EE359 – Lecture 8 Outline

- Announcements
  - Makeup class tomorrow, 10/20 (no lecture next Tues 10/24) at 10:30AM in Thornton 102 (here, with donuts)
    - Tom's OHs 10/20: 9:30-10:20 (3rd Floor Packard), email OHs 1-2pm
  - New discussion section and OH times starting next week
    - Wednesdays 5-6pm Discussion session (Packard 361), Tom's OHs afterwards
  - Project proposals due 10/28; I can provide early feedback
  - Midterm Nov. 9, 6-8pm (pizza after), more details next week
    - Email me/TAs if you have a conflict
- Capacity of Fading channels
  - Recap Optimal Rate/Power Adaptation with TX/RX CSI
  - Channel Inversion with Fixed Rate
- Capacity of Freq. Selective Fading Channels
- Linear Digital Modulation Review
- Performance of Linear Modulation in AWGN

Review of Last Lecture

- 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
  - $\gamma=P_r/(N_0B)$ 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)

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

Review of Last Lecture (ctd)

- **Capacity in Flat-Fading: γ known at TX/RX**

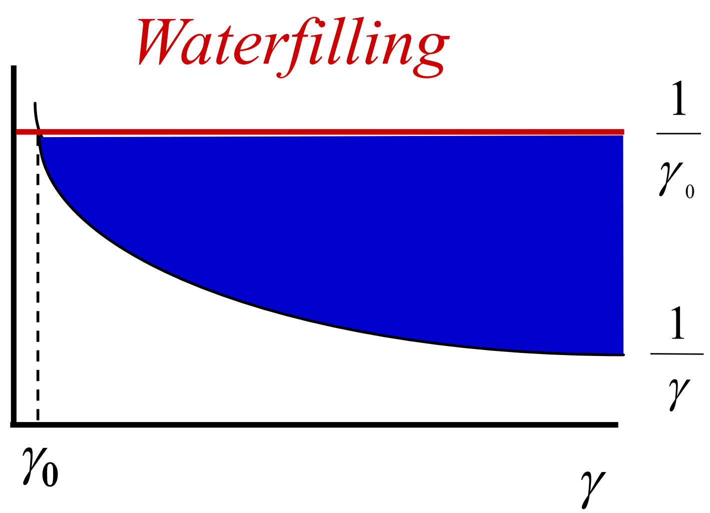
$$C = \max_{P(\gamma):E[P(\gamma)] \leq \overline{P}} \int_0^\infty B \log_2\left(1 + \frac{\gamma P(\gamma)}{\overline{P}}\right) p(\gamma) d\gamma$$

Same result with equality

- **Optimal Rate and Power Adaptation**

$$\frac{P(\gamma)}{\overline{P}} = \begin{cases} \frac{1}{\gamma_0} - \frac{1}{\gamma} & \gamma \geq \gamma_0 \\ 0 & \textbf{else} \end{cases}$$

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



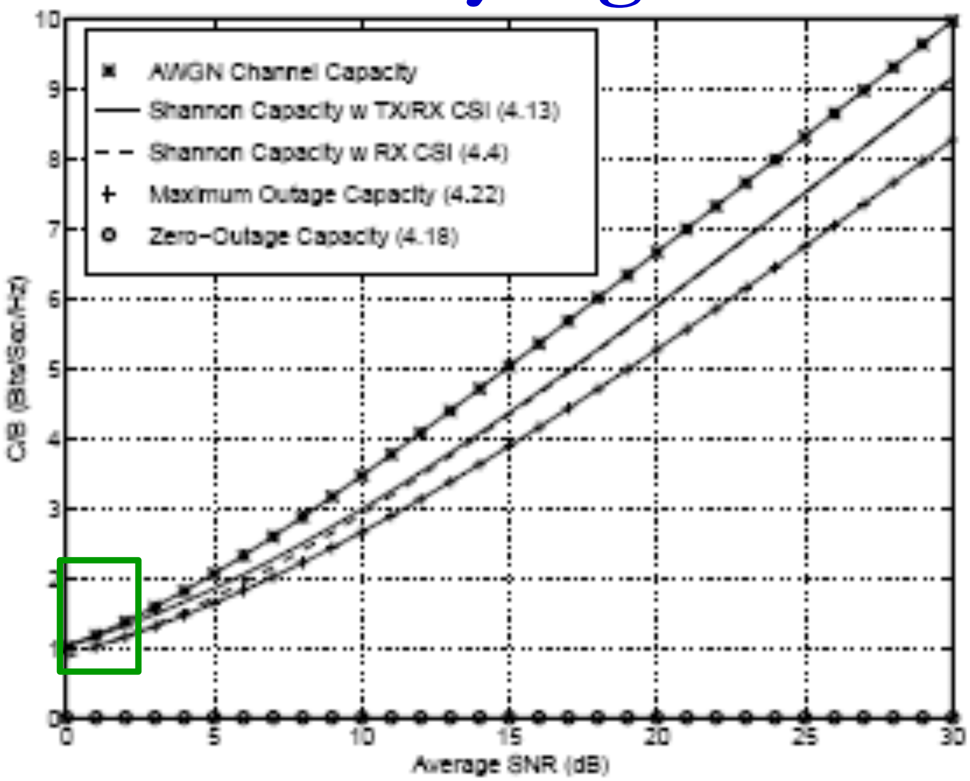
- **The instantaneous power/rate only depend on p(γ) through γ_0**

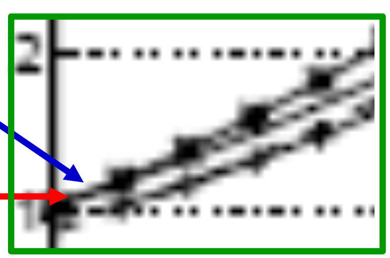
Channel Inversion

- 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

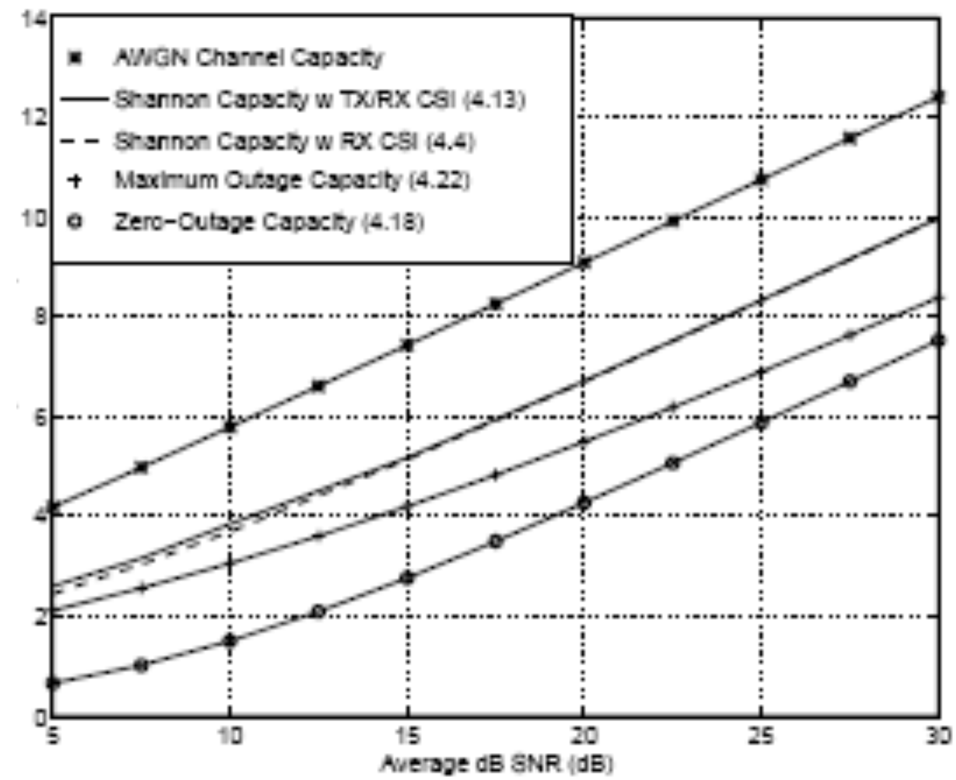
Rayleigh





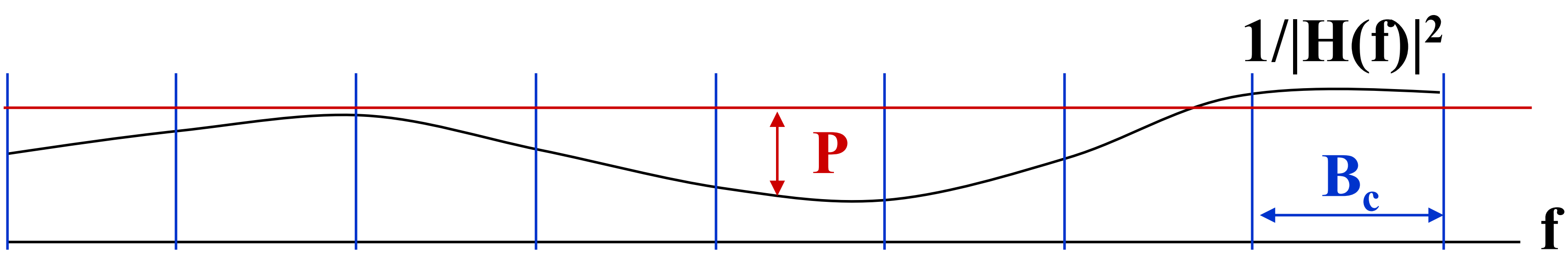
AWGN capacity
lower than w/fading
under TX/RX CSI

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/OFDM).
  - Independent fading in each subband
  - Capacity is the sum of subband capacities



Review of Linear Digital 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

- P_s depends on
  - Minimum distance d_{min} *(depends on γ_s)*
  - # of nearest neighbors α_M
  - Approximate expression:
    - Standard/alternate Q function

$$P_s \approx \alpha_M Q\left(\sqrt{\beta_M \gamma_s}\right)$$

Main Points

- Channel inversion practical, but should truncate or get a large capacity loss
- Capacity of wideband channel obtained by breaking up channel into subbands
  - Similar to multicarrier modulation
- Linear modulation dominant in high-rate wireless systems due to its spectral efficiency
- Ps approximation in AWGN: $P_s \approx \alpha_M Q\left(\sqrt{\beta_M \gamma_s}\right)$
  - Alternate Q function useful in diversity analysis