Delay Constrained Communication over Fading Channels: A Queued-Code Approach

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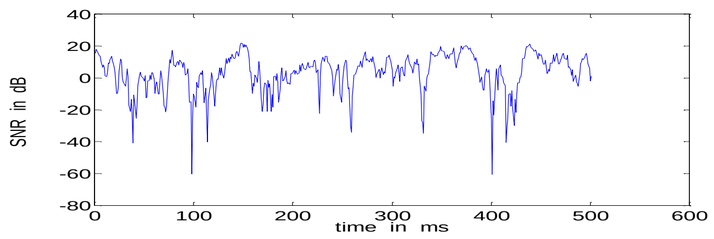
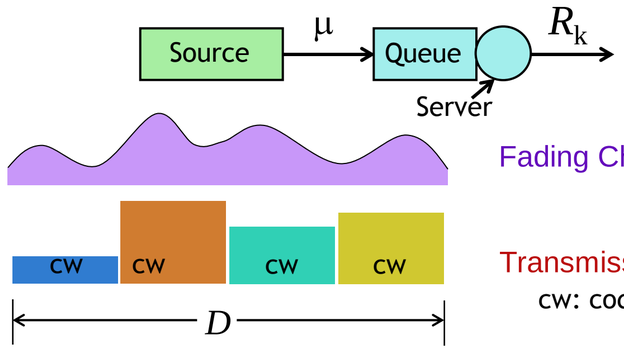
Motivation



- Scenario: Real-time or multimedia traffic over wireless channel
- Quality-of-service requirement
  - Source rate μ
  - delay bound D
  - Probability of violation ε

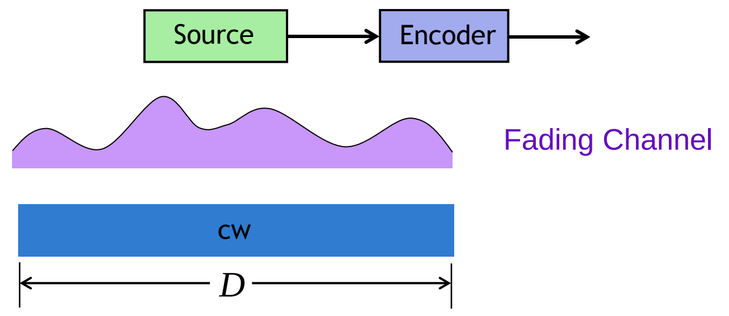
e.g., real-time video (1.5 Mbps, 100 ms, 1%)
real-time gaming (40 kbps, 100 ms, 1%)

Pure Queuing



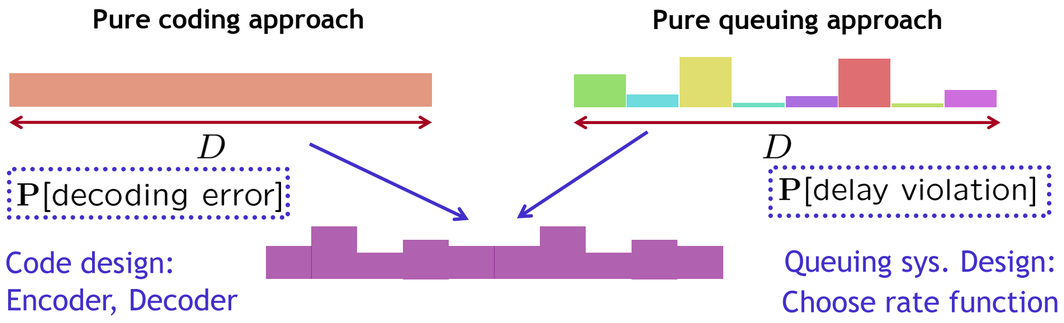
- Model time-varying channel in link layer
- Assumption: 'Block-fading' channel
- Assumption: Capacity achieved within each block
- Queuing Solution: $P_{err} = \Pr\{\text{queuing delay} > D\} = \ldots$

Pure Coding



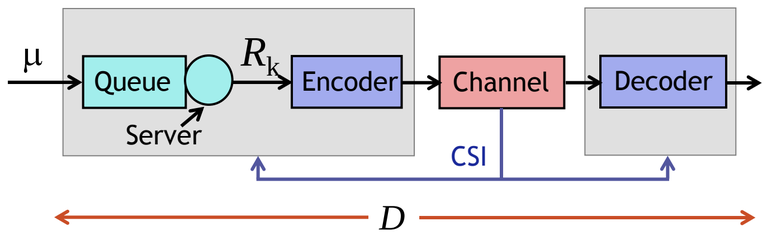
- Model time-varying channel in physical layer
- Channel code spanning D provides diversity
- Limitation: must have constant-rate channel code
- Coding solution: $P_{err} = \Pr\{\text{bit decoding error}\} = \ldots$

Queued-code Approach



- Diversity for low decoding error probability
- Rate adaptation to achieve queuing gain

- Why is this hard?
  Different models and design goals for the two approaches



- Both, physical layer and link layer considered
  - Queuing allows rate-adaptation of channel code
  - Channel code provides diversity and coding gain

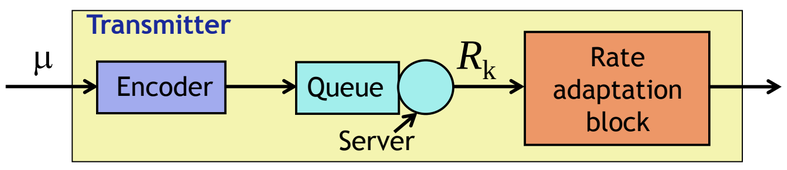
- Design metric for fixed delay bound:

$$P_{err} = \Pr\{\underbrace{\text{decoding error}}_{\text{coding approach}} \text{ OR } \underbrace{\text{delay violation}}_{\text{queuing approach}}\}$$

- Alternative application requirement
  - Fixed probability of violation
  - Delay requirement:
    minimize delay variance (jitter)

- Error metric: $P_{err} = \Pr\{\text{decoding error}\}$

Practical Queued-



- Information theoretic codes – existence results!
- Queued-code requires rate adaptive encoder
- Queue+server and rate adaptation block: allow rate adaptation
- Separate design of code and rate adaptation block

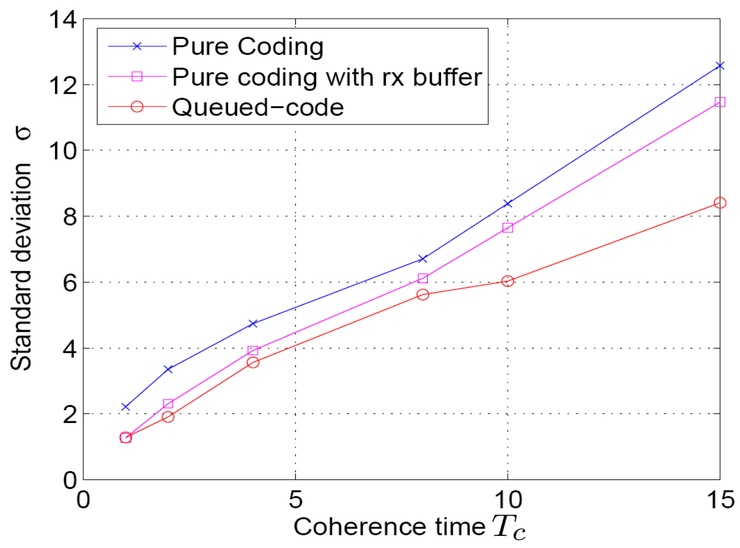
Streaming Encoder

- Streaming (convolutional) LDPC codes[FZ99]
  - Low Density Parity Check (LDPC): large memory
  - Sparse parity check matrix:
    efficient decoding using message passing
  - Block diagonal structure of parity check matrix:
    streaming encoder/decoder

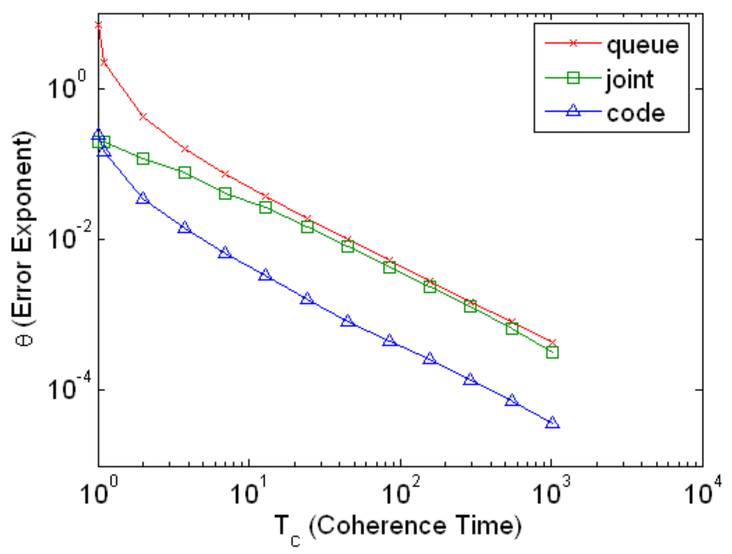
$$\mathbf{H} = \begin{bmatrix} & & 0 \\ & \blacksquare & \\ 0 & & \end{bmatrix}$$

- Rate adaptation through puncturing and repetition

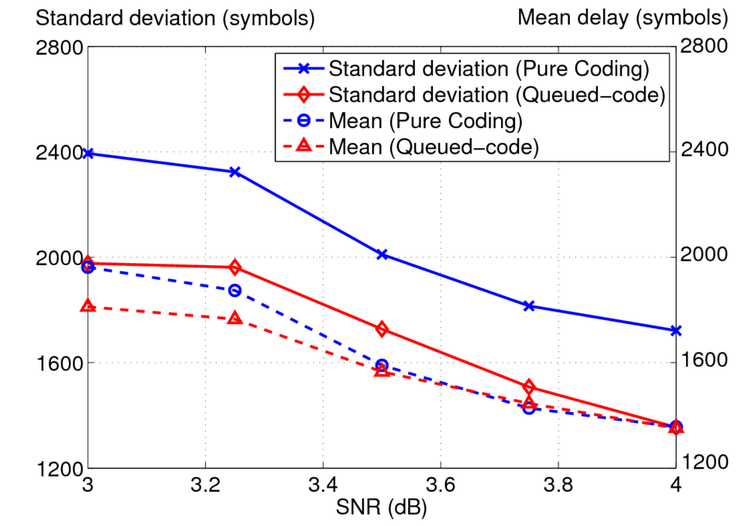
Simulation Results



Delay jitter for fixed probability of error



Error exponents for fixed delay bound



Conclusions

- Queued-code combines key ideas from:
  - Channel coding: provides diversity
  - Queuing: allows rate adaptation

- Queued-code allows trade-offs between delay statistics
  - Lower delay jitter achieved using rate adaptation

- Practical implementation using LDPC codes