

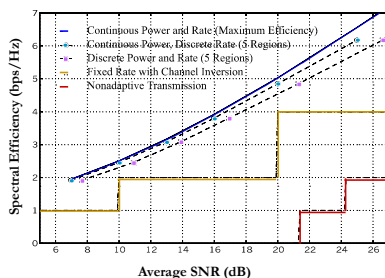
EE359 – Lecture 14 Outline

- Announcements:
 - MT announcements.
 - HW posted Friday, due next Friday
 - Will send project feedback in the next week
- Practical Issues in Adaptive Modulation
 - Finite constellations and update rate
 - Estimation error and delay
- MIMO Channel Decomposition
- MIMO Channel Capacity
- Beamforming
- Diversity vs. Multiplexing Tradeoffs

Review of Last Lecture

- Introduction to adaptive modulation
- Variable-rate variable-power MQAM
 - Optimal power adaptation is water-filling
 - Optimal rate adaptation is $R/B = \log(\gamma/\gamma_k)$
- Finite Constellation Sets
 - Use heuristic to assign rates to regions
 - Channel inversion power control in each region

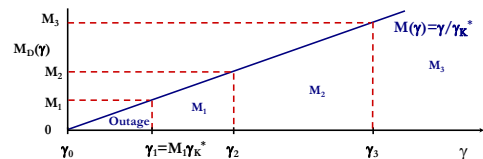
Efficiency in Rayleigh Fading



Midterm Announcements

- MT this Thur Nov. 10, 6-8pm, Room 200-030
 - Open (printed) book/notes (bring textbook/calculators)
 - Covers Chapters 1-7
- Review session tonight, 7-9pm. Hewlett 103
- Extra OHs:
 - 11/9 (today) 11-12pm, 11/10 10:30am-11:30am and by appt.
 - Nima: 11/9 2-3pm, 11/10 2-3pm
- No HW next week
- Midterms from past 3 MTs posted this week
 - 10 bonus points for “taking” a practice exam
 - Solns for all exams given when you turn in practice exam

Constellation Restriction



- Power adaptation:

$$\frac{P_j(\gamma)}{P} = \begin{cases} (M_j - 1)/(\gamma K) & \gamma_j \leq \gamma < \gamma_{j+1}, j > 0 \\ 0 & \gamma < \gamma_1 \end{cases}$$
- Average rate:

$$\frac{R}{B} = \sum_{j=1}^N \log_2 M_j p(\gamma_j \leq \gamma < \gamma_{j+1})$$

Practical Constraints

- Constellation updates: fade region duration
 - $\bar{\tau}_j = \frac{\pi_j}{N_{j+1} + N_j} > T \gg T_M$
 - $\bar{\tau}_j = \text{AFRD}$
 - $T_M = \text{delay spread}$
 - $N_j = \text{level crossing rate at min fade in region}$
 - $N_{j,j} = \text{level crossing rate at max fade in region}$
- Error floor from estimation error
 - Estimation error at RX can cause error in absence of noise (e.g. for MQAM)
 - Estimation error at TX causes mismatch of adaptive power and rate to actual channel
- Error floor from delay: let $\rho(t, \tau) = \gamma(t - \tau)/\gamma(t)$.
 - Feedback delay causes mismatch of adaptive power and rate to actual channel

Multiple Input Multiple Output (MIMO) Systems

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



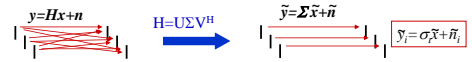
- With perfect channel estimates at TX and RX, decomposes into r independent channels
 - R_{ff} -fold capacity increase over SISO system
 - Demodulation complexity reduction
 - Can also use antennas for diversity (beamforming)
 - Leads to capacity versus diversity tradeoff in MIMO

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.

MIMO Decomposition

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



- Leads to $R_H \leq \min(M_t, M_r)$ independent channels with gain σ_i (i^{th} singular value of \mathbf{H}) and AWGN
- Independent channels lead to simple capacity analysis and modulation/demodulation design

Main Points

- Discretizing the constellation size results in negligible performance loss in adaptive modulation
- Constellations cannot be updated faster than 10s to 100s of symbol times: OK for most dopplers.
- Estimation error/delay causes error floor
- 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
 - Without TX CSI, capacity vs. outage is the capacity metric