

## 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)

## Link layer services (more)

### 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

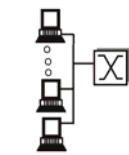
### Half-duplex and full-duplex

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

## Multiple access links

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



shared wire  
(e.g. Ethernet)



shared wireless  
(e.g. Wavelan)



satellite



cocktail party

## 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):*

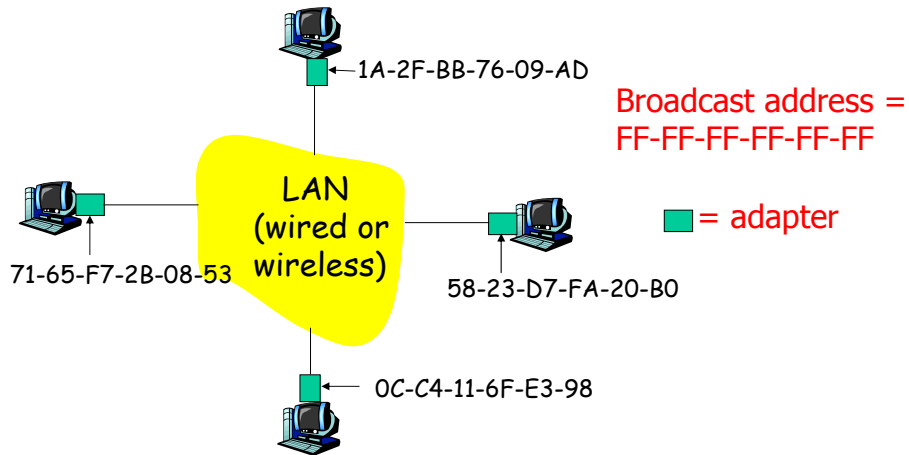
- ❑ Network-layer address
- ❑ Used to get datagram to destination network (recall IP network definition)

### **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



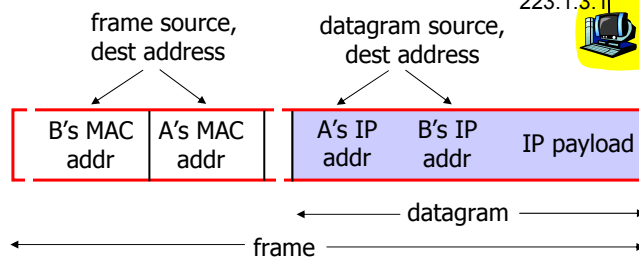
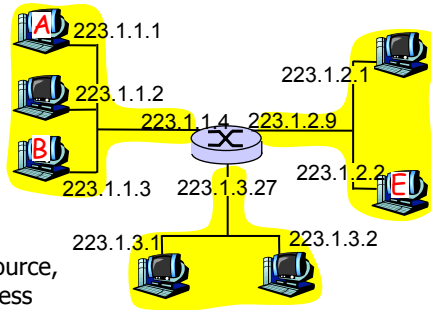
## Addresses (3.)

- ❑ 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 IP datagram addressed to B:

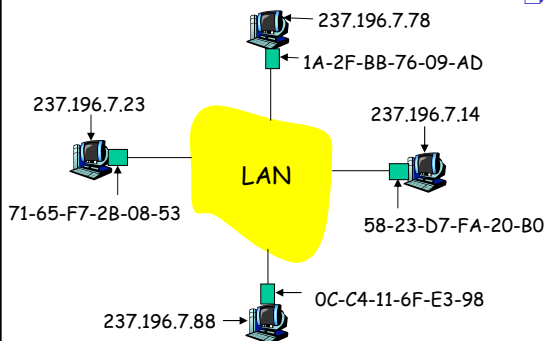
- Look up net. address of B, find B on same net. as A
- Link layer send datagram to B inside link-layer frame



## ARP: Address Resolution Protocol

Question: how to determine 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)



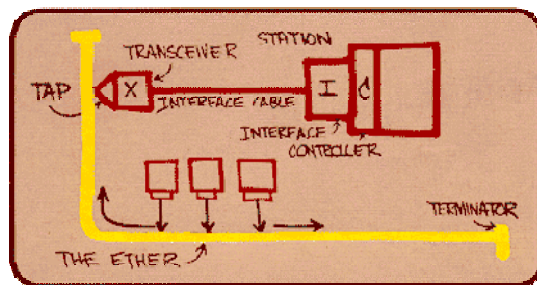
## ARP protocol: Same LAN (Network)

- ❑ 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 \$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 Ethernet 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**

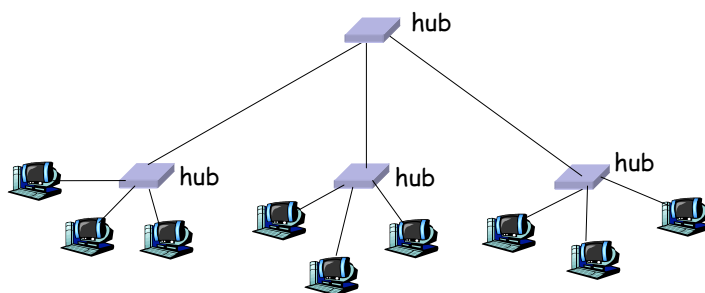
## Interconnecting LANs

**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)

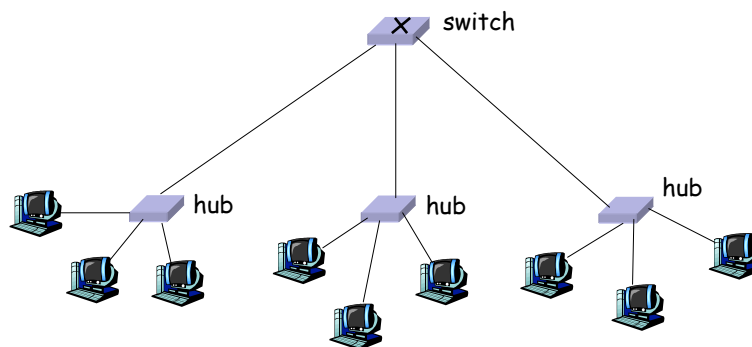
- ❑ **Link layer devices:**
  - Stores and forwards Ethernet frames
  - Examines frame header and **selectively** forwards frame based on MAC dest address
  - When frame is to be forwarded on segment, uses CSMA/CD to access segment
  - ⇒ Bridge **isolates collision** domains: it buffers frames

## 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

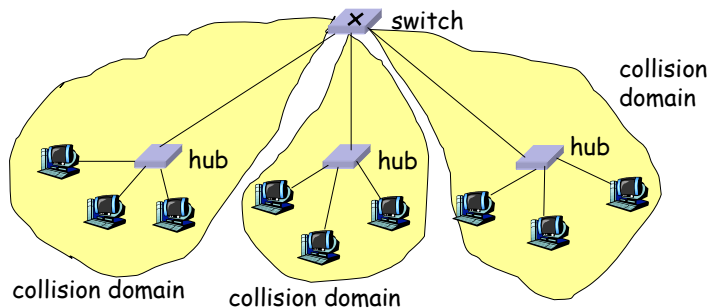
}

**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**

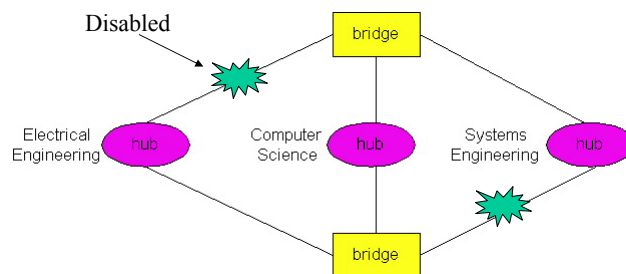


## Redundant networks

- ❑ 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

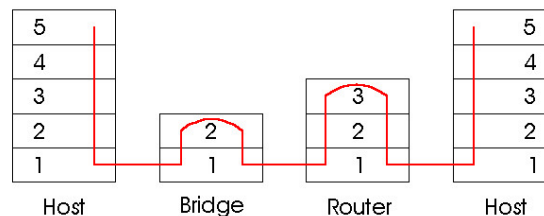
## Bridges spanning tree

- ❑ 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: 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)