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 $\text{BER}(\gamma) = .2\exp[-1.5\gamma P(\gamma)/((M-1)\overline{S})]$ 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 $P[\gamma]$:

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

3. **Optimal Rate and Power Adaptation for Maximum Throughput**
   - Optimal power adaptation $P(\gamma)$ found by maximizing average throughput $\text{E}[\log_2(M[\gamma])] = \text{E}[\log_2(1 + K\gamma P(\gamma)/\overline{P})$ relative to $P(\gamma)$.
   - Optimal power adaptation is the same waterfilling as the capacity-achieving strategy with an effective power loss K.
   - Optimal rate adapation 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-acheiving 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 $\{M_0 = 0, M_1, \ldots, M_{N-1}\}$
   - 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 $\overline{\tau_j} = \pi_j/(N_{j+1} + N_j)$, where π_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.

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.