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 Constellation Size
- Update Rate

1. Introduction to Adaptive Modulation

- Basic idea: 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 \( \text{BER}(\gamma) = 0.2 \exp[-1.5\gamma P(\gamma)/(M-1)] \) 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 \( P(\gamma) \):
  \[
  M[\gamma] = 1 + \frac{-1.5\gamma}{\ln(\text{BER})} \frac{P(\gamma)}{P} = 1 + K\gamma P(\gamma)/P.
  \]

3. Optimal Rate and Power Adaptation for Maximum Throughput

- Optimal power adaptation \( P(\gamma) \) found by maximizing average throughput \( E[\log_2(M[\gamma])] = E[\log_2(1 + K\gamma P(\gamma)/P)] \) 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 \( \gamma_K \) 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.

4. Finite Constellations

• Constellation restricted to finite set \( \{M_0 = 0, M_1, \ldots, M_{N-1}\} \)
• Divide the fading range of \( \gamma \) 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 \( \gamma_K^* \).
• 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 (described in Section 3.2.4 of book) for Rayleigh fading, this average dwell time is \( \tau_j = \pi_j/(N_{j+1} + N_j) \), where \( \pi_j \) is the probability of being in region \( R_j \) and and \( N_j (N_{j+1}) \) is the level crossing rate at the minimum (maximum) fade level in the region.
• The level crossing rate in Rayleigh fading (see Section 3.2.3 of book for derivation) is \( N_j = \sqrt{2\pi A_j/\gamma_f D \exp[-\gamma_j/\gamma]} \) for \( A_j \) the fade level of the \( j \)th fading 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 \( K \). 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.