Discrete Adaptive Transmission for Fading Channels

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Adaptive Modulation

transmission power and code *rate* adaptation

- application in wireless communication of data
- fundamental limits in terms of information throughput
- practical constraints
  - finite number of power/rate levels
  - transmitter has partial knowledge of the channel state

Background

ergodic capacity can be achieved [Goldsmith and Varayia '97]

- infinite number of adaptation levels
- transmitter knows the current channel state
- very slow fading channel (1 codeword/channel state)

Discrete Adaptive Modulation

L-level power and *rate* adaptation

- transmitter knows the quantization level of channel state
- codewords are assigned one of *L* power and rate levels
- generalization:
  - L=1; non-adaptive system
  - L=infinity; continuously adaptive system
- Maximum information throughput with L levels ?

Advantages

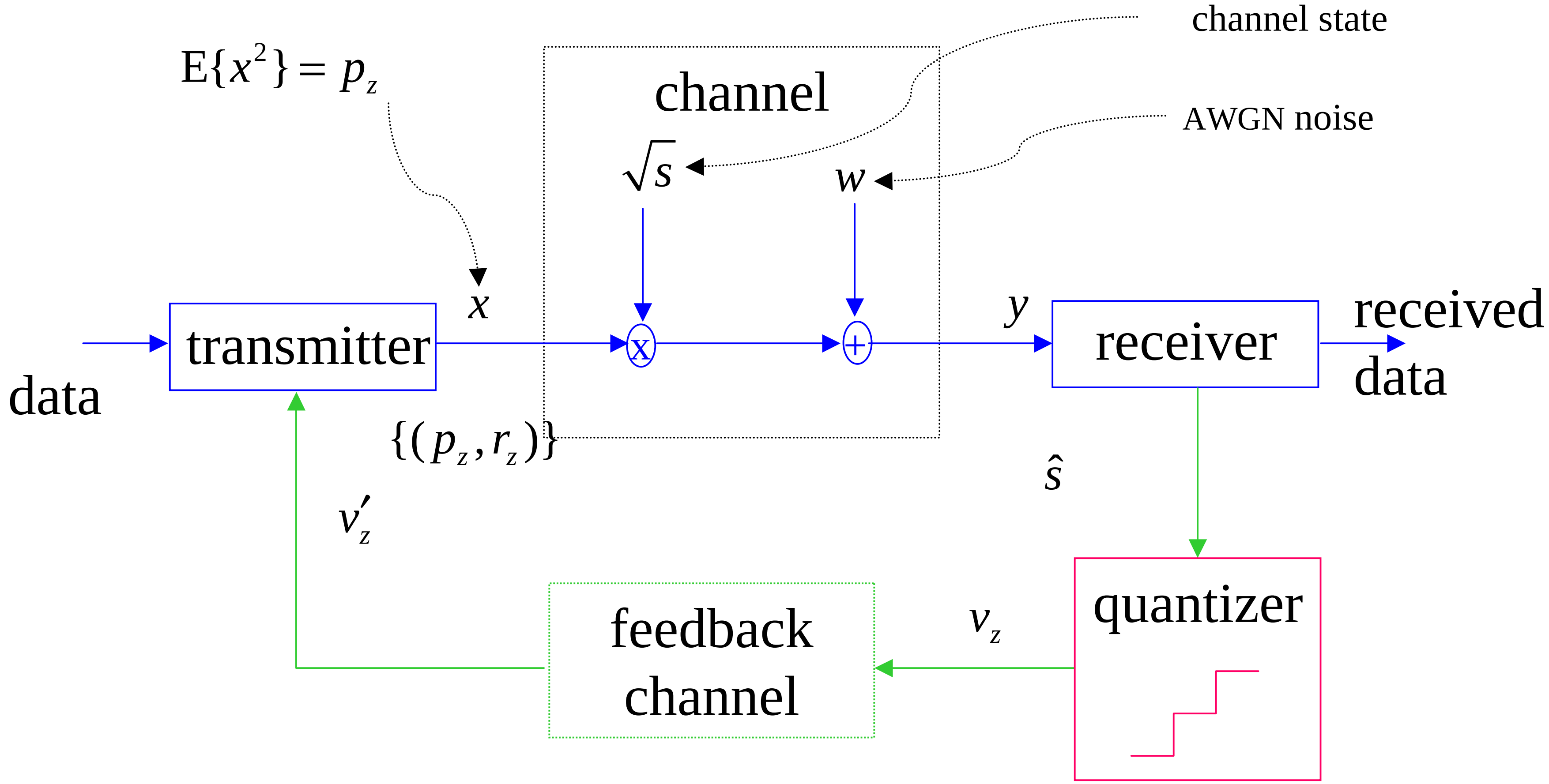
- feedback channel
  - reduced throughput
  - reduced frequency of use
- transmitter/receiver design
  - finite number of power levels to be employed
  - finite number of code rate assignments

System Model

$$y = \sqrt{s}x + w$$

- x – transmitted signal
- y – received signal
- s – channel state
  - non-negative unit-mean random variable.
  - constant during a transmission of a codeword
- w – additive white Gaussian noise

adaptive communication system



adaptive transmission policy

vector triple of real numbers

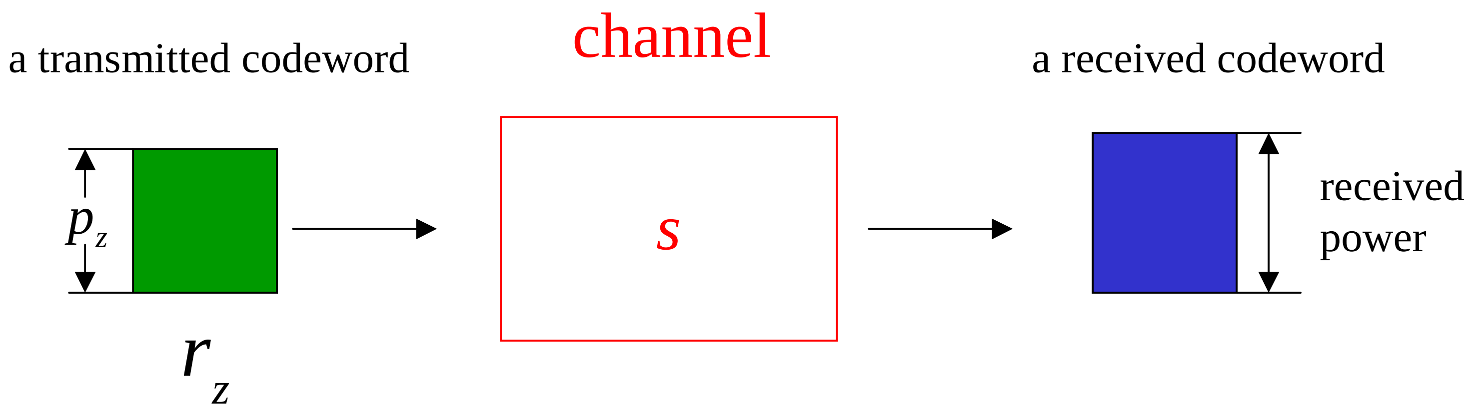
$$(\mathbf{p}, \mathbf{v}, \mathbf{r}) = ([p_0, \ldots, p_{L-1}]^T, [v_0, \ldots, v_{L-1}]^T, [r_0, \ldots, r_{L-1}]^T)$$

denotes the selected transmission policy, where

v_z z-th quantization level for channel state "s"

(p_z, r_z) power and code rate assignments for $v_z \leq s \leq v_{z+1}$

slow fading channel



maximum achievable rate

$$R(p_z s) = \log\left(1 + \frac{p_z s}{N_0}\right)$$

unreliable communications (outage)

$$R(p_z s) < r_z$$

$$s \in [v_z, v_{z+1})$$

average data rate and capacity

- All information transmitted when an outage occurs is discarded
- average (achievable) data rate is

$$R_L(\mathbf{p},\mathbf{v},\mathbf{r}) = \sum_{z=0}^{L-1} r_z \cdot P\left\{R(p_z s) \geq r_z \text{ and } s \in [v_z, v_{z+1})\right\}$$

- capacity

$$C_L = \max_{\rho(\mathbf{p},\mathbf{v},\mathbf{r}) \leq \overline{p}} R_L(\mathbf{p},\mathbf{v},\mathbf{r})$$

- average power assignment

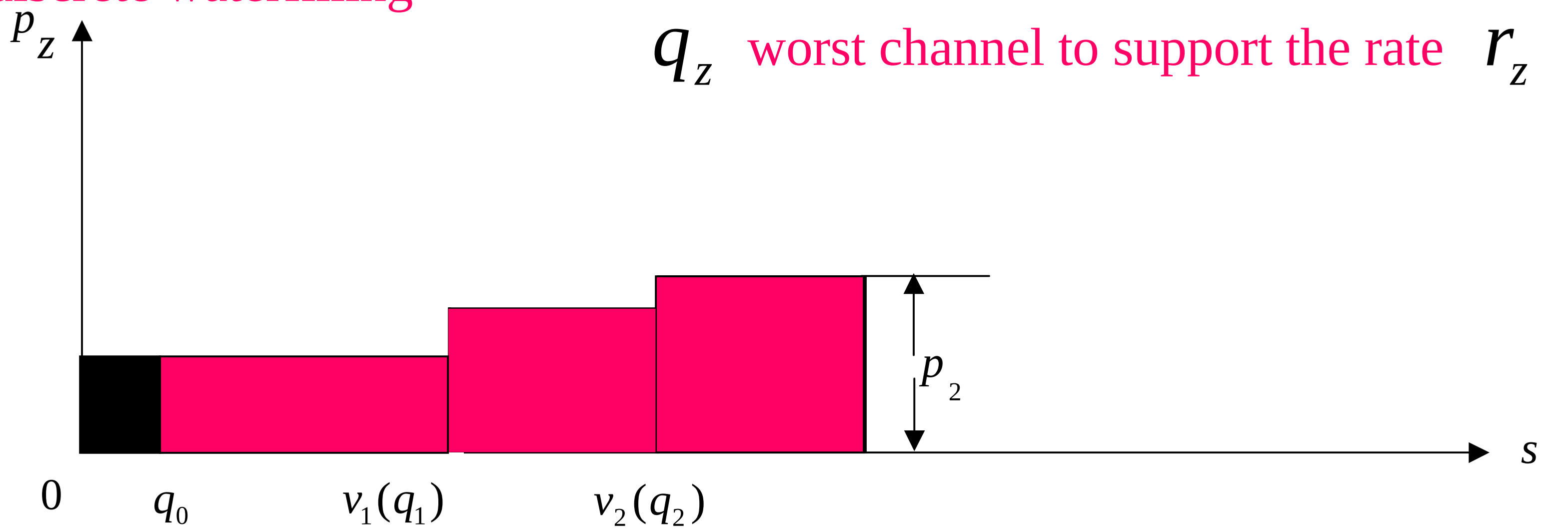
$$\rho(\mathbf{p},\mathbf{v},\mathbf{r}) = \sum_{z=0}^{L-1} P[s \in [v_z, v_{z+1})] p_z$$

illustration of policy optimization

$r_z = R(p_z q_z)$ $q_z \in [v_z, v_{z+1})$

q_z worst channel to support the rate r_z

discrete waterfilling



for any given quantization interval (except the initial one) the optimal rate assignment assures reliable communication for the worst possible channel

optimal policy

The optimal policy pair $(\mathbf{p},\mathbf{q})$ achieves

capacity $$C_L = \max_{\rho(\mathbf{p},\mathbf{q})=\overline{p}} R_L(\mathbf{p},\mathbf{q})$$

average rate $$R_L(\mathbf{p},\mathbf{q}) = \sum_{z=0}^{L-1} P[s \in [q_z, q_{z+1})] R(p_z q_z)$$

average power

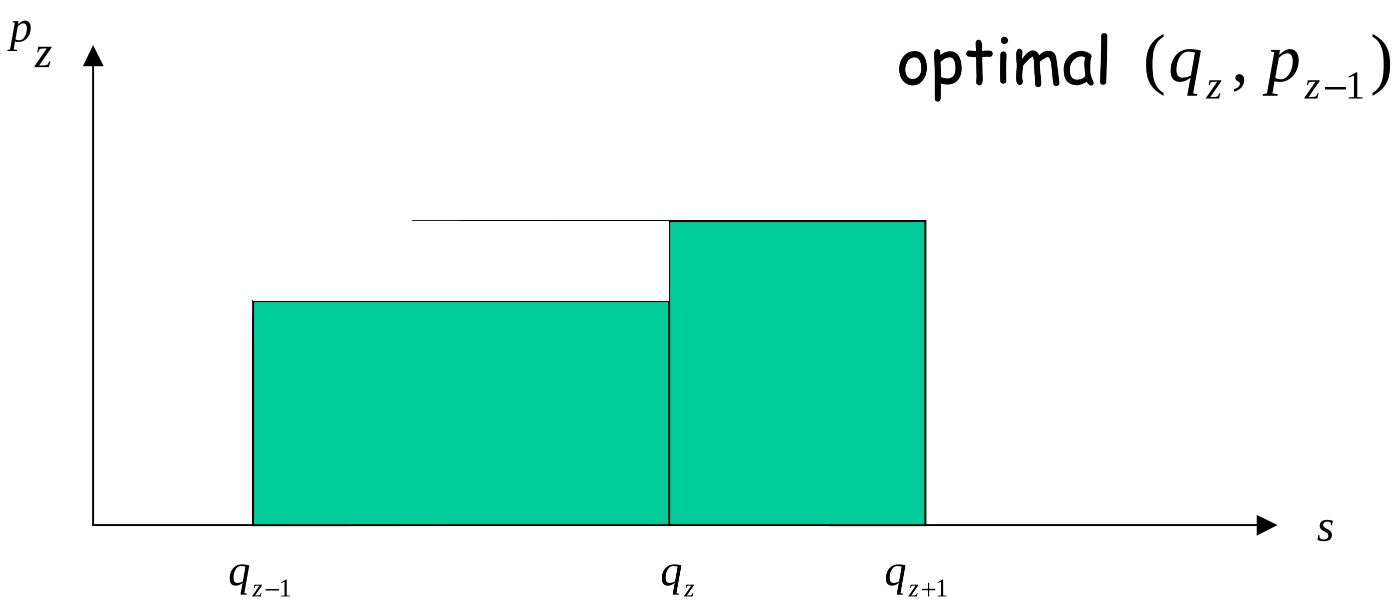
$$\rho(\mathbf{p},\mathbf{q}) = P[s \in [0, q_0)] p_0 + \sum_{z=0}^{L-1} P[s \in [q_z, q_{z+1})] p_z$$

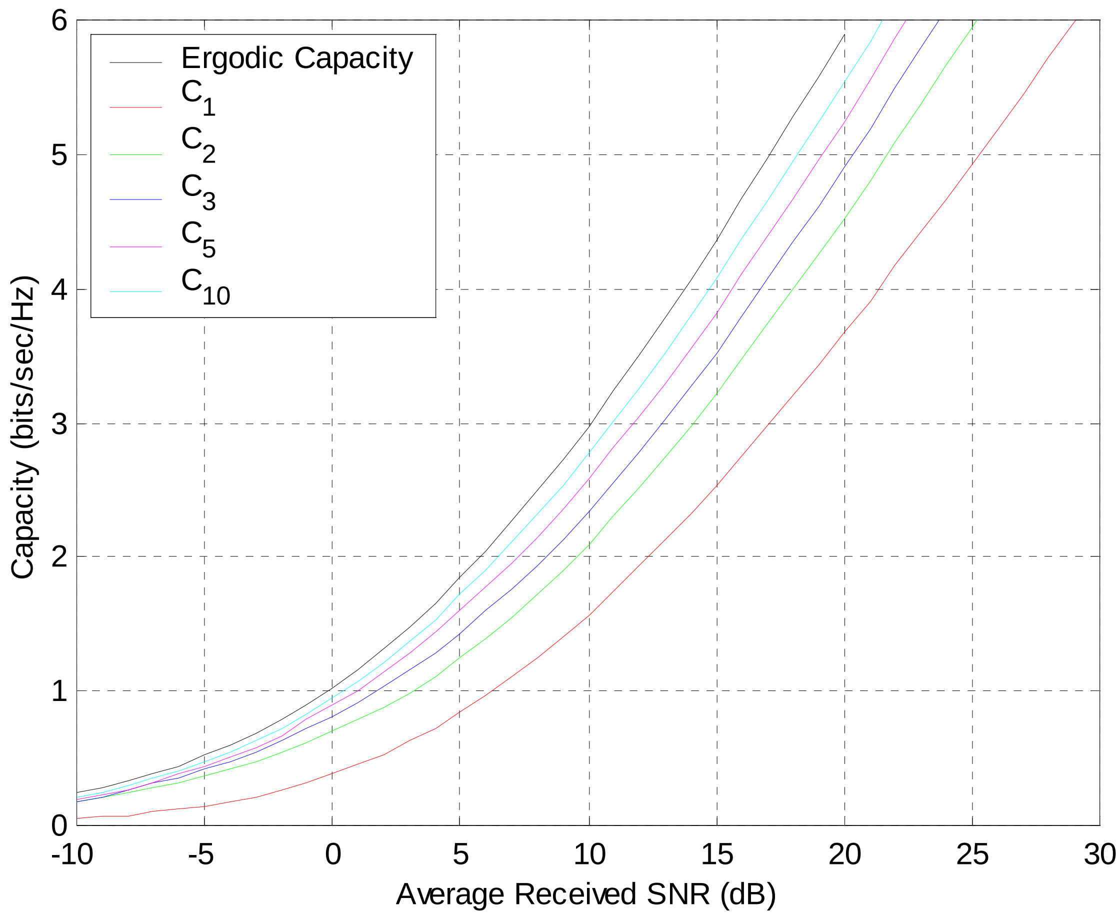
optimal policy computation

Based on the following iterative steps:

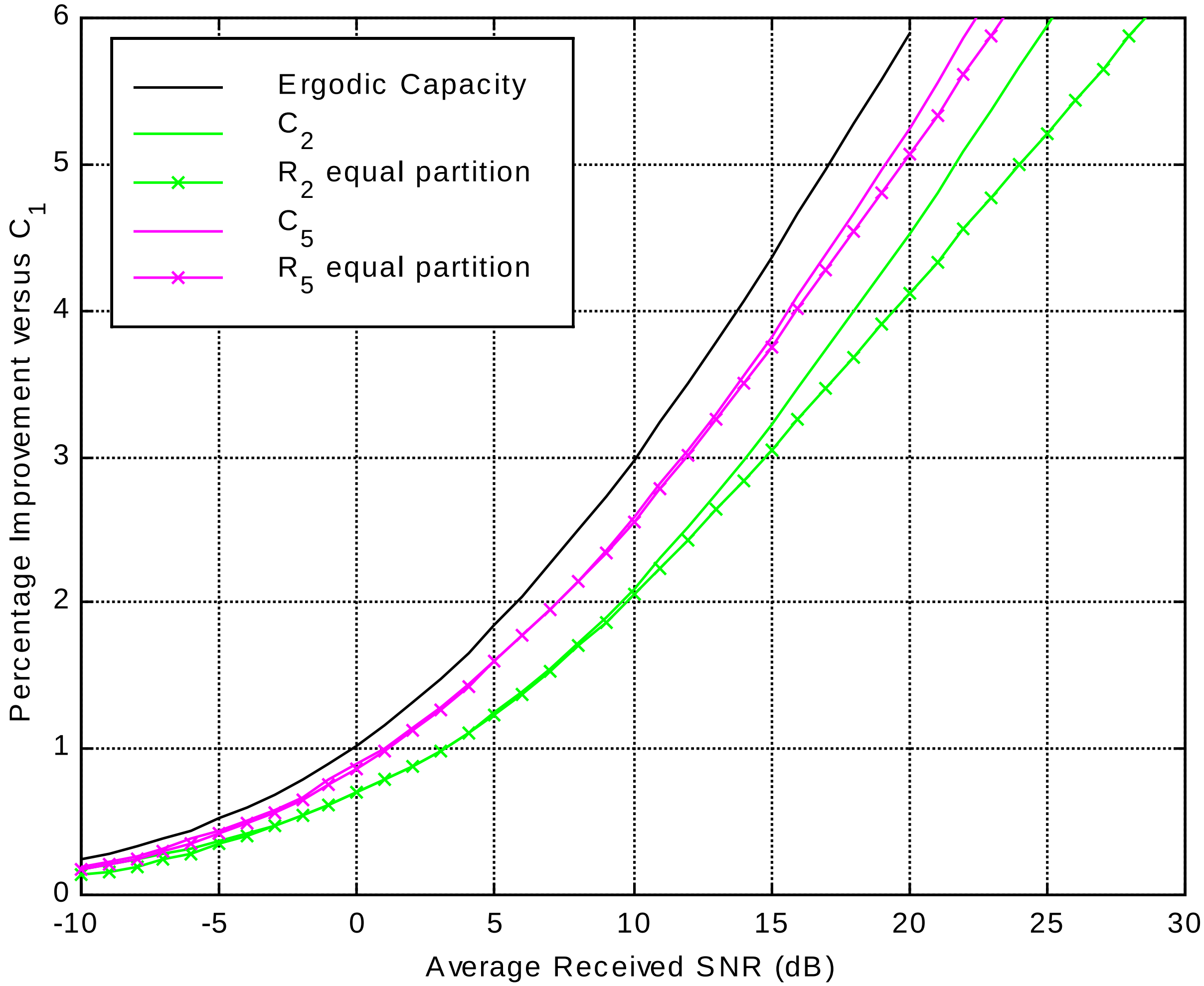
1. initialize
2. water-filling: best $\mathbf{p}$
3. z = 1,…, L-1:
   - water-spilling: best (q_z, p_{z-1})
4. repeat 2 and 3 until convergence

water-spilling





Ergodic Capacity
C_1
C_2
C_3
C_5
C_{10}
Capacity (bits/sec/Hz)
Average Received SNR (dB)
0
1
2
3
4
5
6
-10
-5
0
5
10
15
20
25
30


Ergodic Capacity
C_2
R_2 equal partition
C_5
R_5 equal partition
Percentage Improvement versus C_1
Average Received SNR (dB)
0
1
2
3
4
5
6
-10
-5
0
5
10
15
20
25
30

Conclusion

- we studied an adaptive modulation system
  - with a discrete set of power levels and code rates
  - partial knowledge of channel state at transmitter
- we conclude
  - 3 to 5 channel state quantization levels may be sufficient for the maximum throughput to be sufficiently close to the ergodic capacity