EE359 – Lecture 17 Outline

- Announcements
  - Nima's OH hour Thurs moved to Sun 10am, Packard 3rd floor
  - HW due Sunday 5pm. No late HWs accepted
  - Bonus lecture info and remainder of course
  - Final info (coverage, review, extra OHs, etc) given 12/5
- Review of Last Lecture
- MIMO Sphere Decoders
- Other MIMO Design Issues
- Introduction to ISI Countermeasures
- Multicarrier Modulation
- Overlapping Substreams
- Fading across subcarriers

Remainder of Course

- Today: Sphere-Decoders, MIMO Design Issues, and Multicarrier modulation
- Wednesday: OFDM and Spread Spectrum
  - Lecture will end around 10:35am
- Dec. 5: Spread spectrum
- Bonus lecture: Dec. 5 6-8pm, Hewlett 103
  - Finish Spread Spectrum
  - Class summary
  - Advanced topics in wireless
- Class Ends (no lecture Dec. 7)

MIMO Receiver Design

- Decision-Feedback receiver: Clarification of last lecture
  - QR decomposition: $H=QR$; Q unitary ($M_r x M_t$), R triangular
  - For $M_r>M_t$, $Q^H Q=I_{M_t}$; R is $M_t x M_t$ and upper triangular
  - Use linear transformation on output vector y: $\tilde{y}=Q^H y=Ry+Q^H n$
    - Note that $\tilde{y}$ has dimension M_t (Q^H is $M_t x M_r$)

$$\begin{bmatrix} \tilde{y}_1 \\ \tilde{y}_2 \\ \vdots \\ \tilde{y}_{M_t} \end{bmatrix} = \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1M_t} \\ 0 & r_{22} & \cdots & r_{2M_t} \\ \vdots & \ddots & \ddots & \vdots \\ 0 & 0 & 0 & r_{M_t M_t} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ \vdots \\ x_{M_t} \end{bmatrix} + \begin{bmatrix} \tilde{n}_1 \\ \tilde{n}_2 \\ \vdots \\ \tilde{n}_{M_t} \end{bmatrix}$$

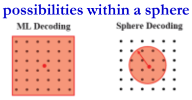
$$\tilde{y}_{M_t} = r_{M_t M_t} x_{M_t} + \tilde{n}_{M_t} \Rightarrow \tilde{x}_{M_t}$$

$$\tilde{y}_{M_{t-1}} = r_{(M_t-1)(M_t-1)} x_{M_t-1} + r_{(M_t-1)M_t} x_{M_t} + \tilde{n}_{(M_t-1)} \Rightarrow \tilde{x}_{M_t-1}$$

$$\vdots$$

$$\tilde{x}_1$$

- Sphere Decoder:
  - Only considers possibilities within a sphere of received symbol.



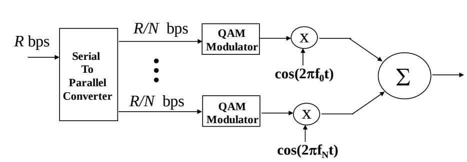
Other MIMO Design Issues

- Space-time coding:
  - Map symbols to both space and time via space-time block and convolutional codes.
  - For multicarrier/OFDM systems, codes are also mapped over frequency tones.
- Adaptive techniques:
  - Fast and accurate channel estimation
  - Adapt the use of transmit/receive antennas
  - Adapting modulation and coding.
- Limited feedback:
  - Partial CSI introduces interference in parallel decomp: can use interference cancellation at RX
  - TX codebook design for quantized channel

ISI Countermeasures

- Equalization
  - Signal processing at receiver to eliminate ISI, must balance ISI removal with noise enhancement
  - Can be very complex at high data rates, and performs poorly in fast-changing channels
  - Not that common in state-of-the-art wireless systems
- Multicarrier Modulation
  - Break data stream into lower-rate substreams modulated onto narrowband flat-fading subchannels
- Spread spectrum
  - Superimpose a fast (wideband) spreading sequence on top of data sequence, allows resolution for combining or attenuation of multipath components.

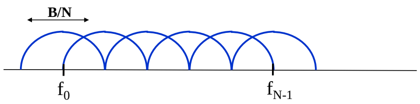
Multicarrier Modulation



- Breaks data into N substreams
- Substream modulated onto separate carriers
  - Substream bandwidth is B/N for B total bandwidth
  - $B/N<B_c$ implies flat fading on each subcarrier (no ISI)

Overlapping Substreams

- Can have completely separate subchannels
  - Required passband bandwidth is B.
- OFDM overlaps substreams
  - Substreams (symbol time T_N) separated in RX
  - Minimum substream separation is $B_N/(1+\beta)$.
  - Total required bandwidth is B/2 (for $T_N=1/B_N$)



Fading Across Subcarriers

- Leads to different BERS
- Compensation techniques
  - Frequency equalization (noise enhancement)
  - Precoding
  - Coding across subcarriers
  - Adaptive loading (power and rate)

Main Points

- MIMO RX design trades complexity for performance
  - Sphere decoders allow performance tradeoff via radius
  - Adaptation requires fast/accurate channel estimation
  - Limited feedback introduces interference between streams: requires codebook design
- ISI can be mitigated through equalization, multicarrier modulation (MCM) or spread spectrum
  - Today, equalizers often too complex or can't track channel.
- MCM splits channel into NB flat fading subchannels
  - Subcarrier fading degrades MCM performance
  - Compensate through precoding (channel inversion), coding across subcarriers, or adaptation