Lecture 14 - EE 359: Wireless Communications - Fall 2009

Practical Aspects of Adaptive MQAM
MIMO and Space/Time Communications

Lecture Outline

- **Finite Constellations**
- **Update Rate in Adaptive Modulation**
- **Effects of Estimation Error on Adaptive MQAM**
- **Effects of Feedback Delay on Adaptive MQAM**
- **Introduction to MIMO Systems.**
- **Parallel Decomposition of MIMO Channels**
- **MIMO Channel Capacity**

1. **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.

2. **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.

3. **Effects of Estimation Error**
   - Can have estimation error at receiver, transmitter, or both.
   - Receiver estimation generally more accurate, since doesn't need to be causal. Generally neglect this error for slowly changing channels.
   - Transmitter estimate must be causal, so is generally less accurate. The effect on BER of imperfect transmitter channel estimates (assuming perfect receiver channel estimates) is $\text{BER}(\gamma, \hat{\gamma}) = .2[5\text{BER}_0]^{\gamma/\hat{\gamma}}$, where γ is the true channel SNR, $\hat{\gamma}$ is its estimate at the receiver, and BER_0 is the target BER.
   - The average BER is obtained by integrating this expression over the joint distribution of γ and $\hat{\gamma}$ or the distribution of the ratio $\gamma/\hat{\gamma}$. This distribution is not easy to obtain and depends on the estimation process.

4. **Effects of Estimation Delay**

   - Assume a fixed estimation delay so that the transmitter and receiver are synchronized to the same constellation.
   - BER degredataion due to delay i_d can be derived as $\text{BER}(\gamma[i], \gamma[i-i_d]) = .2[5\text{BER}_0]^{\gamma[i]/\gamma[i-i_d]}$.
   - The average BER is obtained by integrating this expression over the joint distribution of $\gamma[i]$ and $\gamma[i-i_d]$.
   - A closed-form expression for the ratio $\gamma[i]/\gamma[i-i_d]$ in Nakagami-m (and Rayleigh) fading is known.

5. **MIMO Systems: Parallel Channel Decomposition**

   - MIMO systems have multiple antennas at both the transmitter and receiver.
   - With perfect channel estimates at the transmitter and receiver, the MIMO channel decomposes into $R_{\mathbf{H}}$ independent parallel channels, where $R_{\mathbf{H}}$ is the rank of the channel matrix ($\min(M_t, M_r)$ for M_t transmit and M_r receive antennas under rich scattering).

6. **MIMO Channel Capacity**

   - Capacity depends on whether the channel is static or fading, and what is known about the channel at the transmitter and receiver.
   - For a static channel known at the transmitter and receiver capacity is given by

     $$C = \max_{P_i:\sum_i P_i \leq P} \sum_i B \log_2\left(1 + \frac{\sigma_i^2 P_i}{\sigma_n^2}\right) = \max_{P_i:\sum_i P_i \leq P} \sum_i B \log_2\left(1 + \frac{P_i \gamma_i}{P}\right).$$

     This leads to a water-filling power allocation in space.
   - When channel is unknown at transmitter, uniform power allocation is optimal, but this leads to an outage probability since the transmitter doesn't know what rate to transmit at:

     $$P_{out} = p\left(\mathbf{H} : B \log_2 \det\left[\mathbf{I}_{M_r} + \frac{\rho}{M_t}\mathbf{H}\mathbf{H}^H\right] > C\right).$$
   - In fading, capacity with both transmitter and receiver knowledge is the average of the capacity for the static channel, with power allocated either by a short-term or long-term power constraint.
   - Without transmitter knowledge, outage probability is the right metric for capacity.

Main Points

- Finite constellations has little impact on adaptive MQAM throughput
- Adaptive modulation need not update more frequently then every 10-100 symbols.
- Estimation error and delay in adaptive MQAM lead to irreducible error floors.
- Multiple antennas at both the transmitter and receiver greatly increase channel capacity or provide diversity gain.