Lecture 8 - EE 359: Wireless Communications - Winter 2020

Capacity of Flat and Freq.-Selective Fading Channels Linear Digital Modulation Review

Lecture Outline

- **Channel Inversion with Fixed Rate Transmission**
- **Comparison of Fading Channel Capacity under Different Schemes**
- **Capacity of Frequency Selective Fading Channels**
- **Review of Linear Digital Modulation**
- **Performance of Linear Modulation in AWGN**

1. **Channel Inversion with Fixed Rate Transmission**
    - Suboptimal transmission strategy where fading is inverted to maintain constant received SNR.
    - Simplifies system design and is used in CDMA systems for power control.
    - Capacity with channel inversion greatly reduced over that with optimal adaptation (capacity equals zero in Rayleigh fading).
    - Truncated inversion: performance greatly improved by inverting above a cutoff γ_0.

2. **Comparison of Fading Channel Capacity under Different Schemes:**
    - Fading generally decreases channel capacity.
    - Rate/power adaptation have similar capacity as rate adaptation alone.
    - Rate adaptation alone has same capacity as no adaptation (RX CSI only) but rate adaptation is more practical due to complexity of ML decoding over long blocklengths that experience all fading values. This ML decoding is necesssary to achieve capacity in the RX CSI only case.
    - Truncated channel inversion is more practical than rate adaptation, with significant capacity gain over full channel inversion, which has zero capacity in Rayleigh fading.

3. **Capacity of Frequency Selective Fading Channels**
    - Capacity for time-invariant frequency-selective fading channels is a "water-filling" of power over frequency.
    - For time-varying ISI channels, capacity is unknown in general. Approximate by dividing up the bandwidth subbands of width equal to the coherence bandwidth (same premise as multicarrier modulation) with independent fading in each subband.
    - Capacity in each subband obtained from flat-fading analysis. Power is optimized over both frequency and time.

4. **Linear Digital Modulation**

   - Linear modulation typically used in high-rate systems due to its high spectral efficiency.
   - Over the ith symbol period, bits are encoded in carrier amplitude or phase $s(t) = s_I(t)\cos(2\pi f_c t) - s_Q(t)\sin(2\pi f_c t) = s_{i1}\phi_1(t) + s_{i2}\phi_2(t)$, where $\phi_1(t) = g(t)\cos(2\pi f_c t + \phi_0)$ and $\phi_2(t) = g(t)\sin(2\pi f_c t + \phi_0)$ for initial phase offset ϕ_0.
   - Pulse shape $g(t)$ determines signal bandwidth, and is typically Nyquist.
   - Baseband representation is $s(t) = \Re\{x(t)e^{j\phi_0}e^{j2\pi f_c t}\}$ for $x(t) = (s_{i1} + js_{i2})g(t)$.
   - The constellation point (s_{i1}, s_{i2}) has M possible values, hence there are $\log_2 M$ bits per symbol.

5. **Performance of Linear Modulation in AWGN:**

   - ML detection corresponds to decision regions.
   - For coherent modulation, probability of symbol error P_s depends on the number of nearest neighbors α_M, and the ratio of their distance d_{min} to the square root $\sqrt{N_0}$ of the noise power spectral density (this ratio is a function of the SNR γ_s).
   - P_s approximated by $P_s \approx \alpha_M Q(\sqrt{\beta_M \gamma_s})$, where β_M depends on the modulation.
   - Alternate Q function representation $Q(z) = \frac{1}{\pi}\int_0^{.5\pi} \exp[-z^2/(2\sin^2\phi)]d\phi$ leads to simpler calculations.

Main Points

- Channel inversion practical but has poor performance, which can be improved by truncating.
- Fading generally decreases channel capacity.
- Adapting power in addition to rate has little capacity gain. Adapting rate more practical than no adaptation (RX CSI only) and less practical than truncated channel inversion, which has a lower capacity than adapting the rate.
- Capacity of frequency-selective fading channels obtained by breaking up wideband channel into subbands (similar to multicarrier).
- Linear modulation encodes information in transmitted signal amplitude and/or phase via its signal constellation.
- Can approximate symbol error probability P_s of MPSK and MQAM in AWGN using simple formula: $P_s \approx \alpha_M Q(\sqrt{\beta_M \gamma_s})$.
- Can use standard or alternate Q function representation for calculation: Alternate form greatly simplifies average probability of error calculations in fading and with diversity.