MIMO RX Design, ISI Mitigation Techniques, Multicarrier Modulation and OFDM

Lecture Outline

1. MIMO Receiver Design
   - Optimal MIMO receiver is maximum-likelihood (ML) receiver. Finds input vector $\mathbf{x}$ that minimizes $|\mathbf{y} - \mathbf{Hx}|_F^2$ for $| \cdot |_F$ the Frobenius (matrix) norm.
   - This receiver is exponentially complex in the constellation size and number of transmitted data streams.
   - Can reduce complexity through linear processing of input vector $\mathbf{Ax}$.
   - Zero-forcing receiver forces all interference from other symbols to zero. This can result in significant noise enhancement.
   - MMSE receiver: trades off cancellation of interference from other symbols for noise enhancement. Reduces to zero forcing in the absence of noise.
   - Sphere Decoder: Approximates ML decoder, but only considers symbols that would result in an output, in the absence of noise, within a radius $r$ of the received vector. Can trade performance for complexity via choice of $r$. Decoding reduces to different methods for pruning the tree of possible inputs to be within the given radius (e.g. depth-first versus breadth-search versus other tree search algorithms have different performance tradeoffs).

2. ISI Countermeasures:
   - Equalization: signal processing at receiver to remove ISI. Too complex for high-speed systems with large delay spread.
   - Multicarrier modulation: send data over independent subcarriers at slow enough rate such that they experience flat-fading.
   - Spread spectrum modulation: Use properties of spreading codes to remove or coherently combine ISI at receiver.
   - Use directional antennas to reduce delay spread and ISI.
3. 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.

4. Overlapping Subcarriers
   - More bandwidth-efficient implementation (OFDM) than MCM overlaps the transmitted substreams such that they can be separated at the receiver.
   - For rectangular pulses, minimum required separation is $B/N$. Can be less if phases of subcarriers are aligned.

Main Points

- MIMO RX design trades complexity for performance. ML detector is optimal but exponentially complex. Linear decoders enhance noise. Sphere decoders allow performance vs. complexity tradeoff via radius; most common technique in practice.
- ISI typically mitigated by equalization, multicarrier modulation, spread spectrum, or antenna techniques. Equalization not used in current wireless standards due to complexity.
- Multicarrier modulation splits data into narrowband (flat-fading) substreams.
- Multicarrier modulation made more bandwidth efficient by overlapping subchannels.