Bandwidth-aware Prefetching for Proactive Multi-video Preloading and Improved HAS Performance

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Delays in executing these actions leads to ...

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- Dissatisfaction with the service and service providers
- Terminated sessions

Lost revenue!!
Users of the on-demand video streaming services ... watch the beginning of several videos (~5 seconds) before actually watching a video until the end. 

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• Knowing these patterns, popular streaming services offer several related videos to chose from, based on
  – current video choice
  – user viewing history
  – popular videos in the geographical area
  – many other information sources ...

However, there is a startup time associated with every new video ...
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• Alternate videos must be readily available for playback and played instantaneously
• Prefetching must be quality-adaptive and have no negative effects on the current video’s playback
• These goals need to be achieved with the current state-of-the-art
Contributions

• We present a HAS-based solution that:
  • enables quality adaptive prefetching and instantaneous playback of alternative videos
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  - improves the playback quality of the current video, by addressing the well known on-off problem in HAS
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  - improves the playback quality of the current video, by addressing the well known on-off problem in HAS
  - ensures stall free playback of the current video with improved playback experience
- Our policy classes captures a diverse set of use cases
- We characterize and show the benefits of our prefetching policies through our proof-of-concept implementation
HTTP-based Adaptive Streaming (HAS)

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- HTTP-based adaptive streaming
  - Clients adapt quality encoding based on buffer/network conditions
  - Support for interactive VoD
On-off switching in HAS

• Most HAS players perform ON-OFF switching based on two buffer thresholds: $T_{\text{min}}$ and $T_{\text{max}}$
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Issues with on-off switching in HAS

• Although thresholds on the buffer is beneficial, on-off switching has been shown to lead to:
Issues with on-off switching in HAS

• Although thresholds on the buffer is beneficial, on-off switching has been shown to lead to:
  – Unfair bandwidth allocation
  – Under utilization of bandwidth
  – Unnecessary fluctuations in quality adaptation
Prefetch alternative videos during off periods

• Allow instantaneous playback of alternative videos
• In addition, prefetching during off periods:
Prefetch alternative videos during off periods

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- In addition, prefetching during off periods:
  - Avoids the need to ramp-up from slow-start

Slow-start and ramp up
Prefetch alternative videos during off periods

- Allow instantaneous playback of alternative videos
- In addition, prefetching during off periods:
  - Avoids the need to ramp-up from slow-start
  - Client remains active throughout the duration

With prefetching, data is downloaded faster and the next off period is reached sooner
Prefetch alternative videos during off periods

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- In addition, prefetching during off periods:
  - Avoids the need to ramp-up from slow-
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duration

Greater slope → faster download

With prefetching, data is downloaded faster and the next off period is reached sooner
Prefetching policies

• In order to control the number of prefetched chunks and the time at which alternate videos will be available for playback, we consider three broad classes of prefetching policies:
  – Best-effort
  – Token-based
  – Deadline-based
Prefetching policy: Best-effort

- Prefetching rules:
  - Prefetch alternative chunks when $T \geq T_{\text{max}}$ and $r(T - T_{\text{min}}) > \text{prefetched chunk size}$
Prefetching policy: Best-effort

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  - Prefetch alternative chunks when $T \geq T_{\text{max}}$ and $r(T - T_{\text{min}}) >$ prefetched chunk size
  - Number of chunks per alternate video is controlled by parameter ‘$n$’
Prefetching policy: Token-based

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  - Prefetch alternative chunks when $T \geq T_{max}$ and $r(T - T_{min}) > \text{prefetched chunk size}$
  - Token determines which alternative video to prefetch
Prefetching policy: Token-based

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  - Prefetch alternative chunks when $T \geq T_{\text{max}}$ and $r(T - T_{\text{min}}) > \text{prefetched chunk size}$
  - Token determines which alternative video to prefetch
  - Time $\Delta$ determines time between prefetching of alternative videos
Prefetching policy: Deadline-based

- Prefetching rules:
  - Strict deadlines by which ‘n’ chunks of alternative videos (and ‘m’ chunks of current video) must be downloaded
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\[
\text{maximize } \sum_{i=1}^{m_a+1} q_i^s l_i^s + \sum_{j=1}^{n} q_j^a l_j^a
\]

Playback quality of streamed video

Playback quality alternative video chunks

The optimization formulation above originally appeared in our ACM MM 2014 paper.

Quality-adaptive Prefetching for Interactive Branched Video using HTTP-based Adaptive Streaming
Policy characterization

• All experiments performed with at least one competing flow
  • Generated from a large file download from a second server
• Results are averages over 20 experiments
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- Example results
  - 4 Mbps (shared) link
  - 1 competing flow
  - 150ms RTT
  - $T_{min}/T_{max} = 8/12$
  - $n$ (chunks to prefetch per alternative video) = 2
Policy characterization: Number of alternative videos

• Best-effort policy
  – Moves to the next alternative video after 2 chunks of the previous alternative video is completed

Figures: Download completion time of the $n=2$ chunks of each alternative video
Policy characterization: Number of alternative videos

- **Token-based policy**
  - Moves to the next alternative video only when the next token is released

Figures: Download completion time of the $n=2$ chunks of each alternative video
Policy characterization: Number of alternative videos

- **Token-based policy**
  - Moves to the next alternative video only when the next token is released
  - Prefetches more chunks of alternative videos in the absence of new tokens

Figures: Download completion time of the $n=2$ chunks of each alternative video
Policy characterization: Number of alternative videos

- Deadline-based policy
  - Deadlines every 20s

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Policy characterization: Number of alternative videos

- Deadline-based policy
  - Deadlines every 20s
  - Evenly spaced download completions, respecting their download deadlines
  - When the deadline is satisfied, the player moves ahead with the next deadline

Figures: Download completion time of the $n=2$ chunks of each alternative video
Policy characterization: Playback quality of streamed video chunks
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Medium quality
**Policy characterization:** Playback quality of streamed video chunks

- **Best-effort** policy achieves better playback rates than the naïve player.
Policy characterization: Playback quality of streamed video chunks

- **Best-effort** policy achieves better playback rates than the naïve player
- **Token-based** policy also achieves better playback rates than the naïve player
Policy characterization: Playback quality of streamed video chunks

- **Best-effort** policy achieves better playback rates than the naïve player
- **Token-based** policy also achieves better playback rates than the naïve player
- Comparatively, **deadline-based** policies achieve lower playback qualities due to deadline constraints
Policy characterization: Playback quality of alternate video chunks

- Lowest-quality prefetching always chooses the lowest encoding available
Policy characterization: Playback quality of alternate video chunks

- Lowest-quality prefetching always chooses the lowest encoding available
- Deadline-based policy trades-off quality of both streamed and alternate videos to achieve the deadlines
Impact of network conditions: Bandwidth

- All policies adapt playback quality based on bandwidth

Stall probabilities

Quality of streamed video

Quality of alternate video
Impact of network conditions: Bandwidth

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- Deadline-based policy consistently trades-off playback quality in order to meet deadlines

Stall probabilities

Quality of streamed video

Quality of alternate video
Impact of network conditions: Bandwidth

- All policies adapt playback quality based on bandwidth
- Deadline-based policy consistently trades-off playback quality in order to meet deadlines
- Best-effort and token-based policies perform slightly better than the naïve player at low bandwidths
The video flow experiences increasing RTTs while the competing flows RTT remains constant at 50ms.
Impact of network conditions: RTT

- In general, TCP throughput decreases with increasing RTTs, as shown by playback qualities.
Impact of network conditions: RTT

- In general, TCP throughput decreases with increasing RTTs, as shown by playback qualities.
- Playback stalls experienced at high RTTs, although all three policies outperform the naïve player.
## Startup times

<table>
<thead>
<tr>
<th></th>
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<tbody>
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<td>Prefetched chunk</td>
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- With prefetching, startup times are low and independent of throughput or RTT
- Fetch time of the chunk from cache ~0.1 second, the additional time is required to change player states
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- With prefetching, startup times are low and independent of throughput or RTT
- Fetch time of the chunk from cache ~0.1 second, the additional time is required to change player states
- Startup times decrease with increasing bandwidth, but are always constrained by the larger RTT and network conditions to reach the server
Other experimental results

• Also performed experiments under wide range of other scenarios, including
  – different buffer sizes (4/6, 8/16, 12/24, 12/30 seconds)
  – different real-world bandwidth traces
  – different number of competing flows
  – different OSes running different TCP versions

• Our conclusions and relative performance across policies remain consistent in all scenarios
Conclusions

• We have designed, implemented and evaluated a HAS-based solution, which:
  – enables quality-adaptive prefetching and instantaneous playback of alternative videos
  – leads to perceptible gains for the streamed video in terms of stall-free playback and better playback quality

• Considered three different policy classes and two quality adaptation methods to cater for different real-world use cases

• Overall, our solutions improve the bandwidth utilization and playback experience by leveraging off periods to download alternative videos that are most likely to be watched
Bandwidth-aware Prefetching for Proactive Multi-video Preloading and Improved HAS Performance

Our source codes are available for download here:
http://www.ida.liu.se/~nikca/papers/mm15.html