Impact of Router Queuing Disciplines on Multimedia QoE in IPTV Deployments

Prashanth Chandrasekaran
Microsoft

Joint work with:
Prasad Calyam, Ph.D., Gregg Trueb, Nathan Howes, Rajiv Ramnath, Ph.D.
Ohio Supercomputer Center
Ying Liu, Delei Yu, Lixia Xiong, Qi Wang, Daoyan Yang
Huawei Technologies

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Topics of Discussion

• Background and Motivation
• Testbed Setup and Methodology
• Performance Analysis
• Conclusion and Future Work
IPTV Background

• Internet TV (IPTV) is starting to be widely deployed on the Internet
  – Subscribers: France (4 Million), Korea (1.8 Million); Gartner estimates 49 Million world-wide subscribers by 2010
  – Will replace the Television technology established for the past 60 years
    • Cost savings (VoIP, IPTV and Internet bundles)
    • Increased accessibility (e.g. hand-holds)
    • Compatible with modern content distribution (e.g., social networks, online movie rentals)

• Challenge is to provide same if not better QoE than traditional TV
  – Providers need to understand user, application, and network factors to ensure their services satisfy end users’ expectations of quality
Study Motivation

• Many earlier studies have studied factors that affect multimedia QoE
  – [Muntean, et. al.] [Lu, et. al.,] High activity level video more sensitive to network congestion by 1 to 10% compared to Low activity level video
  – [Ghanbari, et. al.] Performance of MPEG and H.26x codecs for multi-resolution video

• This paper has early results of our IPTV multimedia QoE study
  – We show the impact of network QoS on multimedia QoE for router queuing disciplines: (i) Packet-ordered FIFO, and (ii) Time-ordered FIFO
  – We develop two novel metrics: “perceptible impairment rate” (User-level), and “frame packet loss” (Network-level)
  – For PFIFO and TFIFO paths, we use the metrics to develop mappings of Good, Acceptable and Poor user QoE grades to network QoS levels
  – Within the GAP network levels, we present analysis of the interplay of user and application factors under PFIFO and TFIFO queuing disciplines

• Our findings will help content/network providers, and app. developers
Router Queuing Disciplines

- **PFIFO** – packet egress of a flow is ordered based on packet sequence numbers
- **TFIFO** – packet egress is ordered based on packet timestamps
- Major difference is in the handling of inter-packet jitter
  - Iperf (10 Mbps UDP mode) and Ping experiments with Netem network emulator

<table>
<thead>
<tr>
<th>Netem Configured</th>
<th>Iperf Measured</th>
<th>Ping Measured</th>
</tr>
</thead>
<tbody>
<tr>
<td>6 ms</td>
<td>6 ms</td>
<td>6 ms</td>
</tr>
<tr>
<td>18 ms</td>
<td>18 ms</td>
<td>17 ms</td>
</tr>
<tr>
<td>75 ms</td>
<td>75 ms</td>
<td>69 ms</td>
</tr>
<tr>
<td>120 ms</td>
<td>120 ms</td>
<td>110 ms</td>
</tr>
</tbody>
</table>

**Table 2.** End-to-end jitter measurements under PFIFO

<table>
<thead>
<tr>
<th>Netem Configured</th>
<th>Iperf Measured</th>
<th>Ping Measured</th>
</tr>
</thead>
<tbody>
<tr>
<td>6 ms</td>
<td>1.861 ms</td>
<td>6 ms</td>
</tr>
<tr>
<td>18 ms</td>
<td>1.891 ms</td>
<td>16 ms</td>
</tr>
<tr>
<td>75 ms</td>
<td>1.494 ms</td>
<td>61 ms</td>
</tr>
<tr>
<td>120 ms</td>
<td>1.056 ms</td>
<td>105 ms</td>
</tr>
</tbody>
</table>
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IPTV Testbed Components
## Component Configurations in our Study

### Codec Combinations
- MPEG2 Video – MPEG2 Audio
- MPEG4 Video – AAC Audio
- H.264 – AAC Audio

### Video Resolutions
- QCIF (177X140), QVGA (340X240), SD (720X480), HD (1280X720)

### Peak Encoding Bit Rates

<table>
<thead>
<tr>
<th>Resolution</th>
<th>Peak Encoding Bit Rates (bps)</th>
</tr>
</thead>
<tbody>
<tr>
<td>QCIF (177 X 140)</td>
<td>32K, 64K, 128K, 256K, 512K</td>
</tr>
<tr>
<td>QVGA (340 X 240)</td>
<td>128K, 192K, 256K, 512K, 768K</td>
</tr>
<tr>
<td>SD (720 X 480)</td>
<td>512K, 1M, 2M, 3M, 5M</td>
</tr>
<tr>
<td>HD (1280 X 720)</td>
<td>1M, 2M, 5M, 8M, 12M</td>
</tr>
</tbody>
</table>

### Video Sequences

- **Low Activity Level:** Talking-head (e.g. *Kelly*);
- **Medium Activity Level:** Talking-head with sudden changes (e.g. *Wanted*);
- **High Activity Level:** Rapid scene changes (e.g. *Timelapse*)

*NOTE:* Video sequences produced by us with audio + video and ~16 seconds duration

### Protocols
- UDP/RTP transport with MPEG-TS container format

### Caching/Buffering at Client
- 0 seconds i.e., no caching/buffering
Objective QoE Metrics

• Perceptible Impairment Rate (PIR) events/sec
  – Sum of the audio impairment events (e.g., dropouts, echoes) and video impairment events (e.g., tiling, frame freezing, jerkiness, blur) counted by two human observers at the receiver-end (one ‘listener’ for audio and one ‘viewer’ for video) divided by the length of the video clip

• Frame Packet Loss (FPL) %
  – Percentage of the number of packets lost (audio and video combined) in a frame
  – Calculated from the traffic traces as a ratio of number of packets lost to the number of frames in a video clip

• We used both FPL and PIR metrics interchangeably to support our analysis of the factors that impact multimedia QoE
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QoE Grades Mapping to QoS Levels

• For systematically analyzing multimedia QoE, major challenge is to deal with the large sample space of network health conditions
  – [Claypool, et. al.] [Calyam, et. al.] and other empirical studies have shown multimedia QoE tends to be in Good, Acceptable or Poor (GAP) grades of subjective user perception for certain ranges of network QoS levels

• We determined GAP ranges of jitter and loss for the various resolutions
  – Gradually increased one of the QoS metric (i.e., jitter or loss) levels till PIR measurements crossed thresholds for GAP QoE grades.
  – Threshold values: PIR ≤ 0.2 for Good grade, ≤ 1.2 for Acceptable grade, and >1.2 for Poor grade
  – We found that loss characteristics were independent of the queuing discipline (i.e., loss GAP ranges are the same for PFIFO and TFIFO)

Fig: Loss GAP levels for SD resolution
GAP Ranges under PFIFO and TFIFO

### Table: Jitter and Loss GAP ranges under PFIFO resolution

<table>
<thead>
<tr>
<th>Display</th>
<th>Metric</th>
<th>Good</th>
<th>Acceptable</th>
<th>Poor</th>
</tr>
</thead>
<tbody>
<tr>
<td>QCIF</td>
<td>Jitter (ms)</td>
<td>[0 - 200)</td>
<td>(200 - 400)</td>
<td>(&gt; 400]</td>
</tr>
<tr>
<td></td>
<td>Loss (%)</td>
<td>[0 - 2)</td>
<td>(2 - 4.4)</td>
<td>(&gt; 4.4]</td>
</tr>
<tr>
<td>QVGA</td>
<td>Jitter (ms)</td>
<td>[0 - 200)</td>
<td>(200 - 350)</td>
<td>(&gt; 350]</td>
</tr>
<tr>
<td></td>
<td>Loss (%)</td>
<td>[0 - 1.4)</td>
<td>(1.4 - 2.8)</td>
<td>(&gt; 2.8]</td>
</tr>
<tr>
<td>SD</td>
<td>Jitter (ms)</td>
<td>[0 - 175)</td>
<td>(175 - 300)</td>
<td>(&gt; 300]</td>
</tr>
<tr>
<td></td>
<td>Loss (%)</td>
<td>[0 - 0.6)</td>
<td>(0.6 - 2.5)</td>
<td>(&gt; 2.5]</td>
</tr>
<tr>
<td>HD</td>
<td>Jitter (ms)</td>
<td>[0 - 125)</td>
<td>(125 - 225)</td>
<td>(&gt; 225]</td>
</tr>
<tr>
<td></td>
<td>Loss (%)</td>
<td>[0 - 0.3)</td>
<td>(0.3 - 1.3)</td>
<td>(&gt; 1.3]</td>
</tr>
</tbody>
</table>

### Table: Jitter and Loss GAP ranges under TFIFO resolution

<table>
<thead>
<tr>
<th>Display</th>
<th>Metric</th>
<th>Good</th>
<th>Acceptable</th>
<th>Poor</th>
</tr>
</thead>
<tbody>
<tr>
<td>QCIF</td>
<td>Jitter (ms)</td>
<td>[0 - 50)</td>
<td>(50 - 80)</td>
<td>(&gt; 80]</td>
</tr>
<tr>
<td></td>
<td>Loss (%)</td>
<td>[0 - 2)</td>
<td>(2 - 4.4)</td>
<td>(&gt; 4.4]</td>
</tr>
<tr>
<td>QVGA</td>
<td>Jitter (ms)</td>
<td>[0 - 40)</td>
<td>(40 - 70)</td>
<td>(&gt; 70]</td>
</tr>
<tr>
<td></td>
<td>Loss (%)</td>
<td>[0 - 1.4)</td>
<td>(1.4 - 2.8)</td>
<td>(&gt; 2.8]</td>
</tr>
<tr>
<td>SD</td>
<td>Jitter (ms)</td>
<td>[0 - 30)</td>
<td>(30 - 60)</td>
<td>(&gt; 60]</td>
</tr>
<tr>
<td></td>
<td>Loss (%)</td>
<td>[0 - 0.6)</td>
<td>(0.6 - 2.5)</td>
<td>(&gt; 2.5]</td>
</tr>
<tr>
<td>HD</td>
<td>Jitter (ms)</td>
<td>[0 - 20)</td>
<td>(20 - 50)</td>
<td>(&gt; 50]</td>
</tr>
<tr>
<td></td>
<td>Loss (%)</td>
<td>[0 - 0.3)</td>
<td>(0.3 - 1.3)</td>
<td>(&gt; 1.3]</td>
</tr>
</tbody>
</table>
Salient Observations Discussion

• Higher resolutions are more sensitive to degrading network QoS
  – Evident from the narrow ranges of jitter and loss when compared to lower resolutions
  – E.g., the loss range for Good grade is [0 - 0.3) for HD, whereas the same for QCIF is [0 - 2)
  – Conclusion: Higher resolution streams in IPTV deployments demand notably higher QoS levels than lower resolution streams

• PFIFO queuing makes the IPTV streams more tolerant to network jitter compared to TFIFO
  – Evident from the higher ranges of jitter at all resolutions
  – E.g., the jitter range for Good grade is [0 - 175) for SD under PFIFO, whereas the same for TFIFO is [0 - 30)
  – Conclusion: Having PFIFO in routers at congestion points in the network or at the edges of access networks can:
    • Reduce the burden of ordering packets for media player playback at the consumer sites
    • Significantly increases the multimedia QoE resilience at the consumer sites towards higher network jitter levels
**User and Application Factors Interplay**

- PIR increases as the bit rate increases under both PFIFO and TFIFO.
- For a given bit rate, PIR increases as the activity level increases.
- Impact of activity level and bit rate on the PIR is similar under PFIFO and TFIFO (i.e., independent of the queuing discipline).
- PIR has direct correlation with the corresponding FPL under both PFIFO and TFIFO.

![Fig: Under PFIFO; MPEG-2 audio and video; AA Network Condition](image1)

![Fig: Under TFIFO; AAC audio and MPEG-4 video; AA Network Condition](image2)
Salient Observations Discussion

• Activity level is a more dominant factor than bit rate under both PFIFO and TFIFO
  – ‘Low Bit Rate with High Activity Level’ clips have greater PIR and FPL than ‘High Bit Rate with Low Activity Level’ clips under same network condition
  – **Conclusion:** For streaming a high activity level clip, choose a lower peak encoding rate rather than a higher rate under adverse network conditions

**Fig:** PIR Comparison under TFIFO; AAC audio and MPEG-4 video; AA Network Condition

**Fig:** FPL Comparison under TFIFO; AAC audio and MPEG-4 video; AA Network Condition
Topics of Discussion

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Conclusion and Future Work

• Paper Contributions
  – Studied the impact of network QoS on multimedia QoE for: (i) Packet-ordered FIFO, and (ii) Time-ordered FIFO router queuing disciplines
  – Used novel metrics: (i) PIR, and (ii) FPL to develop mappings of GAP user QoE grades to network QoS levels, for both PFIFO and TFIFO
  – Within the GAP network levels, analyzed the interplay of user and application factors under PFIFO and TFIFO

• Future Work
  – Develop an online multimedia QoE estimation model that can be used to monitor and adapt system and network resources in IPTV deployments
  – Contribute findings to IPTV industry forums such as Video Quality Experts Group (VQEG), International Telecommunications Union (ITU-T), Alliance for Telecommunications Industry Solutions (ATIS)
Thank you for your attention!