

CSE/EE 461 – Lecture 3



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Last Time ...



- How to send a message across a wire
 - Media and their transmission limits
 - Encoding data for clock recovery and framing
 - Detecting and correcting bit errors
- The Physical layer and some of the Data Link layer

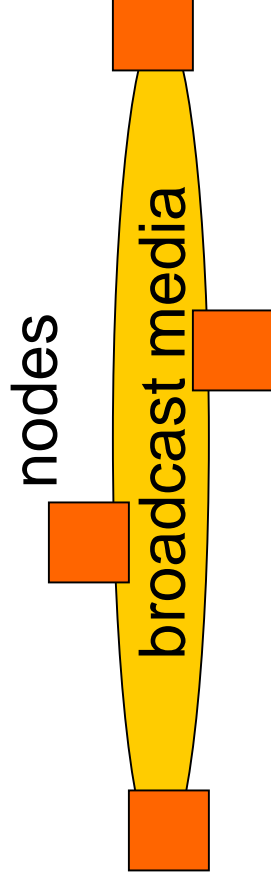
This Time



- The Medium Access Control portion of the Link Layer
 1. Partitioning schemes
 2. Statistical multiplexing
 3. Random access protocols (CSMA variants / Ethernet)
- Key Focus:
 - How do multiple parties share the air or a wire?

The Problem of Multiple Access

- Multiple nodes share a broadcast channel
 - wired LAN, wireless LAN, cell phones, packet radio, satellites
 - How do they coordinate their transmissions?



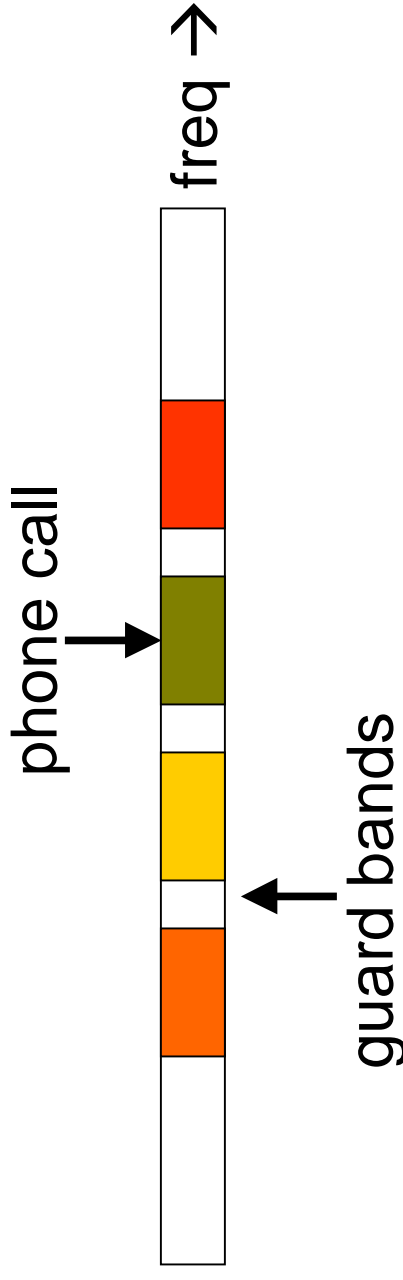
- Ideal solution for N nodes sharing bandwidth B bps:
 - high goodput (B), low delay (0), fair (B/N), decentralized, stable, and simple!

1. Partitioning Schemes

- Techniques for carving up the channel:
 - Frequency Division Multiple Access (FDMA)
 - Time Division Multiple Access (TDMA)
 - Code Division Multiple Access (CDMA)

FDMA

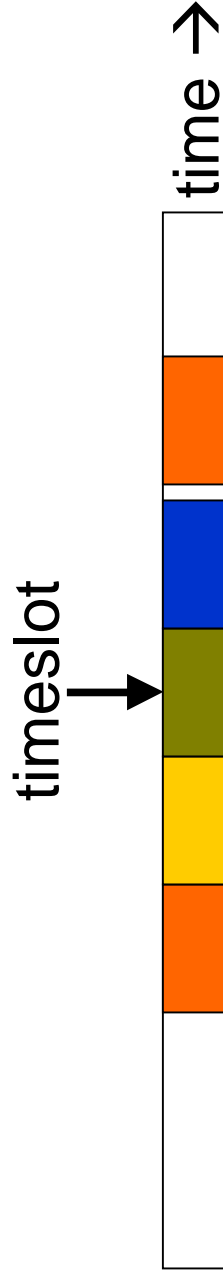
- Simultaneous transmission in different frequency bands
 - Analog: Radio/TV, AMPS cell phones (800MHz)
 - Also called Wavelength DMA (WDM) for fiber



“Speaking at different pitches”

TDMA

- Timeslice given frequency band between users
 - Digital: used extensively inside the telephone network
 - T1 (1.5Mbps) is 24 x 8 bits/125us; also E1 (2Mbps, 32 slots)



“Speaking at different times”

- Advantage: lower delay; Disadvantage: synchronization

CDMA (Spread Spectrum)

- Uses codes to “smear” bits over the frequency band:
 - send a codeword (e.g. 10001101) for “1”, complement for “0”
 - codes carefully chosen to be orthogonal to each other
 - the signals are sent at the chipping rate over a wide band
- We use orthogonality to separate interfering signals from different users at the receiver (example over).
- This is direct sequence; also frequency hopping

“Speaking in different languages”

CDMA Example

- A: $(1, -1, -1, 1)$ for "1", B: $(1, 1, -1, -1)$ and C: $(1, -1, 1, -1)$
- We have $A \cdot B$ (sum of inner products) = $A \cdot C = B \cdot C = 0$
- Now A sends "1", B sends "0" and C is not sending:
- Signal $S = (1, -1, -1, 1) + (-1, -1, 1, 1) + (0, 0, 0, 0) = (0, -2, 0, 2)$
- $S \cdot A = 0 + 2 + 0 + 2 = 4 \rightarrow$ A sent a "1"
- $S \cdot B = 0 - 2 + 0 - 2 = -4 \rightarrow$ B send a "0"
- $S \cdot C = 0 + 2 + 0 - 2 = 0 \rightarrow$ C didn't send

CDMA Continued



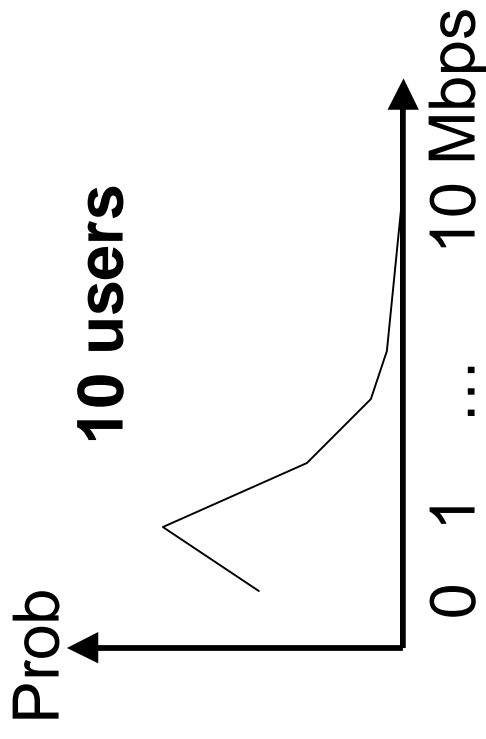
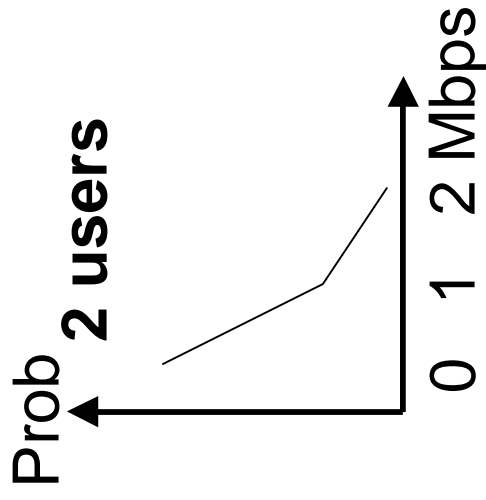
- **Advantages:**
 - Resistant to narrowband interference
 - Other senders appear as noise
 - Reuse of single frequency band
- **Disadvantages:**
 - Wideband
 - Synchronization
 - Power management

2. Statistical Multiplexing

- Static partitioning schemes work well for a fixed number of users that always have data to send
- Not suited to data communications: peak > average
- If we share on demand we can support more users
 - Based on the statistics of their transmissions
 - Occasionally we might be oversubscribed
- Statistical multiplexing is heavily used in data networks

Example

- One user sends at 1 Mbps and is idle 90% of the time.
 - 10 Mbps channel; 10 users if statically allocated



- What are the likely loads if we share on demand?

Example continued

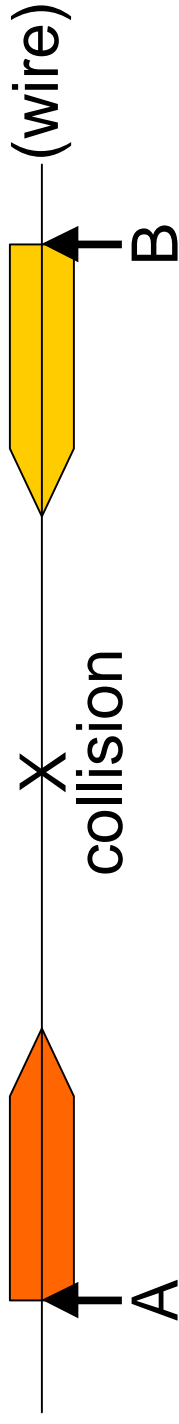
- For 10 users, $\text{Prob}(\text{need } 10 \text{ Mbps}) = 10^{-10}$
- So keep adding users ...
- For 35 users, $\text{Prob}(>10 \text{ active users}) = 0.17\%$
- We can support three times as many users!

3. Random Access – ALOHA

- Wireless links between the Hawaiian islands in the 70s
- Want distributed allocation
 - no special channels, or single point of failure
- Aloha protocol:
 - Just send when you have data!
 - There will be some collisions of course ...
 - Detect errored frames and retransmit a random time later
- Simple, decentralized and works well for low load
 - For many users, analytic traffic model, max efficiency is 18%

Carrier Sense Multiple Access

- “a” parameter: number of packets that fit on the wire
 - $a = \text{delay} / (\text{packet size} * \text{sending rate})$
 - Small ($\ll 1$) for LANs, large ($\gg 1$) for satellites



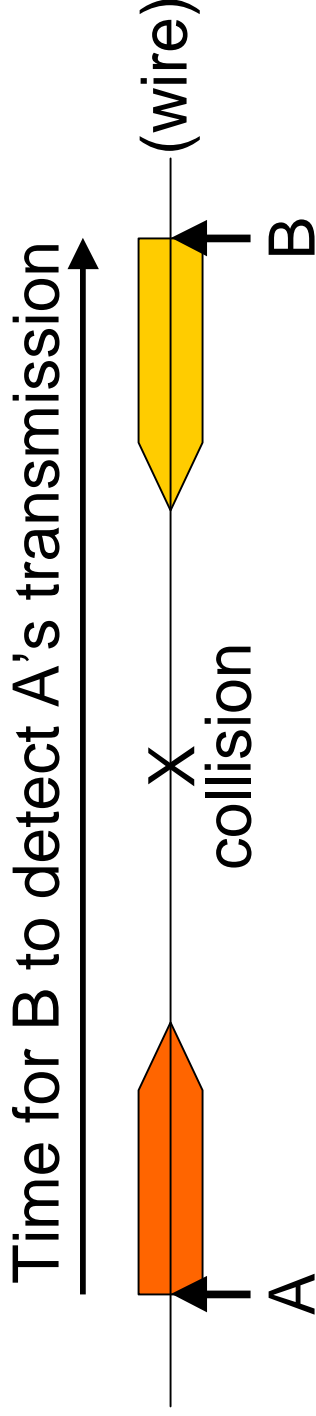
- We can do better by listening before we send (CSMA)
 - good defense against collisions only if “a” is small (LANs)

What if the Channel is Busy?

- 1-persistent CSMA
 - Wait until idle then go for it
 - Blocked senders can queue up and collide
- non-persistent CSMA
 - Wait a random time and try again
 - Less greedy when loaded, but larger delay
- p-persistent CSMA
 - If idle send with prob p until done; if busy wait a random time
 - Choose p so $p * \#$ senders < 1 ; avoids collisions at cost of delay

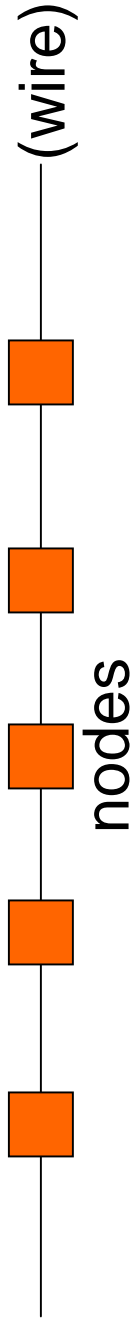
CSMA with Collision Detection

- Even with CSMA there can still be collisions. Why?
 - For wired media we can detect collisions and abort (CSMA/CD):
 - e.g., measure average voltage for Manchester encoding
 - Requires a minimum frame size (“acquiring the medium”)
 - B must continue sending (“jam”) until A detects collision

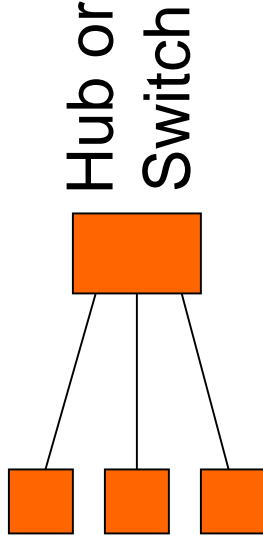


Ethernet

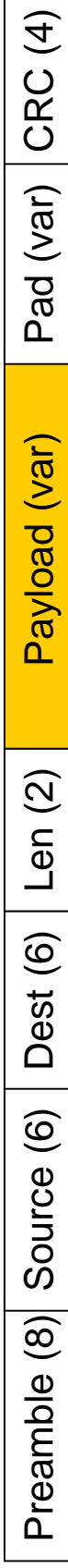
- IEEE 802.3 standard wired LAN (1-persistent CSMA/CD)
- Classic Ethernet: 10 Mbps over coaxial cable
 - baseband signals, Manchester encoding, preamble, 32 bit CRC



- Newer standards
 - UTP, 100 Mbps (Fast), 1 Gbps
- Modern equipment
 - hubs and switches



Ethernet Frames



- Min frame 64 bytes, max 1500 bytes
- Max length 2.5km, max between stations 500m (repeaters)
- Addresses unique per adaptor; globally assigned
- Broadcast media is readily tapped:
 - Promiscuous mode; multicast addresses

Some Algorithm Details

- 1-persistent CSMA/CD
- On collision: jam and exponential backoff
- Jamming:
 - Send 48 bit sequence to ensure collision detection
- Backoff:
 - First collision: wait 0 or 1 frame times at random and retry
 - Second time: wait 0, 1, 2, or 3 frame times
 - Nth time ($N \leq 10$): wait 0, 1, ..., 2^{N-1} times
 - Max wait 1023 frames, give up after 16 attempts
 - Scheme balances average wait with load

Ethernet Capture

- Randomized access scheme is not fair
- Stations A and B always have data to send
 - They will collide at some time
 - Suppose A wins and sends, while B backs off
 - Next time they collide and B's chances of winning are halved!

Ethernet Performance

- Much better than Aloha or CSMA!
 - Works very well in practice
- Source of protocol inefficiency: collisions
 - More efficient to send larger frames
 - Acquire the medium and send lots of data
 - Less efficient as the network grows in terms of frames
 - recall “a” = delay / (frame size * transmission rate)
 - “a” grows as the path gets longer (satellite)
 - “a” grows as the bit rates increase (Fast, Gigabit Ethernet)

Ethernet Perspective



- Ethernet is wildly successful!
 - Simple yet effective
- What more could we want?
 - Deterministic service
 - Priorities
 - Scalable

Key Concepts



- FDMA, TDMA, CDMA are channel sharing techniques
- Data networks benefit from statistical multiplexing
- Ethernet (CSMA/CD): randomness can be effective