Chapter 5
Data Link Layer

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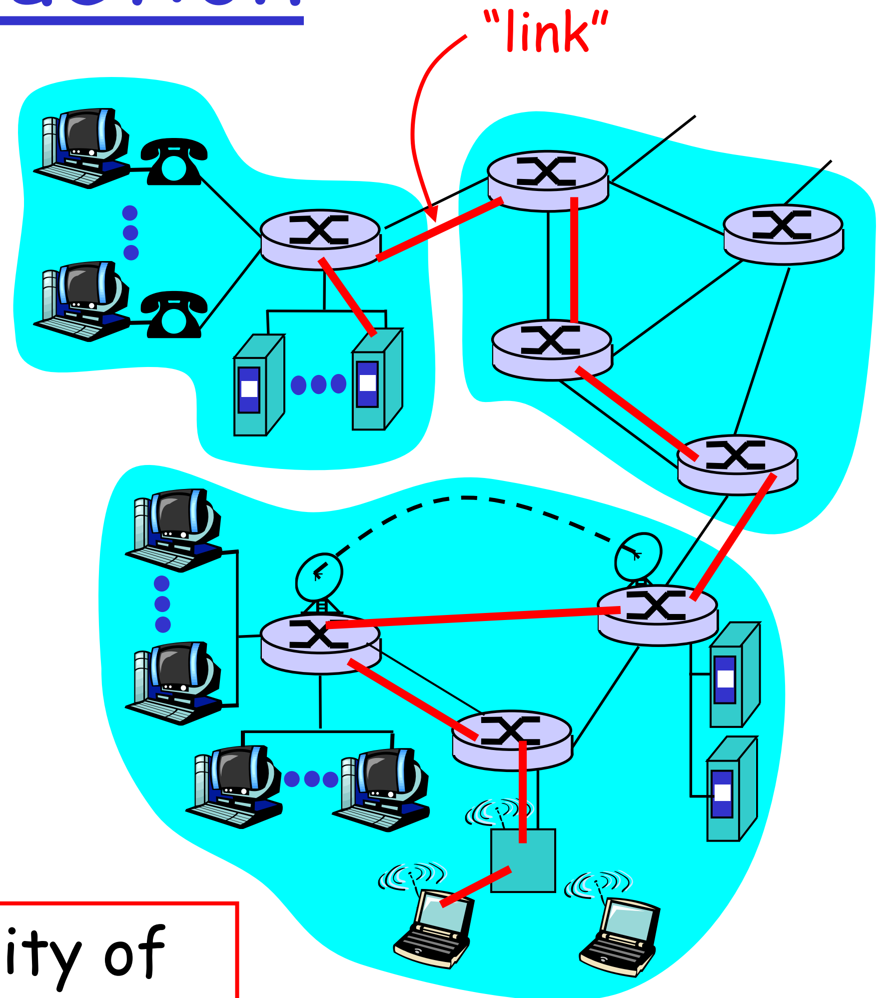
Computer Networking: A Top Down Approach Featuring the Internet,
Jim Kurose, Keith Ross
Addison-Wesley, 2012-2022

Chapter 5: The Data Link Layer

Our goals:

- understand principles behind data link layer services:
  - error detection, correction
  - sharing a broadcast channel: multiple access
  - link layer addressing
  - reliable data transfer, flow control: *done!*
- instantiation and implementation of various link layer technologies

Link Layer: Introduction



Some terminology:

- hosts and routers are **nodes** (bridges and switches too)
- communication channels that connect adjacent nodes along communication path are **links**
  - wired links
  - wireless links
  - LANs
- 2-PDU 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 rdt over link

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

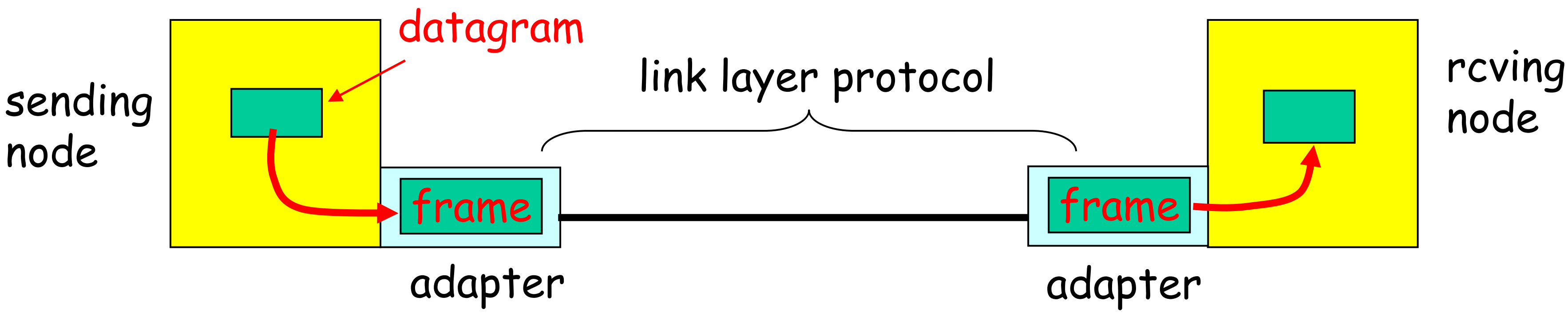
Link Layer Services

- Framing, link access:
  - encapsulate datagram into frame, adding header, trailer
  - channel access if shared medium
  - 'physical addresses' used in frame headers to identify source, dest
    - different from IP address!
- Reliable delivery between adjacent nodes
  - we learned how to do this already (chapter 3)!
  - seldom used on low bit error link (fiber, some twisted pair)
  - wireless links: high error rates
    - Q: why both link-level and end-end reliability?

Link Layer Services (more)

- *Flow Control:*
  - pacing between adjacent sending and receiving nodes
- *Error Detection*:
  - errors caused by signal attenuation, noise.
  - receiver detects presence of errors:
    - signals sender for retransmission 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

Adaptors Communicating

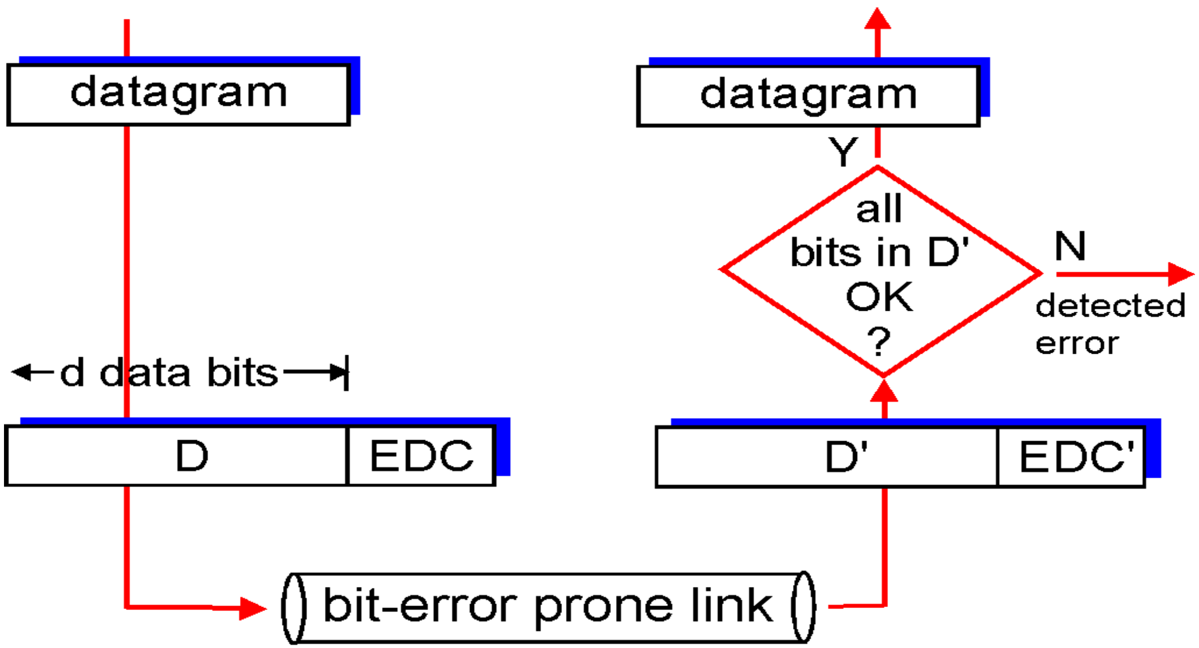


- link layer implemented in "adaptor" (aka NIC)
  - Ethernet card, PCMCI card, 802.11 card
- sending side:
  - encapsulates datagram in a frame
  - adds error checking bits, rdt, flow control, etc.
- receiving side
  - looks for errors, rdt, flow control, etc
  - extracts datagram, passes to rcving node
- adapter is semi-autonomous
- link & physical layers

Error Detection

EDC= Error Detection and Correction bits (redundancy)
D = Data protected by error checking, may include header fields

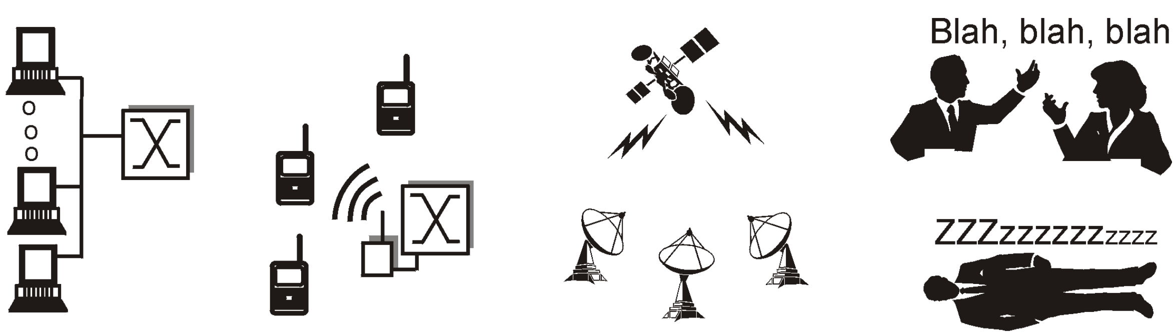
- Error detection not 100% reliable!
  - protocol may miss some errors, but rarely
  - larger EDC field yields better detection and correction



Multiple Access Links and 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)

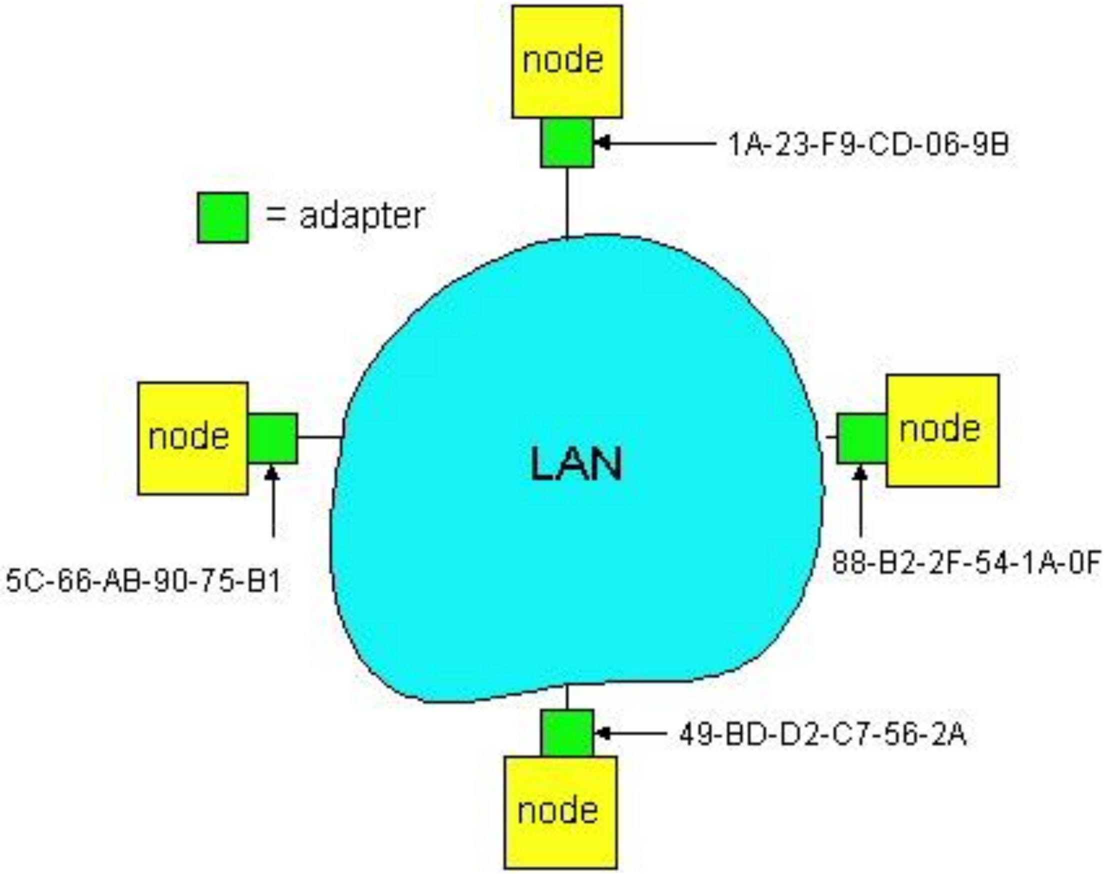
shared wireless (e.g. Wavelan)

satellite

cocktail party

LAN Addresses and ARP

Each adapter on LAN has unique LAN address



LAN Address (more)

- MAC address allocation administered by IEEE
- manufacturer buys portion of MAC address space (to assure uniqueness)
- Analogy:

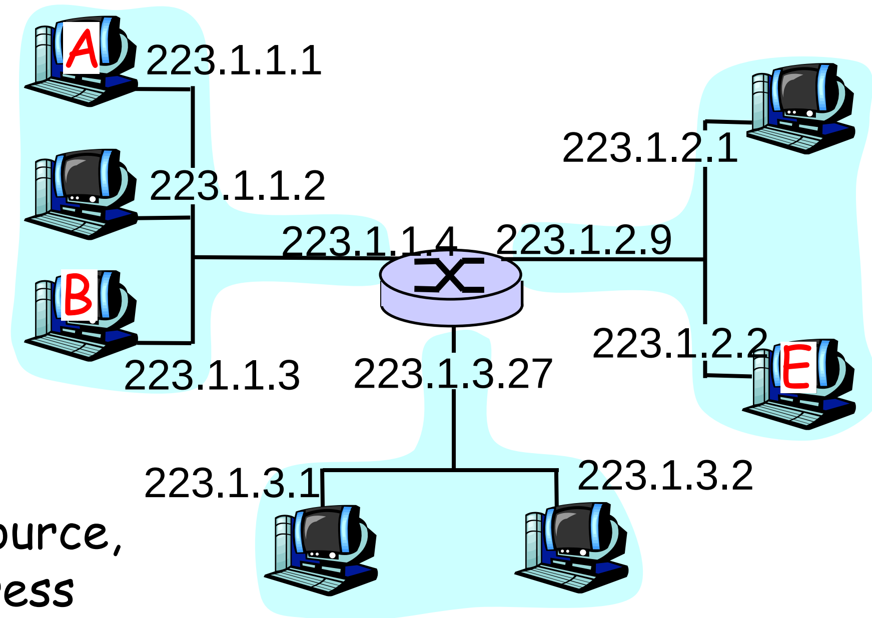
  (a) MAC address: like Social Security Number

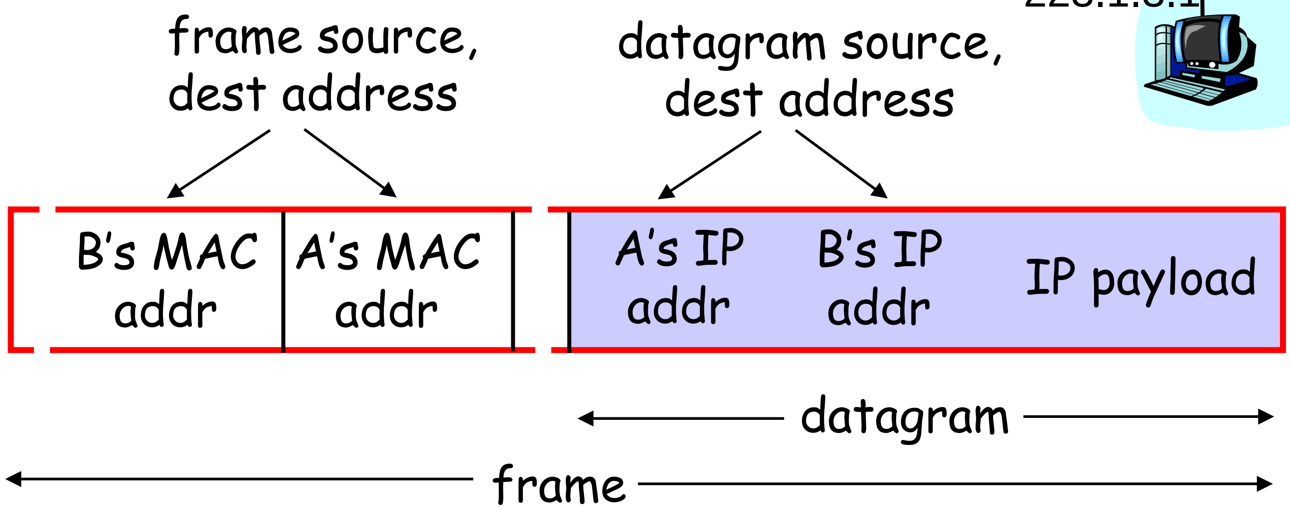
  (b) IP address: like postal address
- MAC flat address => portability
  - can move LAN card from one LAN to another
- IP hierarchical address NOT portable
  - depends on IP network to which node is attached

Recall earlier routing discussion

Starting at A, given IP datagram addressed to B:

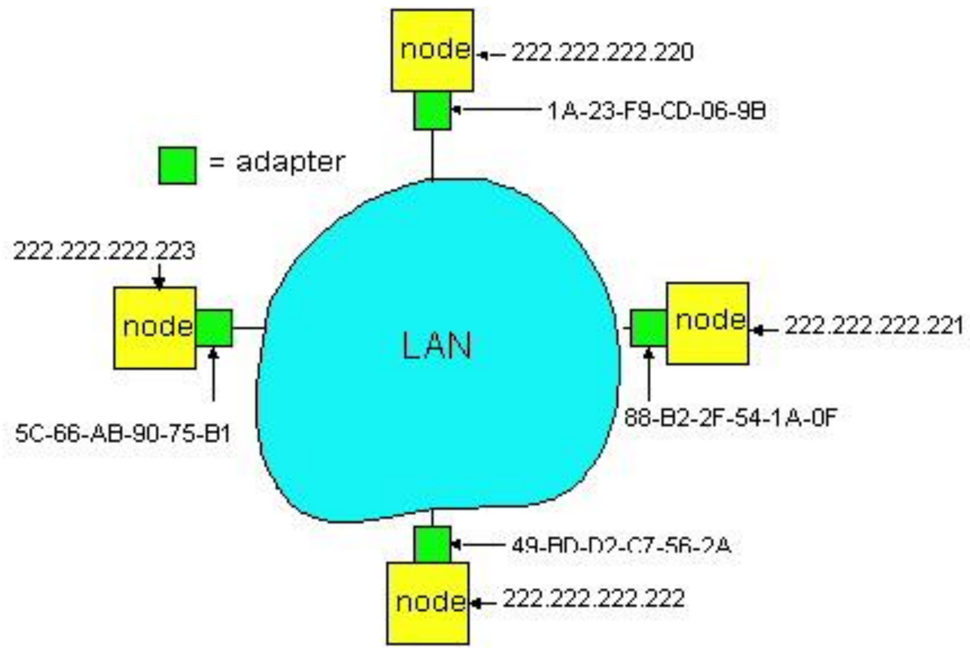
- look up net. address of B, find B on same net. as A
- link layer send datagram to B inside link-layer frame





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)

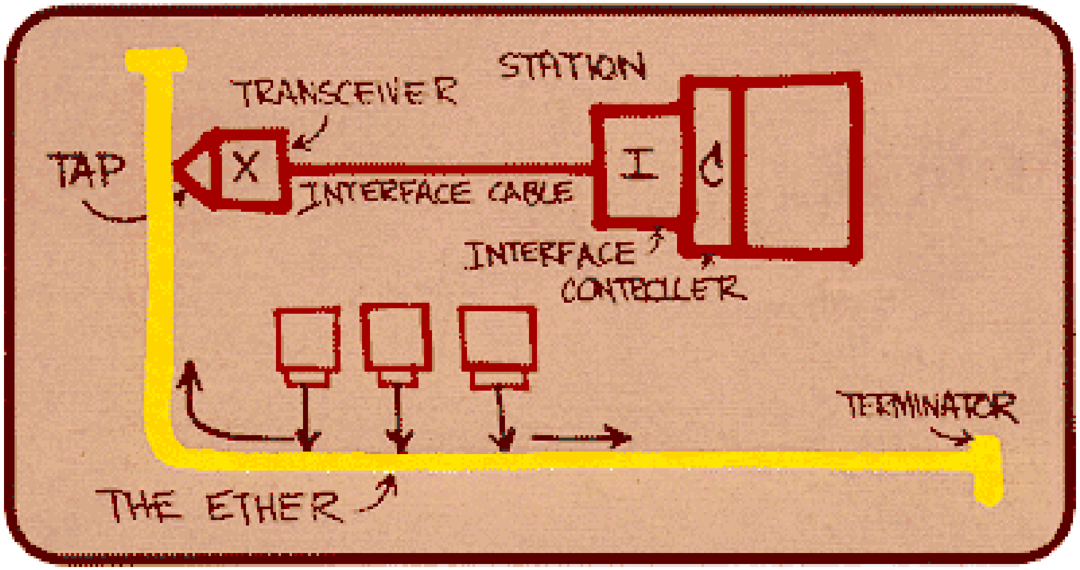
ARP protocol

- A wants to send datagram to B, and A knows B's IP address.
- Suppose B's MAC address is not in A's ARP table.
- A broadcasts ARP query packet, containing B's IP address
  - 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:

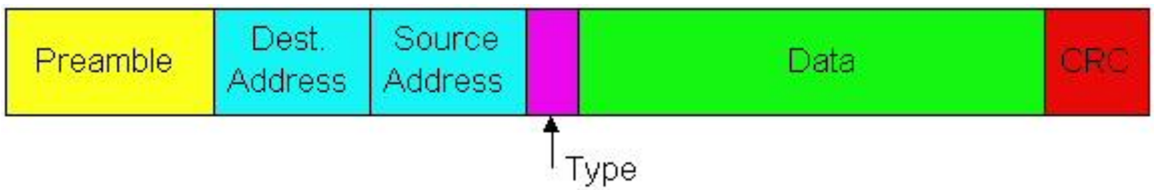
- cheap $20 for 100Mbs!
- first widely used LAN technology
- Simpler, cheaper than token LANs and ATM
- Kept up with speed race: 10, 100, 1000 Mbps



Metcalfe's Ethernet sketch

Ethernet Frame Structure

Sending adapter encapsulates IP datagram (or other network layer protocol packet) in Ethernet frame



Type: Indicates higher layer protocol, mainly IP

Preamble:

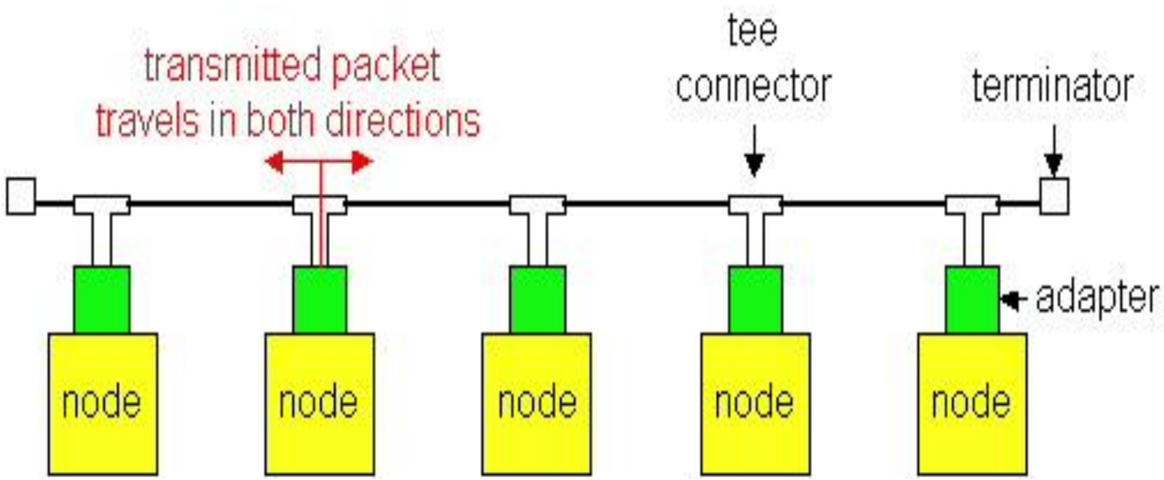
- 7 bytes with pattern 10101010 followed by one byte with pattern 10101011
- used to synchronize receiver, sender clock rates

Ethernet uses CSMA/CD

- No slots
- adapter doesn't 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 Technologies: 10Base2

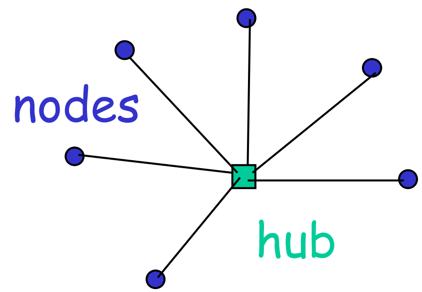
- 10: 10Mbps; 2: under 200 meters max cable length
- thin coaxial cable in a bus topology



- repeaters used to connect up to multiple segments
- repeater repeats bits it hears on one interface to its other interfaces: physical layer device only!
- has become a legacy technology

10BaseT and 100BaseT

- 10/100 Mbps rate; latter called "fast ethernet"
- T stands for Twisted Pair
- Nodes connect to a hub: "star topology"; 100 m max distance between nodes and hub



- Hubs are essentially physical-layer repeaters:
  - bits coming in one link go out all other links
  - no frame buffering
  - no CSMA/CD at hub: adapters detect collisions
  - provides net management functionality

Gbit Ethernet

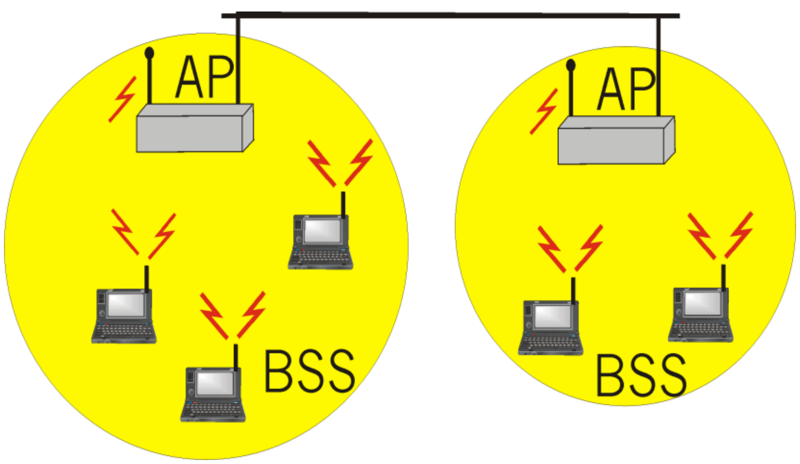
- use standard Ethernet frame format
- allows for point-to-point links and shared broadcast channels
- in shared mode, CSMA/CD is used; short distances between nodes to be efficient
- uses hubs, called here "Buffered Distributors"
- Full-Duplex at 1 Gbps for point-to-point links
- 10 Gbps now !

IEEE 802.11 Wireless LAN

- 802.11b
  - 2.4-2.5 GHz unlicensed radio spectrum
  - up to 11 Mbps
  - direct sequence spread spectrum (DSSS) in physical layer
    - all hosts use same chipping code
  - widely deployed, using base stations
- 802.11a
  - 5-6 GHz range
  - up to 54 Mbps
- 802.11g
  - 2.4-2.5 GHz range
  - up to 54 Mbps
- All use CSMA/CA for multiple access
- All have base-station and ad-hoc network versions

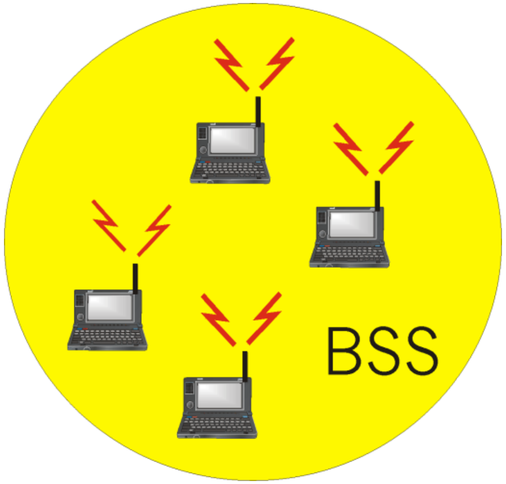
Base station approch

- Wireless host communicates with a base station
  - base station = access point (AP)
- Basic Service Set (BSS) (a.k.a. "cell") contains:
  - wireless hosts
  - access point (AP): base station
- BSS's combined to form distribution system (DS)



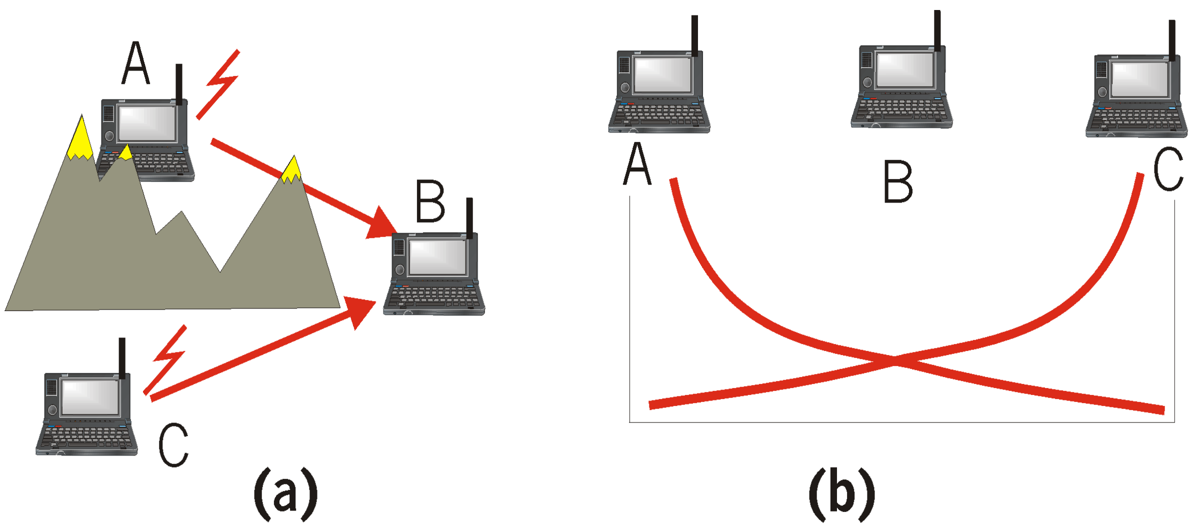
Ad Hoc Network approach

- No AP (i.e., base station)
- wireless hosts communicate with each other
  - to get packet from wireless host A to B may need to route through wireless hosts X,Y,Z
- Applications:
  - "laptop" meeting in conference room, car
  - interconnection of "personal" devices
  - battlefield
- IETF MANET (Mobile Ad hoc Networks) working group



IEEE 802.11: multiple access

- Collision if 2 or more nodes transmit at same time
- CSMA makes sense:
  - get all the bandwidth if you're the only one transmitting
  - shouldn't cause a collision if you sense another transmission
- Collision detection doesn't work: hidden terminal problem



IEEE 802.11 MAC Protocol: CSMA/CA

802.11 CSMA: sender

- if sense channel idle for **DIFS** (DCF Interframe Space. DCF-Distributed coordination function) sec.

  then transmit entire frame (no collision detection)

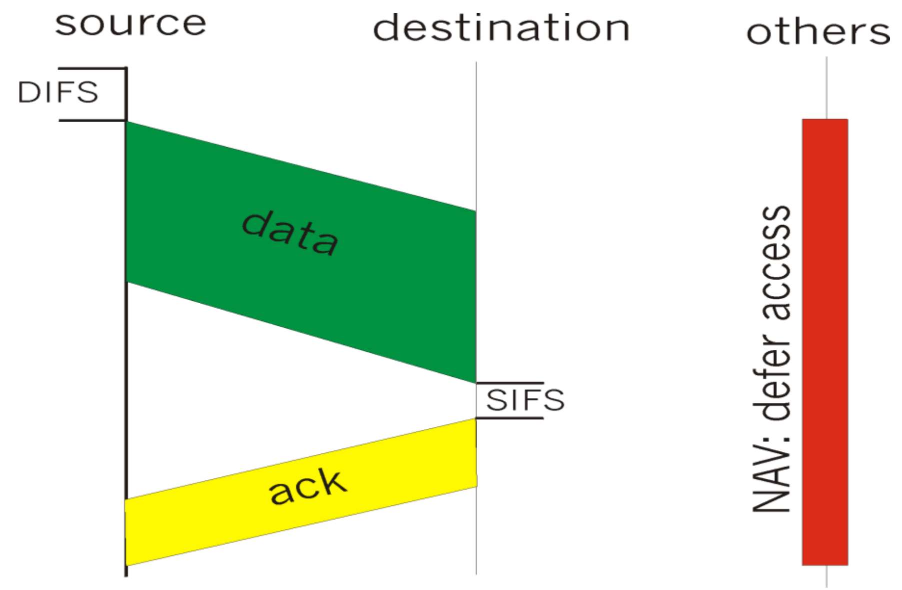
- if sense channel busy then binary backoff

802.11 CSMA receiver

- if received OK

  return ACK after **SIFS** (Short Interframe Spacing)

  (ACK is needed due to hidden terminal problem)

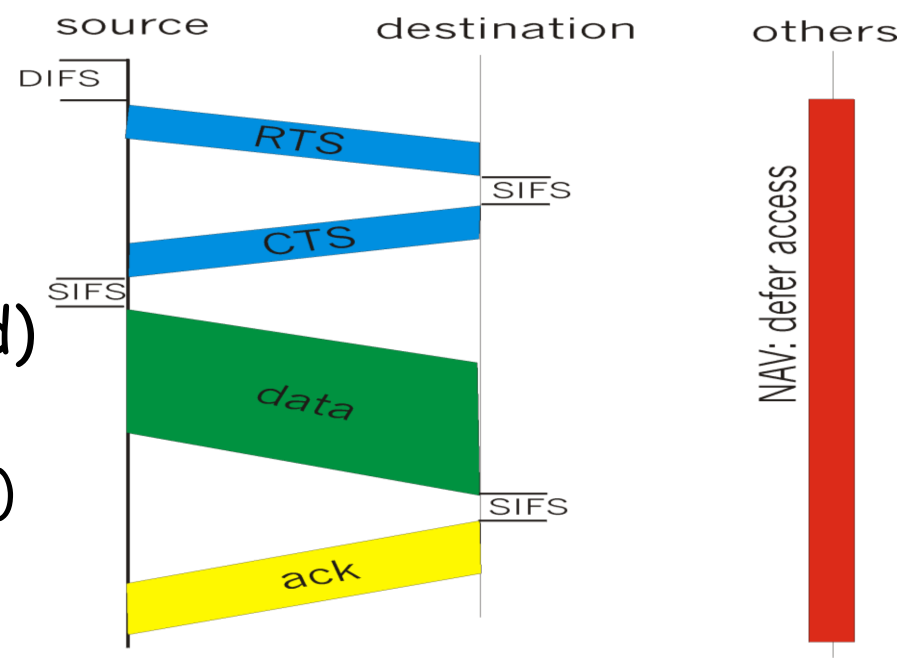


Collision avoidance mechanisms

- Problem:
  - two nodes, hidden from each other, transmit complete frames to base station
  - wasted bandwidth for long duration !
- Solution:
  - small reservation packets
  - nodes track reservation interval with internal "network allocation vector" (NAV)

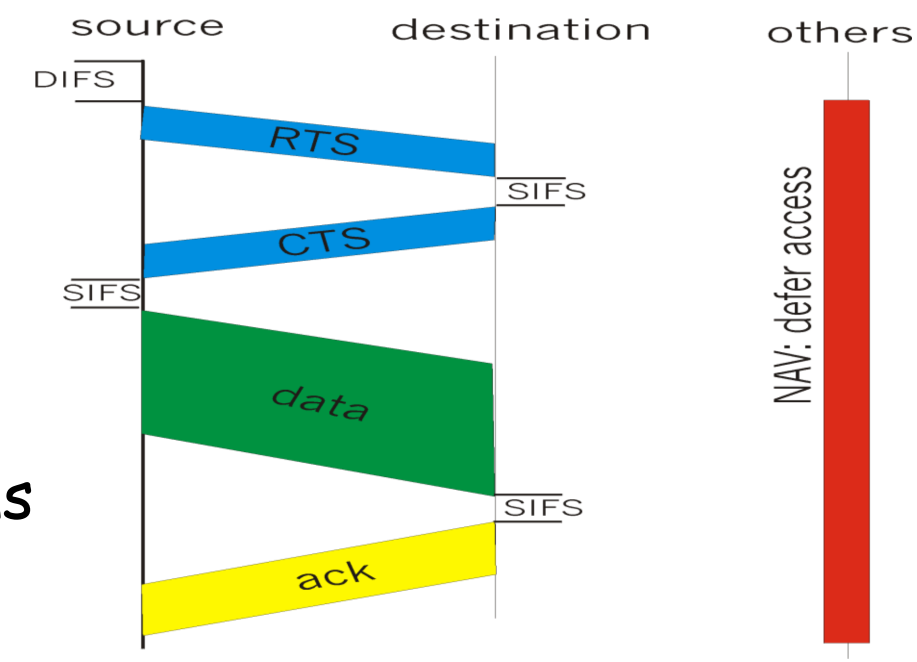
Collision Avoidance: RTS-CTS exchange

- sender transmits short RTS (request to send) packet: indicates duration of transmission
- receiver replies with short CTS (clear to send) packet
  - notifying (possibly hidden) nodes
- hidden nodes will not transmit for specified duration: NAV



Collision Avoidance: RTS-CTS exchange

- RTS and CTS short:
  - collisions less likely, of shorter duration
  - end result similar to collision detection
- IEEE 802.11 allows:
  - CSMA
  - CSMA/CA: reservations
  - polling from AP



A word about Bluetooth

- Low-power, small radius, wireless networking technology
  - 10-100 meters
- omnidirectional
  - not line-of-sight infared
- Interconnects gadgets
- 2.4-2.5 GHz unlicensed radio band
- up to 721 kbps
- Interference from wireless LANs, digital cordless phones, microwave ovens:
  - frequency hopping helps
- MAC protocol supports:
  - error correction
  - ARQ
- Each node has a 12-bit address

Binary exponential back off (Ethernet)

- After i collisions skips random no of time slots in range 0 to $2^i - 1$
  - after first collision (1), waits 0 or 1 slot time (selected at random). 0 to $2^1 - 1 = 0, 1$
  - if collided again (second time), waits 0, 1, 2 or 3 slots (at random). 0 to $2^2 - 1 = 0, 1, 2, 3$
  - if collided for the i^{th} time, waits 0, 1, …, or 2^i-1 slots (at random)
  - the randomization interval is fixed to 0 … 1023 after 10^{th} collision
  - station tries a total of 16 times and then gives up if cannot transmit