CSE/EE 461 – Lecture 3

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Last Time …

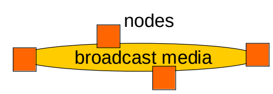
- How to send a message across a wire
  - Media and their transmission limits
  - Encoding data for clock recovery and framing
  - Detecting and correcting bit errors
- The Physical layer and some of the Data Link layer

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?



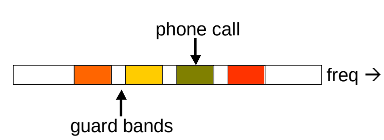
- Ideal solution for N nodes sharing bandwidth B bps:
  - high goodput (B), low delay (0), fair (B/N), decentralized, stable, and simple!

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

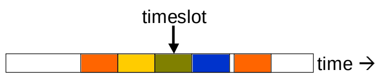
- Simultaneous transmission in different frequency bands
  - Analog: Radio/TV, AMPS cell phones (800MHz)
  - Also called Wavelength DMA (WDMA) for fiber



"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·B (sum of inner products) = A·C = B·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·A = 0+2+0+2 = 4 → A sent a "1"
- S·B = 0-2+0-2 = -4 → B send a "0"
- S·C = 0+2+0-2 = 0 → C didn't send

CDMA Continued

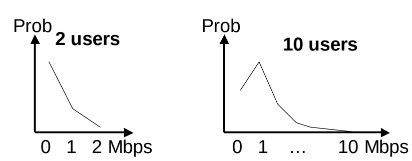
- Advantages:
  - Resistant to narrowband interference
  - Other senders appear as noise
  - Reuse of single frequency band
- Disadvantages:
  - Wideband
  - Synchronization
  - Power management

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, Prob(need 10 Mbps) = 10^{-10}
- So keep adding users …
- For 35 users, Prob(>10 active users) = 0.17%

- We can support three times as many users!

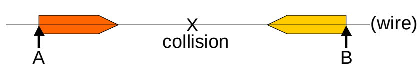
3. Random Access – ALOHA

- 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 = delay / (packet size * sending rate)
  - Small (<<1) for LANs, large (>>1) for satellites



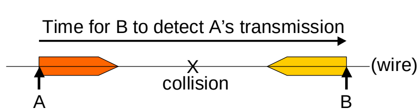
- We can do better by listening before we send (CSMA)
  - good defense against collisions only if "a" is small (LANs)

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

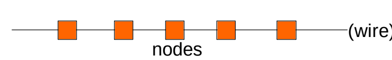
- Even with CSMA there can still be collisions. Why?



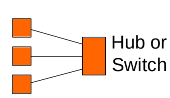
- For wired media we can detect collisions and abort (CSMA/CD):
  - e.g., measure average voltage for Manchester encoding
  - Requires a minimum frame size ("acquiring the medium")
  - B must continue sending ("jam") until A detects collision

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

Preamble (8)	Source (6)	Dest (6)	Len (2)	Payload (var)	Pad (var)	CRC (4)

- 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<=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