Distributed Rate Control for Video Streaming with Intersession Network Coding

Hülya Seferoğlu, Athina Markopoulou
UC Irvine
Outline

- Introduction
- General Rate Control over NC
- Video Rate Control over NC
- Performance Evaluation
- Summary
Outline

- Introduction
  - Motivation
  - Problem Statement

- General Rate Control over NC

- Video Rate Control over NC

- Performance Evaluation

- Summary
Motivation

Video Streaming

Maximize video quality
- Transmission history
- Packet deadlines
- Distortion values
- Packet dependencies
- Channel state

Network Coding

Mix packets from different flows
Maximize Throughput
Motivation

**Video Streaming**

- Rate Control
  - Time varying video content
  - Channel capacity

**Network Coding**

- Mix packets from different flows
- Maximize Throughput

Affect NC Opportunities
Achievable Rate Region

Interaction of rate control and network coding
No Network Coding
(achievable region)

A \rightarrow Relay \rightarrow B

A_1: no NC: \ 2x_1 + 2x_2 \leq R

A_B (achievable region)
Network Coding for Wireless
(achievable region)

\[ A \rightleftharpoons A \text{ Relay} \rightleftharpoons B \]

- \( x_1 \) (no NC)
- \( x_2 \) (no NC)
- \( \max\{x_1, x_2\} \) (NC)

- \( x_{1_{A\text{, Relay}}} \) (no NC)
- \( x_{1_{\text{Relay,B}}} \) (no NC)
- \( x_{1_{\text{Relay,A,B}}} \) (NC)

- \( x_{2_{\text{Relay,A}}} \) (no NC)
- \( x_{2_{B\text{, Relay}}} \) (no NC)
- \( x_{2_{\text{Relay,A,B}}} \) (NC)

\[ A_2: \text{NC: } x_1 + x_2 + \max\{x_1, x_2\} \leq R \]

\[ A_1: \text{no NC: } 2x_1 + 2x_2 \leq R \]
Network Coding for Wireless
(achievable region)
Problem Statement:
Rate control for video with network coding

Optimal e2e rate and network coding in the core!
Outline

- Introduction

- General Rate Control over NC
  - Formulation
  - Distributed Solution
  - Convergence

- Video Rate Control over NC

- Performance Evaluation

- Summary
**General Rate Control over NC**

**Formulation**

\[
\begin{align*}
\text{max} & \quad \sum_{s \in S} U_s(x_s) \\
\text{s.t.} & \quad x_s = \sum_{J \in (i, J) \in A, i \in I_s} x_{i, J}^s \\
& \quad z_{i, J}^k = R_{i, J} \tau_{i, J}^k \\
& \quad \sum_{(i, J) \in A^g} \sum_{k \in K} \tau_{i, J}^k \leq \gamma \\
& \quad H_{i, J}^s x_{i, J}^s \leq z_{i, J}^s \xi_{i, J}^s \\
\end{align*}
\]

- \( \text{Optimize total utility} \)
- \( \text{Flow Conservation} \)
- \( \text{Available Capacity} \)
- \( \text{Interference} \)
- \( \text{Capacity constraint} \)

\[
\begin{align*}
U(x_1) & = U(x_1) \\
\text{max} & \quad \{x_1, x_2\} \\
\text{max} & \quad U(x_1) + U(x_2) \\
\end{align*}
\]

- \( x_1 = x_{1, \text{Relay}} \) (no NC) = \( x_{1, \text{Relay}} + x_{1, \text{Relay}, \{A, B\}} \)
- \( x_2 = x_{2, \text{Relay}} \) (no NC) = \( x_{2, \text{Relay}, \{A\}} + x_{2, \text{Relay}, \{A, B\}} \)
General Rate Control over NC
Distributed solution

Rate Control

\[
\max_{x_s} \ U_s(x_s) - \sum_{i \in I_s} \sum_{\{J|(i,J) \in A, i \in I_s\}} q_{i,J}^{\eta_i,J(s),s} H_{i,J}^{s} x_{i,J}^{s}
\]

\[
s.t. \quad x_s = \sum_{\{J|(i,J) \in A, i \in I_s\}} x_{i,J}^{s}, \quad \forall s \in S
\]

\[
x_s, x_{i,J}^{s} \geq 0, \quad \forall (i, J) \in A
\]

Parameter Update

\[
q_{i,J}^{k,s}(t+1) = \left\{ q_{i,J}^{k,s}(t) + \beta_t \left[ H_{i,J}^{s} x_{i,J}^{s} - z_{i,J}^{k} \xi_{i,J}^{s} \right] \right\}^+
\]

Scheduling

\[
\max_{\tau} \ \sum_{(i,J) \in A} \sum_{k \in K} R_{i,J}^{k} \tau_{i,J}^{k} Q_{i,J}^{k}
\]

\[
s.t. \quad \sum_{(i,J) \in A^q} \sum_{k \in K} \tau_{i,J}^{k} \leq \gamma, \quad \forall A^q \in A
\]

\[
\tau_{i,J}^{k} \geq 0, \quad \forall k \in K, \forall (i, J) \in A.
\]
**General Rate Control over NC**

**Convergence**

**Case I:** \( U_1(x_1) = \log(x_1) \),
\( U_2(x_2) = \log(x_2) \)

**Case II:** \( U_1(x_1) = 4\log(x_1) \),
\( U_2(x_2) = \log(x_2) \)
Outline

- Introduction
- General Rate Control over NC
- Video Rate Control over NC
  - Key Observations
  - Formulation
- Performance Evaluation
- Summary
Key observation I: Video rate requirements affect the underlying network coding opportunities.
Key observation II: Delaying some scenes and optimizing the rate allocation create more network coding opportunities.

Goal

\[ \text{Goal: } s_1(A), s_1(B), s_2(A), s_2(B) \]
Video Rate Control over NC

Key observations

- **Key observation II:** Delaying some scenes and optimizing the rate allocation create more network coding opportunities.
Video Rate Control over NC

Formulation

\[
\max_{x,\tau} \sum_{s \in S} \sum_{f \in F_s} U_s(x_s(f)) \delta(f)
\]

s.t.

\[
x_s(f) = \sum_{\{J| (i,J) \in A, i \in I_s\}} x_{i,J}(f)
\]

\[
\tau_{i,J} = R_{i,J} \gamma_{i,J}
\]

\[
\sum_{(i,J) \in A} \sum_{k \in K} \tau_{i,J} \leq \gamma
\]

\[
\sum_{f \in F_s} H_{s,J} x_{i,J}(f) \leq z_{i,J} \xi_{i,J}
\]

\[
x_s(f) \geq x_{s,\min}(f)
\]
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Performance Evaluation
Log utilities - setup

- A and B example
- Two sequences with six scenes
- Scenes consist of 250 packets
- Utility function of each stream:
  - $U_1 = [4 \log x(1), \log x(2), 4 \log x(3), \log x(4), 4 \log x(4), \log x(4)]$
  - $U_2 = [\log x(1), 4 \log x(2), \log x(3), 4 \log x(4), \log x(4), 4 \log x(4)]$
- Channel capacity of each link is considered as 10 packets/transmission
Performance Evaluation
Log utilities - results

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<th>Scene Number</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
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Performance Evaluation
Real video - setup

- A and B example
- Two sequences with six scenes
  - Scenes consist of QCIF size video sequences; Carphone, Foreman, Grandma, Mother & Daughter. 30 fps, IPP.. structure, average packet size is 1000B.
- Utility function of each stream determined according to DR curve and weighted according to content;
  - $w_1 = [0.19, 4.45, 0.18, 3.57]$  
  - $w_2 = [2.56, 0.19, 2.56, 0.14]$  
- Channel capacity of each link is considered as 1Mbps.
Performance Evaluation

Real video - results

Graph 1: Rate (kbps) vs. Iteration Number
- General rate control over NC
- Video rate control over NC - T=500
- Video rate control over NC - T=1000

Graph 2: PSNR (dB) vs. Optimization Interval (T)
Summary

- Proposed distributed rate control schemes for video streaming over wireless networks with intersession network coding.
- Improved total rate and video quality.
- Ongoing work...