Lecture 2
Wireless & 802.11

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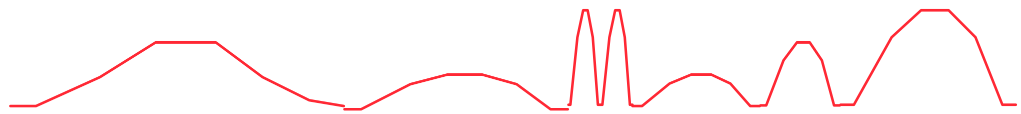
From Signals to Packets

Analog Signal



“Digital” Signal

Bit Stream

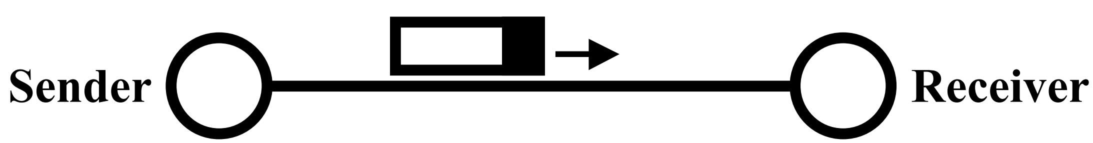
0 0 1 0 1 1 1 0 0 0 1

Packets

0100010101011100101010101011101110000001111010101110101010101101011010111001

Header/Body **Header/Body** **Header/Body**

Packet Transmission



Today's Lecture

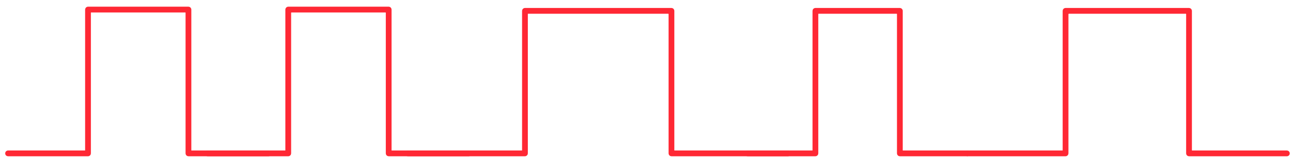
- Modulation.
- Bandwidth limitations.
- Frequency spectrum and its use.
- Multiplexing.

- Coding.
- Framing.

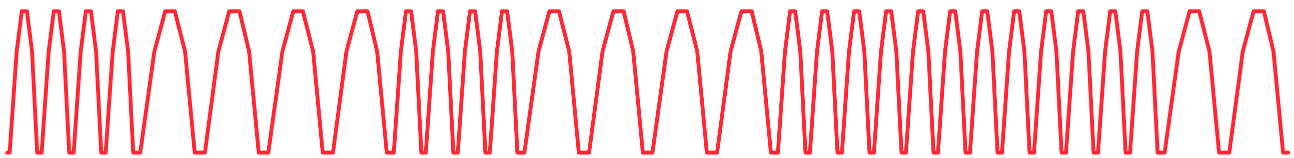
Modulation

- Sender changes the nature of the signal in a way that the receiver can recognize.
  - » Similar to radio: AM or FM
- Digital transmission: encodes the values 0 or 1 in the signal.
  - » It is also possible to encode multi-valued symbols
- Amplitude modulation: change the strength of the signal, typically between on and off.
  - » Sender and receiver agree on a “rate”
  - » On means 1, Off means 0
- Similar: frequency or phase modulation.
- Can also combine method modulation types.

Amplitude and Frequency Modulation



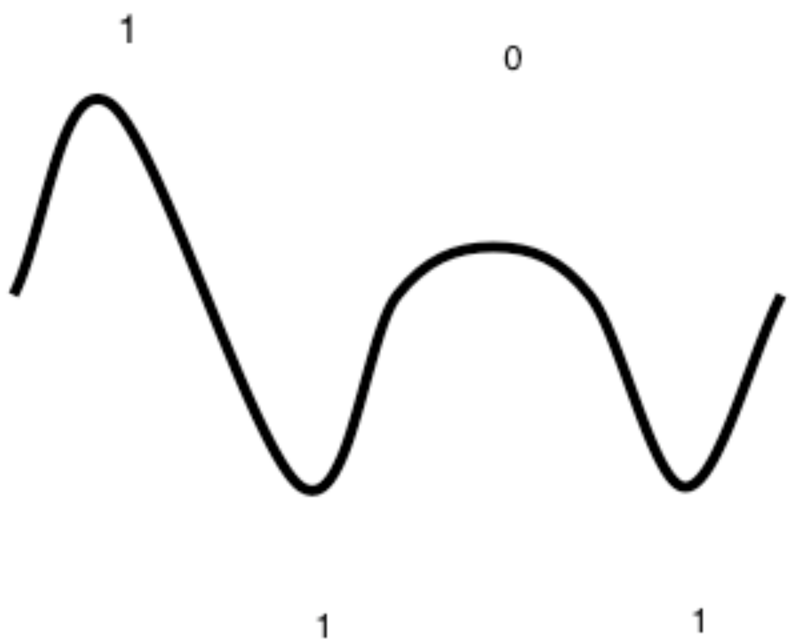
0 0 1 1 0 0 1 1 0 0 0 1 1 1 0 0 0 1 1 0 0 0 1 1 1 0



0 1 1 0 1 1 0 0 0 1

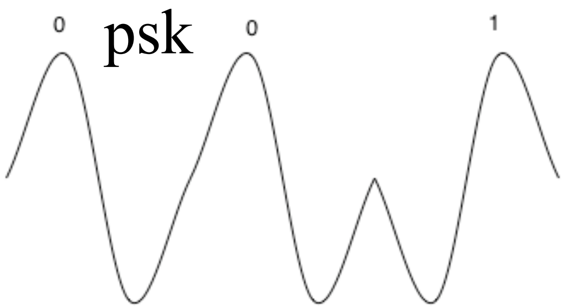
The Nyquist Limit

- A noiseless channel of width H can at most transmit a binary signal at a rate 2 x H.
  - » E.g. a 3000 Hz channel can transmit data at a rate of at most 6000 bits/second
  - » Assumes binary amplitude encoding

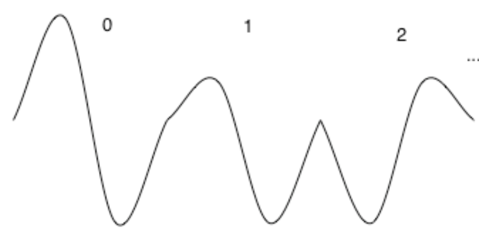


Past the Nyquist Limit

- More aggressive encoding can increase the channel bandwidth.
  - » Example: modems
    - – Same *frequency* - number of symbols per second
    - – Symbols have more possible values



Psk
+
AM



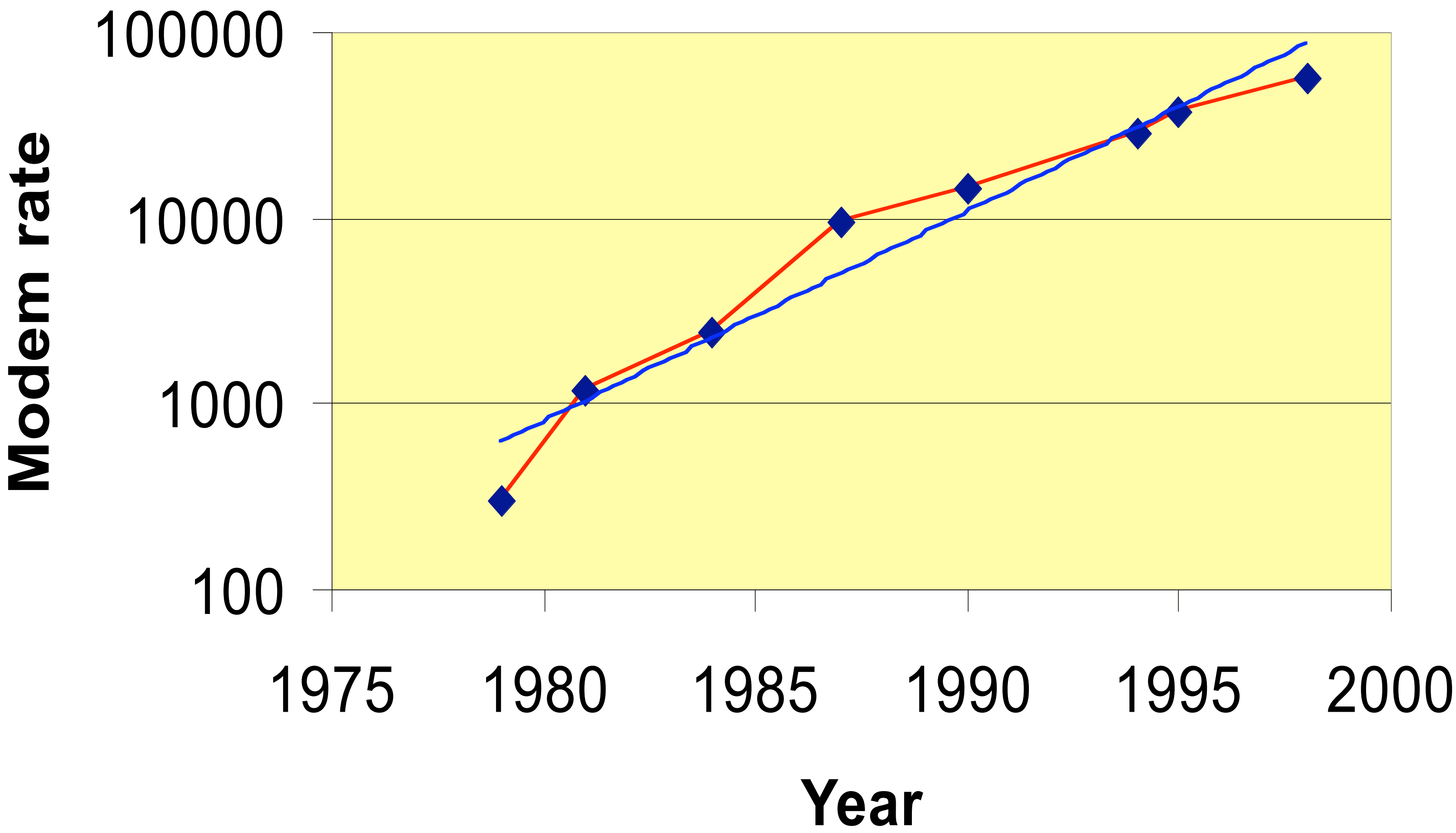
- Every transmission medium supports transmission in a certain frequency range.
  - » The channel bandwidth is determined by the transmission medium and the quality of the transmitter and receivers
  - » Channel capacity increases over time

Capacity of a Noisy Channel

- Can't add infinite symbols - you have to be able to tell them apart. This is where noise comes in.

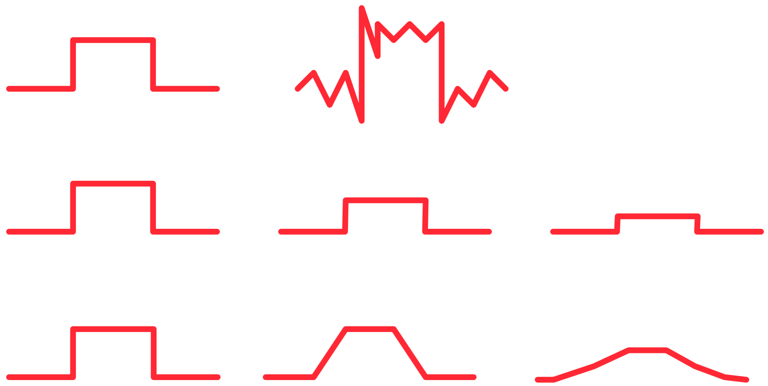
- Shannon's theorem:
  - » C = B x log(1 + S/N)
  - » C: maximum capacity (bps)
  - » B: channel bandwidth (Hz)
  - » S/N: signal to noise ratio of the channel
    - – Often expressed in decibels (db). 10 log(S/N).
- Example:
  - » Local loop bandwidth: 3200 Hz
  - » Typical S/N: 1000 (30db)
  - » What is the upper limit on capacity?
    - – Modems: Teleco internally converts to 56kbit/s digital signal, which sets a limit on B and the S/N.

Example: Modem Rates



Limits to Speed and Distance

- Noise: “random” energy is added to the signal.
- Attenuation: some of the energy in the signal leaks away.
- Dispersion: attenuation and propagation speed are frequency dependent.
  - » Changes the shape of the signal



- Attenuation: Loss (dB) = 20 log(4 pi d / lambda)
  - Loss ratio is proportional to: square of distance, frequency
- BUT: Antennas can be smaller with higher frequencies
  - Gain can compensate for the attenuation…

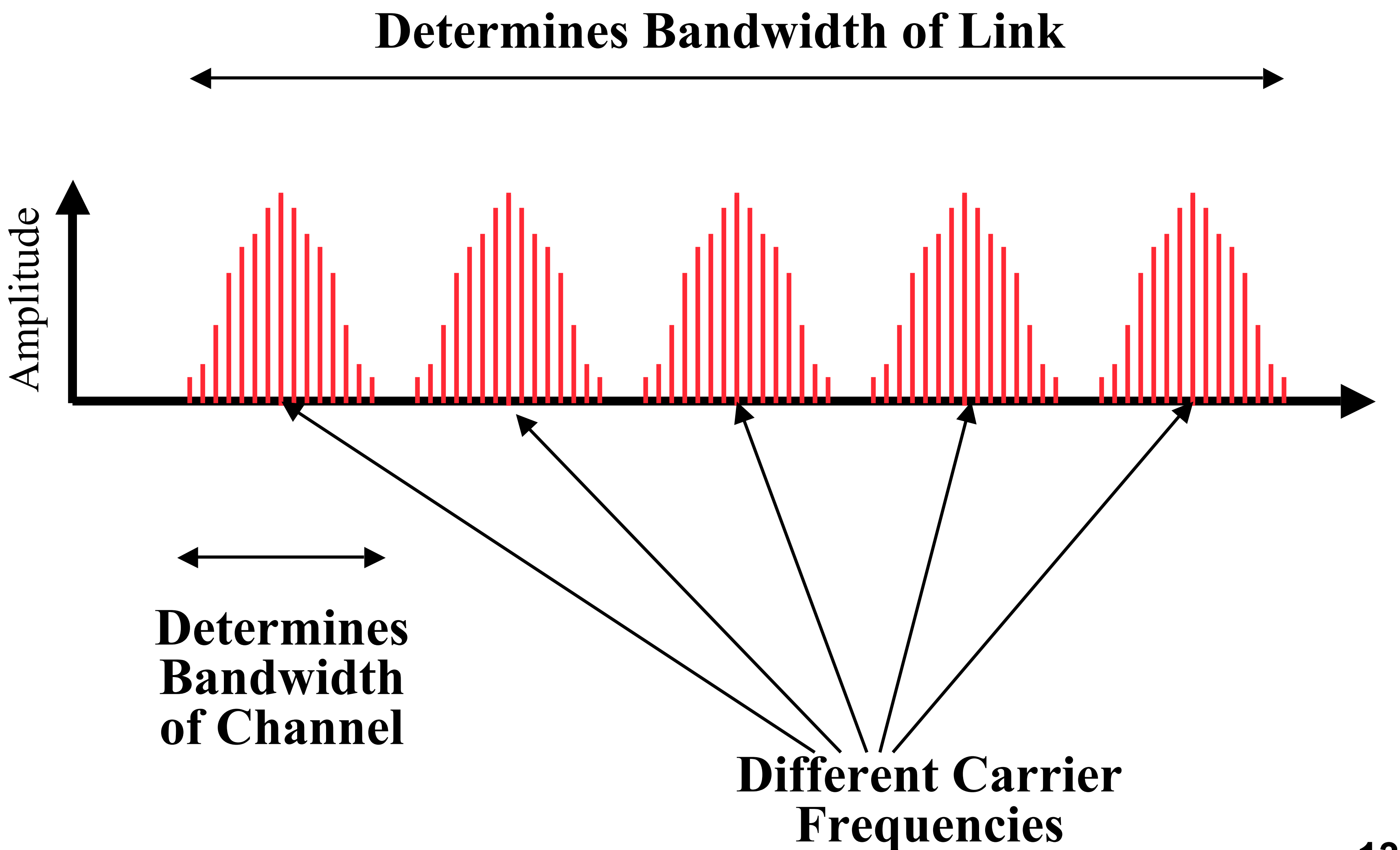
Modulation vs. BER

- More symbols =
  - » Higher data rate: More information per baud
  - » Higher bit error rate: Harder to distinguish symbols
- Why useful?
  - » 802.11b uses DBPSK (differential binary phase shift keying) for 1Mbps, and DQPSK (quadriture) for 2, 5.5, and 11.
  - » 802.11a uses four schemes - BPSK, PSK, 16-QAM, and 64-AM, as its rates go higher.
- Effect: If your BER / packet loss rate is too high, drop down the speed: more noise resistance.
- We'll see in some papers later in the semester that this means noise resistance isn't always linear with speed.

Interference and Noise

- Noise figure: Property of the receiver circuitry. How good amplifiers, etc., are.
  - Noise is random white noise. Major cause: Thermal agitation of electrons.
- Attenuation is also termed “large scale path loss”
- Interference: Other signals
  - Microwaves, equipment, etc. But not only source:
  - Multipath: Signals bounce off of walls, etc., and cancel out the desired signal in different places.
  - Causes “small-scale fading”, particularly when mobile, or when the reflective environment is mobile. Effects vary in under a wavelength.

Frequency Division Multiplexing: Multiple Channels



Wireless Technologies

- Great technology: no wires to install, convenient mobility, ..
- High attenuation limits distances.
  - » Wave propagates out as a sphere
  - » Signal strength reduces quickly $(1/\text{distance})^3$
- High noise due to interference from other transmitters.
  - » Use MAC and other rules to limit interference
  - » Aggressive encoding techniques to make signal less sensitive to noise
- Other effects: multipath fading, security, ..
- Ether has limited bandwidth.
  - » Try to maximize its use
  - » Government oversight to control use

Antennas and Attenuation

- Isotropic Radiator: A theoretical antenna
  - Perfectly spherical radiation.
  - Used for reference and FCC regulations.
- Dipole antenna (vertical wire)
  - Radiation pattern like a doughnut
- Parabolic antenna
  - Radiation pattern like a long balloon
- Yagi antenna (common in 802.11)
  - Looks like |--|--|--|--|--|--|
  - Directional, pretty much like a parabolic reflector

Antennas

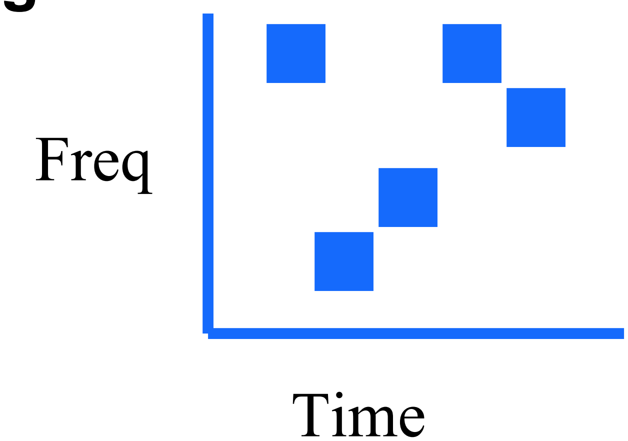
- **Spatial reuse:**
  - » **Directional antennas allow more communication in same 3D space**
- **Gain:**
  - » **Focus RF energy in a certain direction**
  - » **Works for both transmission and reception**
- **Frequency specific**
  - » **Frequency range dependant on length / design of antenna, relative to wavelength.**
- **FCC bit: Effective Isotropic Radiated Power. (EIRP).**
  - » Favors directionality. E.g., you can use an 8dB gain antenna b/c of spatial characteristics, but not always an 8dB amplifier.

Spread Spectrum and CDMA

- Basic idea: Use a wider bandwidth than needed to transmit the signal.
- Why??
  - » Resistance to jamming and interference
    - – If one sub-channel is blocked, you still have the others
  - » Pseudo-encryption
    - – Have to know what frequencies it will use
- Two techniques for spread spectrum…

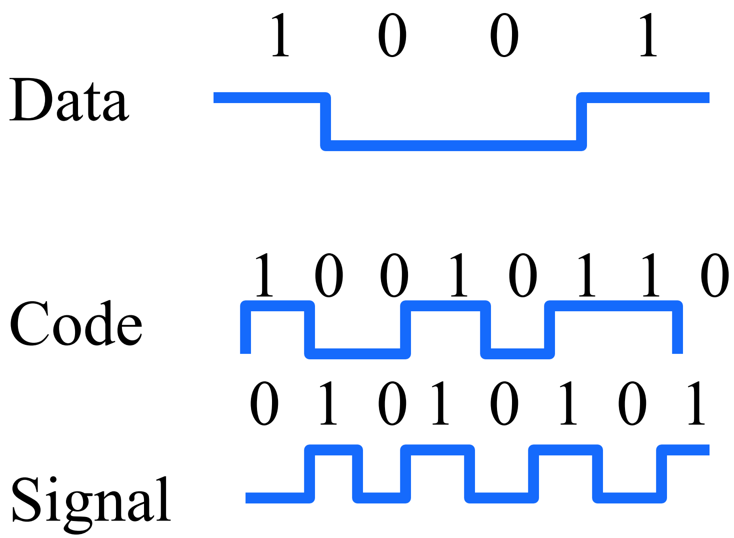
Frequency Hopping SS

- Pick a set of frequencies within a band
- At each time slot, pick a new frequency
  - » Ex: original 1Mbit 802.11 used 300ms time slots
- Frequency determined by a pseudorandom generator function with a shared seed.



Direct Sequence SS

- Use more bandwidth than you need to
  - » Generate extra bits via a spreading sequence



CDMA

- **DSS with orthogonal codes**
  - » **If receiver is using code 'A':**
    - – **Data xor A = signal**
    - – **Output = sum(signal xor A)**
  - » **Let's say someone else transmits with code 'B' at the same time:**
    - – **Signal = Data xor A + other xor B**
    - – **Output: sum((signal xor A + other xor B) xor A)**
      - = Data if A and B or *orthogonal* (dot product is zero)
      - Ex: A: 1 -1 -1 1 -1 1
      - B: 1 1 -1 -1 1 1
      - Decode function: sum (bitwise received)
      - Rx A1: 1*1 + -1*-1 + -1*-1 + 1*1 + -1*-1 + 1*1 = 6
      - A1 + B1 signal: 2 0 -2 0 0 2
      - Decode at A: 2*1 + 0 + -2*-1 + 0 + 0 + 2*1 = 6 (!)
  - » **In practice: use pseudorandom numbers, depend on balance and uniform distribution to make other transmissions look like noise.**

CDMA, continued

- Lots of codes
  - Useful if many transmitters are quiescent

Medium Access Control

- Think back to Ethernet MAC:
  - » Wireless is a shared medium
  - » Transmitters interfere
  - » Need a way to ensure that (usually) only one person talks at a time.
    - – Goals: Efficiency, possibly fairness
- But wireless is harder!
  - » Can’t really do collision detection:
    - – Can’t listen while you’re transmitting. You overwhelm your antenna…
  - » Carrier sense is a bit weaker:
    - – Takes a while to switch between Tx/Rx.
  - » Wireless is not perfectly broadcast

Hidden and Exposed Terminal

- A B C
- When B transmits, both A and C hear.
- When A transmits, B hears, but C does not
- … so C doesn’t know that if it transmits, it will clobber the packet that B is receiving!
  - » Hidden terminal
- When B transmits to A, C hears it…
  - » … and so mistakenly believes that it can’t send anything to a node other than B.
  - » Exposed terminal

MAC discussion

802.11 particulars

- 802.11b (WiFi)
  - » Frequency: 2.4 - 2.4835 Ghz DSSS
  - » Modulation: DBPSK (1Mbps) / DQPSK (faster)
  - » Orthogonal channels: 3
    - – There are others, but they interfere. (!)
  - » Rates: 1, 2, 5.5, 11 Mbps
- 802.11a: Faster, 5Ghz OFDM. Up to 54Mbps
- 802.11g: Faster, 2.4Ghz, up to 54Mbps

802.11 details

- Fragmentation
  - 802.11 can fragment large packets (this is separate from IP fragmentation).
- Preamble
  - 72 bits @ 1Mbps, 48 bits @ 2Mbps
  - Note the relatively high per-packet overhead.
- Control frames
  - RTS/CTS/ACK/etc.
- Management frames
  - Association request, beacons, authentication, etc.

802.11 DCF

- Distributed Coordination Function (CSMA/CA)
- Sense medium. Wait for a DIFS (50 μs)
- If busy, wait ‘till not busy. Random backoff.
- If not busy, Tx.
- Backoff is binary exponential

- Acknowledgements use SIFS (short interframe spacing). 10 μs.

802.11 RTS/CTS

- RTS sets “duration” field in header to
  - CTS time + SIFS + CTS time + SIFS + data pkt time
- Receiver responds with a CTS
  - Field also known as the “NAV” - network allocation vector
  - Duration set to RTS dur - CTS/SIFS time
  - This reserves the medium for people who hear the CTS

802.11 modes

- Infrastructure mode
  - » All packets go through a base station
  - » Cards associate with a BSS (basic service set)
  - » Multiple BSSs can be linked into an Extended Service Set (ESS)
    - – Handoff to new BSS in ESS is pretty quick
      - Wandering around CMU
    - – Moving to new ESS is slower, may require re-addressing
      - Wandering from CMU to Pitt
- Ad Hoc mode
  - » Cards communicate directly.
  - » Perform some, but not all, of the AP functions

802.11 continued

- 802.11b packet header: (MPDU has its own)

Preamble	PLCP header	MPDU

56 bits sync	16 bit Start of Frame

Signal 8 bits	Service 8 bits	Length 16 bits	CRC 16 bits

802.11 packet

FC D/I Addr Addr SC Addr DATA FCS