Lecture 16 - EE 359: Wireless Communications - Fall 2009

MIMO Beamforming and Diversity vs. Multiplexing. Multicarrier Modulation and OFDM

Lecture Outline

- **MIMO Systems: Beamforming and Diversity/Multiplexing Tradeoffs**
- **ISI Countermeasures**
- **Multicarrier Modulation**
- **Overlapping Subcarriers**
- **Fading Across Subchannels**

1. **MIMO Systems: Beamforming**
   - Beamforming sends the same symbol over each transmit antenna with a different scale factor.
   - At the receiver, all received signals are coherently combined using a different scale factor.
   - This produces a transmit/receiver diversity system, whose SNR can be maximized by optimizing the scale factors (MRC).
   - Beamforming leads to a much higher SNR than on the individual channels in the parallel channel decomposition.
   - Thus, there is a design tradeoff in MIMO systems between capacity and diversity.

2. **Diversity versus Multiplexing in MIMO Systems**
   - Can exchange data rate for probability of error.
   - Define rate scale factor $r = R/\log(SNR)$. Define diversity gain $d = \log)P_e)/\log(SNR)/$.
   - Can show (Zheng/Tse'02) that in high SNR regime, the optimal tradeoff is $d^*(r) = (M_t - r)(M_r - r)$..
   - The optimal operating point on this traedeoff curve depends on the application.

3. **MIMO System Design Issues**
   - Low Complexity Receivers: ML receivers are exponentially complex in the number of streams and constellation size. Reduced-complexity via sphere decoding, which only considers possibilities within a sphere of received symbol.
   - Space-time coding: MIMO adds a spatial dimension so that coded symbols can be mapped to both space and time via space-time block and convolutional codes. For OFDM systems, codes are also mapped over frequency tones.
   - Adaptive techniques: MIMO systems can adapt the use of transmit/receive antennas in addition to adapting modulation and coding.
   - Limited feedback: For adaptive systems with limited capacity on the feedback path, MIMO techniques must be developed that rely on only partial information about the channel.

4. **Delay Spread Countermeasures:**

   - Equalization: signal processing at receiver to remove ISI.
   - Multicarrier and spread spectrum modulation: transmission strategies to mitigate effects of delay spread on received signal.
   - Antenna solutions: change propagation environment to reduce delay spread.

5. **Multicarrier Modulation (MCM):**

   - Mitigates ISI by dividing the transmit bit stream into N substreams.
   - Each substream modulated by a separate subcarrier with signal bandwidth B/N.
   - N is made sufficiently large so that $B/N < B_c$, so substreams experience flat-fading.
   - MCM can be implemented using frequency division multiplexing.
   - More bandwidth-efficient implementation (OFDM) overlaps the transmitted substreams such that they can be separated at the receiver.

6. **Fading Across Subcarriers**

   - Frequency-selective fading leads to different gains (and BERs) on different carrier streams.
   - Can compensate using a frequency-domain equalizer, but leads to noise enhancement.
   - Precoding compensates for FS fading by inverting subcarrier fading at transmitter. Basically channel inversion: power inefficient. Also requires channel knowledge at transmitter.
   - Coding across subchannels sends each bit of a codeword on a different subcarrier. Takes advantage of frequency diversity.
   - Adaptive loading adapts power and rate on subcarriers relative to their gain. Optimization similar to that of adaptive modulation in time.

Main Points

- Multiple antennas can also be used for diversity via beamforming, this can be optimal for capacity.
- Fundamental tradoeff of diversity and multiplexing in MIMO.
- Many challenges in practical MIMO system design.
- ISI typically mitigated by equalization, multicarrier modulation, or spread spectrum. Equalization too complex for many high-speed systems.
- Multicarrier modulation splits data into narrowband (flat-fading) substreams.
- Multicarrier modulation made more bandwidth efficient by overlapping subchannels.
- Fading Across subchannels compensated by adaptive loading, precoding, or coding across subchannels.