

EE359 – Lecture 13 Outline

- Announcements
 - Midterm announcements
 - No HW this week (study for MT; HW due next week)
- Adaptive MQAM: optimal power and rate
- Finite Constellation Sets
- Practical Constraints
 - Update rate
 - Estimation error
 - Estimation delay

Review of Last Lecture

- Maximal Ratio Combining

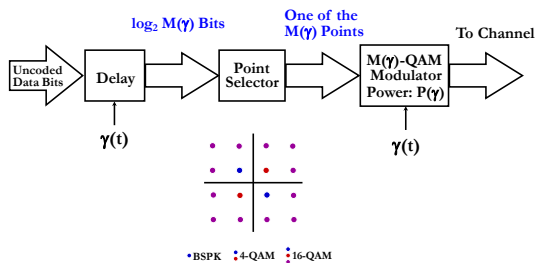
$$\bar{P}_b = \int P_b(\gamma_2) p(\gamma_2) d\gamma_2 = \int \dots \int P_b(\gamma_2) p(\gamma_1) \dots p(\gamma_M) d\gamma_1 d\gamma_2 \dots d\gamma_M$$

- MGF Approach for Performance of MRC

$$\bar{P}_b = \frac{1}{\pi} \int_0^{\pi/2} \prod_{i=1}^M \mathcal{M}_i \left[\frac{-g}{\sin^2 \varphi}; \gamma_i \right] d\varphi$$

- EGC
 - Harder to analyze than MRC; lose ~1 dB
- Transmit diversity
 - With channel knowledge, similar to receiver diversity, same array/diversity gain
 - Without channel knowledge, can obtain diversity gain through Alamouti scheme over 2 consecutive symbols

Variable-Rate Variable-Power MQAM



Goal: Optimize $P(\gamma)$ and $M(\gamma)$ to maximize $R = E \log[M(\gamma)]$

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:
 - Me: 11/7 11-12pm, 11/9 12-1pm, 11/10 11-12pm and by appt.
 - Nima: 11/8 6-9pm, 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

Adaptive Modulation

- Change modulation relative to fading

- Parameters to adapt:

- Constellation size
- Transmit power
- Instantaneous BER
- Symbol time
- Coding rate/scheme

Only 1-2 degrees of freedom needed for good performance

- Optimization criterion:

- Maximize throughput
- Minimize average power
- Minimize average BER

Optimization Formulation

- Adaptive MQAM: Rate for fixed BER

$$M(\gamma) = 1 + \frac{1.5\gamma}{-\ln(5BER)} \frac{P(\gamma)}{P} = 1 + K\gamma \frac{P(\gamma)}{P}$$

- Rate and Power Optimization

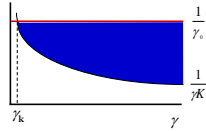
$$\max_{P(\gamma)} E \log_2[M(\gamma)] = \max_{P(\gamma)} E \log_2 \left[1 + K\gamma \frac{P(\gamma)}{P} \right]$$

Same maximization as for capacity, except for $K=1.5\ln(5BER)$.

Optimal Adaptive Scheme

- Power Adaptation

$$\frac{P(\gamma)}{P} = \begin{cases} \frac{1}{\gamma_0} - \frac{1}{\gamma K} & \gamma \geq \frac{\gamma_0}{K} = \gamma_K \\ 0 & \text{else} \end{cases}$$

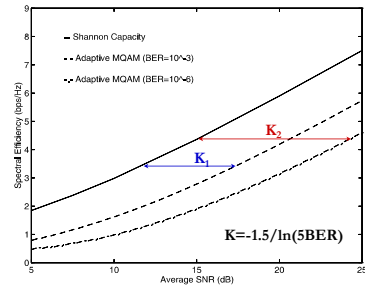


- Spectral Efficiency

$$\frac{R}{B} = \int_{\gamma_K}^{\infty} \log_2 \left(\frac{\gamma}{\gamma_K} \right) p(\gamma) d\gamma.$$

Equals capacity with effective power loss $K=1.5/\ln(5BER)$.

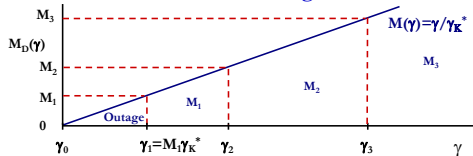
Spectral Efficiency



Can reduce gap by superimposing a trellis code

Constellation Restriction

- Restrict $M_D(\gamma)$ to $\{M_0=0, \dots, M_N\}$.
- Let $M(\gamma) = \gamma/\gamma_K^*$, where γ_K^* is later optimized.
- Set $M_D(\gamma)$ to $\max_j M_j$; $M_j \leq M(\gamma)$.
- Region boundaries are $\gamma_j = M_j \gamma_K^*$, $j=0, \dots, N$
- Power control maintains target BER



Power Adaptation and Average Rate

- Power adaptation:

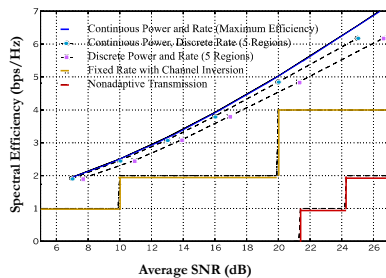
- Fixed BER within each region
 - $E_s/N_0 = (M_j - 1)/K$
 - Channel inversion within a region
- Requires power increase when increasing $M(\gamma)$

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

- Average Rate

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

Efficiency in Rayleigh Fading



Practical Constraints

- Constellation updates: fade region duration

$$\bar{\tau}_j = \frac{\pi_j}{N_{j+1} + N_j} > T \gg T_M$$

$\bar{\tau}_j$ = AFRD
 T_M = delay spread
 N_j = level crossing rate at min fade in region
 N_{j+1} = 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

Main Points

- Adaptive modulation leverages fast fading to improve performance (throughput, BER, etc.)
- Adaptive MQAM uses capacity-achieving power and rate adaptation, with power penalty K .
 - Comes within 5-6 dB of capacity
- Discretizing the constellation size results in negligible performance loss.
- Constellations cannot be updated faster than 10s to 100s of symbol times: OK for most dopplers.
- Estimation error/delay causes error floor