Announcements

- HW due Fri; last HW posted, due Friday 12/9 at 4 pm (no late HWs)
- MIMO decoder supplemental handout posted
- Lectures next week are Monday 12/5 12-1:20 (Thornton 102 with lunch) and Friday 12/9 9:30-11:30 (here, rm 18, Huang, with donuts)
- Final info (coverage, format, extra OHs, etc) given in 12/5 lecture
- End-of-Quarter bonus lecture+course summary will be 12/9 lecture2 from 4-6pm (12-2pm is backup) with lunch or dinner.
- Final exam 12/15, 12:15pm-3:15pm
- Final projects must be posted 12/5 at midnight.

Spread Spectrum

- Direct sequence (DSSS)
- ISI and Interference Rejection of DSSS
- Time and Frequency Domain Analysis

Introduction to Multiuser Systems
Review of Last Lecture

OFDM: Overlapping Subcarriers and FFT Implementation

- Overlapping subcarriers reduces BW by factor of 2
- Use IFFT at TX to modulate symbols on each subcarrier
- Cyclic prefix makes linear convolution of channel circular, so no interference between FFT blocks in RX processing
- Reverse structure (with FFT) at receiver
Review Continued

OFDM Design Issues

- Timing/frequency offset:
  - Impacts subcarrier orthogonality; self-interference

- Peak-to-Average Power Ratio (PAPR)
  - Adding subcarrier signals creates large signal peaks
  - Solve with clipping or PAPR-optimized coding

- Mitigation for fading across subcarriers
  - Precoding (fading inversion): Used in DSL as there is minimal deep fades, not used in wireless systems
  - Adaptive modulation: data rate (and power) adapted to subcarrier SNR. Used in LTE and 802.11a-g-n-ac
  - Coding across subcarriers: bits are encoded into a block code of length N for N subcarriers. Each coded symbol is sent on a different subcarrier.
Intro. to Spread Spectrum

- Modulation that increases signal BW
  - Mitigates or coherently combines ISI
  - Mitigates narrowband interference/jamming
  - Hides signal below noise (DSSS) or makes it hard to track (FH)
  - Also used as a multiple access technique

- Two types
  - Frequency Hopping:
    - Narrowband signal hopped over wide bandwidth
  - Direction Sequence:
    - Modulated signal multiplied by faster chip sequence
Direct Sequence Spread Spectrum

- Bit sequence modulated by chip sequence
- Spreads bandwidth by large factor (G)
- Despread by multiplying by $s_c(t)$ again ($s_c^2(t) = 1$)
- Mitigates ISI and narrowband interference
ISI and Interference Rejection

- **Narrowband Interference Rejection (1/K)**
  
  Info. Signal
  
  $S(f)$
  
  Receiver Input
  
  $S(f) \ast S_c(f)$
  
  Despread Signal
  
  $I(f) \ast S_c(f)$

- **Multipath Rejection (Autocorrelation $\rho(\tau)$)**
  
  Info. Signal
  
  $S(f)$
  
  Receiver Input
  
  $S(f) \ast S_c(f)[\alpha \delta(t) + \beta(t-\tau)]$
  
  Despread Signal
  
  $\alpha S(f)$
  
  $\beta \rho S'(f)$

Can coherently combine all multipath components via a RAKE receiver
Multiuser Channels: Uplink and Downlink

**Uplink (Multiple Access Channel or MAC):**
Many Transmitters to One Receiver.

**Downlink (Broadcast Channel or BC):**
One Transmitter to Many Receivers.

Uplink and Downlink typically duplexed in time or frequency

Full-duplex radios are being considered for 5G systems
Bandwidth Sharing

- Frequency Division
- Time Division
- Code Division
  - Code cross-correlation dictates interference
  - Multiuser Detection
- Space (MIMO Systems)
- Hybrid Schemes
Main Points

- Spread spectrum increases signal bandwidth above that required for information transmission

- Benefits of spread spectrum:
  - ISI/narrowband interference rejection by spreading gain
  - Also used as a multiuser/multiple access technique

- Multiple users can share the same spectrum via time/frequency/code/space division