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: *Done!*
- Example link layer technology: Ethernet

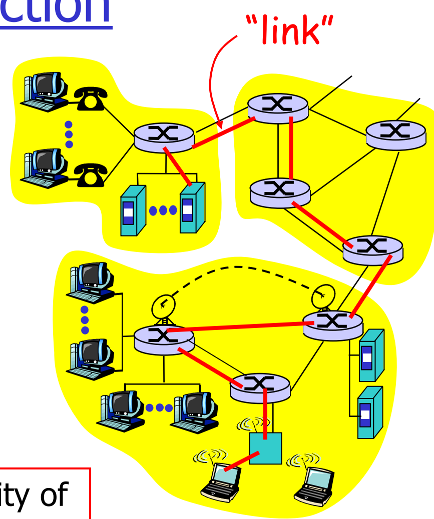
Data Link Layer

- Link layer services
- Multiple access protocols
- Link-Layer Addressing
- Ethernet
  - Basic idea
  - Hubs and switches

Link Layer: Introduction

Some terminology:

- Hosts and routers are **nodes**
- Communication channels that connect adjacent nodes along communication path are **links**
  - Wired links
  - Wireless links
  - LANs
- Layer-2 packet is a **frame**, encapsulates datagram



data-link layer has responsibility of transferring datagram from one node to adjacent node over a link

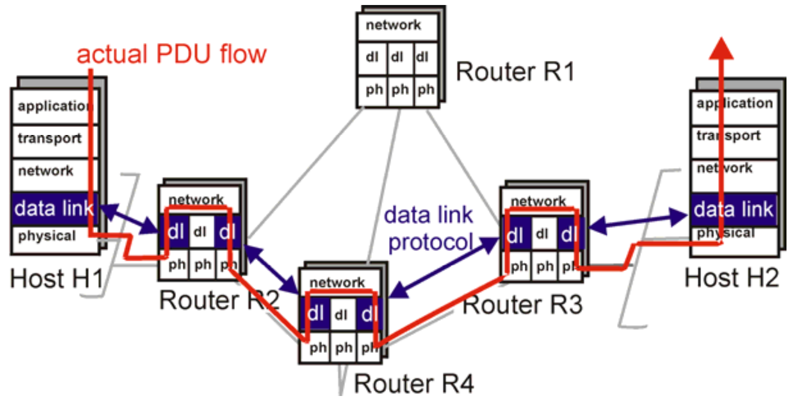
Link Layer: Context

- Datagram transferred by different link protocols over different links:
  - e.g., Ethernet on first link, frame relay on intermediate links, 802.11 on last link
- Each link protocol provides different services
  - e.g., may or may not provide reliable data transport

Transportation analogy

- Trip from Princeton to Lausanne
  - limo: Princeton to JFK
  - plane: JFK to Geneva
  - train: Geneva to Lausanne
- Tourist = datagram
- Transport segment = communication link
- Transportation mode = link layer protocol
- Travel agent = routing algorithm

Link Layer: Setting the Context



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

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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

shared wire (e.g. Ethernet) | shared wireless (e.g. Wavelan) | satellite | cocktail party

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

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Addresses

IP address (32-bit):

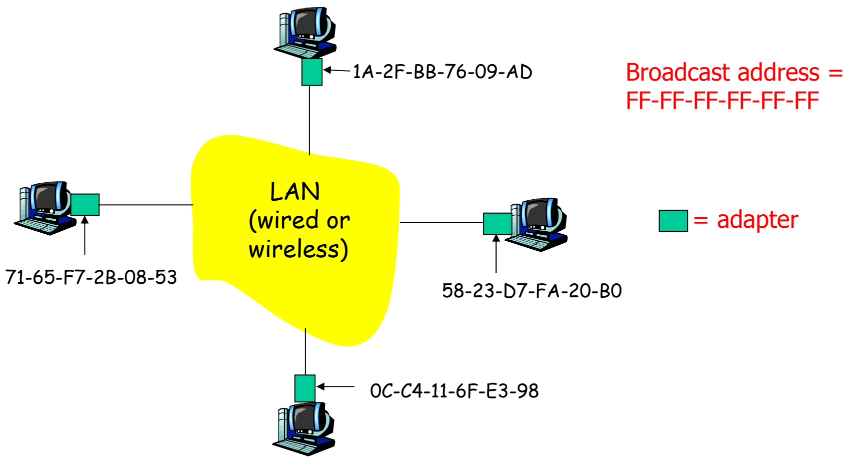
- Network-layer address
- Used to get datagram to destination network (recall IP network definition)

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



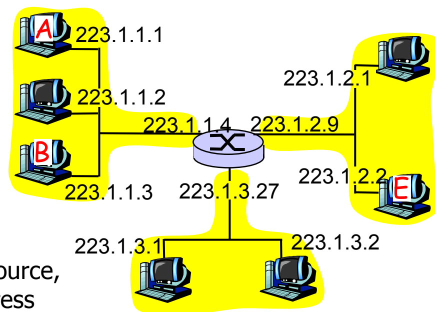
Addresses (3.)

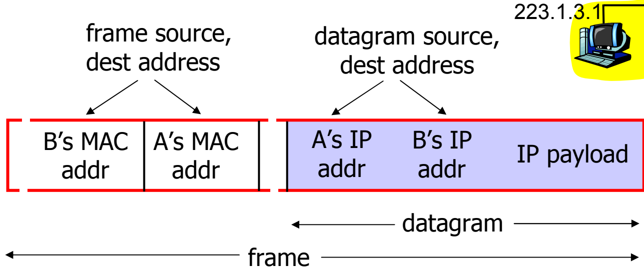
- MAC address allocation administered by IEEE
- Manufacturer buys portion of MAC address space (to assure uniqueness)
- Analogy:
  - MAC address: like Social Security Number
  - IP address: like postal address
- MAC flat address ⇨ portability
  - can move LAN card from one LAN to another
- IP hierarchical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

Example

Starting at A, given IP datagram addressed to B:

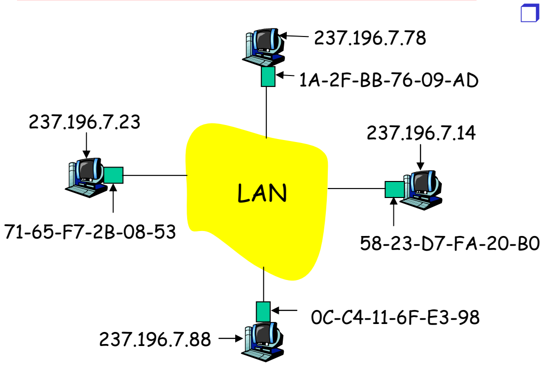
- Look up net. address of B, find B on same net. as A
- Link layer send datagram to B inside link-layer frame





ARP: Address Resolution Protocol

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



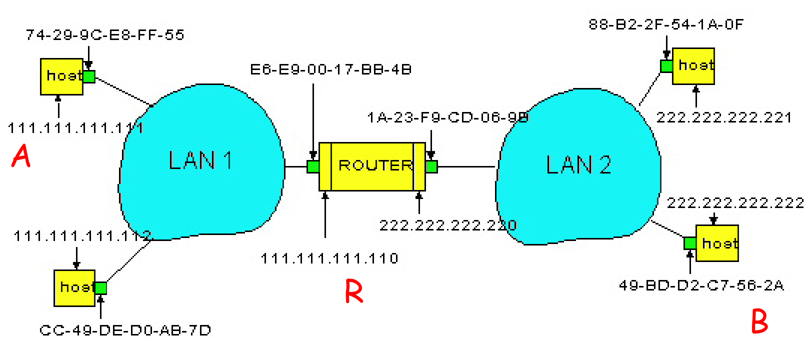
- Each IP node (Host, Router) on LAN has ARP table
- ARP Table: IP/MAC address mappings for some LAN nodes
  < IP address; MAC address; TTL>
  - TTL (Time To Live): time after which address mapping will be forgotten (typically 20 min)

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

Routing to Another LAN

- Two ARP tables in router R, one for each LAN



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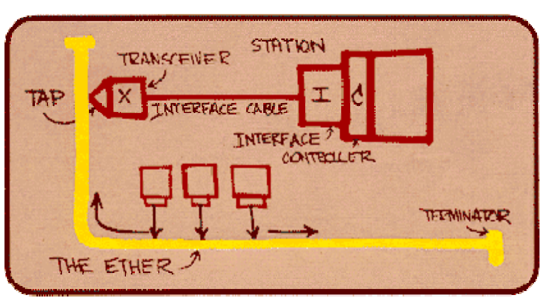
Ethernet

"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

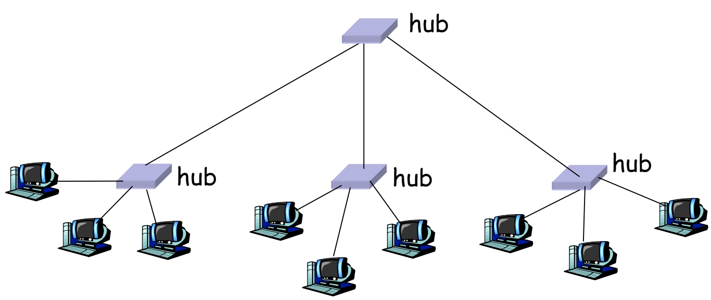
Interconnecting LANs

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)

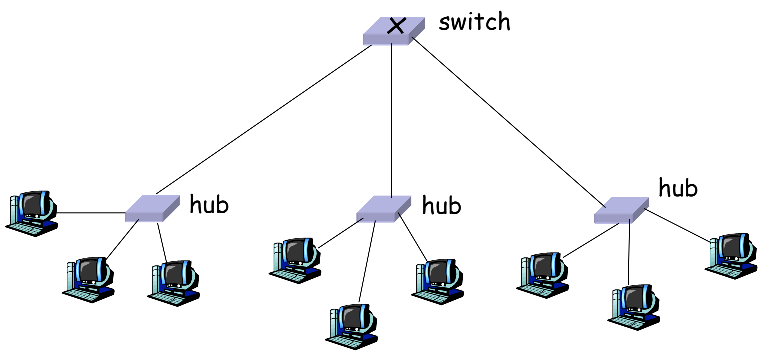
- Link Layer devices:
  - Stores and forwards Ethernet frames
  - Examines frame header and selectively forwards frame based on MAC dest address
  - When frame is to be forwarded on segment, uses CSMA/CD to access segment
  - ⇨ Bridge isolates collision domains: it buffers frames

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

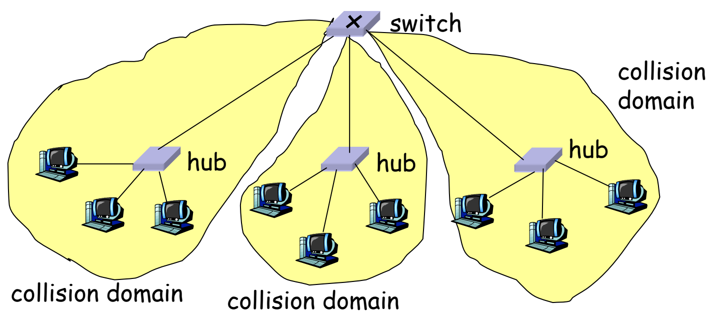
When switch receives a frame:

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

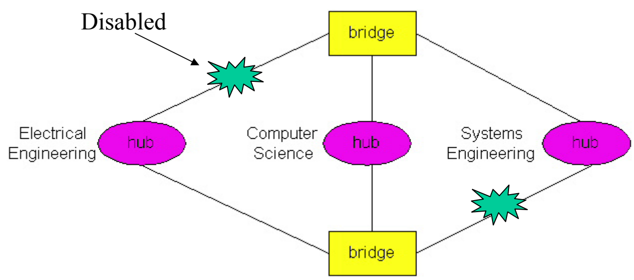


Redundant Networks

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

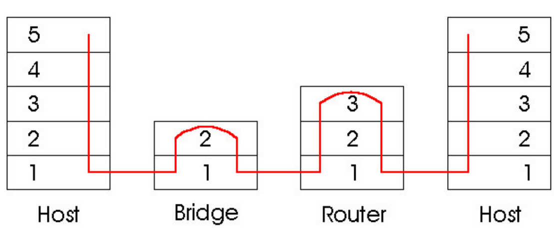
Bridges Spanning Tree

- 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)