Delay-constrained Rate Adaptation for Robust Video Transmission over Home Networks

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Video Transmission over Home Networks

- **Goals:**
  - Streaming high-quality video from a server to one or more receivers over IP-based home networks, in particular wireless IEEE 802.11 LAN (stored as well as live video)
  - Maintaining highest possible video quality and avoiding glitches / interruptions while keeping end-to-end delay to a minimum

- **Challenges:**
  - High bit rate of (MPEG-2) video: SDTV or HDTV quality
  - Multiple video streams may contend for limited network resources
  - Wireless network throughput is unpredictable and time-varying
  - Compressed video data has high sensitivity to loss (error propagation)
  - Low viewer tolerance to video distortions due to delays/loss
<table>
<thead>
<tr>
<th>IEEE standard</th>
<th>Frequency band</th>
<th>Link rates</th>
<th>PHY</th>
</tr>
</thead>
<tbody>
<tr>
<td>802.11b</td>
<td>2.4 GHz (ISM)</td>
<td>1, 2, 5.5, 11 Mbps</td>
<td>Direct Sequence Spread Spectrum (DSSS)</td>
</tr>
<tr>
<td>802.11a</td>
<td>5 GHz (UNII)</td>
<td>6, 12, 18, 24, 36, 48, 54 Mbps</td>
<td>Orthogonal Frequency Division Multiplexing (OFDM)</td>
</tr>
<tr>
<td>802.11g</td>
<td>2.4 GHz (ISM)</td>
<td>1, 2, 5.5, 11, 6, 12, 18, 24, 36, 48, 54 Mbps</td>
<td>Orthogonal Frequency Division Multiplexing (OFDM)</td>
</tr>
</tbody>
</table>

- Actual IEEE 802.11 Wireless LAN throughput performance is unpredictable and varies dynamically. Performance depends on:
  - Distance between stations
  - Presence of walls, doors and other structures
  - Interferers (cordless phone, microwave, etc.)
  - Mobility (varying distance)
  - Protocol stack (e.g. UDP/IP) and data encapsulation (payload size)
  - Competing cross-traffic on the network
- No guaranteed quality-of-service, even with 802.11e enhancements
Wireless medium prone to degradations due to path loss, fading and interference

IEEE 802.11 PHY & MAC error control mechanisms for reducing inherent error rate of wireless medium:
- Retransmissions of packets that were not acknowledged (at MAC)
- (Automatic) switching (reducing) of PHY link data rates

Experienced at application/transport layers as variations in packet delays and arrival rate (time-varying throughput)
- Packet loss rate at transport layer is very low (near 0)
Our overall approach: Real-time feedback-based video adaptation to channel/network

Focus of this paper: Delay-constrained video bit rate adaptation
  - Goal: on-time delivery (no decoder buffer underflows)
  - Estimate expected delay for transmission of video frame, given time-varying channel throughput and sender queue size
  - Select optimal bit rate for video frame, subject to delay constraint
Let $\Delta t_j$ be the transmission duration for video frame $j$ over the wireless channel (from the head of MAC queue to the receiver):

- $\Delta t_j$ depends on channel condition, e.g., available bandwidth $H_j$ at transmission time of frame $j$.
- $\Delta t_j$ depends on number of bits used to encode frame $j$, and on packetization, i.e., packet size $P_j$ and number of packets $M_j$.
- A simple approximation: $E[\Delta t_j] \approx (M_j \cdot P_j) / H_j$.

Let $d_i$ be the total transmission delay for video frame $i$ (to be encoded/transcoded):

- $E[d_i] \approx E[\Delta t_k + \Delta t_{k+1} + \ldots + \Delta t_j + \ldots + \Delta t_{i-1} + \Delta t_i]$
  
  \[ \approx (M_k \cdot P_k + M_{k+1} \cdot P_{k+1} + M_j \cdot P_j + \ldots + M_{i-1} \cdot P_{i-1} + M_i \cdot P_i) / H_{est} \]
Delay-constrained bit rate adaptation

- **Goal:** on-time delivery

- **Delay constraint:** \( d_i \leq \Delta T_E \)
- **Expected delay approach:** \( E[d_i] = F \cdot \Delta T_E \) with \( 0 \leq F \leq 1 \)
- **Select number of packets for frame** \( i, M_i \), such that:

\[
(\sum_{k} M_k \cdot P_k + M_{k+1} \cdot P_{k+1} + \sum_{j} M_j \cdot P_j + \ldots + M_{i-1} \cdot P_{i-1} + M_i \cdot P_i) / H_{est} = F \cdot \Delta T_E
\]
Bandwidth estimation

- **Bandwidth**: *maximum throughput available to application layer*
- Use *packet bursts*: groups of $M$ back-to-back packets corresponding to a single video frame
  - Packet burst (video frame) submitted by sender application layer
  - Measure arrival times of packets at receiver application layer
  - Bandwidth sample obtained from $M$, time duration $\Delta \tau$ and payload $P$:
    \[ H_j \approx P_j \cdot (M_j - 1) / \Delta \tau_j \]
  - Final estimate formed by first-order IIR filtering of bandwidth samples
    \[ H_{\text{est},j} = (1 - w) \cdot H_{\text{est},j-1} + w \cdot H_j \]

```
+-------------------+-------------------+
|   Sender          |   Receiver        |
+-------------------+-------------------+
|      ↓             |      ↓            |
+-------------------+-------------------+
|                    | $\Delta \tau_1$   |
+-------------------+-------------------+
|                    |      ↓            |
+-------------------+-------------------+
|                    | $\Delta \tau_2$   |
+-------------------+-------------------+
```
Simulation setup

Channel Trace Collection

Client

Channel Trace

NS-2 Network Simulator

Application Layer - Server and client implement bandwidth estimation, feedback, and bit rate adaptation

Transport Layer – UDP

Network Layer – IP

Data Link Layer – Wireless IEEE 802.11 MAC

Physical Link Layer – Wireless IEEE 802.11 PHY
Channel traces simulating PHY and wireless channel

Video Trace

Input video bit-stream

Transcoding & Injecting lost/late packets

Output video bit-stream

Server

NS-2 Output Traces
Input and Algorithms

- **Channel traces**
  - 802.11B (2.4 GHz) – average bandwidth ≈ 4.5 Mbps (100 s)
  - 802.11A (5 GHz) – average bandwidth ≈ 14 Mbps (10 s)

- **Test video streams** (MPEG-2 encoded IBBP)
  - Mobile: 352x288 (CIF) 30p @ 4 Mbps 802.11B
  - Crew: 704x576 (4CIF) 30p @ 6 Mbps 802.11B
  - Harbour: 1280x720 (HD) 60p @ 16.9 Mbps 802.11A

- **Schemes compared**
  - I: Non-adaptive – attempts to transport all video data
  - I’: Non-adaptive with dropping of packets expected to arrive late
  - II: Basic bit rate adaptation – adapts only to estimated bandwidth
  - III: Proposed delay-constrained bit rate adaptation
Simulation Results – Mobile

CIF, 30p, input 34.2 dB at 4 Mbps, 802.11b channel

Percentage of frames with PSNR lower than 20 dB (occurrence of glitches):

<table>
<thead>
<tr>
<th></th>
<th>I</th>
<th>I’</th>
<th>II</th>
<th>III F=0.3</th>
<th>III F=0.5</th>
<th>III F=0.7</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>95.2 - 95.7</td>
<td>42.9 - 65.1</td>
<td>0.2 - 5.5</td>
<td>0.0 - 1.7</td>
<td>1.2 - 2.0</td>
<td>1.5 – 4.0</td>
</tr>
</tbody>
</table>
4CIF, 30p, input 38.6 dB at 6 Mbps, 802.11b channel

Percentage of frames with PSNR lower than 20 dB (occurrence of glitches):

<table>
<thead>
<tr>
<th></th>
<th>I</th>
<th>I'</th>
<th>II</th>
<th>III F=0.3</th>
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<th>III F=0.7</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>98.8 - 100</td>
<td>52.8 - 64.6</td>
<td>66.0 – 90.8</td>
<td>0.1 – 0.6</td>
<td>0.5 – 0.9</td>
<td>1.1 – 1.9</td>
</tr>
</tbody>
</table>
Simulation Results – Harbour

HD, 60p, input 35.3 dB at 16.9 Mbps, 802.11a channel

Percentage of frames with PSNR lower than 25 dB (occurrence of glitches):

<table>
<thead>
<tr>
<th></th>
<th>I</th>
<th>I’</th>
<th>II</th>
<th>III F=0.3</th>
<th>III F=0.5</th>
<th>III F=0.7</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>92.8 – 97.5</td>
<td>37.0 – 49.2</td>
<td>0.0 – 0.0</td>
<td>0.0 – 0.0</td>
<td>0.0 – 0.2</td>
<td></td>
</tr>
</tbody>
</table>
Conclusions

- Proposed practical algorithm for delay-constrained bit rate adaptation for video transmission over (quasi-)reliable channel with time-varying bandwidth (WLAN links)

- Extensive simulations with NS-2 using real channel traces and various MPEG-2 video sequences
  - Significant PSNR gains achieved by bit rate adaptation (use of transcoding)
  - Significant PSNR gains achieved by delay-constrained algorithm (compared to basic non-delay constrained algorithm)
  - Delay-constrained algorithm significantly reduces the number of buffer underflow events (glitches)

- Other work:
  - 802.11e WLAN links (reported at ICME 2005)
  - Pro-active approach
  - Distortion optimization
## Visual comparisons

<table>
<thead>
<tr>
<th>Device</th>
<th>Resolution</th>
<th>Frame Rate</th>
<th>Standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mobile</td>
<td>352x288 (CIF)</td>
<td>30p</td>
<td>802.11B</td>
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<tr>
<td>Crew</td>
<td>704x576 (4CIF)</td>
<td>30p</td>
<td>802.11B</td>
</tr>
<tr>
<td>Harbour</td>
<td>1280x720 (HD)</td>
<td>60p</td>
<td>802.11A</td>
</tr>
</tbody>
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Thank you for your attention.