EE359 – Lecture 17 Outline

- **Announcements:**
  - New HW posted, due Friday
  - End-of-Quarter schedule and possible bonus lecture
    - No lecture March 5
    - Advanced topics lecture will extend last class March 12 (1-2:50 or 1:30-3:30)
    - Final exam: Tues March 17, 3:30-6:30pm, here. More details soon.

- **FFT implementation of MCM (OFDM)**
- **Implementation Challenges in OFDM**
- **Fading across Subcarriers**
- **MIMO-OFDM**

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**Review of Last Lecture**

- **MIMO RX Design** (see supplemental handout):
  - Optimal Receiver is ML: finds input symbol most likely to have resulted in received vector, exponentially complex in M.
  - Linear Receivers: First performs linear equalization: then quantizes to nearest constellation point.
    - Zero-Forcing: \( \hat{x} = \mathbf{A} y \) (if \( \mathbf{H} \) invertible, equals inverse, else \( \mathbf{H}^H (\mathbf{H}^H \mathbf{H})^{-1} \mathbf{H}^T \); forces off-diagonal terms to zero)
    - Minimum Mean Square Error: \( \hat{x} = \mathbf{A} y \mathbf{H}^T x \) (\( \frac{1}{\text{SNR}} \) balances zero forcing against noise enhancement)
  - Sphere Decoder: Uses QR decomposition of \( \mathbf{H} \)
    - Considers possibilities within sphere of transformed received symbol.
    - If minimum distance symbol is within sphere, optimal, otherwise null is returned

**Review Continued**

- **ISI Mitigation:** Can mitigate ISI with equalization (not covered), multicarrier modulation, or spread spectrum
- **Multicarrier Modulation:** breaks data into \( N \) substreams (\( B/N < B_c \)); Substreams modulated onto separate carriers
  - Substream passband BW is \( B/N \) for \( B \) total BW
  - \( B/N < B_c \) implies flat fading on each subcarrier (no ISI)
  - Can overlap channels for \( f_i - f_{i+1} = T_N = N/B \) (ortho. carriers)

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**How does this reduce search complexity?**

\[ \hat{x} = \arg \min |y - Hx| \]
\[ \hat{x} = \arg \min |Q^H y - Rx| \]

Need to compute \( |Q^H y - Rx| \) to see if less than \( r \)

- Use tree search and upper triangular properties of \( R \) to prune search for \( x = (x_1, x_2, x_3, \ldots, x_N) \)

If \( |Q^H y - x_1| > r \), prune entire branch
FFT Implementation of MCM (OFDM)

- 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

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
- Different fading across subcarriers
  - Mitigate by precoding (fading inversion), adaptive modulation over frequency, and coding across subcarriers
- MIMO-OFDM
  - Apply OFDM across each spatial dimension
  - Can adapt across space, time, and frequency
  - MIMO-OFDM represented by a matrix, extends matrix representation of OFDM alone (considered in HW)

Main Points

- MCM implemented with IFFTs/FFT (OFDM)
  - Block size depends on data rate relative to delay spread
- OFDM challenges: timing/frequency offset, PAPR
- Subcarrier fading degrades OFDM performance
  - Compensate through precoding (channel inversion), coding across subcarriers, or adaptation
- OFDM naturally combined with MIMO
  - Orthogonal in space/freq; extended matrix representation
  - 4G Cellular and 802.11n/ac/ax all use OFDM+MIMO