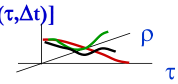
EE359 – Lecture 8 Outline

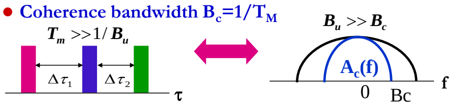
- Announcements
  - HW due today at 5pm, next HW posted today, due Thurs
  - Midterm week of Nov. 7, will schedule next week
  - Project proposal due Oct. 28 5pm (create website)
- Capacity of Fading channels
  - Fading Known at TX and RX
  - Optimal Rate and Power Adaptation
  - Channel Inversion with Fixed Rate
- Capacity of Freq. Selective Fading Channels
- Linear Modulation Review

Review of Last Lecture

- Scattering Function: $s(\tau,\rho)=\mathcal{F}_{\Delta t}[A_c(\tau,\Delta t)]$
  - Used to characterize $c(\tau,t)$ statistically



- Multipath Intensity Profile
  - Determines average (T_M) and rms (σ_τ) delay spread
  - Coherence bandwidth $B_c=1/T_M$



- Doppler Power Spectrum: $S_c(\rho)= F[A_c(\Delta t)]$
  - Power of multipath at given Doppler

Review of Last Lecture (Ctd)

- Channel Capacity
  - Maximum data rate that can be transmitted over a channel with arbitrarily small error
- Capacity of AWGN Channel: $B\log_2[1+\gamma]$ bps
  - $\gamma=P_r/N$ is the receiver SNR
- Capacity of Flat-Fading Channels
  - Nothing known: capacity typically zero
  - Fading Statistics Known (few results)
  - Fading Known at RX (average capacity)

$$C=\int_0^\infty B\log_2(1+\gamma)p(\gamma)d\gamma \le B\log_2(1+\bar{\gamma})$$

Capacity with Fading Known at Transmitter and Receiver

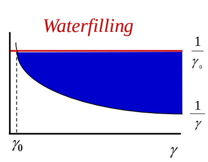
- For fixed transmit power, same as with only receiver knowledge of fading
- Transmit power $P(\gamma)$ can also be adapted
- Leads to optimization problem

$$C=\max_{P(\gamma):E[P(\gamma)]=\bar{P}} \int_0^\infty B\log_2\left(1+\frac{\gamma P(\gamma)}{\bar{P}}\right)p(\gamma)d\gamma$$

Optimal Adaptive Scheme

- Power Adaptation

$$\frac{P(\gamma)}{\bar{P}}=\begin{cases}\frac{1}{\gamma_0}-\frac{1}{\gamma} & \gamma\ge\gamma_0\\ 0 & \text{else}\end{cases}$$



- Capacity

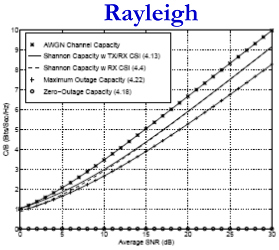
$$\frac{R}{B}=\int_{\gamma_0}^\infty \log_2\left(\frac{\gamma}{\gamma_0}\right)p(\gamma)d\gamma.$$

Channel Inversion

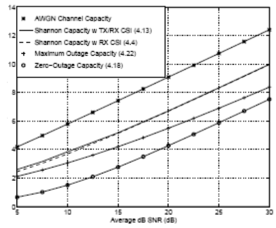
- Fading inverted to maintain constant SNR
- Simplifies design (fixed rate)
- Greatly reduces capacity
  - Capacity is zero in Rayleigh fading
- Truncated inversion
  - Invert channel above cutoff fade depth
  - Constant SNR (fixed rate) above cutoff
  - Cutoff greatly increases capacity
    - Close to optimal

Capacity in Flat-Fading

Rayleigh

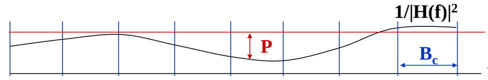


Log-Normal



Frequency Selective Fading Channels

- For time-invariant channels, capacity achieved by water-filling in frequency
- Capacity of time-varying channel unknown
- Approximate by dividing into subbands
  - Each subband has width B_c (like MCM).
  - Independent fading in each subband
  - Capacity is the sum of subband capacities



Passband Modulation Tradeoffs

- Want high rates, high spectral efficiency, high power efficiency, robust to channel, cheap. **Our focus**
- Amplitude/Phase Modulation (MPSK,MQAM)
  - Information encoded in amplitude/phase
  - More spectrally efficient than frequency modulation
  - Issues: differential encoding, pulse shaping, bit mapping.
- Frequency Modulation (FSK)
  - Information encoded in frequency
  - Continuous phase (CPFSK) special case of FM
  - Bandwidth determined by Carson's rule (pulse shaping)
  - More robust to channel and amplifier nonlinearities

Amplitude/Phase Modulation

- Signal over *i*th symbol period:

$$s(t) = s_{i1} g(t)\cos(2\pi f_c t + \phi_0) - s_{i2} g(t)\sin(2\pi f_c t + \phi_0)$$

- Pulse shape g(t) typically Nyquist
- Signal constellation defined by (s_{i1},s_{i2}) pairs
- Can be differentially encoded
- M values for $(s_{i1},s_{i2}) \Rightarrow \log_2 M$ bits per symbol

Main Points

- Fundamental capacity of flat-fading channels depends on what is known at TX and RX.
  - Capacity with TX/RX knowledge: variable-rate variable-power transmission (water filling) optimal
  - Almost same capacity as with RX knowledge only
  - Channel inversion practical, but should truncate
- Capacity of wideband channel obtained by breaking up channel into subbands
  - Similar to multicarrier modulation
- Linear modulation more spectrally efficient but less robust than nonlinear modulation