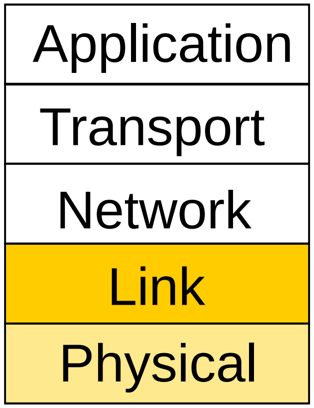
CSEP 561 – Multiple Access

David Wetherall
djw@cs.washington.edu

How to share a channel

- Topics:
  - Multiplexing methods (context)
  - Statistical multiplexing (general principle)
  - Random access protocols (designs)
  - Contention-free protocols (designs)

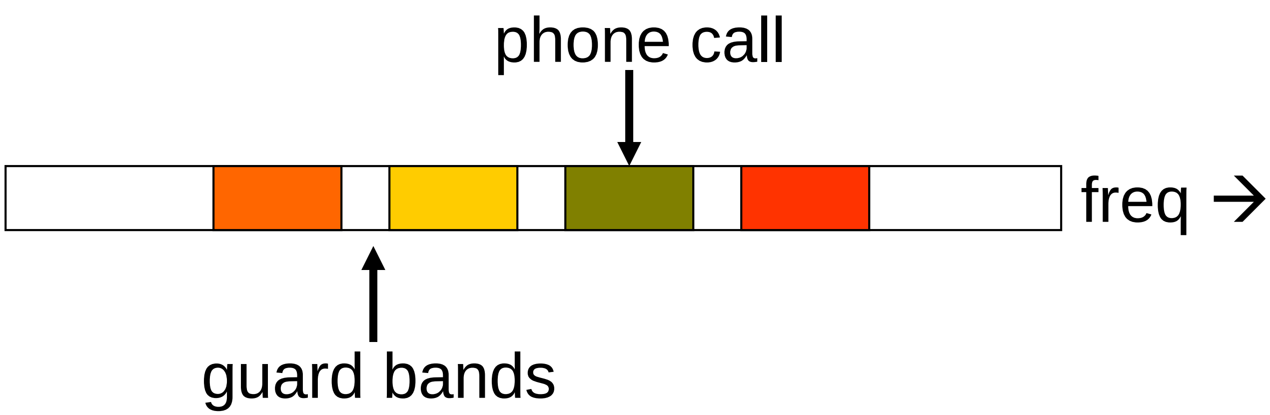


Basic multiplexing methods

- Division permits multiple “users” to share the channel
- Divide channels over:
  - Time (TDM)
  - Frequency, or wavelength (FDM / WDM)
  - Codes (CDMA)
  - Also spatial for wireless, e.g., directional antenna
- Often used in combination
  - E.g., 802.11 uses FDM for 20 MHz channels, then dynamic TDM as stations take turns, then FDM via OFDM within the channel to combat wireless degradations. Wow!

Frequency Division Multiple Access

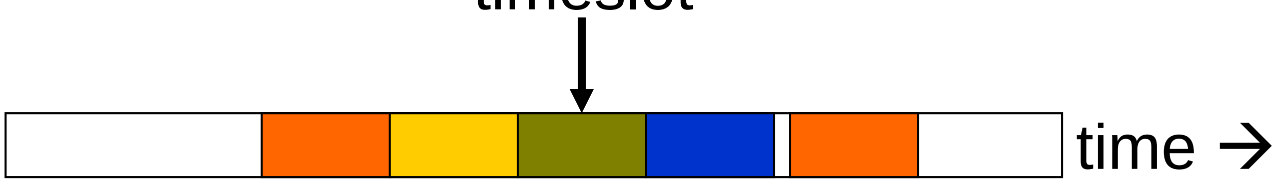
- Simultaneous transmission in different frequency bands
  - Analog: Radio/TV, AMPS cell phones (800MHz)
  - Also called Wavelength DMA (WDMA) for fiber



"Speaking at different pitches"

Time Division Multiple Access

- 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)

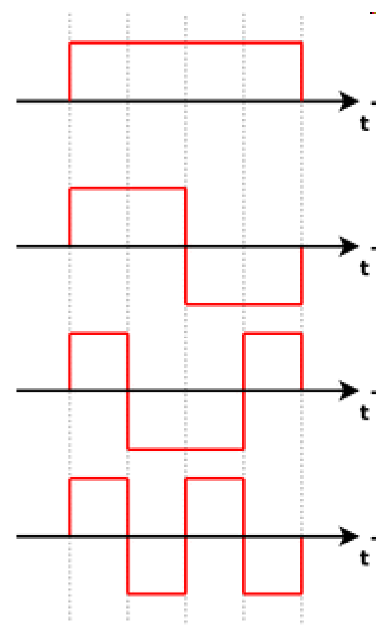


"Speaking at different times"

- Advantage: lower delay; Disadvantage: synchronization

Code Division Multiple Access

- Give each user a different code (right)
  - Send +ve or –ve code for 1/0
  - All users send at once
  - Uses bandwidth for N users
    - “chip rate” >> data rate
  - Mixes time and frequency
- Codes are orthogonal to each other
  - Can correlate for one code
    - This will ignore the rest
- Widely used for 3G mobile phones



Four “4 chip” orthogonal codes

Statistical Multiplexing

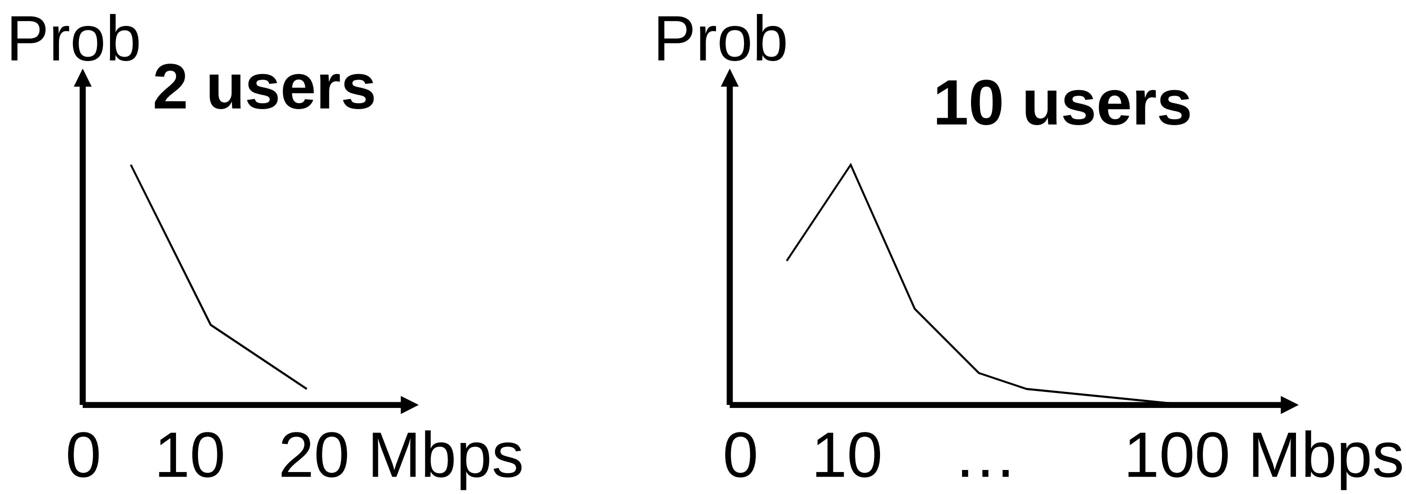
- Static partitioning schemes are not suited to data communications where peak rate >> average rate.

- If we share on demand we can support more users
  - Based on the statistics of their transmissions
  - Occasionally we might be oversubscribed
  - This is called statistical multiplexing

- Statistical multiplexing is heavily used in data networks
  - But only at a high-level (tied to users) – this is a poor model for the details of traffic due to heavy-tailed distributions.

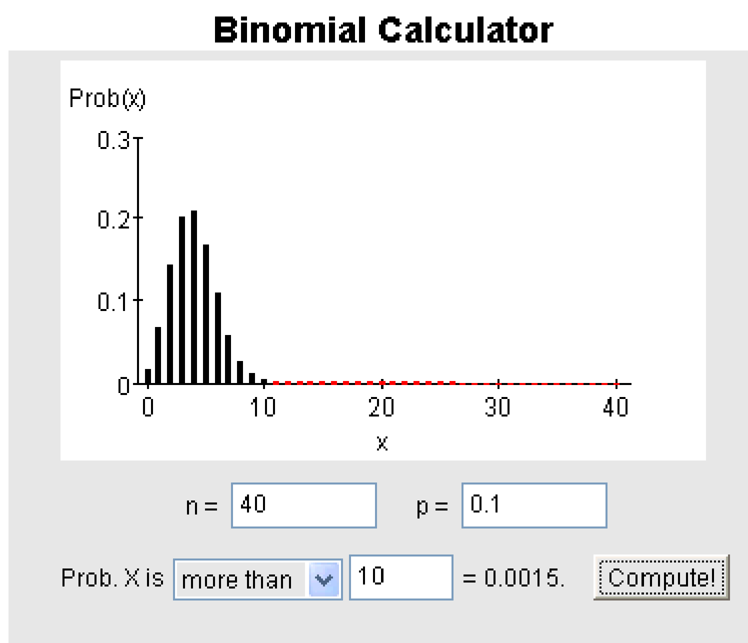
Example

- DSL user sends at 10 Mbps but is idle 90% of the time.
- What are the likely loads if we share on demand?
  - Say 100 Mbps channel; 10 users if statically allocated



Example continued

- For 10 users, Prob(need 100 Mbps) = 10^{-10} Not likely!
- For 40 users, Prob(>10 active users) = 0.15%, very low!



- We can support 4X users!
- But: important caveats …

Random Access Protocols

- Let stations try to send when they have traffic
  - Contention leads to collisions (inefficiency, non-determinism)

- Designs:
  - Aloha
  - (greedy) Carrier Sense Multiple Access (CSMA)
  - (non-greedy) CSMA (p-persistent, CSMA/CA)
  - (greedy) CSMA with Collision Detection (CSMA/CD)
  - Above with Binary Exponential Backoff

- In increasing order of sophistication and performance

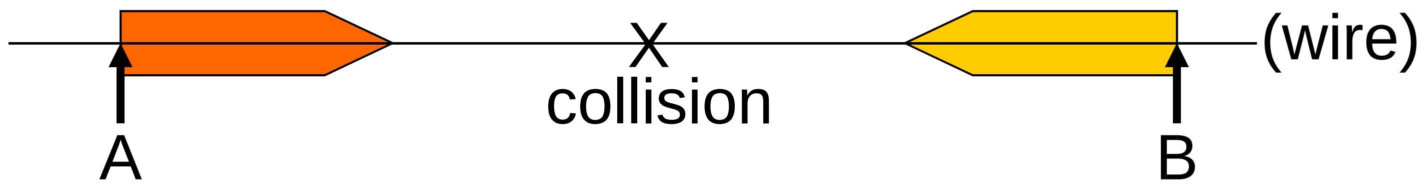
ALOHA

- 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

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



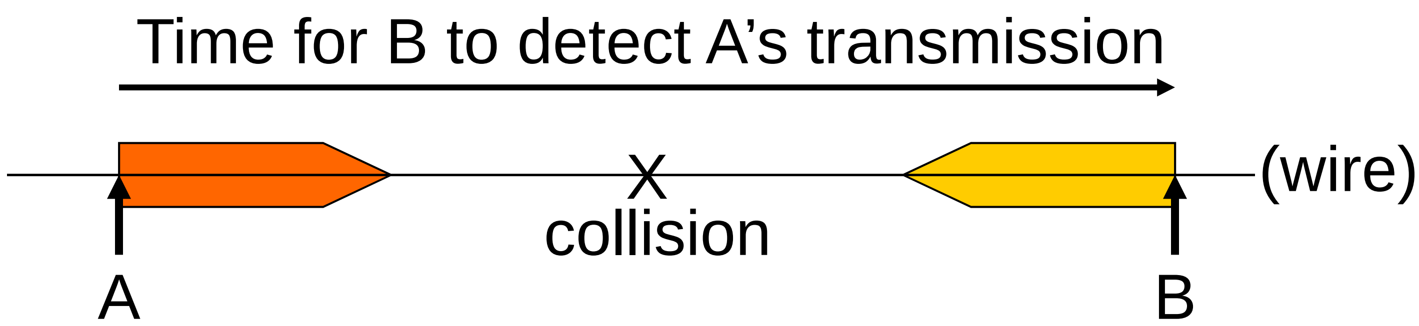
- “a” parameter: number of packets that fit on the wire
  - a = bandwidth * delay / packet size; a BD product measure
  - Small (<<1) for LANs, large (>>1) for satellites

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; assumed slotted time
  – Choose p so p * # senders < 1; avoids collisions at cost of delay
  – CSMA/CA ("Collision Avoidance") used in 802.11 is a refinement of p-persistence

CSMA with Collision Detection

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



- For wired media we can detect all collisions and abort (CSMA/CD):
  – Requires a minimum frame size ("acquiring the medium")
  – B must continue sending ("jam") until A detects collision

Binary Exponential Backoff

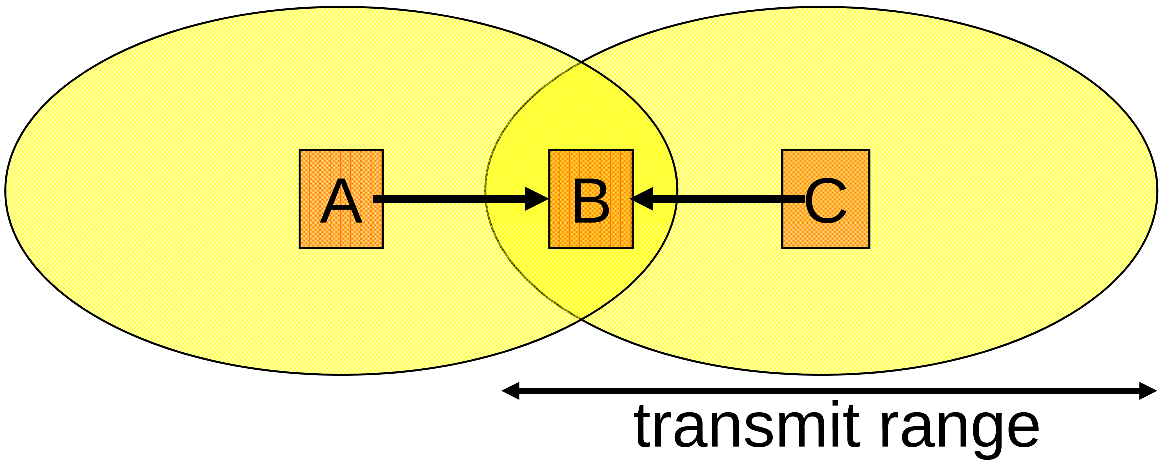
- Build on CSMA to balance average wait with load
  - Become less greedy if there is more contention
- On collision: jam and exponential backoff
  - Jamming: send 48 bit sequence to ensure collision detection
- Backoff:
  - First collision: wait 0 or 1 frame times at random and retry
  - Second time: 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
- Classic Ethernet is “1-persistent CSMA/CD with BEB”

Wireless Multiple Access

Wireless is more complicated than wired …

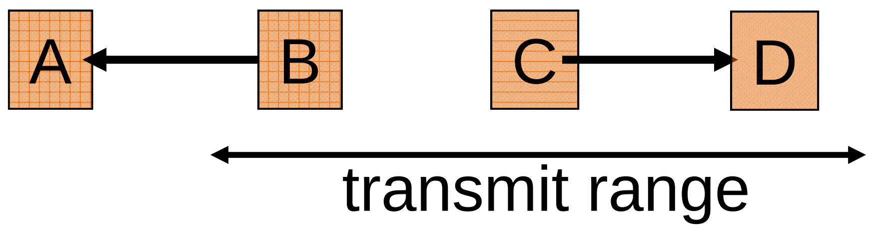
1. Cannot reliably detect collisions
   – Transmitter swamps co-located receiver
2. Different transmitters have different coverage areas
   – Asymmetries lead to hidden/exposed terminal problems

Hidden Terminals

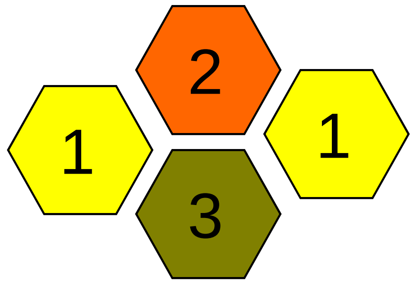


- A and C can both send to B but can’t hear each other
  - A is a hidden terminal for C and vice versa
- CSMA not always effective – want to sense at receiver

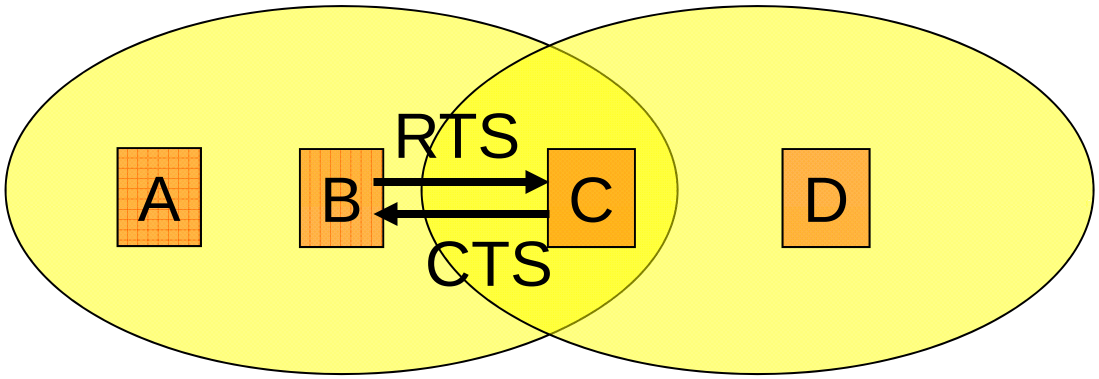
Exposed Terminals



- B, C can hear each other but can safely send to A, D

- Compare to spatial  reuse in cell phones:

Aside: RTS / CTS for hidden terminals



1. B stimulates C with Request To Send (RTS)
2. A hears RTS and defers to allow the CTS
3. C replies to B with Clear To Send (CTS)
4. D hears CTS and defers to allow the data
5. B sends to C

Contention-free Protocols

- Collisions are the main difficulty with random schemes
- Q: Can we avoid collisions altogether?
- A: Yes. By taking turns or with reservations
- More generally, what else might we want?
  - Deterministic service, priorities/QOS, reliability

- Combinations are possible too:
  - To improve efficiency/scalability, many schemes grant ongoing bandwidth and use random schemes for request traffic
  - E.g., cable modems, 3G wireless

FDDI (Fiber Distributed Data Interface)

- Roughly a large, fast token ring
  - 100 Mbps and 200km
  - Dual counter-rotating rings for redundancy
  - Complex token holding policies for voice etc. traffic
- Token ring advantages
  - No contention, bounded access delay
  - Support fair, reserved, priority access
- Disadvantages
  - Complexity, reliability, scalability