

Adaptive Modulation and Adaptive MQAM. Impact of Finite Constellations.

Lecture Outline

- Introduction to Adaptive Modulation
- Variable-Rate Variable-Power MQAM
- Optimal Rate and Power Adaptation
- Impact of Finite Constellations

1. Introduction to Adaptive Modulation

- Basic idea is to adapt at transmitter relative to channel fade level (borrows from capacity ideas).
- Parameters to adapt (degrees of freedom) include constellation size, transmit power, instantaneous BER, symbol time, coding rate/scheme, and combinations.
- Optimization criterion for adaptation is typically maximizing average rate, minimizing average power, or minimizing average BER.
- Few degrees of freedom need be exploited for near-optimal performance.

2. Variable-Rate Variable-Power MQAM

- Constellation size and power adapted to maximize average throughput given an instantaneous BER constraint.
- BER bound $\text{BER}(\gamma) = .2 \exp[-1.5\gamma P(\gamma)/((M-1)\bar{S})]$ inverted to get adaptive constellation size $M[\gamma]$ below with $K = -1.5/\ln(\text{BER})$ that meets the BER constraint for any adaptive power policy $P[\gamma]$:

$$M[\gamma] = 1 + \frac{-1.5\gamma}{-\ln(\text{BER})} \frac{P(\gamma)}{\bar{P}} = 1 + K\gamma P(\gamma)/\bar{P}.$$

3. Optimal Rate and Power Adaptation for Maximum Throughput

- Optimal power adaptation $P(\gamma)$ found by maximizing average throughput $E[\log_2(M[\gamma])] = E[\log_2(1 + K\gamma P(\gamma)/\bar{P})]$ relative to $P(\gamma)$.
- Optimal power adaptation is the same waterfilling as the capacity-achieving strategy with an effective power loss K .
- Optimal rate adaptation found by substituting optimal power adaptation into $M(\gamma)$, yielding $R(\gamma) = \log_2(\gamma/\gamma_K)$, $\gamma > \gamma_K$, where γ_K is cutoff value for the water-filling power policy.
- Same optimal power and rate adaptation as the capacity-achieving strategies with an effective power reduction $K = -1.5/\ln(5\text{BER})$. Throughput is within 5-6 dB of channel capacity.

- Different modulations and BER bounds result in different adaptive policies.
- Trellis codes for an AWGN channel can be superimposed on top of the adaptive modulation to partially bridge the gap with capacity.

4. Finite Constellations

- Constellation restricted to finite set $\{M_0 = 0, M_1, \dots, M_{N-1}\}$
- Divide the fading range of γ into N discrete fading regions R_j .
- Within each region “conservatively” assign constellation $M_j : M_j \leq M(\gamma) \leq M_{j+1}$, where $M(\gamma) = \gamma/\gamma_K^*$ for some optimized γ_K^* .
- Power control based on channel inversion maintains constant BER within region R_j .
- Using large enough constellation set results in near-optimal performance.
- Additional power penalty of 1.5-2 dB if each constellation restricted to a single transmit power.

5. Update Rate in Adaptive Modulation

- Rate at which constellation size changes (should be much more than a symbol time).
- Approximate as the average dwell time in each of the fading regions R_j .
- Using a Markov model approximation for Rayleigh fading, this average dwell time is $\bar{\tau}_j = \pi_j/(N_{j+1} + N_j)$, where π_j is the probability of being in region R_j and N_j (N_{j+1}) is the level crossing rate at the minimum (maximum) fade level in the region.

Main Points

- Adaptive modulation varies modulation parameters relative to fading to improve performance (throughput, BER, etc.).
- Optimizing adaptive MQAM leads to the same variable-rate and power policy that achieves channel capacity, with an effective power loss K .
- Adaptive MQAM comes within 5-6 dB of capacity, and this gap can be bridged through coding.
- Restricting the size of the constellation set in adaptive modulation leads to negligible performance loss.
- Constellations cannot be updated more than 10s to 100s of symbols. Faster adaptation only required at very high dopplers.