Cloud-Assisted Streaming for Low-Latency Applications

Xiaoqing Zhu, Jiang Zhu, Rong Pan, Mythili S. Prabhu, and Flavio Bonomi

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Outline

• Challenges for low-latency mobile media streaming
• Benefits of cloud assistance
• Proposed scheme
  • Architecture overview
  • Video and wireless channel model
  • MDP-based problem formulation
  • SDP-based optimal policy
• Simulation evaluations
Popularity of Low Latency Applications

Remote Desktop

Internet

Conferencing

Online Gaming
Smarter Mobile Devices

[Courtesy: C. Neisinger, Verizon Wireless]
Challenges for Mobile Media Streaming

• Challenges from the mobile network:
  • Time-varying and adversary wireless channel qualities
  • Congested mobile access link
  • Unpredictable mobile user behavior patterns
  • …

• Challenges of the applications:
  • Stringent requirement for timely packet delivery
  • Sensitive to packet losses
  • …

• Challenges of the mobile device:
  • Limited battery life
  • Constrained form factors
  • …
How Media Cloud Can Help

- Offloading: take over heavy-lifting computations
- Proxy-based adaptation: change on behalf of users
- Crowd sourcing: learn from the users
- Data mining: learn about the users
- …
Architecture Overview
Mobile Sender Adaptation

Captured raw frames

Frame rate adaptation

Encoder

Rate Shaping Buffer

Calculate frame drop policy

Feedback on prior packet statistics
Cloud-Assisted Media Streaming Protocol

- mobile sender
  - Send media packet
  - Report shaping delay
  - update operation for future frames

- cloud media proxy
  - Re-calculate frame skipping decision

- mobile receiver
  - Report network delay in ACK

- media packet
- ACK
- control
Modeling Video Content Variation

\[ X(n) = B(n) - \mu_B \]

\[ X(n) = \rho X(n - 1) + Y(n) \]
Modeling Wireless Channel Fluctuation

Good state:

Fading state:
Frame Delivery Timeline

Packet Delivery Time

Content Presentation Time

$T_f$

$T_o$

$d(n)$

$t_s(n)$

$t_r(n)$
End-to-end Frame Delivery Delay

\[ d(n) = d_w(n) + d_q(n) + d_{OWD} \]

- One-way network delay: \( \frac{RTT}{2} \)
- Encoder buffering delay: \( \max[0, d_q(n - 1) + d_w(n - 1) - \tau_f] \)
- Transmission delay: \( \frac{B(n)}{R(n)} \)
MDP Problem Formulation

• System states:

\[ s_n = \{ B(n - k), R(n - k), d_w(n - k), d_q(n - k) \} \]

• Actions:

\[ a_n = \begin{cases} 
0, \text{skip frame } n \\
1, \text{transmit frame } n 
\end{cases} \]

• Cost function

\[ g(s_n, a_n) = \alpha (1 - a_n) + \beta a_n \{ d(n) > T_o \} \]

- penalty for skipped frames
- penalty for dropped frames
**SDP-Based Policy**

\[
J_n(s) = \min_{a_n} \mathbb{E}[g(s_n, a_n) + \sum_{s'} P(s'|s, a_n) J_{n+1}(s')] \\
\text{current cost} \quad \text{future cost}
\]

\[
J_n(s) = \min_{\{a_n\}_{n+1}^N} \mathbb{E} \sum_{n=1}^N g(s_n, a_n)
\]

\[
J_n(s) = \min_{\{a_n\}_{n+1}^N} \mathbb{E} \sum_{n'=n+1}^N g(s_{n'}, a_{n'})
\]
Competing Schemes

• No frame skipping (NFS)
• Random frame skipping (RFS)
  • Sender randomly skips a fixed percentage $\eta$ of content frames
  • Oblivious of packet delivery statistics
  • no cloud assistance
• Delay-based frame skipping (DFS)
  • Dictate the send to skip the next available frame if last observed frame delivery delay exceeds a portion of the deadline: $d(n) > \gamma T_o$
  • Rely on end-to-end delay statistics
  • Can be implemented either at the media cloud, or at the sender
Varying Playout Deadline

- Wireless link bandwidth:
  \[ \mu_G = 1Mbps \]
  \[ \mu_B = 300Kbps \]

- Network round-trip time:
  \[ RTT = 60ms \]
Varying Network Round Trip Time

- Wireless link bandwidth:
  \( \mu_G = 1 \text{Mbps} \)
  \( \mu_B = 300 \text{Kbps} \)

- Playout deadline:
  \( T_o = 60 \text{ms} \)
Varying Wireless Link Bandwidth

• Wireless link bandwidth:
  \[ \mu_F = 0.3\mu_G \]

• Network round-trip time:
  \[ RTT = 60\text{ms} \]

• Playout deadline:
  \[ T_o = 60\text{ms} \]
Conclusions and Future Work

• Cloud-assisted video adaptation for low-latency streaming

• Markov Decision Process (MDP) formulation incorporates dynamic nature of video contents and wireless channel conditions

• Optimal policy based on Stochastic Dynamic Programming (SDP) can be approximated greedy heuristics

• While relaxing the application playout deadline leads to gradual improvement of received video quality, the impact of wireless link bandwidth and network round trip time is more drastic once crossing a threshold

• Future work: more realistic system evaluation based on real-world traces