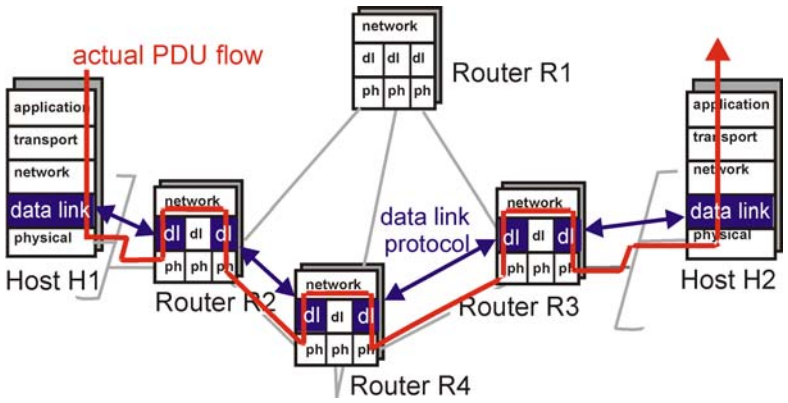
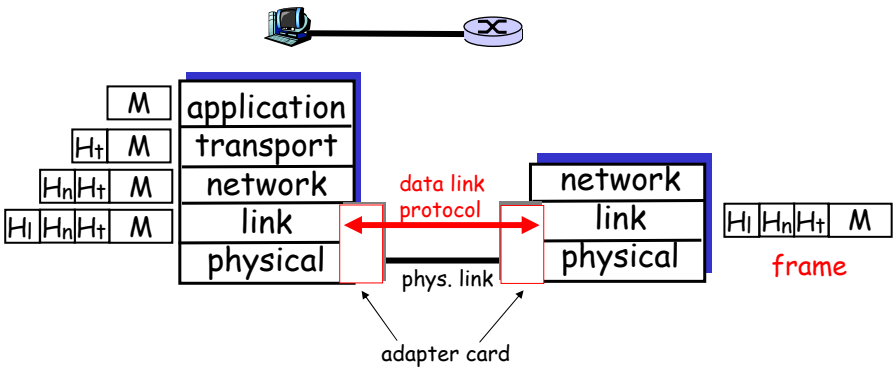
Link Layer: setting the context



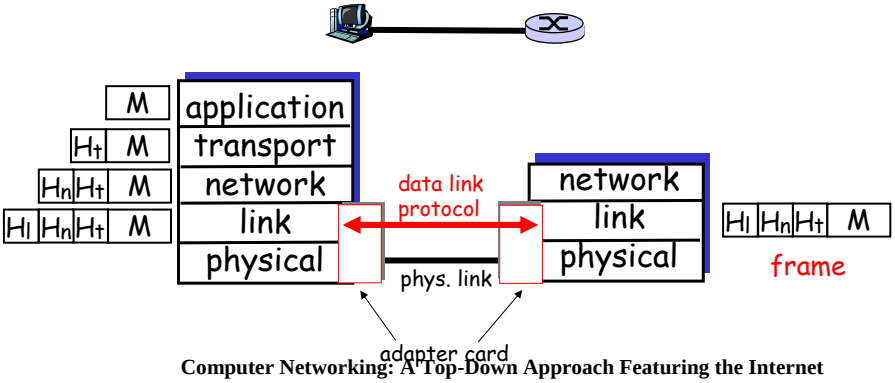
Link Layer: setting the context

- two *physically connected* devices:
  - host-router, router-router, host-host
- unit of data: *frame*



Link Layer: Implementation

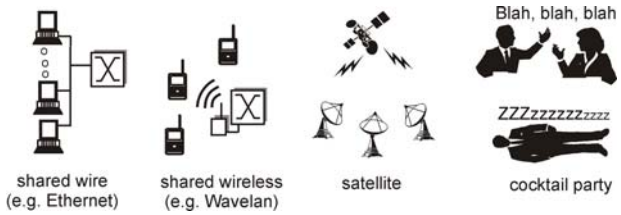
- implemented in "adapter"
  - e.g., PCMCIA card, Ethernet card
  - typically includes: RAM, DSP chips, host bus interface, and link interface



Multiple Access Links and Protocols

Three types of "links":

- point-to-point (single wire, e.g. PPP, SLIP)
- broadcast (shared wire or medium; e.g, Ethernet, Wavelan, etc.)



- switched (e.g., switched Ethernet, ATM etc)

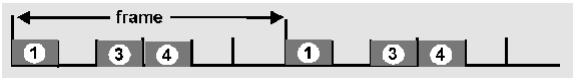
Multiple Access protocols

- single shared communication channel
- two or more simultaneous transmissions by nodes: interference
  - only one node can send successfully at a time
- *multiple access protocol:*
  - distributed algorithm that determines how stations share channel, i.e., determine when station can transmit
  - communication about channel sharing must use channel itself!
  - what to look for in multiple access protocols:
    - synchronous or asynchronous
    - information needed about other stations
    - robustness (e.g., to channel errors)
    - performance

Channel Partitioning MAC protocols: TDMA

TDMA: time division multiple access

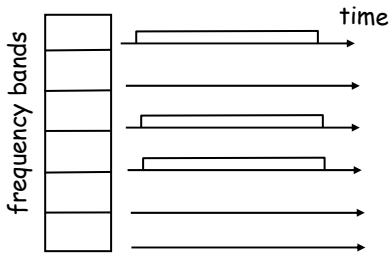
- access to channel in "rounds"
- each station gets fixed length slot (length = pkt trans time) in each round
- unused slots go idle
- example: 6-station LAN, 1,3,4 have pkt, slots 2,5,6 idle



Channel Partitioning MAC protocols: FDMA

FDMA: frequency division multiple access

- channel spectrum divided into frequency bands
- each station assigned fixed frequency band
- unused transmission time in frequency bands go idle
- example: 6-station LAN, 1,3,4 have pkt, frequency bands 2,5,6 idle

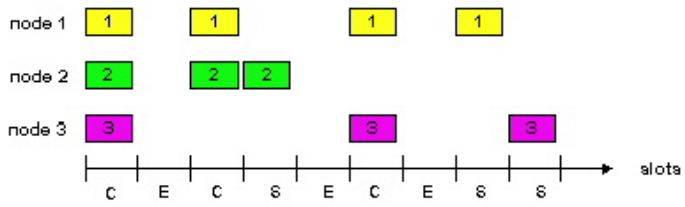


Random Access protocols

- When node has packet to send
  - transmit at full channel data rate R.
  - no *a priori* coordination among nodes
- two or more trasnmitting nodes -> "collision",
- random access MAC protocol specifies:
  - how to detect collisions
  - how to recover from collisions (e.g., via delayed retransmissions)
- Examples of random access MAC protocols:
  - slotted ALOHA
  - ALOHA
  - CSMA and CSMA/CD

Slotted Aloha

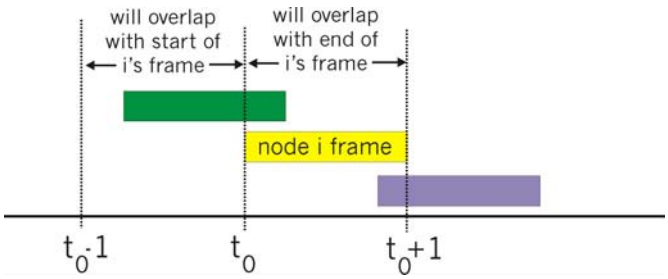
- time is divided into equal size slots (= pkt trans. time)
- node with new arriving pkt: transmit at beginning of next slot
- if collision: retransmit pkt in future slots with probability p, until successful.



Success (S), Collision (C), Empty (E) slots

Pure (unslotted) ALOHA

- unslotted Aloha: simpler, no synchronization
- pkt needs transmission:
  - send without awaiting for beginning of slot
- collision probability increases:
  - pkt sent at t_0 collide with other pkts sent in $[t_0-1, t_0+1]$



CSMA: Carrier Sense Multiple Access)

CSMA: listen before transmit:

- If channel sensed idle: transmit entire pkt
- If channel sensed busy, defer transmission
  - Persistent CSMA: retry immediately with probability p when channel becomes idle (may cause instability)
  - Non-persistent CSMA: retry after random interval
- human analogy: don't interrupt others!

CSMA/CD (Collision Detection)

CSMA/CD: carrier sensing, deferral as in CSMA

- collisions *detected* within short time
- colliding transmissions aborted, reducing channel wastage
- persistent or non-persistent retransmission

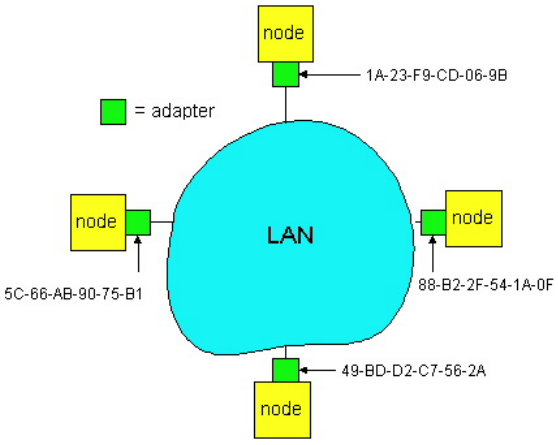
- collision detection:
  - easy in wired LANs: measure signal strengths, compare transmitted, received signals
  - difficult in wireless LANs: receiver shut off while transmitting
- human analogy: the polite conversationalist

Summary of MAC protocols

- What do you do with a shared media?
  - Channel Partitioning, by time, frequency or code
    - Time Division,Code Division, Frequency Division
  - Random partitioning (dynamic),
    - ALOHA, S-ALOHA, CSMA, CSMA/CD
    - carrier sensing: easy in some technoligies (wire), hard in others (wireless)
    - CSMA/CD used in Ethernet
  - Taking Turns
    - polling from a central cite, token passing

LAN Addresses and ARP

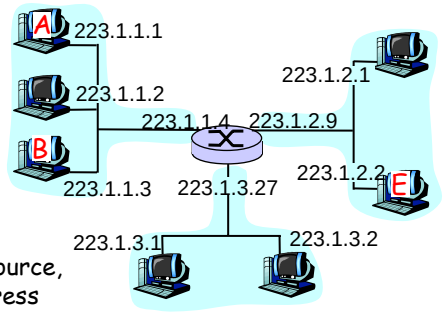
Each adapter on LAN has unique LAN address

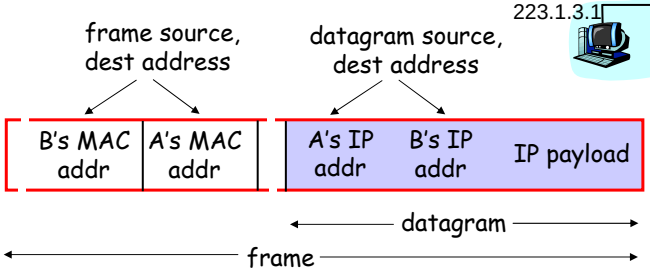


Recall earlier routing discussion

Starting at A, given IP datagram addressed to B:

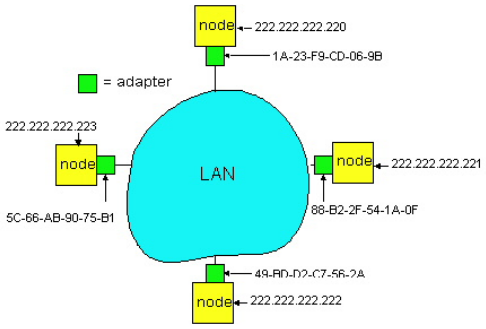
- look up net. address of B, find B on same net. as A
- link layer send datagram to B inside link-layer frame





ARP: Address Resolution Protocol

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



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

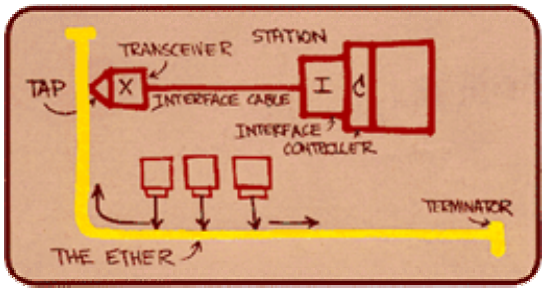
  < IP address; MAC address; TTL>

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

Ethernet

"dominant" LAN technology:

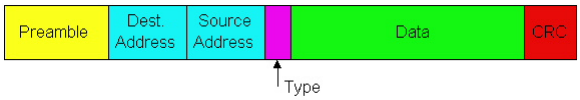
- cheap $20 for 100Mbs!
- first wildey used LAN technology
- Simpler, cheaper than token LANs and ATM
- Kept up with speed race: 10, 100, 1000 Mbps



Metcalfe's Etheret sketch

Ethernet Frame Structure

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

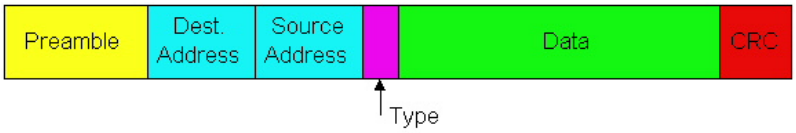


Preamble:

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

Ethernet Frame Structure (more)

- Addresses: 6 bytes, frame is received by all adapters on a LAN and dropped if address does not match
- Type: indicates the higher layer protocol, mostly IP but others may be supported such as Novell IPX and AppleTalk)
- CRC: checked at receiver, if error is detected, the frame is simply dropped



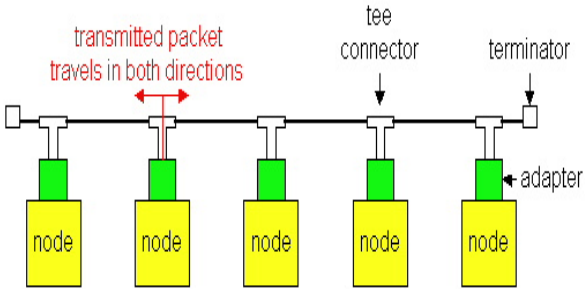
Ethernet: uses CSMA/CD

A: sense channel, **if** idle

```
then {
        transmit and monitor the channel;
        If detect another transmission
          then {
            abort and send jam signal;
            update # collisions;
            delay as required by exponential backoff algorithm;
            goto A
            }
          else {done with the frame; set collisions to zero}
    }
else {wait until ongoing transmission is over and goto A}
```

Ethernet Technologies: 10Base2

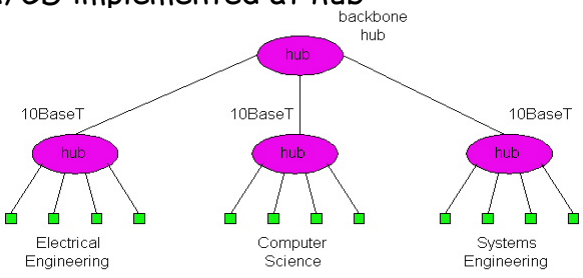
- 10: 10Mbps; 2: under 200 meters max cable length
- thin coaxial cable in a bus topology



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

10BaseT and 100BaseT

- 10/100 Mbps rate; latter called "fast ethernet"
- T stands for Twisted Pair
- Hub to which nodes are connected by twisted pair, thus "star topology"
- CSMA/CD implemented at hub



Gigabit 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

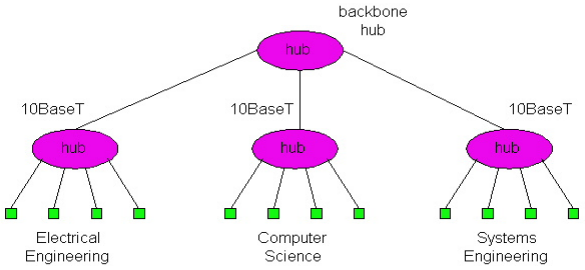
Interconnecting LANs

Q: Why not just one big LAN?

- Limited amount of supportable traffic: on single LAN, all stations must share bandwidth
- limited length: 802.3 specifies maximum cable length
- large "collision domain" (can collide with many stations)
- limited number of stations: 802.5 have token passing delays at each station

Hubs

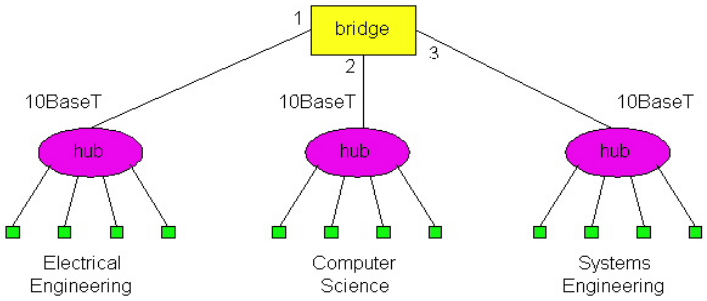
- Physical Layer devices: essentially repeaters operating at bit levels: repeat received bits on one interface to all other interfaces
- Hubs can be arranged in a hierarchy (or multi-tier design), with backbone hub at its top



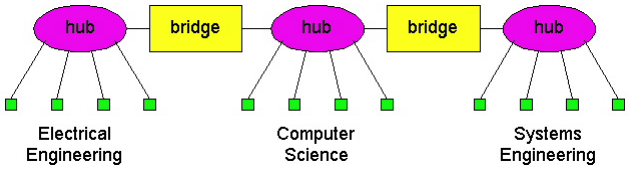
Bridges

- Link Layer devices: operate on Ethernet frames, examining frame header and selectively forwarding frame based on its destination
- Bridge isolates collision domains since it buffers frames
- When frame is to be forwarded on segment, bridge uses CSMA/CD to access segment and transmit

Backbone Bridge



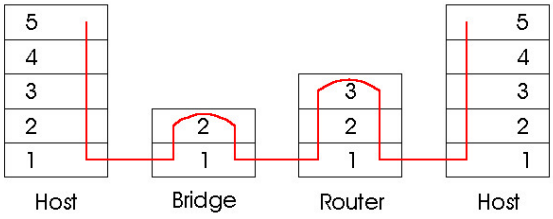
Interconnection Without Backbone



- Not recommended for two reasons:
  - single point of failure at Computer Science hub
  - all traffic between EE and SE must path over CS segment

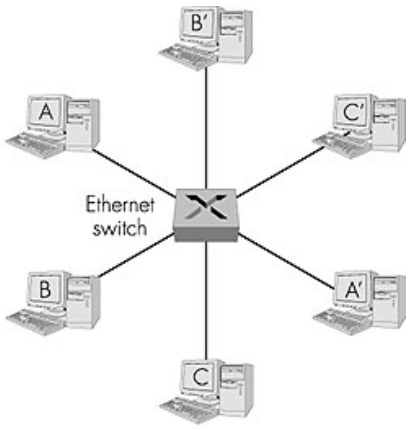
WWF Bridges vs. Routers

- both store-and-forward devices
  - routers: network layer devices (examine network layer headers)
  - bridges are Link Layer devices
- routers maintain routing tables, implement routing algorithms
- bridges maintain filtering tables, implement filtering, learning and spanning tree algorithms

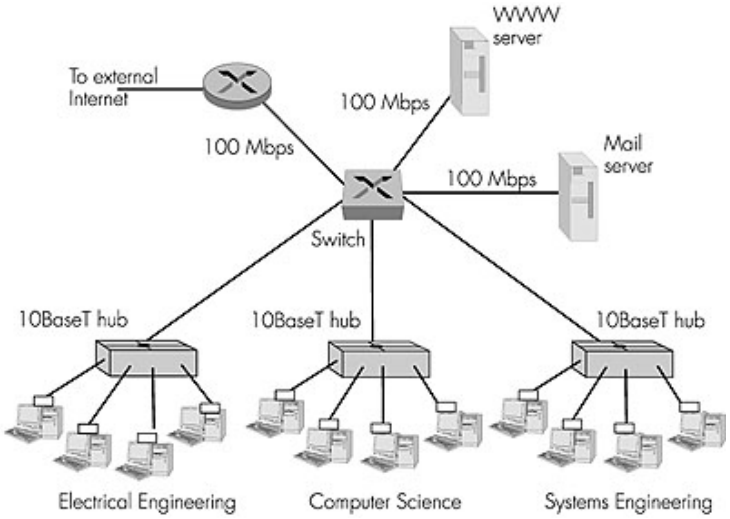


Ethernet Switches

- layer 2 (frame) forwarding, filtering using LAN addresses
- Switching: A-to-B and A'-to-B' simultaneously, no collisions
- large number of interfaces
- often: individual hosts, star-connected into switch
  - Ethernet, but no collisions!

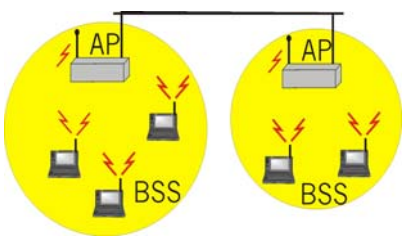


Ethernet Switches (more)



IEEE 802.11 Wireless LAN

- wireless LANs: untethered (often mobile) networking
- IEEE 802.11 standard:
  - MAC protocol
  - unlicensed frequency spectrum: 900Mhz, 2.4Ghz
- **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 Networks

- Ad hoc network: IEEE 802.11 stations can dynamically form network *without* AP
- Applications:
  - "laptop" meeting in conference room, car
  - interconnection of "personal" devices
  - battlefield
- IETF MANET (Mobile Ad hoc Networks) working group

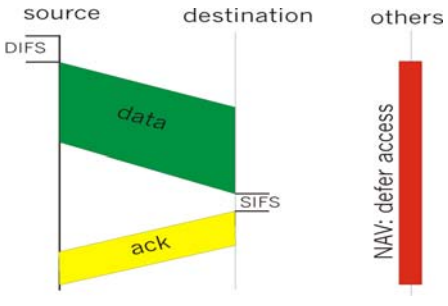
IEEE 802.11 MAC Protocol: CSMA/CA

802.11 CSMA: sender

- if sense channel idle for **DISF** sec.
  then transmit entire frame (no collision detection)
- if sense channel busy
  then binary backoff

802.11 CSMA receiver:

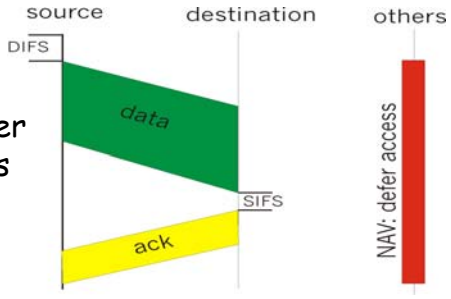
if received OK
  return ACK after **SIFS**



IEEE 802.11 MAC Protocol

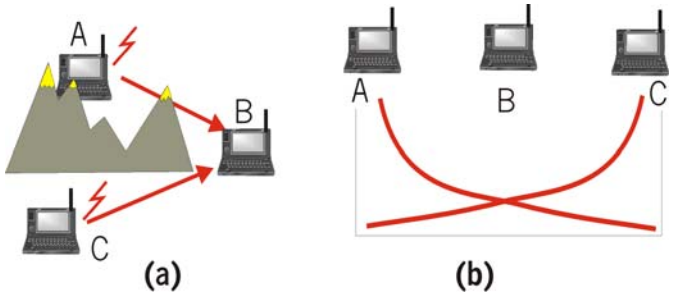
802.11 CSMA Protocol: others

- **NAV**: Network Allocation Vector
- 802.11 frame has transmission time field
- others (hearing sata) defer access for NAV time units



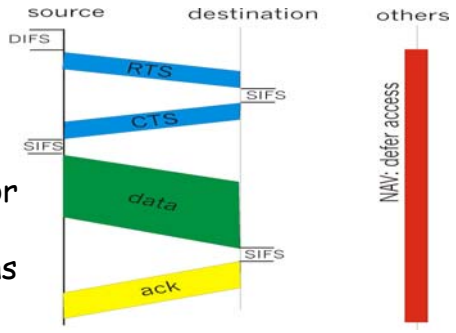
Hidden Terminal effect

- hidden terminals: A, C cannot hear each other
  - obstacles, signal attenuation
  - collisions at B
- goal: avoid collisions at B
- **CSMA/CA**: **CSMA with C**ollision Avoidance



Collision Avoidance: RTS-CTS exchange

- CSMA/CA: explicit channel reservation
  - sender: send short RTS: request to send
  - receiver: reply with short CTS: clear to send
- CTS reserves channel for sender, notifying (possibly hidden) stations
- avoid hidden station collisions



Collision Avoidance: RTS-CTS exchange

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