EE359 – Lecture 15 Outline

- Review of Last Lecture
- Introduction to MIMO Systems
- MIMO Channel Decomposition
- MIMO Channel Capacity
- Beamforming
- Diversity vs. Multiplexing Tradeoffs

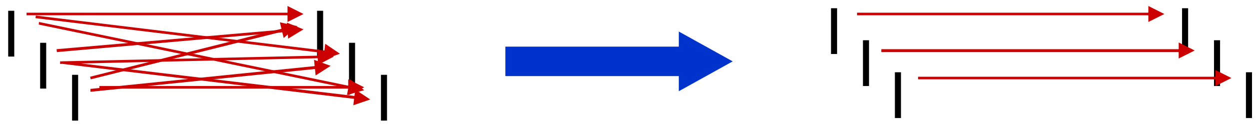
Review of Last Lecture

- Finite Constellation Sets
  - Use heuristic to assign rates to regions
  - Channel inversion power control in each region
  - Near-optimal performance

- Practical Issues in Adaptive Modulation
  - Update rate based on AFRD in Markov fading model: At f_D=80 Hz and 100 Kbps, adapt every 10-100 Ts.
  - Estimation error/delay lead to irreducible errors floors: must estimate well (within 1 dB) and feedback in $t \ll T_c$

Multiple Input Multiple Output (MIMO)Systems

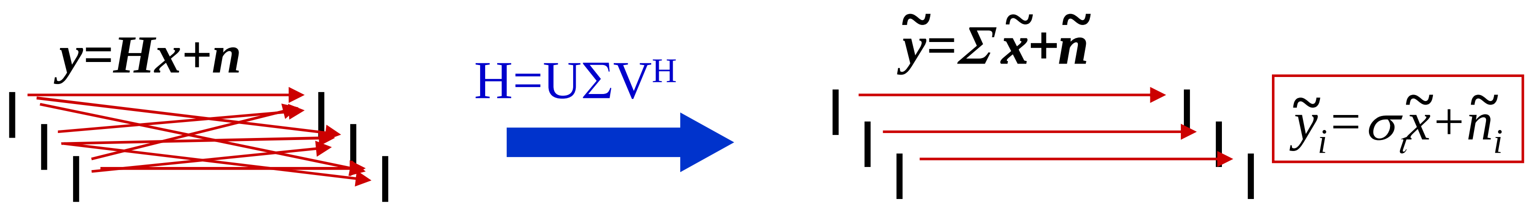
- MIMO systems have multiple (r) transmit and receiver antennas



- With perfect channel estimates at TX and RX, decomposes into r independent channels
  - R_H-fold capacity increase over SISO system
  - Demodulation complexity reduction
  - Can also use antennas for diversity (beamforming)
  - Leads to capacity versus diversity tradeoff in MIMO

MIMO Decomposition

- Decompose channel through transmit precoding ($x=V\tilde{x}$) and receiver shaping ($\tilde{y}=U^H y$)



- Leads to $R_H \le \min(M_t,M_r)$ independent channels with gain σ_i (i^{th} singular value of H) and AWGN

- Independent channels lead to simple capacity analysis and modulation/demodulation design

Capacity of MIMO Systems

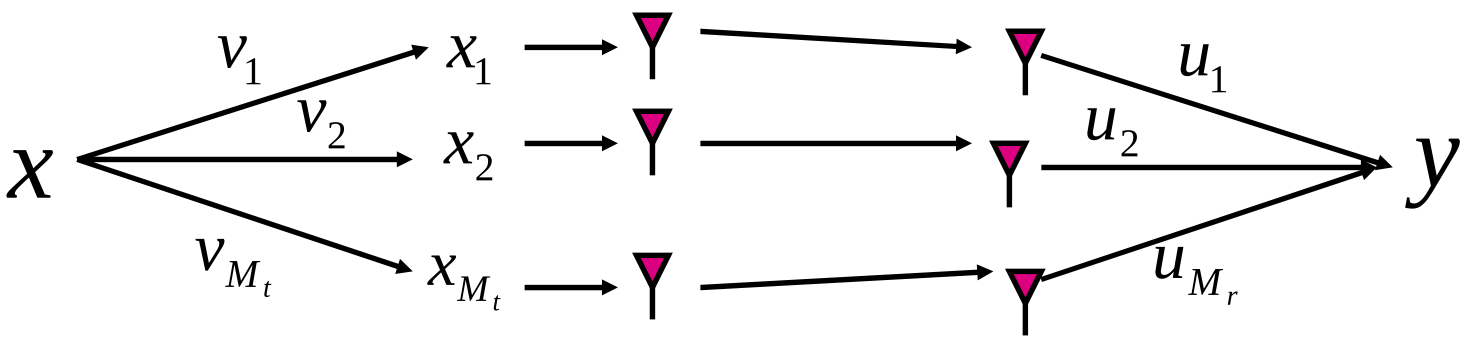
- Depends on what is known at TX and RX and if channel is static or fading

- For static channel with perfect CSI at TX and RX, power water-filling over space is optimal:
  - In fading waterfill over space (based on short-term power constraint) or space-time (long-term constraint)

- Without transmitter channel knowledge, capacity metric is based on an outage probability
  - P_{out} is the probability that the channel capacity given the channel realization is below the transmission rate.

Beamforming

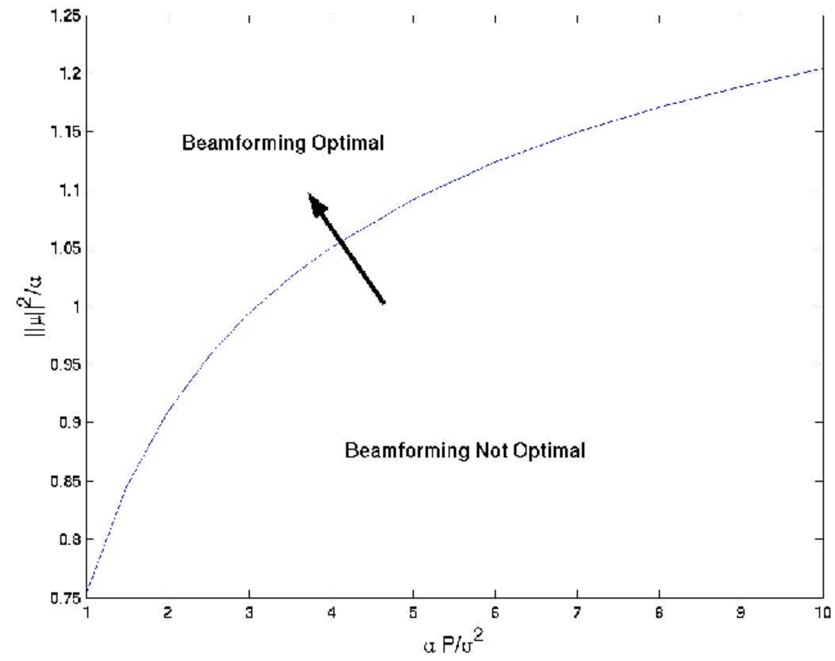
- Scalar codes with transmit precoding



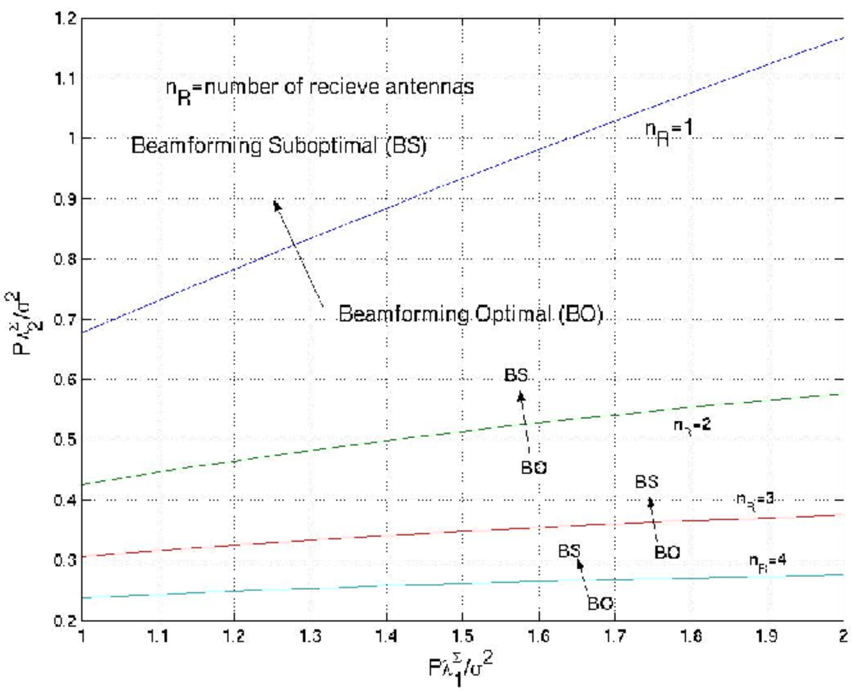
$$\boxed{y=\boldsymbol{u}^H\boldsymbol{H}\boldsymbol{v}x+\boldsymbol{u}^H\boldsymbol{n}}$$

- Transforms system into a SISO system with diversity.
  - Array and diversity gain
  - Greatly simplifies encoding and decoding.
  - Channel indicates the best direction to beamform
  - Need "sufficient" knowledge for optimality of beamforming

Optimality of Beamforming



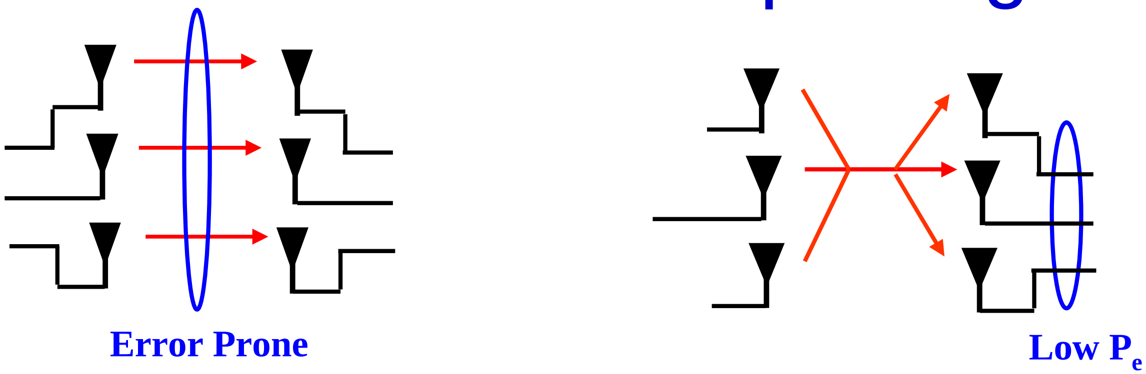
Mean Information



Covariance Information

Diversity vs. Multiplexing

- Use antennas for multiplexing or diversity



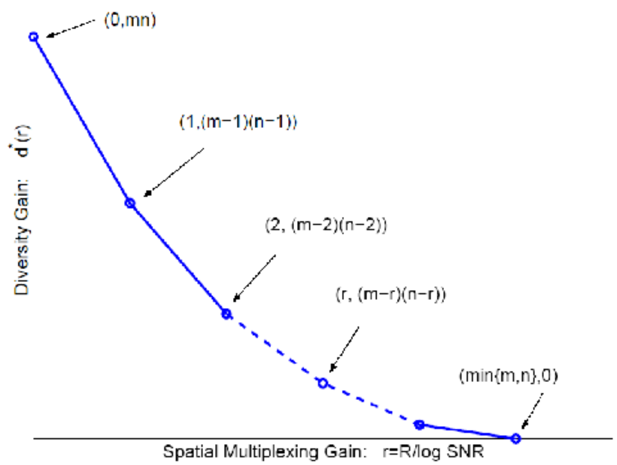
Best use depends on the application

- Diversity/Multiplexing tradeoffs (Zheng/Tse)

$$\lim_{SNR\to\infty} \frac{\log \mathbf{P_e}(SNR)}{\log \mathbf{SNR}} = -\mathbf{d}$$

$$\lim_{SNR\to\infty} \frac{\mathrm{R(SNR)}}{\log \mathrm{SNR}} = \mathrm{r}$$

$$\boxed{\mathbf{d^*(r) = (M_t - r)(M_r - r)}}$$



Main Points

- MIMO systems exploit multiple antennas at both TX and RX for capacity and/or diversity gain
- With TX and RX channel knowledge, channel decomposes into independent channels
  - Linear capacity increase with number of TX/RX antennas
  - With TX/RX channel knowledge, capacity vs. outage is the capacity metric
- Beamforming provides diversity gain in direction of dominent channel eigenvectors
- Fundamental tradeoff between capacity increase and diversity gain: optimization depends on application