Impact of FEC Overhead on Scalable Video Streaming

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Outline

- Motivation
- Background
- Impact of FEC on Scalable Video
- Adaptive FEC Control
- Evaluation
- Conclusion

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- Internet streaming is an important part of the Internet
- Streaming applications usually require special mechanisms that can overcome packet loss without utilizing retransmission
- FEC is often considered for recovering lost data segments
- However, studies reported conflicting results on the benefits of FEC

- Our work aims to:
    - address this uncertainty and
    - provide additional insight into understanding how FEC overhead affects the performance of scalable video streaming

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Background

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FEC

- FEC schemes require application servers to send extra information along with the original data
- Media independent FEC
    - Based on (N, k) block codes (such as parity or Reed-Solomon codes), where N is the size of an FEC block and k is the the number of FEC packets in the block
- All data packets are recovered if the number of lost packets in a block is no more than k
- If more than k packets are lost, none of them can be recovered by the receiver

Background

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FGS

- Streaming profile of the ISO/IEC MPEG-4 standard
- Method of compressing residual video signal into a single enhancement layer
- Allows application servers to scale the enhancement layer to match variable network capacity during streaming
- The enhancement layer is typically coded at some fixed bitrate and can be rescaled to any desired bitrate

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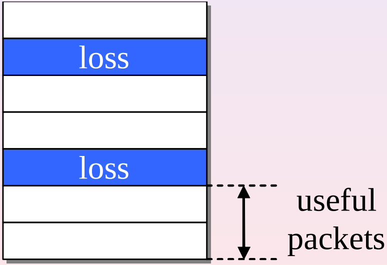

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- Note that many studies show that Internet packet loss can be captured by Markov models
    - Alternating ON/OFF renewal process can model more general distribution of packet loss and allows heavy-tailed burst lengths

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- Note that many studies show that Internet packet loss can be captured by Markov models
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- In what follows, we derive the expected amount of *useful* data $E[Z_j]$ recovered from each frame
    - Z_j is the number of consecutively received packets in a frame j

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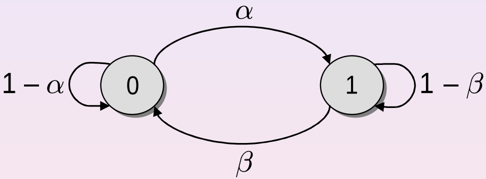

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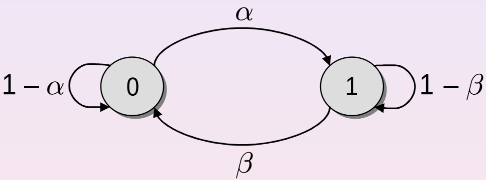

  - α and β are transition probabilities
  - In the stationary state, probabilities π_0 and π_1 to find the process in each of its two states are given by:

$$\pi_0 = \frac{\beta}{\alpha+\beta}, \ \pi_1 = p = \frac{\alpha}{\alpha+\beta}. \tag{1}$$

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Lemma 1

Assuming a two-state Markov packet loss and $L > k$, the expected number of useful video packets recovered per frame is:

$$\bar{Q} = E[Z_j | L > k] = \frac{1-p}{\alpha}\left(1 - (1-\alpha)^H\right), \tag{2}$$

where $H = N - k$ is the number of video packets in an FEC block

Analysis of video streaming

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Theorem 1

Assuming two-state Markov packet loss with average loss probability p, the expected number of useful packets recovered per FEC block of size N is:

$$\begin{aligned} E[Z_j] &= \sum_{i=0}^{k} P(N,i)H \\ &\quad + \left(\sum_{i=k+1}^{N} P(N,i)\right)\left(\frac{1-p}{\alpha}\left(1-(1-\alpha)^{H}\right)\right), \end{aligned} \tag{3}$$

where $P(N,i)$ is the probability of losing exactly i packets out of N transmitted packets.

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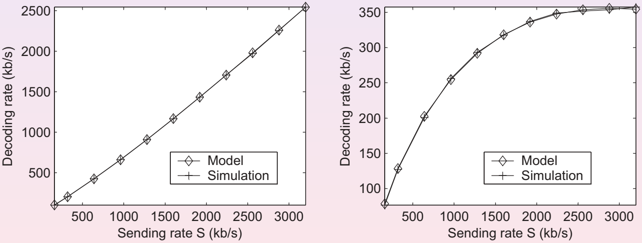

(a) $\psi = 1.1p$ (b) $\psi = 0.9p$

Figure: Expected decoding rate $\tilde{R}$ ($p = 0.1$, $\alpha = 0.08$, and $\beta = 0.72$)

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- Next, we derive the utility of received video and examine how FEC overhead affects the quality of video

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- The amount of overhead in FEC-based streaming plays a significant role in determining video quality
- Next, we derive the utility of received video and examine how FEC overhead affects the quality of video
- Define the utility U as the fraction of received data that is useful for decoding

Analysis of video streaming

Theorem 2

Assuming Bernoulli packet loss in an FEC block of size N, average loss probability p, and FEC overhead rate $\psi = \eta p$, $(0 < \psi < 1)$, the utility of received video for each FEC block converges to the following as $H \to \infty$:

$$\lim_{H\to\infty} U = \begin{cases} 0 & 0 < \eta < 1 \\ 0.5 & \eta = 1 \\ \frac{1-\psi}{1-p} & 1 < \eta < 1/p \end{cases}, \tag{4}$$

where η is constant.

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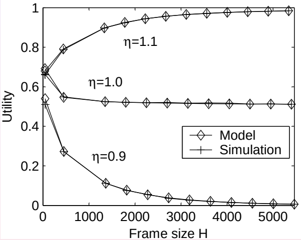

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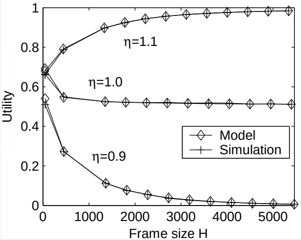

Note that U indeed converges to $0, 0.5$ or $(1-\psi)/(1-p)$ depending on the value of ψ as the streaming rate becomes large

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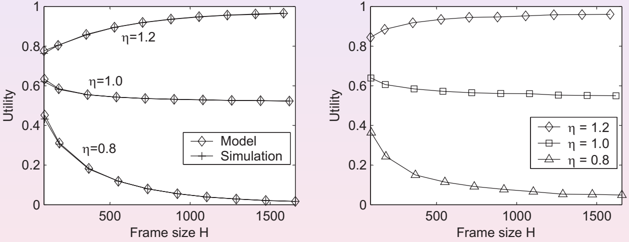

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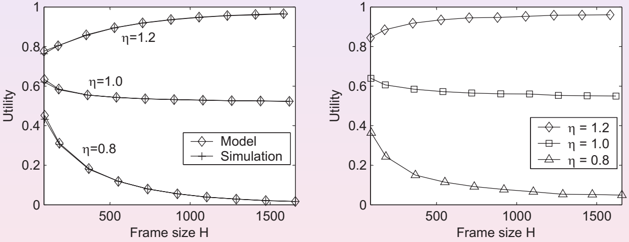

(a) Markov loss (b) Renewal loss

Again, U exhibits percolation and converges to $0, 0.5$ or $(1-\psi)/(1-p)$ depending on ψ

Discussion

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- Effectiveness of FEC depends on how the server uses redundant packets based on packet-loss dynamics
- Using fixed amount of overhead may cause significant quality degradation when packet loss fluctuates

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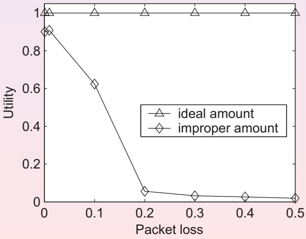
- Using fixed amount of overhead may cause significant quality degradation when packet loss fluctuates

- Simulation results of U for different packet loss p under improper amount of FEC overhead



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Adaptive FEC control

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Needs for adaptive control

- In a practical network environment, packet loss changes dynamically, depending on
    - cross-traffic
    - link quality
    - routing updates, etc
- The amount of FEC needs to be adjusted according to changing packet loss to maintain high end-user utility

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$$\psi_i(n) = \psi_i(n - D_i) + \tau\left(\eta p_i(n - D_i) - \psi_i(n - D_i)\right), \quad (5)$$

where index i represents flow number, $p_i(n)$ is the measured average packet loss in the FGS layer for flow i during interval n, τ is the controller's gain parameter, D_i is the round-trip delay for flow i.

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Lemma 2

Controller (5) is stable if and only if $0 < \tau < 2$.

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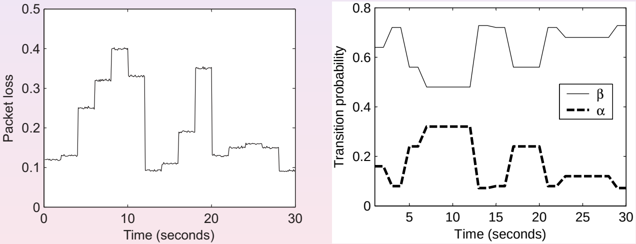

(a) Packet loss pattern (b) Transition probability α,β

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    - To illustrate the adaptivity of the controller, we use target utility $U_T = 0.8$
- For comparison, we apply two different scenarios that use fixed amount of overhead
    - The fixed-overhead amount is driven by the lower and upper bounds on packet loss $\tilde{p}$

- The evolution of achieved utility U

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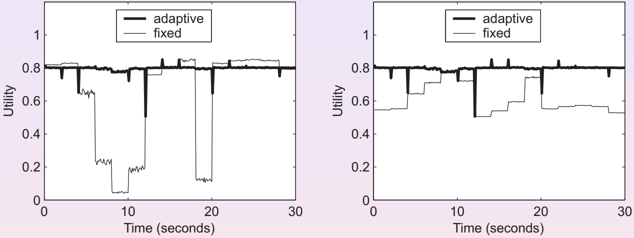

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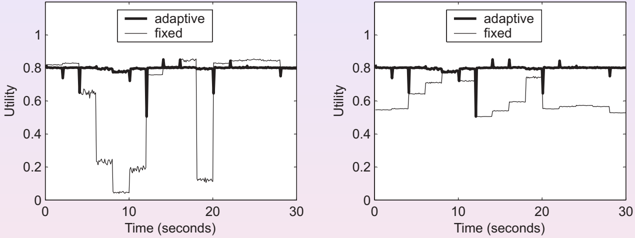

(a) $\tilde{p} = 0.1$ (b) $\tilde{p} = 0.4$

- Our adaptive controller maintains the target utility U_T very well along the entire streaming session
- However, fixed-overhead schemes cannot maintain high utility as packet loss varies

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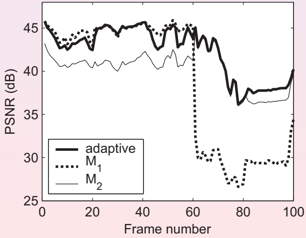

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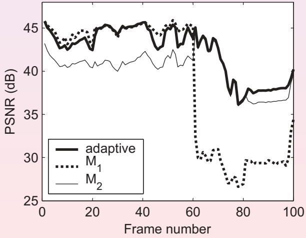

- The adaptive method offers as much as 2.5 dB higher PSNR than M_2 for the first 60 frames
- Also, outperforms M_1 by almost 10 dB for the last 40 frames

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- FEC has conflicting effects on video quality depending on the amount of overhead used
- Adaptive FEC overhead control can provide a high quality of video to end-users
- Proper control of FEC overhead can significantly improve the utility of received video over lossy channels

Thank you!

Any questions?