Impact of FEC Overhead on Scalable Video Streaming

Seong-ryong Kang and Dmitri Loguinov

Department of Computer Science
Texas A&M University
College Station, TX 77843

June 14, 2005
Outline

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

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

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.
Motivation of this work

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.
Motivation of this work

- Internet streaming is an important part of the Internet
Motivation of this work

- Internet streaming is an important part of the Internet
- Streaming applications usually require special mechanisms that can overcome packet loss without utilizing retransmission
Motivation of this work

- 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
Motivation of this work

- 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
Motivation of this work

- 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
Motivation

Background

Impact of FEC on Scalable Video

Adaptive FEC Control

Evaluation

Conclusion
Background

FEC schemes require application servers to send extra information along with the original data. Media independent FEC is 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 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**

**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 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

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
Background

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
Motivation

Background

Impact of FEC on Scalable Video
Adaptive FEC Control
Evaluation
Conclusion

Because of dependency in the enhancement layer, higher sections of FGS cannot be used in decoding the frame without the presence of lower sections.

S. Kang and D. Loguinov
Impact of FEC Overhead on Scalable Video Streaming
Background

Because of dependency in the enhancement layer, higher sections of FGS cannot be used in decoding the frame without the presence of lower sections.
Because of dependency in the enhancement layer, higher sections of FGS cannot be used in decoding the frame without the presence of lower sections.
Outline

- Motivation
- Background
- Impact of FEC on Scalable Video
- Adaptive FEC Control
- Evaluation
- Conclusion
We investigate the performance of FEC-based streaming considering Markov and renewal patterns of packet loss. We use MPEG-4 FGS as an example and only examine the enhancement layer. 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. 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.
We investigate the performance of FEC-based streaming considering Markov and renewal patterns of packet loss.
Analysis of video streaming

- We investigate the performance of FEC-based streaming considering Markov and renewal patterns of packet loss.
- We use MPEG-4 FGS as an example and only examine the enhancement layer.
Analysis of video streaming

- We investigate the performance of FEC-based streaming considering Markov and renewal patterns of packet loss.
  - We use MPEG-4 FGS as an example and only examine the enhancement layer.
- 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.
We investigate the performance of FEC-based streaming considering Markov and renewal patterns of packet loss.

- We use MPEG-4 FGS as an example and only examine the enhancement layer.

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.

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 $j$. 
Analysis of video streaming

Assume that long-term network packet loss is given by \( p \). The loss process can be modeled by a two-state Markov chain:

\[
\begin{pmatrix}
0 & \alpha \\
\beta & 1
\end{pmatrix}
\]

where \( \alpha \) and \( \beta \) are transition probabilities. In the stationary state, the probabilities \( \pi_0 \) and \( \pi_1 \) to find the process in each of its two states are given by:

\[
\pi_0 = \frac{\beta}{\alpha + \beta}, \quad \pi_1 = \frac{p}{\alpha + \beta}.
\]
Assume that long-term network packet loss is given by $p$.
Analysis of video streaming

- Assume that long-term network packet loss is given by $p$.
- Loss process can be modeled by a two-state Markov chain:
Assume that long-term network packet loss is given by $p$.

Loss process can be modeled by a two-state Markov chain:

$$\begin{align*}
\text{0} & \quad \text{1} \\
1-\alpha & \quad \alpha \\
\beta & \quad 1-\beta
\end{align*}$$

In the stationary state, probabilities $\pi_0$ and $\pi_1$ to find the process in each of its two states are given by:

$$\begin{align*}
\pi_0 &= \beta / (\alpha + \beta) \\
\pi_1 &= p = \alpha / (\alpha + \beta)
\end{align*}$$
Analysis of video streaming

- Assume that long-term network packet loss is given by $p$.
- Loss process can be modeled by a two-state Markov chain:

\[\begin{array}{cc}
0 & 1 \\
\alpha & 1 - \alpha \\
1 - \beta & \beta \\
\end{array}\]

- $\alpha$ and $\beta$ are transition probabilities.
- In the stationary state, probabilities $\pi_0$ and $\pi_1$ to find the process in each of its two states are given by:

\[
\pi_0 = \frac{\beta}{\alpha + \beta}, \quad \pi_1 = p = \frac{\alpha}{\alpha + \beta}.
\]
Analysis of video streaming

To derive $E[Z_j]$, we define:

$L$ to be the number of packets lost in an FEC block

$\bar{Q} = E[Z_j | L > k]$ to be the expected number of useful video packets recovered from the front of an FEC block when $L > k$

Then, we have the following result:

**Lemma 1**

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

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

(2)

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

S. Kang and D. Loguinov
Impact of FEC Overhead on Scalable Video Streaming
Analysis of video streaming

- To derive $E[Z_j]$, we define:
To derive $E[Z_j]$, we define:

- $L$ to be the number of packets lost in an FEC block
- $\bar{Q} = E[Z_j|L > k]$ to be the expected number of useful video packets recovered from the front of an FEC block when $L > k$
Analysis of video streaming

To derive $E[Z_j]$, we define:

- $L$ to be the number of packets lost in an FEC block
- $\bar{Q} = E[Z_j|L > k]$ to be the expected number of useful video packets recovered from the front of an FEC block when $L > k$

Then, we have the following result:
Analysis of video streaming

To derive $E[Z_j]$, we define:

- $L$ to be the number of packets lost in an FEC block
- $\bar{Q} = E[Z_j|L > k]$ to be the expected number of useful video packets recovered from the front of an FEC block when $L > k$

Then, we have the following result:

**Lemma 1**

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

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

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

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:

$$E[Z] = \sum_{i=0}^{k} P(N,i) H(3) + \left(\sum_{i=k+1}^{N} P(N,i) \right) \left(1 - p^\alpha \left(1 - (1 - \alpha) H\right)\right),$$

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

**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:

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

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

Define $\psi$ to be the fraction of FEC packets in a block. To verify the model, we simulate a Markov loss process with two different values of $\psi$:

- $\psi = 1.1p$
- $\psi = 0.9p$

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

- Define $\psi$ to be the fraction of FEC packets in a block
Define $\psi$ to be the fraction of FEC packets in a block.

To verify the model, we simulate Markov loss process with two different values of $\psi$. 

Simulation results
Simulation results

- Define $\psi$ to be the fraction of FEC packets in a block.
- To verify the model, we simulate Markov loss process with two different values of $\psi$.

\[ \psi = 1.1p \]  
\[ \psi = 0.9p \]

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

• Note that the behavior of expected decoding rate changes for different $\psi$. 
Simulation results

- Note that the behavior of expected decoding rate changes for different $\psi$
- The amount of overhead in FEC-based streaming plays a significant role in determining video quality.
Simulation results

- Note that the behavior of expected decoding rate changes for different $\psi$.
- 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.
Simulation results

- Note that the behavior of expected decoding rate changes for different $\psi$
- 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
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 $H \to \infty$:

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

(4)

where $\eta$ is constant.
Simulation results

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

- Simulation results under Bernoulli loss

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

- Simulation results under Bernoulli loss

![Graph showing simulation results for different values of \( \eta \).]
Simulation results

- Simulation results under Bernoulli loss

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

Figure: Simulation results of $U$ for Markov loss ($\alpha = 0.08$, $\beta = 0.72$) and renewal loss with different $\eta$. For both figures, $p = 0.1$. Again, $U$ exhibits percolation and converges to $0$, $0.5$ or $(1 - \psi)/(1 - p)$ depending on $\psi$. 

S. Kang and D. Loguinov
Simulation results

- Note that the asymptotic behavior of $U$ in Theorem 2 holds for Markov and renewal patterns of packet loss.
Simulation results

- Note that the asymptotic behavior of $U$ in Theorem 2 holds for Markov and renewal patterns of packet loss.

![Graphs showing simulation results for Markov and renewal loss](chart.png)

(a) Markov loss  
(b) Renewal loss
Simulation results

- Note that the asymptotic behavior of $U$ in Theorem 2 holds for Markov and renewal patterns of packet loss.

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

(a) Markov loss

(b) Renewal loss
Discussion

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.

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

- 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.
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.

Simulation results of $U$ for different packet loss $p$ under improper amount of FEC overhead.
Adaptive FEC control

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.
Adaptive FEC control

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.
For adaptive FEC rate control, we use a simple proportional controller:

$$\psi_i(n) = \psi_i(n-D_i) + \tau \left( \eta_p^i(n-D_i) - \psi_i(n-D_i) \right),$$

(5)

where index $i$ represents flow number, $\eta_p^i(n)$ is the measured average packet loss in the FGS layer for flow $i$ during interval $n$, $\tau$ is the controller's gain parameter, $D_i$ is the round-trip delay for flow $i$.
For adaptive FEC rate control, we use a simple proportional controller:

$$\psi_i(n) = \psi_i(n-D_i) + \tau (\eta_{pi}(n-D_i) - \psi_i(n-D_i)),$$

where index $i$ represents flow number, $\eta_{pi}(n)$ is the measured average packet loss in the FGS layer for flow $i$ during interval $n$, $\tau$ is the controller's gain parameter, and $D_i$ is the round-trip delay for flow $i$.

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

S. Kang and D. Loguinov  Impact of FEC Overhead on Scalable Video Streaming 22/30
For adaptive FEC rate control, we use a simple proportional controller:

$$\psi_i(n) = \psi_i(n - D_i) + \tau (\eta p_i(n - D_i) - \psi_i(n - D_i)),$$

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

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

S. Kang and D. Loguinov

Impact of FEC Overhead on Scalable Video Streaming 22/30
For adaptive FEC rate control, we use a simple proportional controller:

\[
\psi_i(n) = \psi_i(n - D_i) + \tau (\eta p_i(n - D_i) - \psi_i(n - D_i)),
\]

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

Lemma 2

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

- Motivation
- Background
- Impact of FEC on Scalable Video
- Adaptive FEC Control
- Evaluation
- Conclusion
We simulate a streaming session with a hypothetical packet loss pattern.

Figure: The packet loss pattern and transition probabilities used in the simulation.
Packet loss pattern

- We simulate a streaming session with a hypothetical packet loss pattern
We simulate a streaming session with a hypothetical packet loss pattern.
We investigate adaptive FEC overhead controller with the behavior of achieved utility. To illustrate the adaptivity of the controller, we use target utility $U_T = 0$. 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.
We investigate adaptive FEC overhead controller (5) with the behavior of achieved utility.
We investigate adaptive FEC overhead controller (5) with the behavior of achieved utility.

To illustrate the adaptivity of the controller, we use target utility $U_T = 0.8$. 
We investigate adaptive FEC overhead controller (5) with the behavior of achieved utility.

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.
We investigate adaptive FEC overhead controller (5) with the behavior of achieved utility.

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 $U$
The evolution of achieved utility $U$

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

(b) $\tilde{p} = 0.4$
The evolution of achieved utility $U$

![Graph showing utility over time for adaptive and fixed controllers.](image)

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

- PSNR of CIF Foreman reconstructed with different FEC overhead control.

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.
PSNR quality

- PSNR of CIF Foreman reconstructed with different FEC overhead control
- $M_1$ and $M_2$ use fixed amount of overhead driven by $\tilde{p} = 0.1$ and $\tilde{p} = 0.4$, respectively

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

- PSNR of CIF Foreman reconstructed with different FEC overhead control
- $M_1$ and $M_2$ use fixed amount of overhead driven by $\tilde{p} = 0.1$ and $\tilde{p} = 0.4$, respectively

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.
PSNR quality

- PSNR of CIF Foreman reconstructed with different FEC overhead control
- \( M_1 \) and \( M_2 \) use fixed amount of overhead driven by \( \tilde{\rho} = 0.1 \) and \( \tilde{\rho} = 0.4 \), respectively

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.
Outline

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