Analysis of Delay Statistics for the Queued-code

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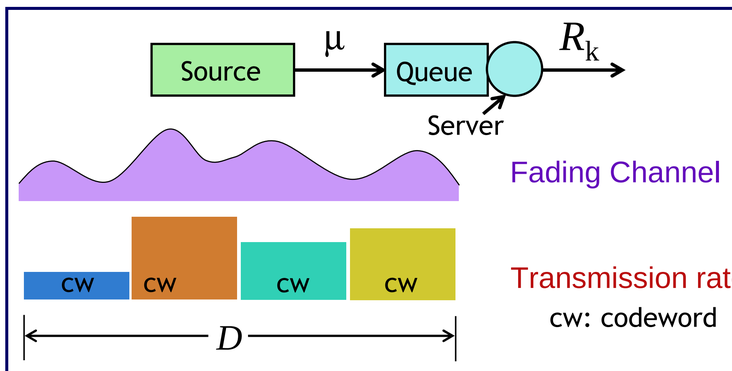
Motivation

• Scenario : Real-time or multimedia traffic over wireless channel
• Quality-of-service requirement
- Fixed source rate μ
- Probability of violation ε
- Optimize delay statistic (e.g., mean delay, delay variance)

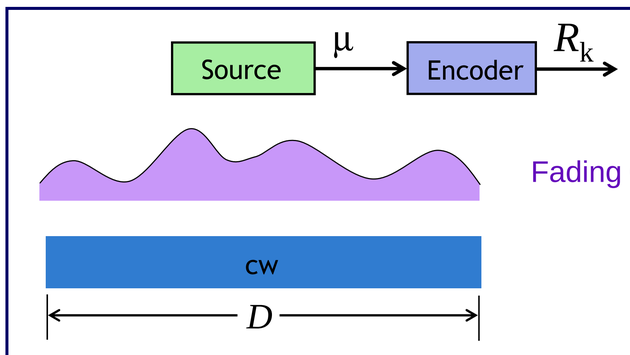
e.g., voice (8 kbps, 1% error)
video (1.5 Mbps, 1% error)
minimize delay jitter

Pure Queuing Approach



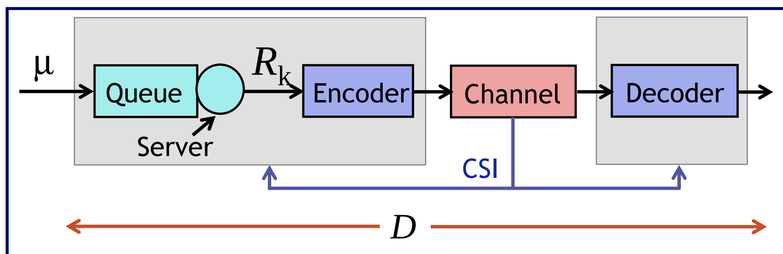
•Model time-varying channel in link layer
•Assumption: 'Block-fading' channel
•Assumption: Capacity achieved within each block
•Queuing Solution: $P_{err} = \Pr\{\text{queuing delay} > D\} = \ldots$

Pure Coding Approach



•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



•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 [NG04]:

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

Problem Statement

•Different application requirement
- Fixed probability of violation
- Delay requirement: minimize a delay metric, e.g., mean delay

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

•Minimize delay variance: bounded mean delay

$$\min_{R(g)\geq 0} \ \text{var}(D_{qc})$$

$$\overline{D}_{qc} \leq (1+\delta)\overline{D}_{code}$$

$$P_{err} \leq \varepsilon$$

Relaxation parameter

Stopping Rule

•Main result: If bits are decoded at the smallest D such that

$$\sum_{i=k}^{k+D-1} \underbrace{(E(g_i) - \rho R(g_i))}_{\text{Error exponent}} \geq \tau \equiv -\log(\varepsilon / c_1)$$

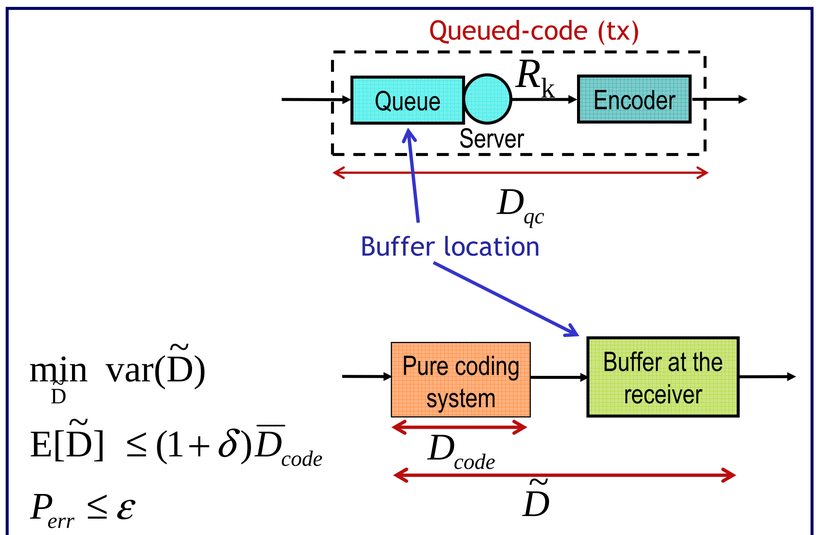
[TG95]

Bound on decoding error probability

average probability of decoding error $\leq \varepsilon$

•Pure coding system obtained by choosing $R_k \equiv \mu$

Buffer at Transmitter vs at Receiver



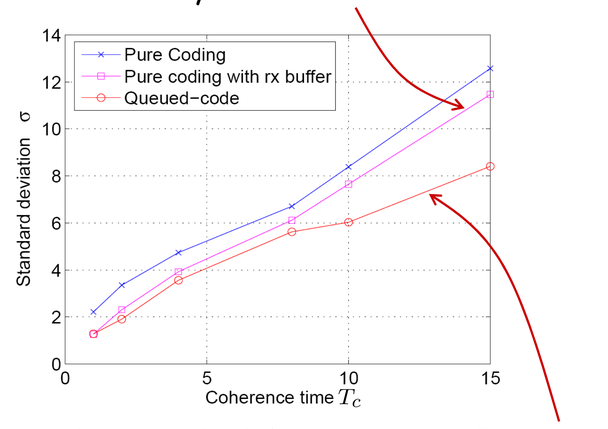
$$\min_{\tilde{D}} \ \text{var}(\tilde{D})$$

$$E[\tilde{D}] \leq (1+\delta)\overline{D}_{code}$$

$$P_{err} \leq \varepsilon$$

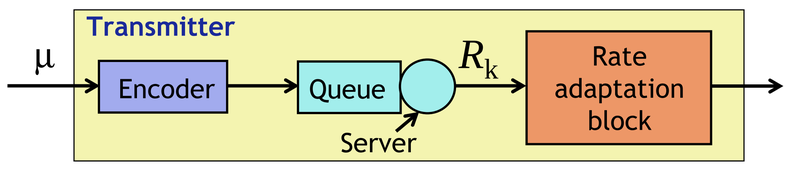
Numerical Result

Receiver buffer - delay variance can be reduced



Queued-code is more flexible – better performance

Practical Queued-code



•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

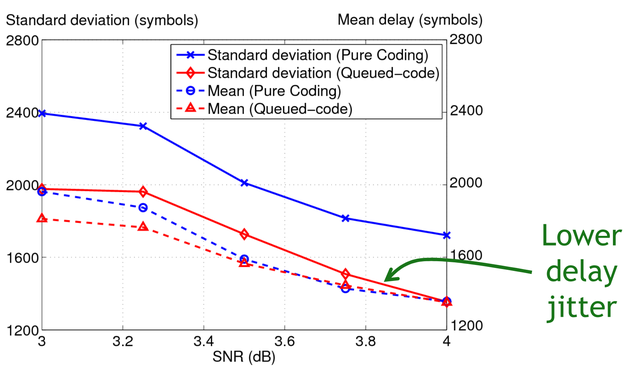
Encoder and Rate Adaptation Block

•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 Result



LDPC convolutional code, rate $\frac{1}{2}$, Tc = 64 symbols
Queued-code: R(g) = (0.59, 0.5, 0.25)

Conclusions and Future Work

•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
- Utility of buffer at transmitter vs at receiver

•Practical implementation using LDPC convolutional codes

•Generalizing the queued-code
•Structured construction of queued-codes