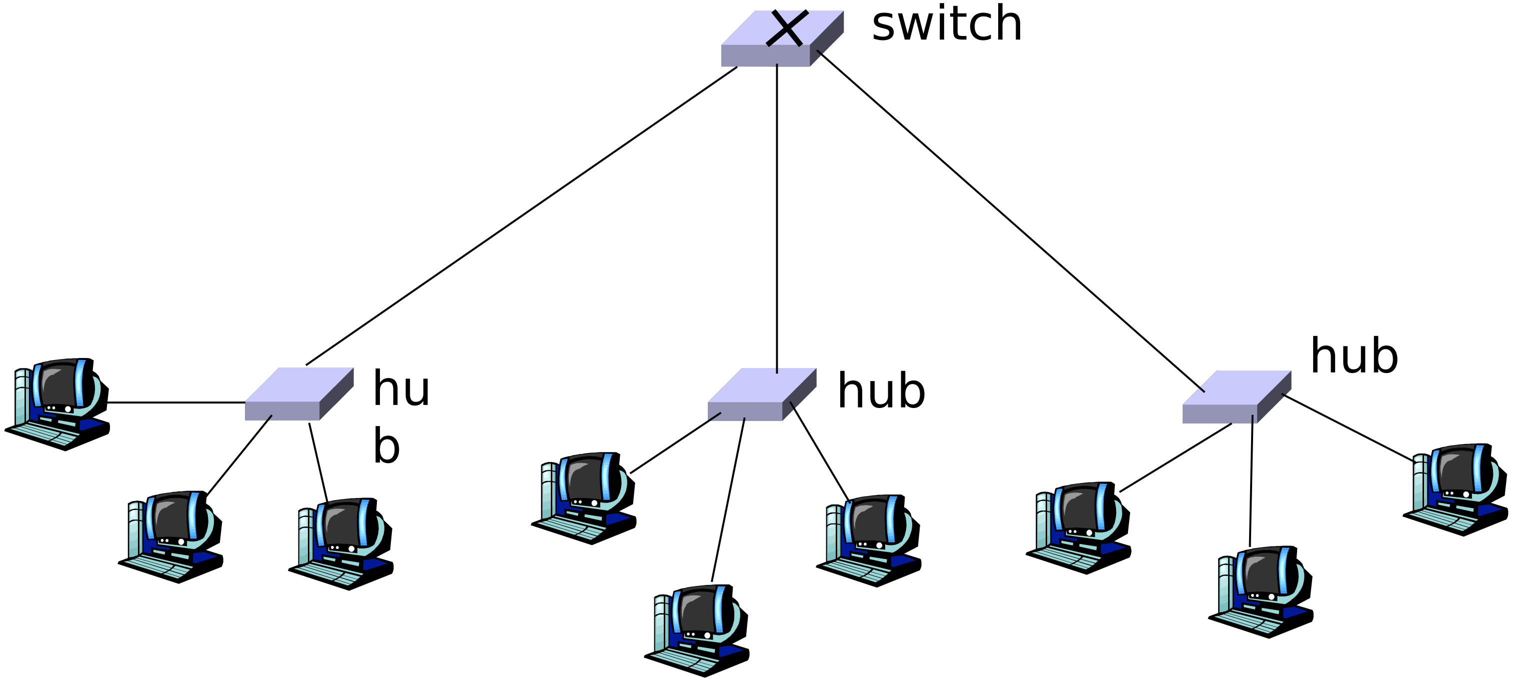
- **Link layer devices:**
  - Stores and forwards Ethernet frames
  - Examines frame header and selectively forwards  frame based on MAC dst address
  - When frame is to be forwarded on segment, uses CSMA/CD to access segment
  - ⇨ Bridge isolates collision domains: it buffers frames

# 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**

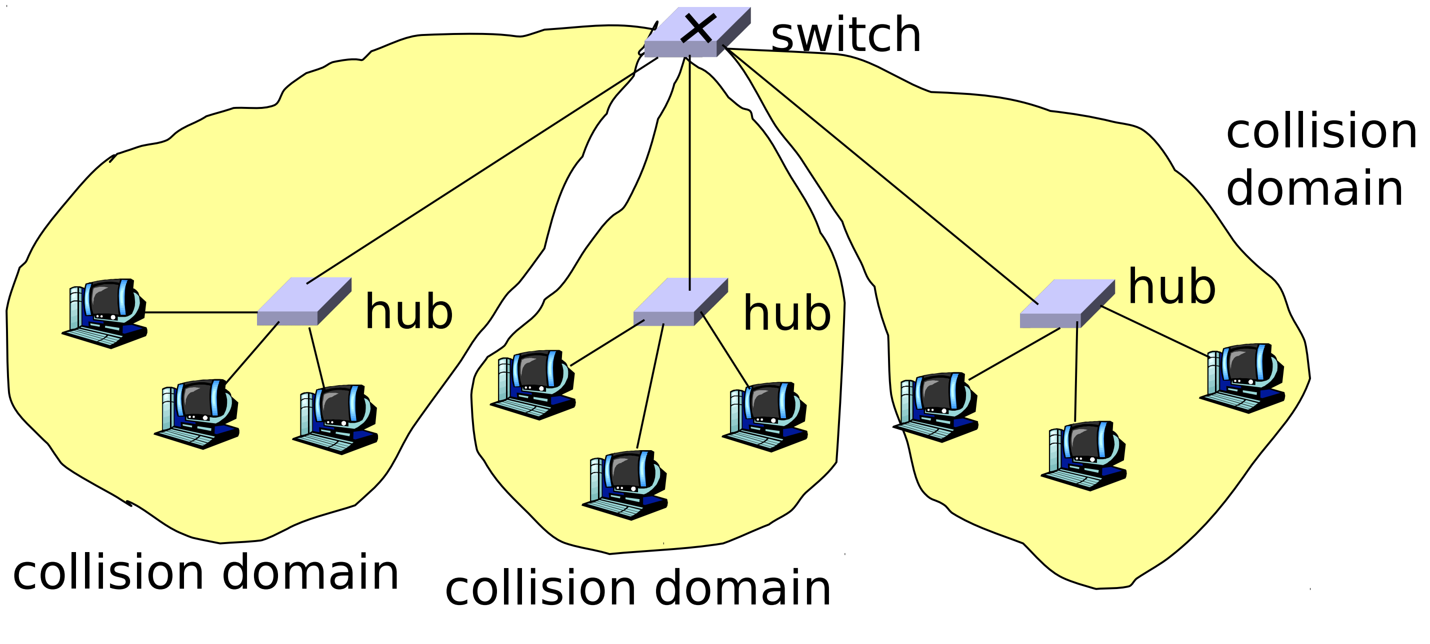
**}**

**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

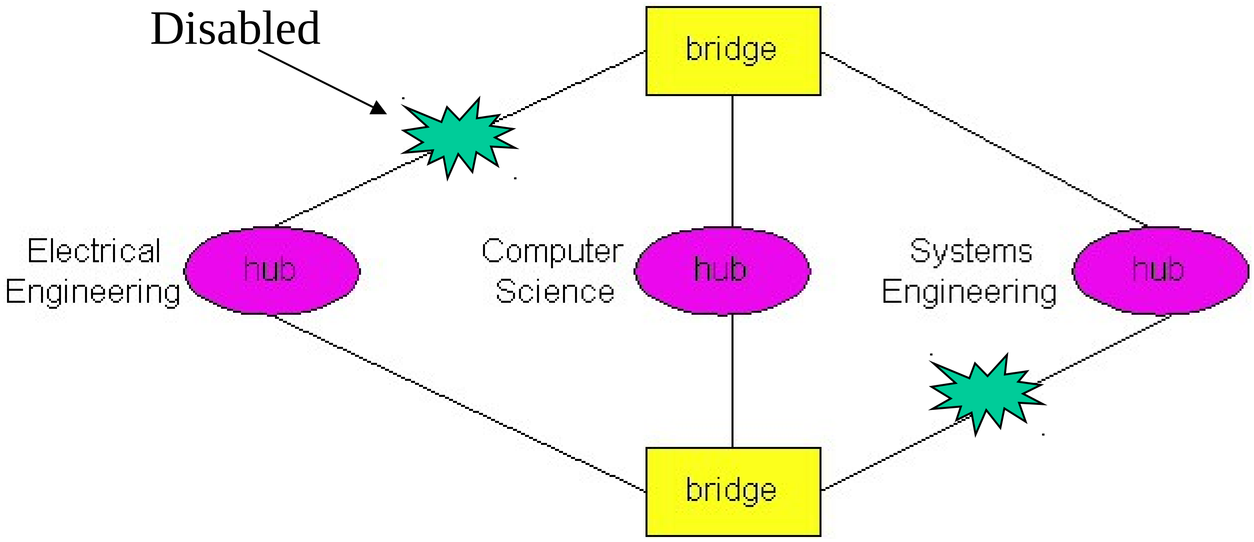


# Redundant networks

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

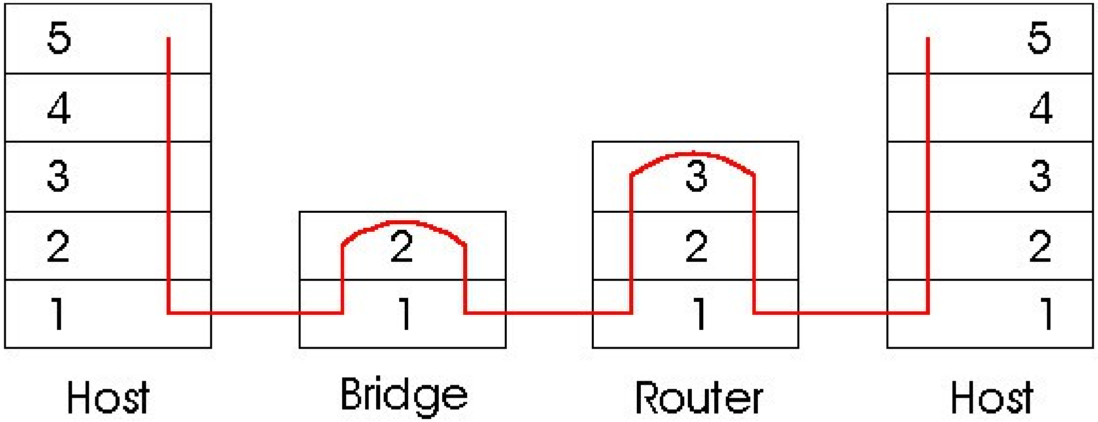
# Bridges spanning tree

- **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: 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)