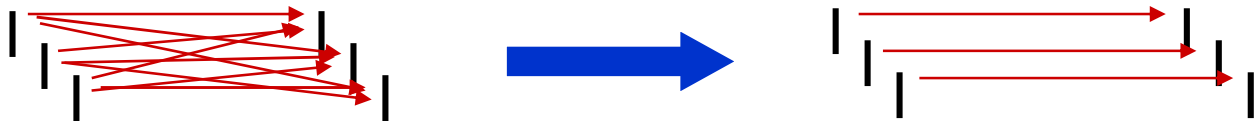
EE359 – Lecture 16 Outline

- Announcements
  - HW 7 due Friday 5pm
  - Bonus lecture 11/30, 5:15 with pizza (send topics)
- MIMO Beamforming (Diversity)
- MIMO Diversity/Multiplexing Tradeoffs
- Introduction to ISI Countermeasures
- Multicarrier Modulation
- Overlapping Substreams
- Fading Across Subcarriers

Review of Last Lecture

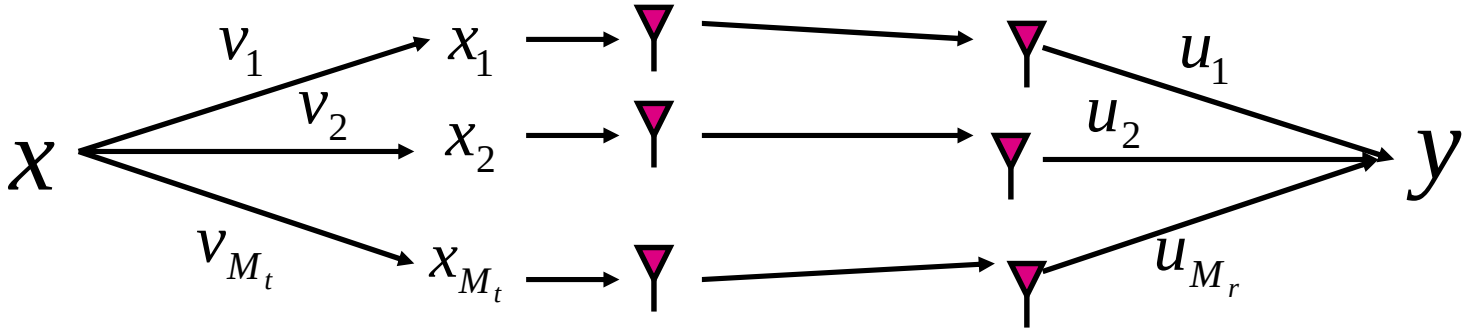
- MIMO Systems



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

Beamforming

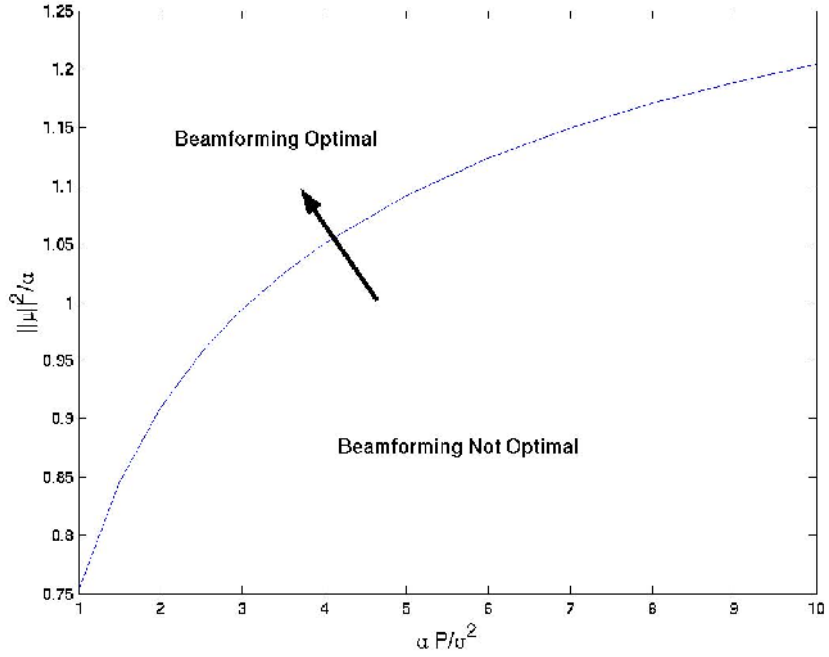
- Scalar codes with transmit precoding



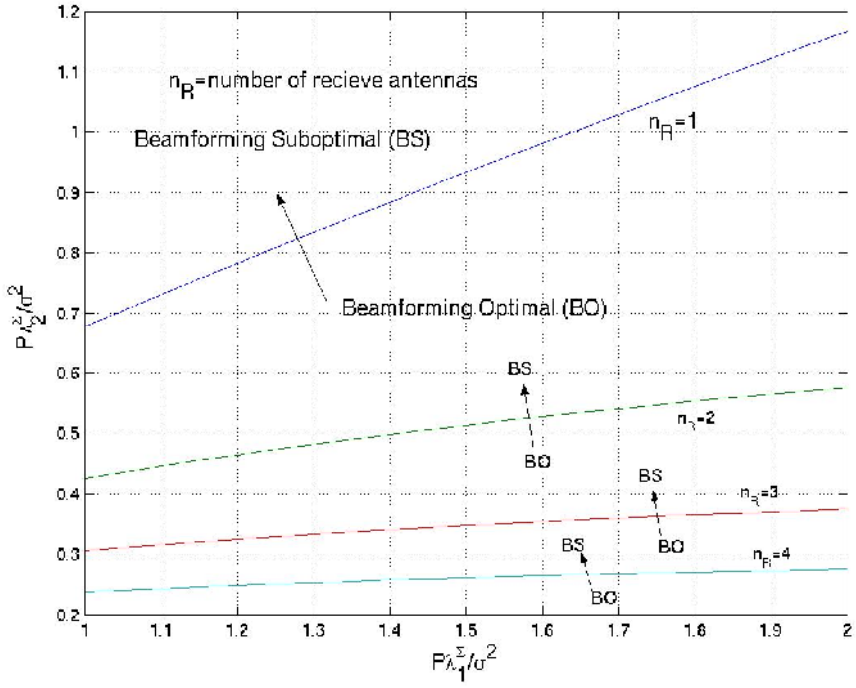
$$y = \boldsymbol{u}^H \boldsymbol{H} \boldsymbol{v} x + \boldsymbol{u}^H \boldsymbol{n}$$

- 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
- Precoding transmits more than 1 and less than R_H streams
  - Transmits along some number of dominant singular values

Optimality of Beamforming



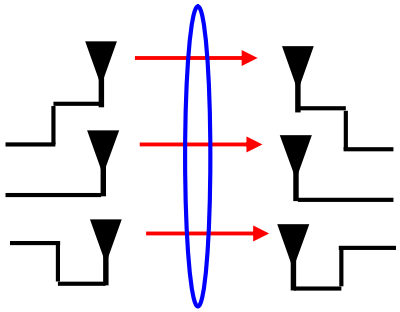
Mean Information



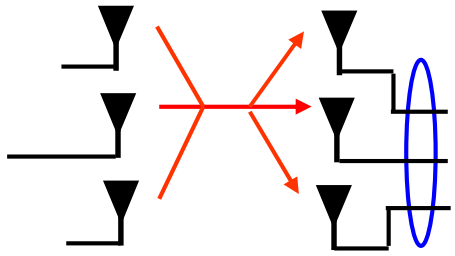
Covariance Information

Diversity vs. Multiplexing

- Use antennas for multiplexing or diversity



Error Prone



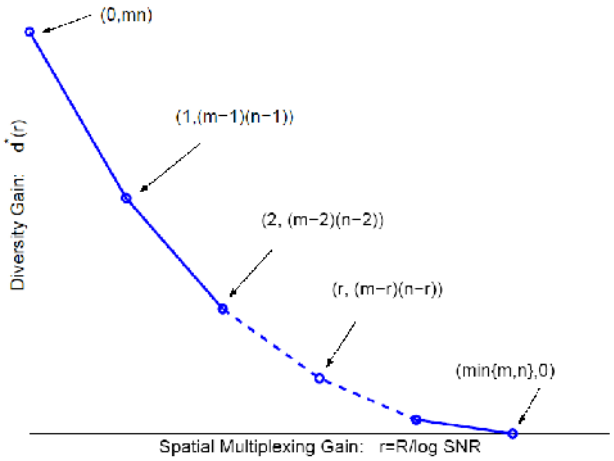
Low P_e

- Diversity / Multiplexing tradeoffs (Zheng / Tse)

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

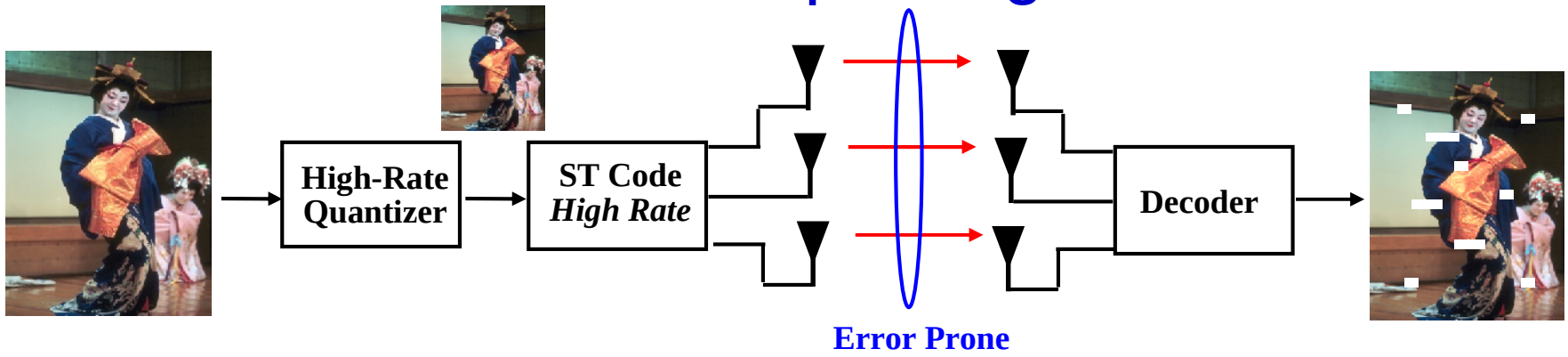
$$\lim_{SNR\to\infty} \frac{R(SNR)}{\log SNR} = r$$

$$d^*(r) = (M_t - r)(M_r - r)$$

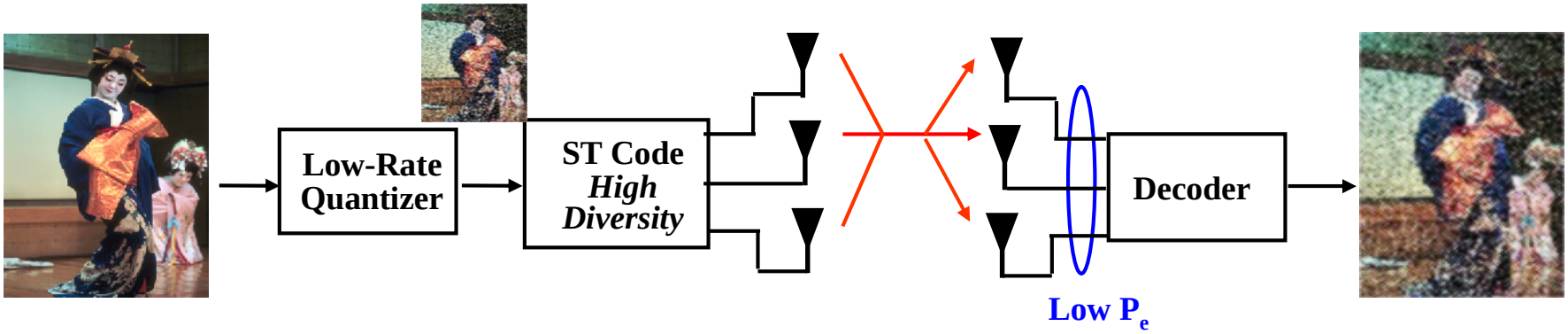


How should antennas be used?

- Use antennas for multiplexing:



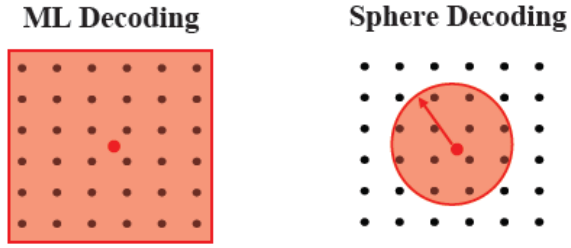
- Use antennas for diversity



Depends on end-to-end metric: Solve by optimizing app. metric

MIMO System Design Issues

- Low Complexity Receivers
  - ML receivers exponentially complex # of streams and constellation size
  - Sphere decoding, only considers possibilities within a sphere of received symbol.

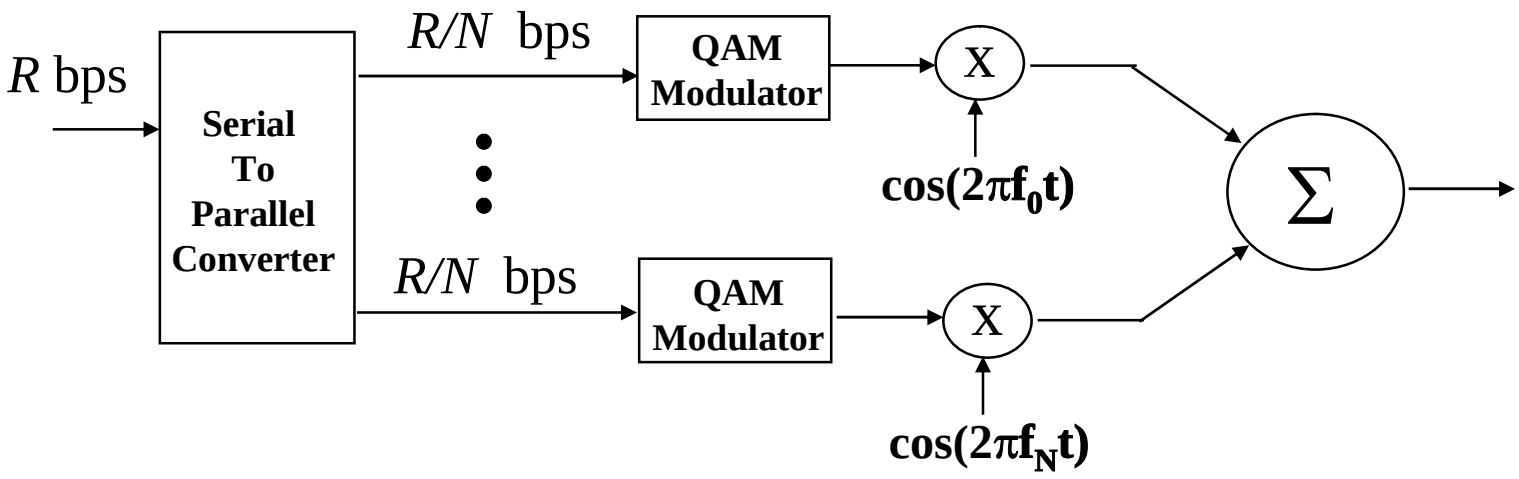


- Space-time coding:
  - Map symbols to both space and time via space-time block and convolutional codes.
  - For OFDM systems, codes are also mapped over frequency tones.
- Adaptive techniques:
  - MIMO systems adapt the use of transmit/receive antennas in addition to adapting modulation and coding.
  - Limited feedback: With limited capacity on the feedback path, techniques rely on partial CSI

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.

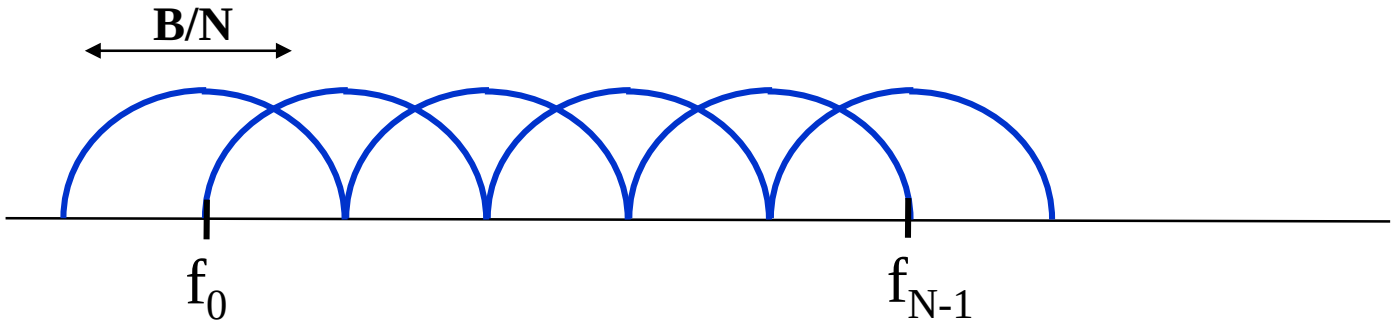
Multicarrier Modulation



- 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

- Multiple antennas can also be used for diversity via beamforming – this can be optimal
- MIMO introduces diversity/multiplexing tradeoff
- Many practical MIMO system design issues
- 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
  - Fading across subcarriers degrades performance.
  - Compensate through coding or adaptation