Efficient and Adaptive Content Delivery of Linear and Interactive Branched Videos

Vengatanathan Krishnamoorthi

Licentiate presentation

4 November 2016

LINKÖPING UNIVERSITY

Video streaming landscape

Video streaming landscape

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Motivation

- Efficient and adaptive streaming
  - Streaming services contribute to over 60% of the global Internet traffic currently
  - By 2020, this share is expected to be over 80%
  - Systems need to be well understood, scalable, and efficient to match growth projections

Motivation

- Content personalization and personalized streaming
  – Regular web content is dynamic and personalized, while videos have remained largely unchanged
  – Viewer's tastes vary significantly
  – Personalized streaming is relatively unexplored and several interesting questions remain open

Contributions: overview

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Subtopic 1
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  - Efficient and personalized streaming of interactive videos

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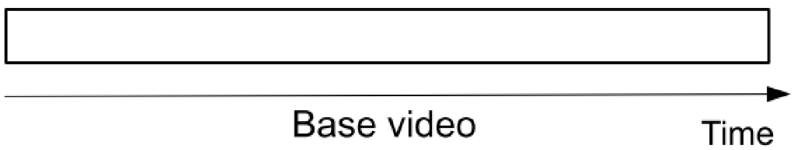
  - Proxy-assisted delivery of linear (regular) videos
  - Subtopic 2 Efficient and personalized streaming of interactive videos

Background

HTTP-based Streaming

HTTP-based Streaming



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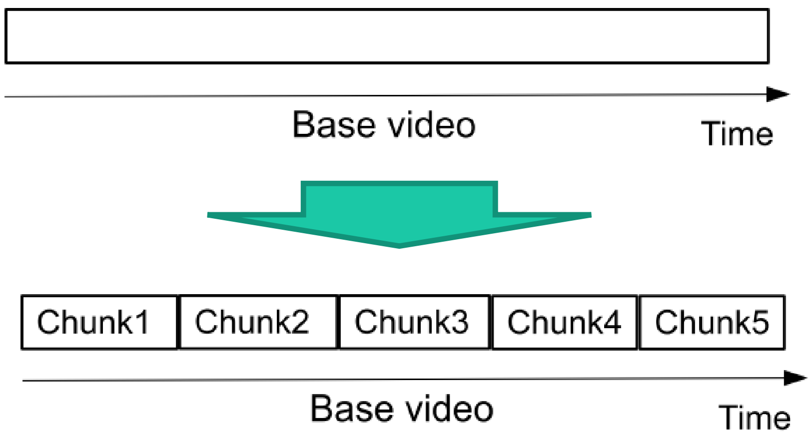

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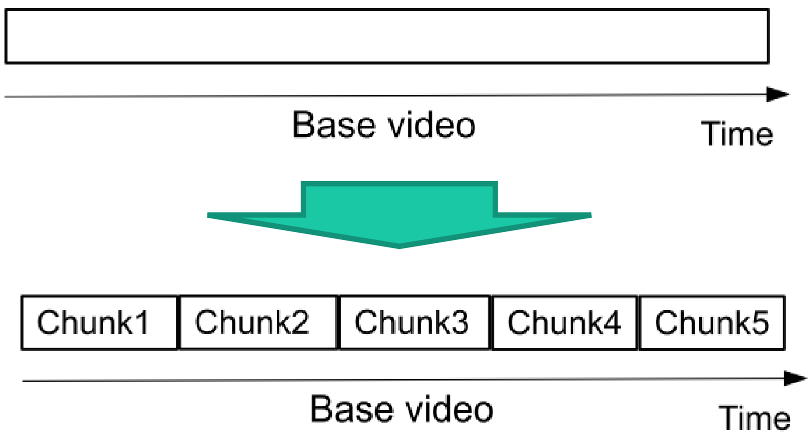

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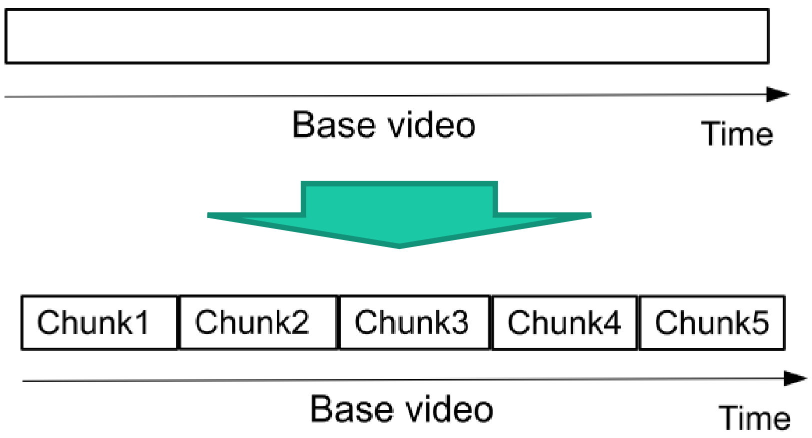

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  - Support for interactive VoD (Video on Demand)

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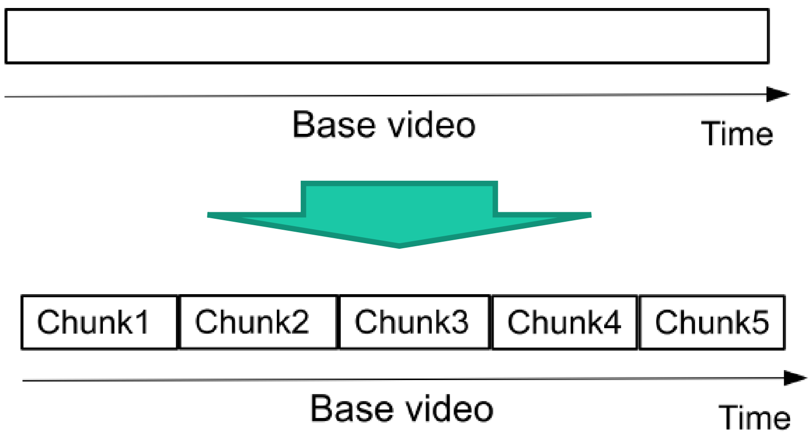

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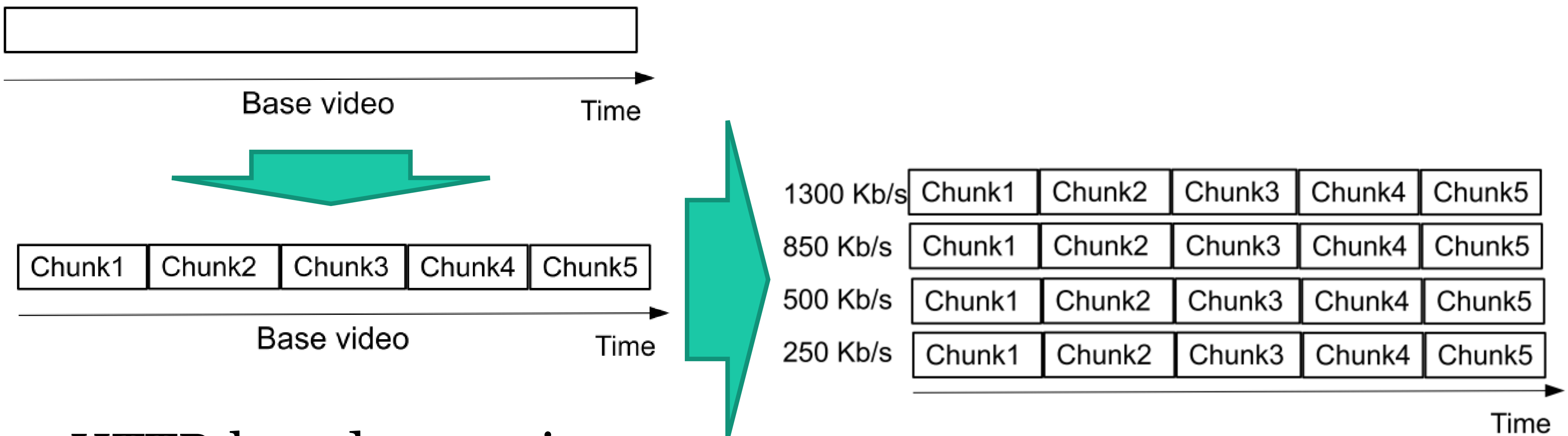

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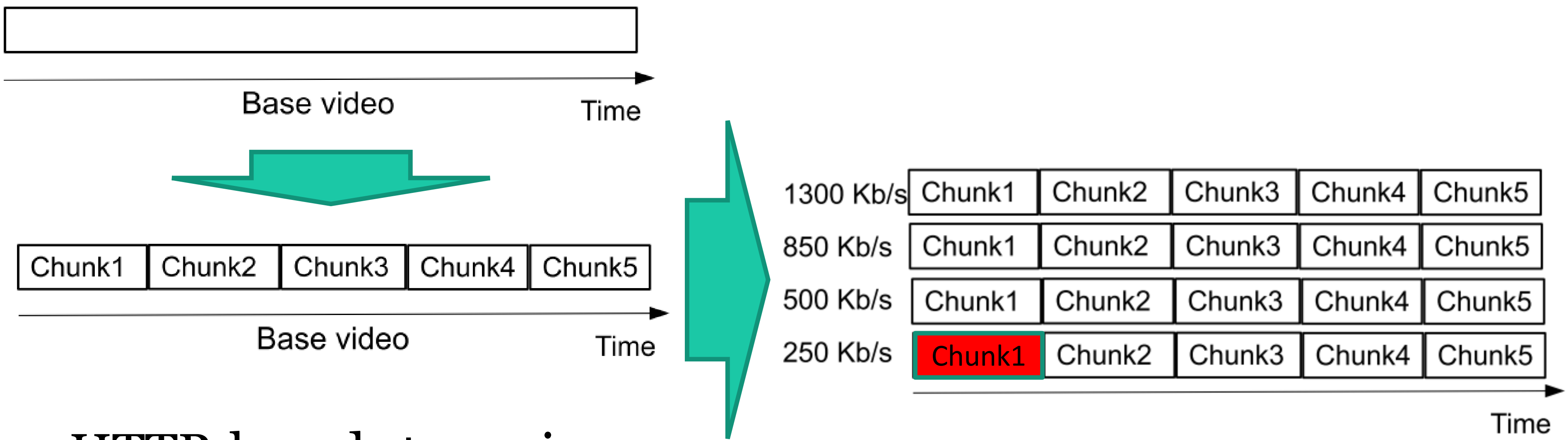

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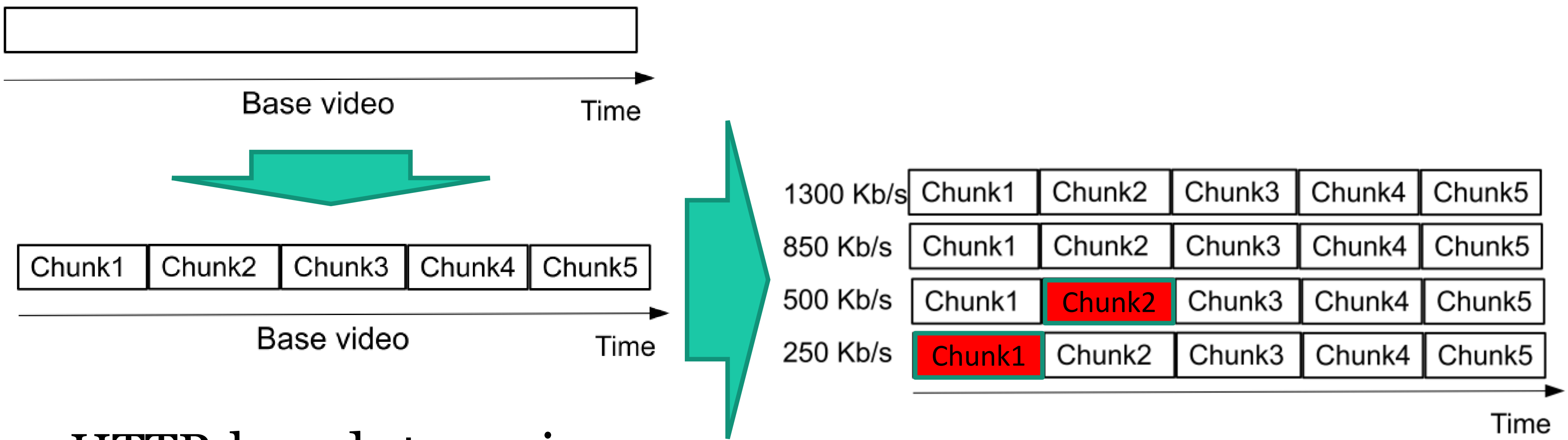

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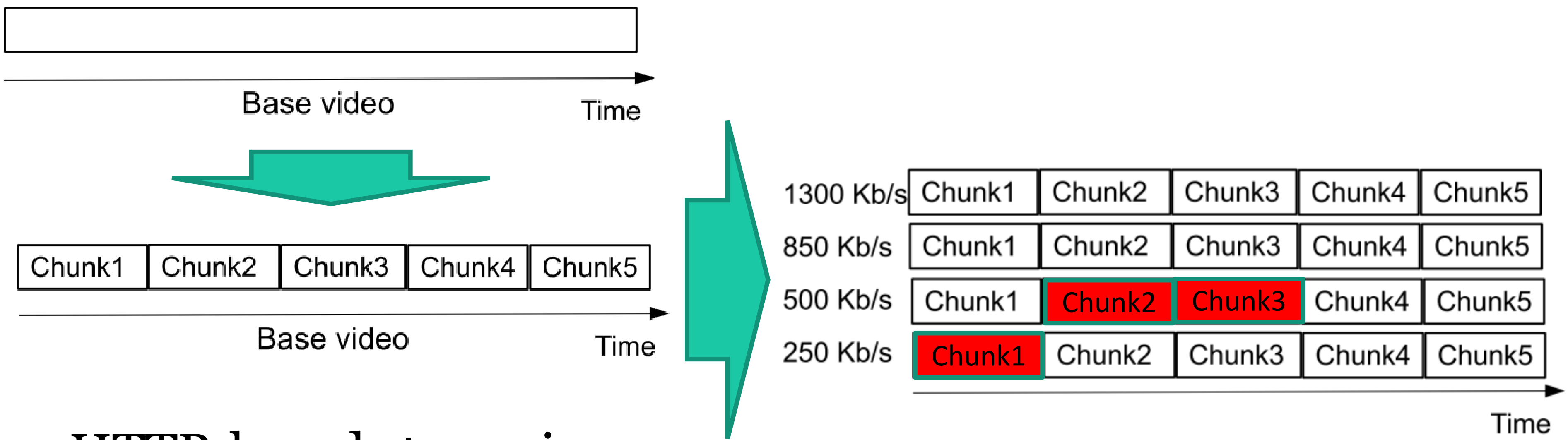

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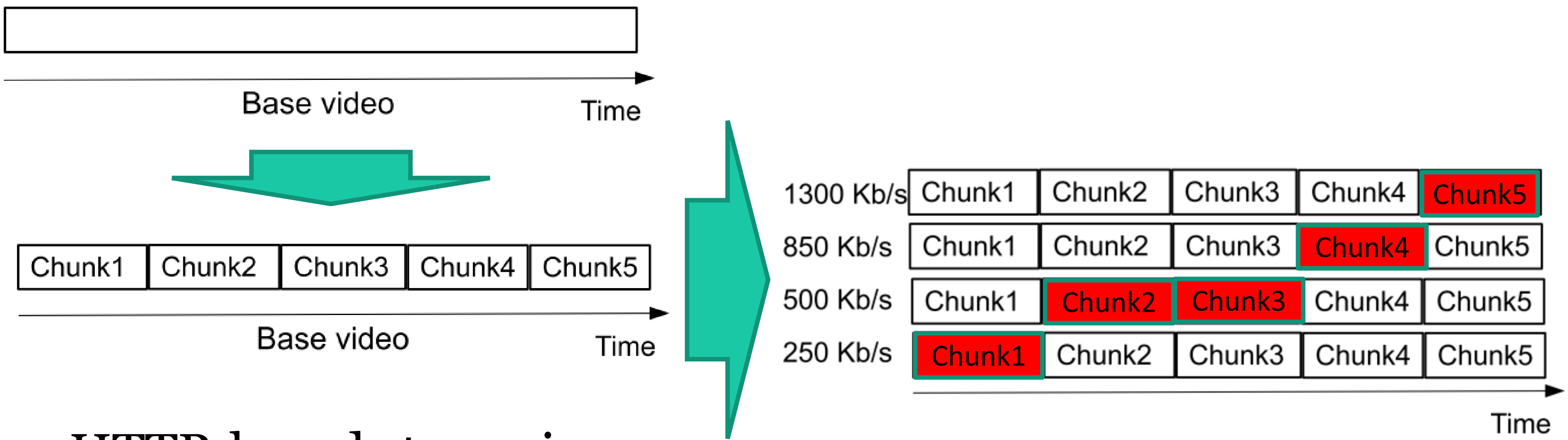

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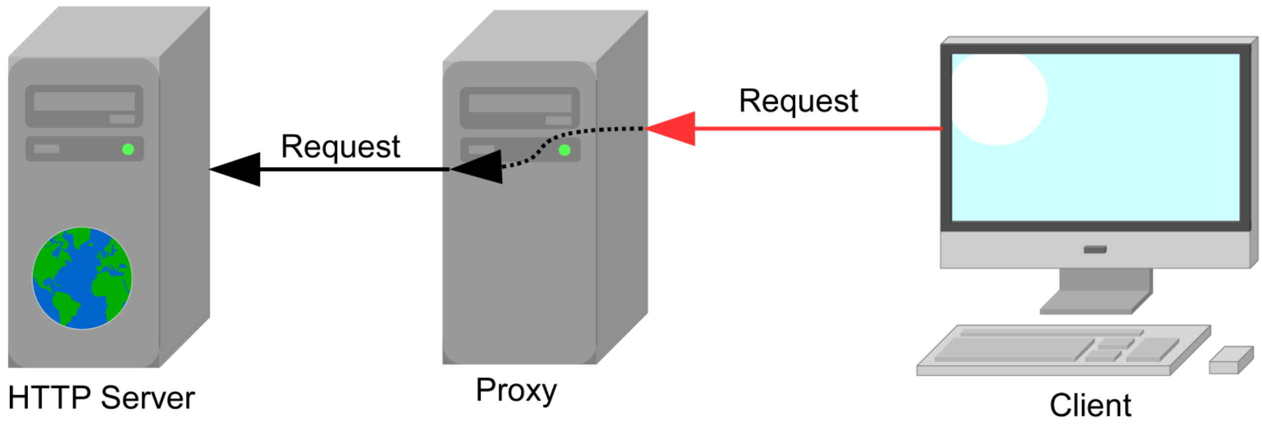
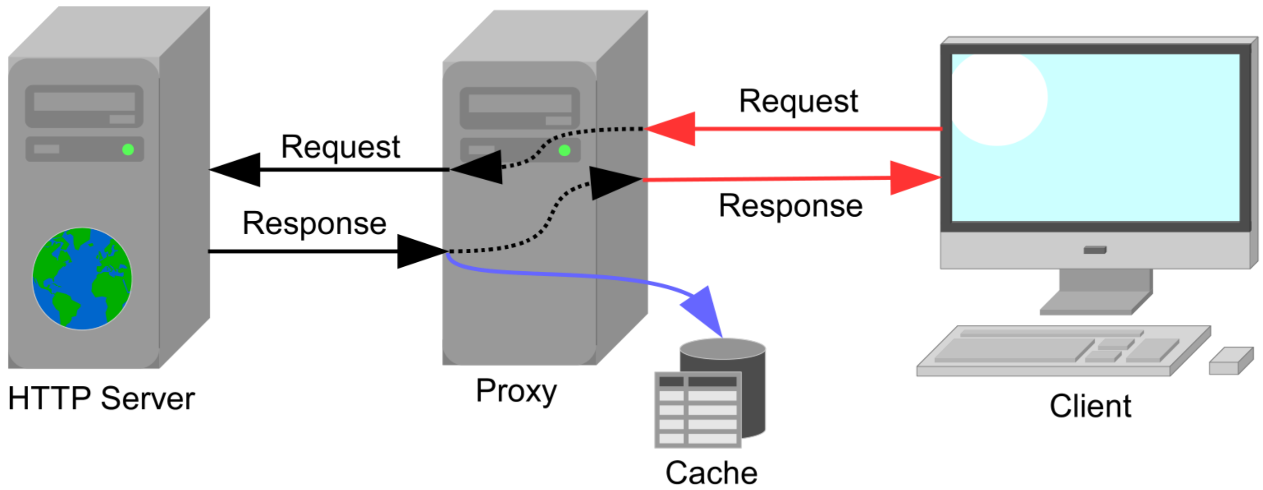
Background

Subtopic 1: Proxy caches

Proxy caches



Proxy caches



Proxy caches and HAS

- Clients typically want:
  - High playback quality
  - No buffer interruptions
  - Small stall times
  - Few quality switches

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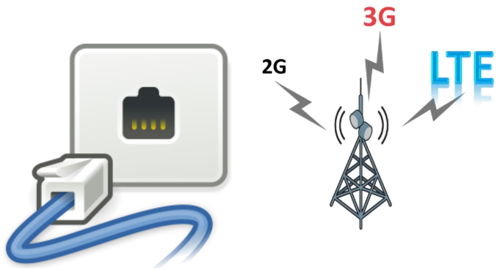
- Clients typically want:
  - High playback quality
  - No buffer interruptions
  - Small stall times
  - Few quality switches
- Service providers typically want:
  - High QoE of customers/clients
  - Low bandwidth usage



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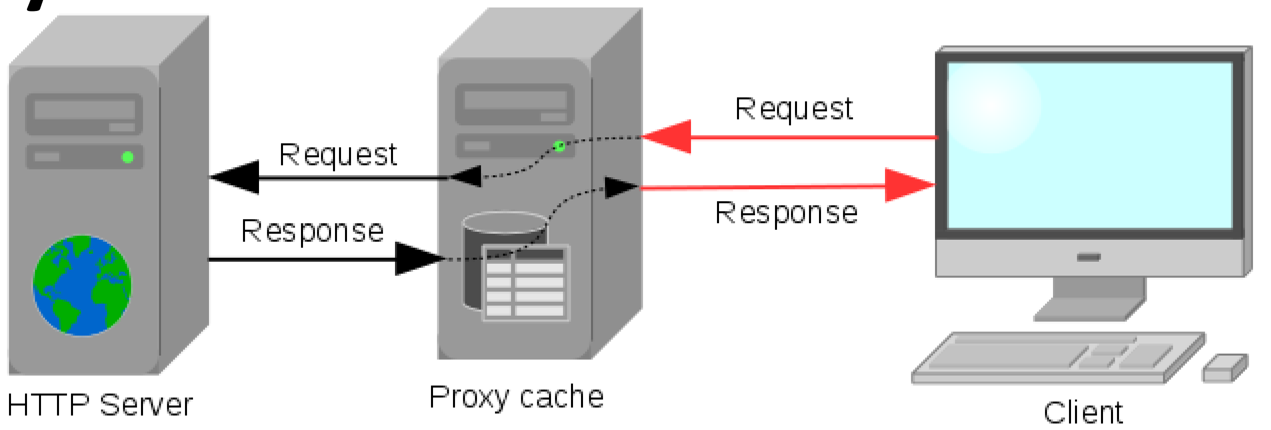

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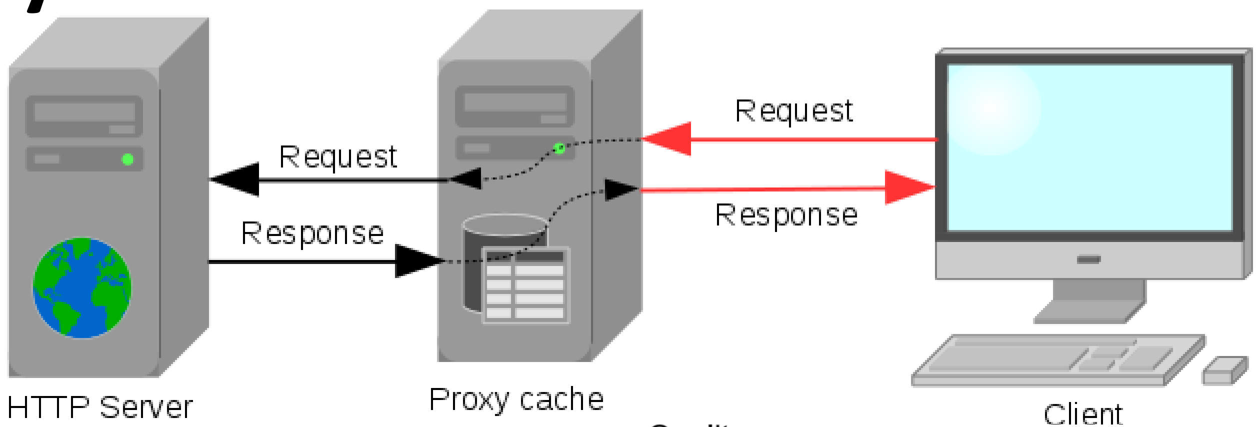
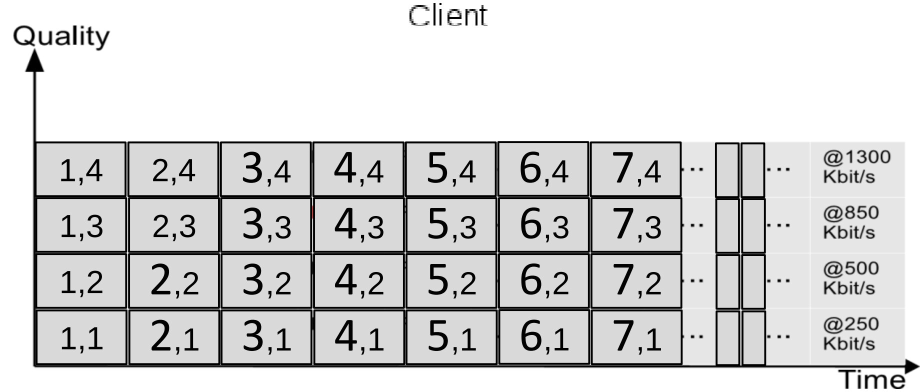
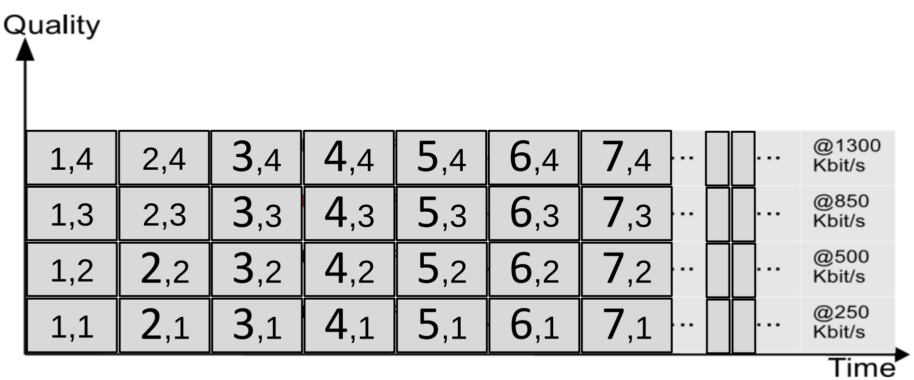
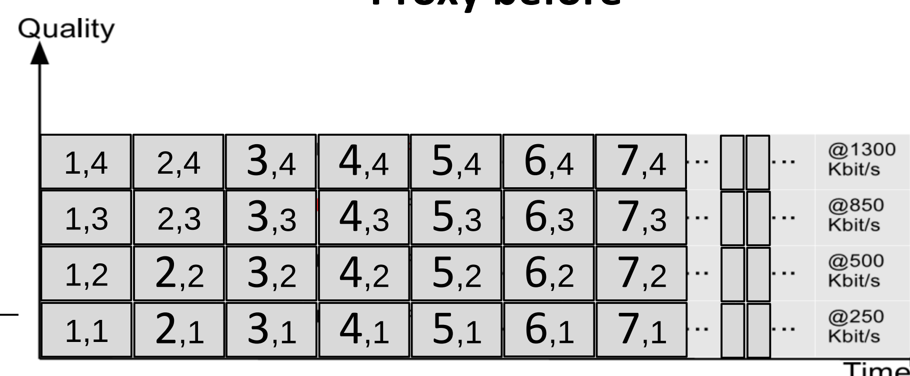




Proxy before



Client 1



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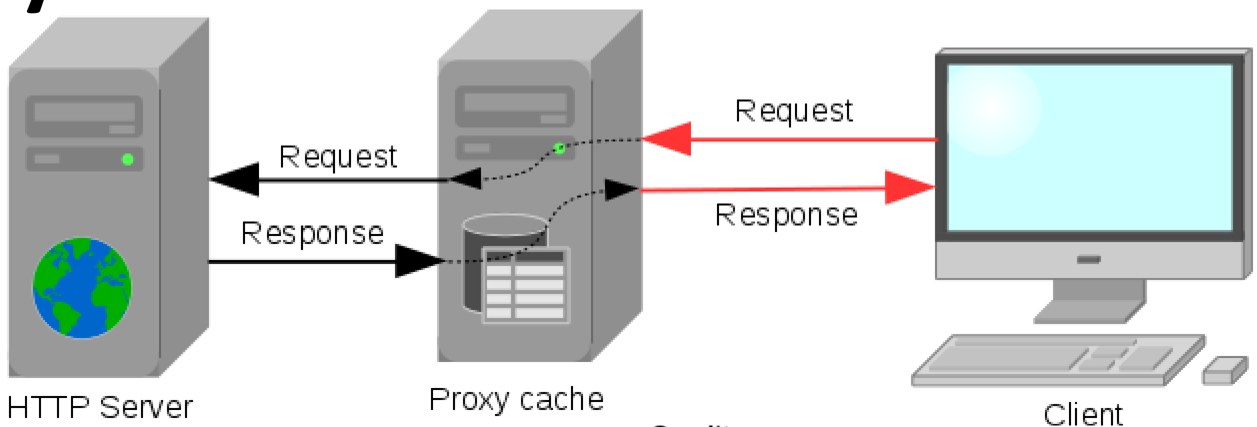

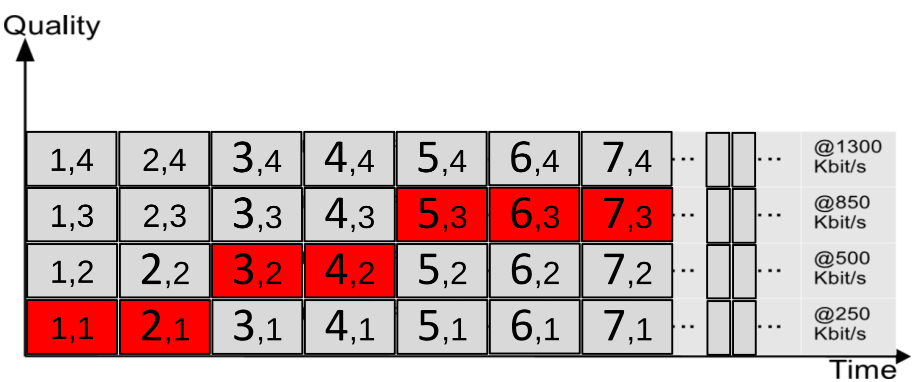

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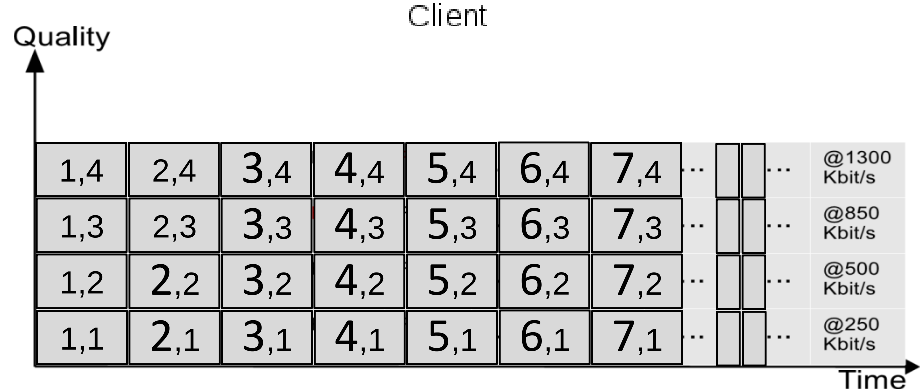

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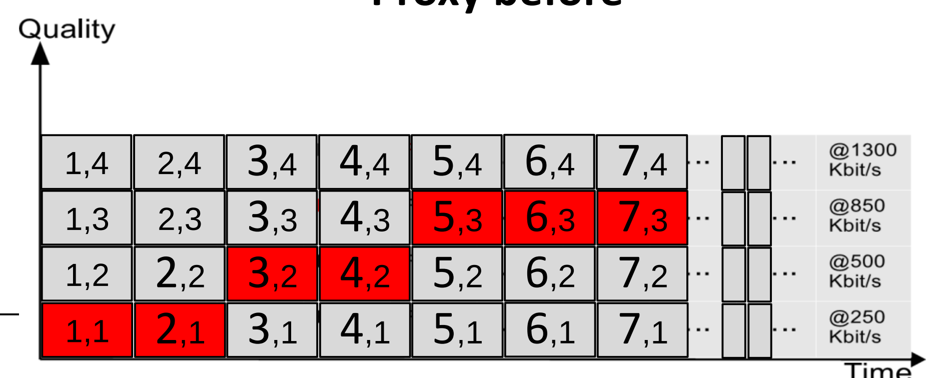

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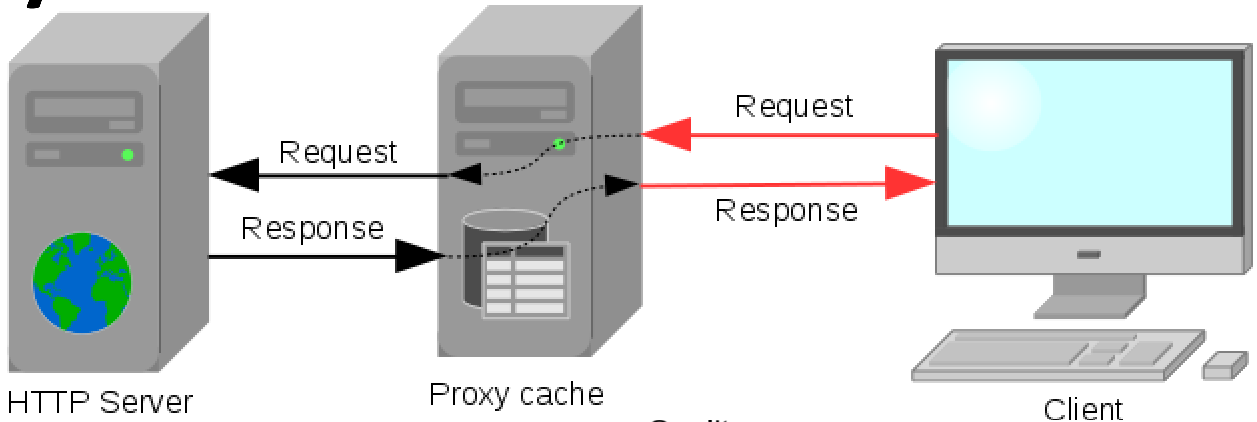

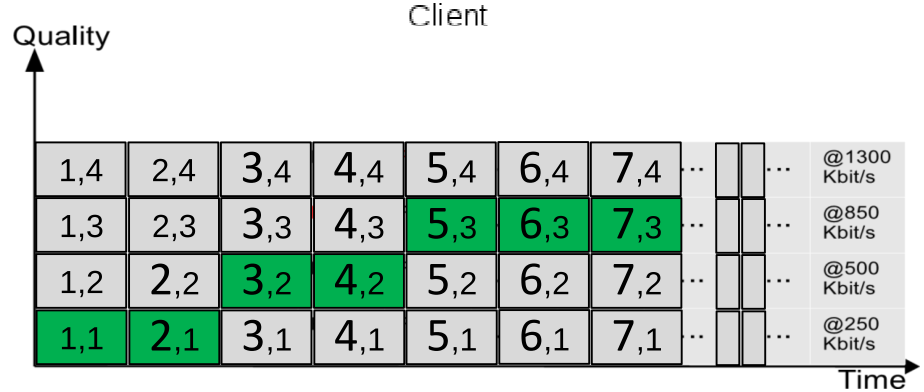

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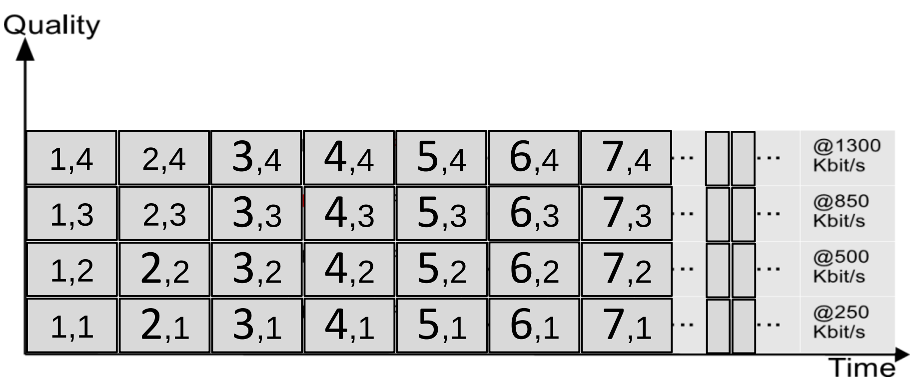
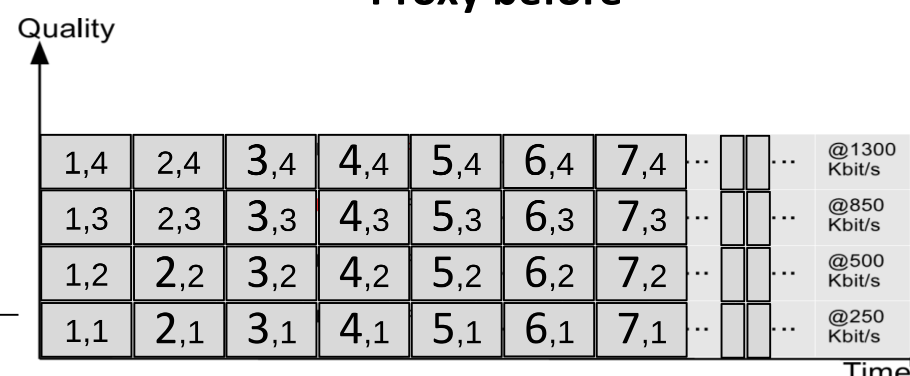


Client 2



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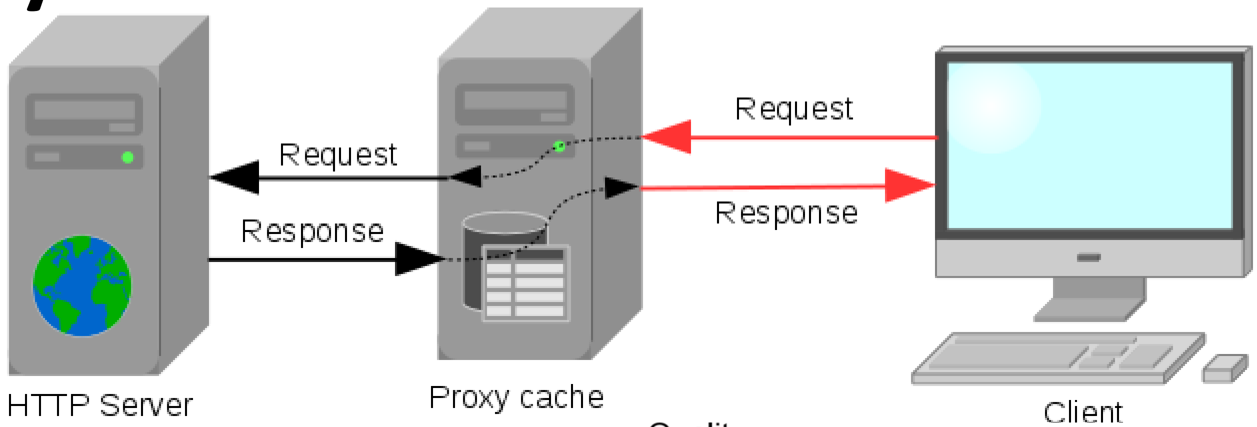

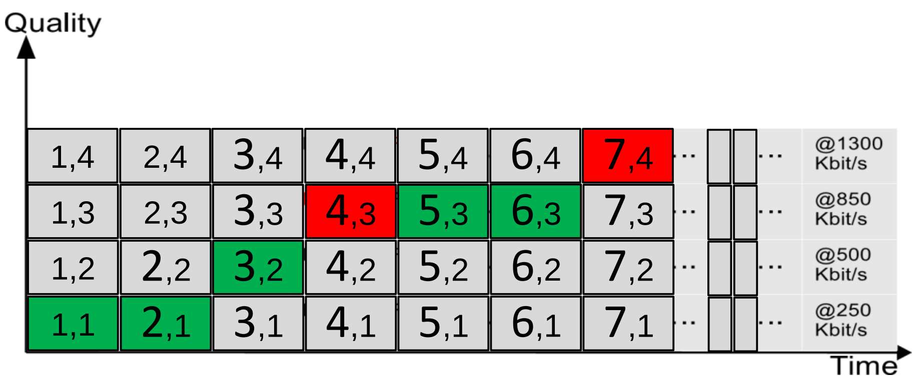

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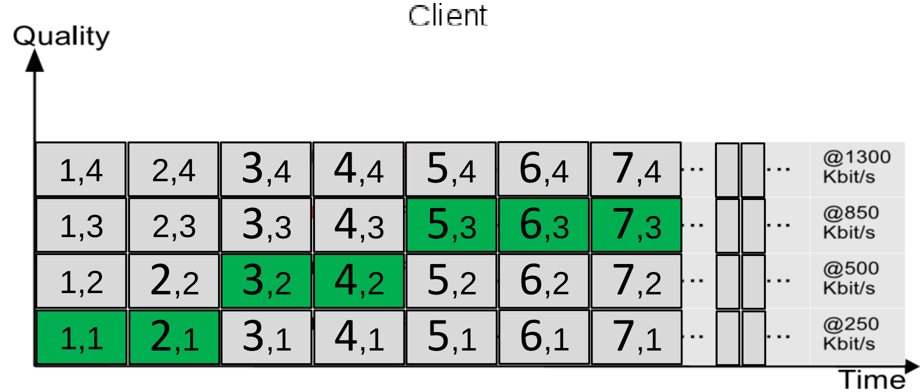

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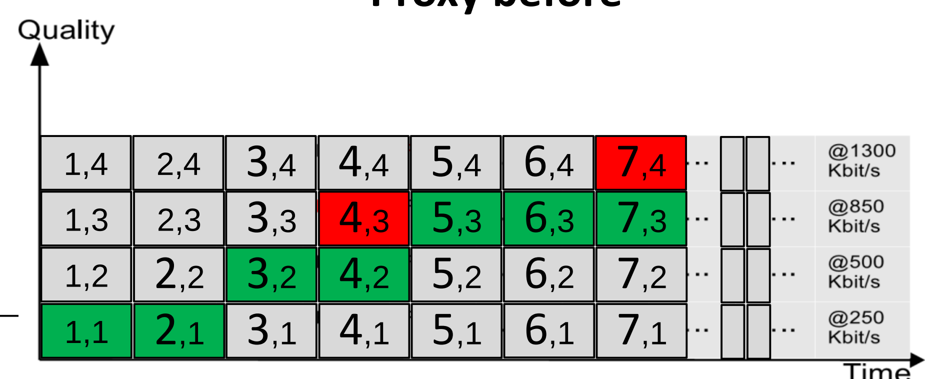

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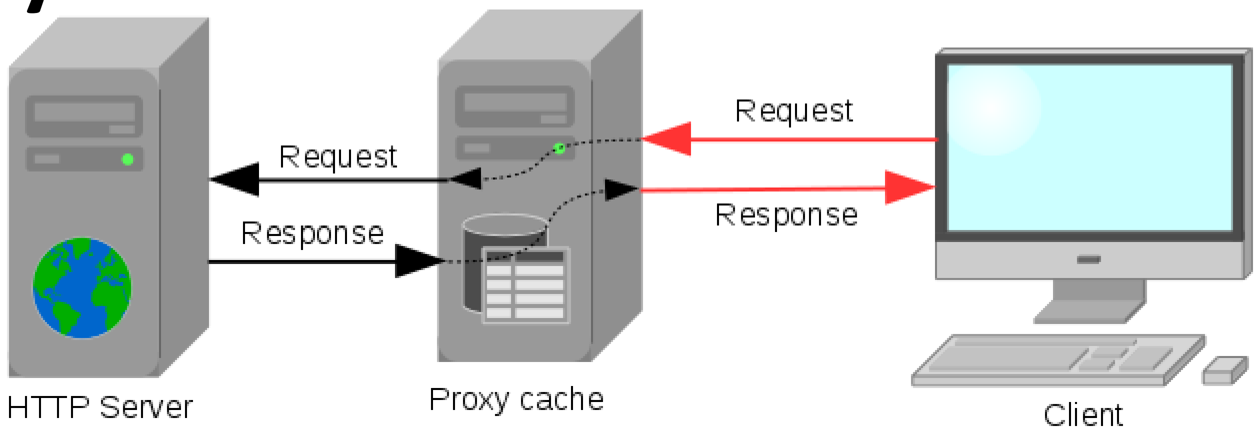
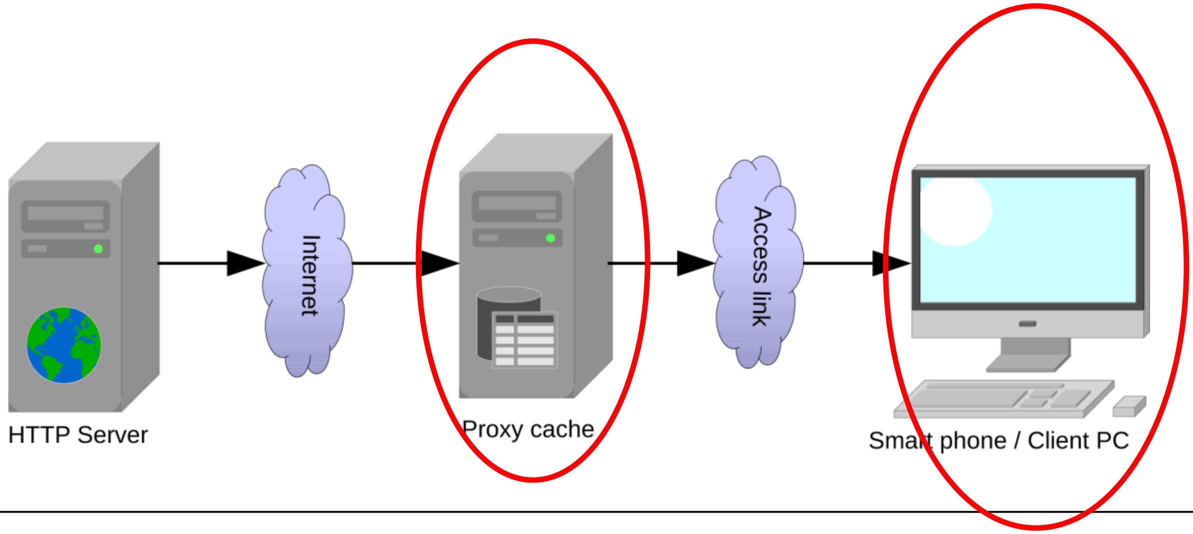


- However,
  - Proxy caches can also inflate client's bandwidth estimates
  - Clients are exposed to actual end-to-end throughput only when cache misses occur

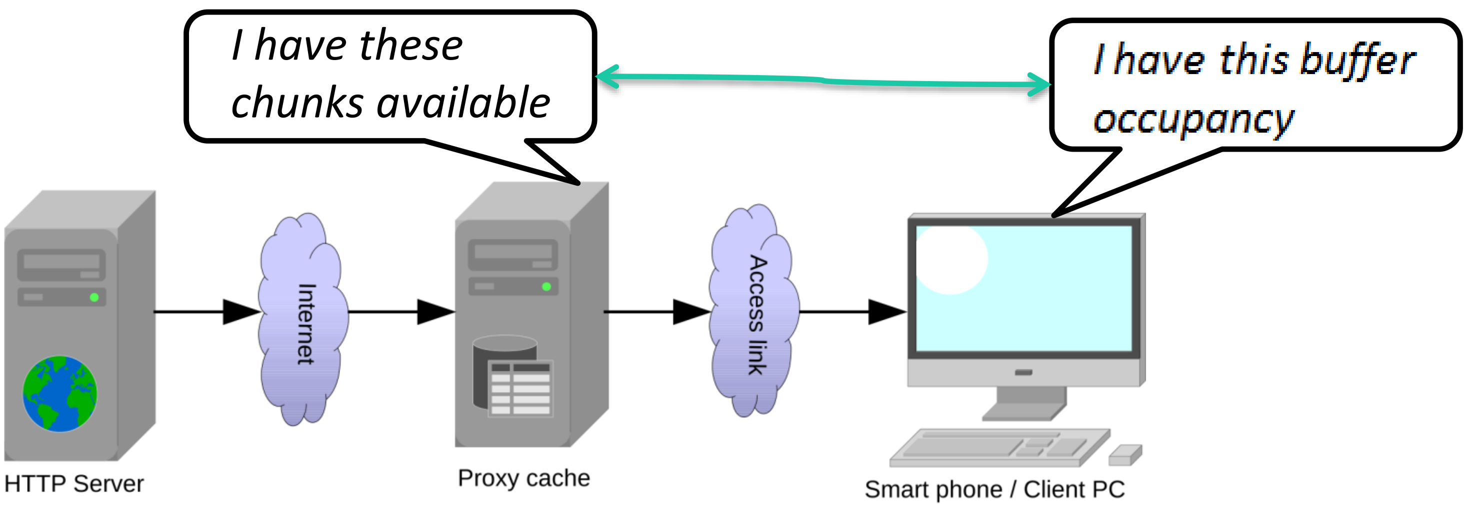
Contributions

- Our main contributions are:
  - Study on effects of proxy caches on HAS streams



Contributions

- Our main contributions are (subtopic 1):
  - Study on effects of proxy caches on HAS streams
  - Propose and evaluate HAS-aware proxy caches to improve bandwidth utilization and QoE



Background

Subtopic 2: Interactive branched video

Interactive branched video

- Video personalization through user interaction

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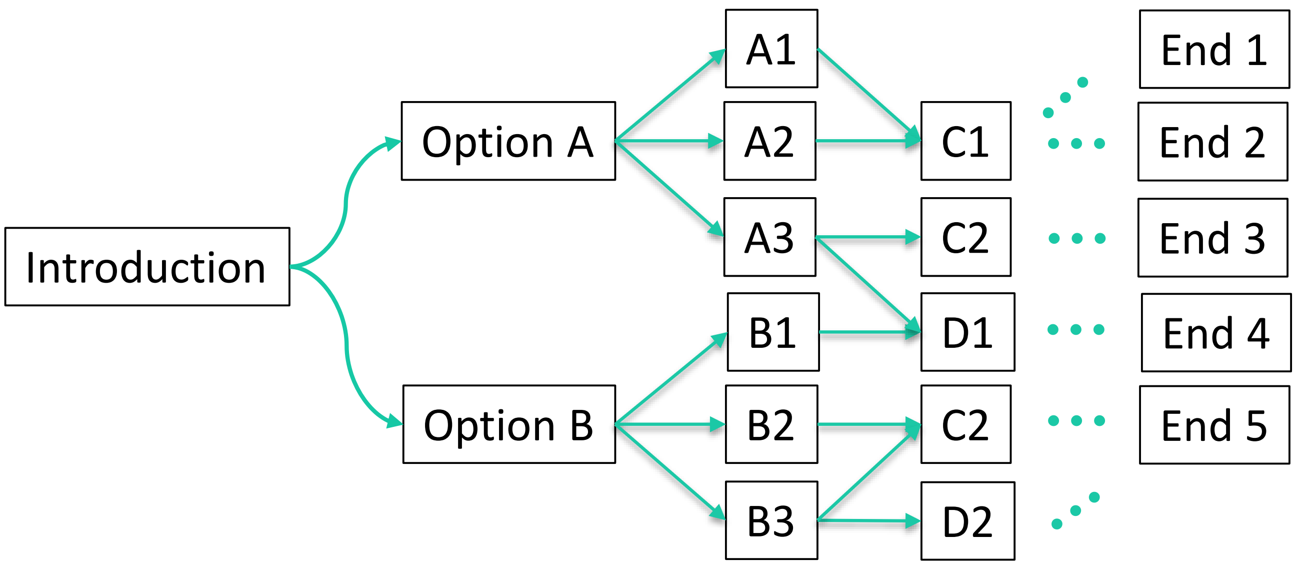

Interactive branched video

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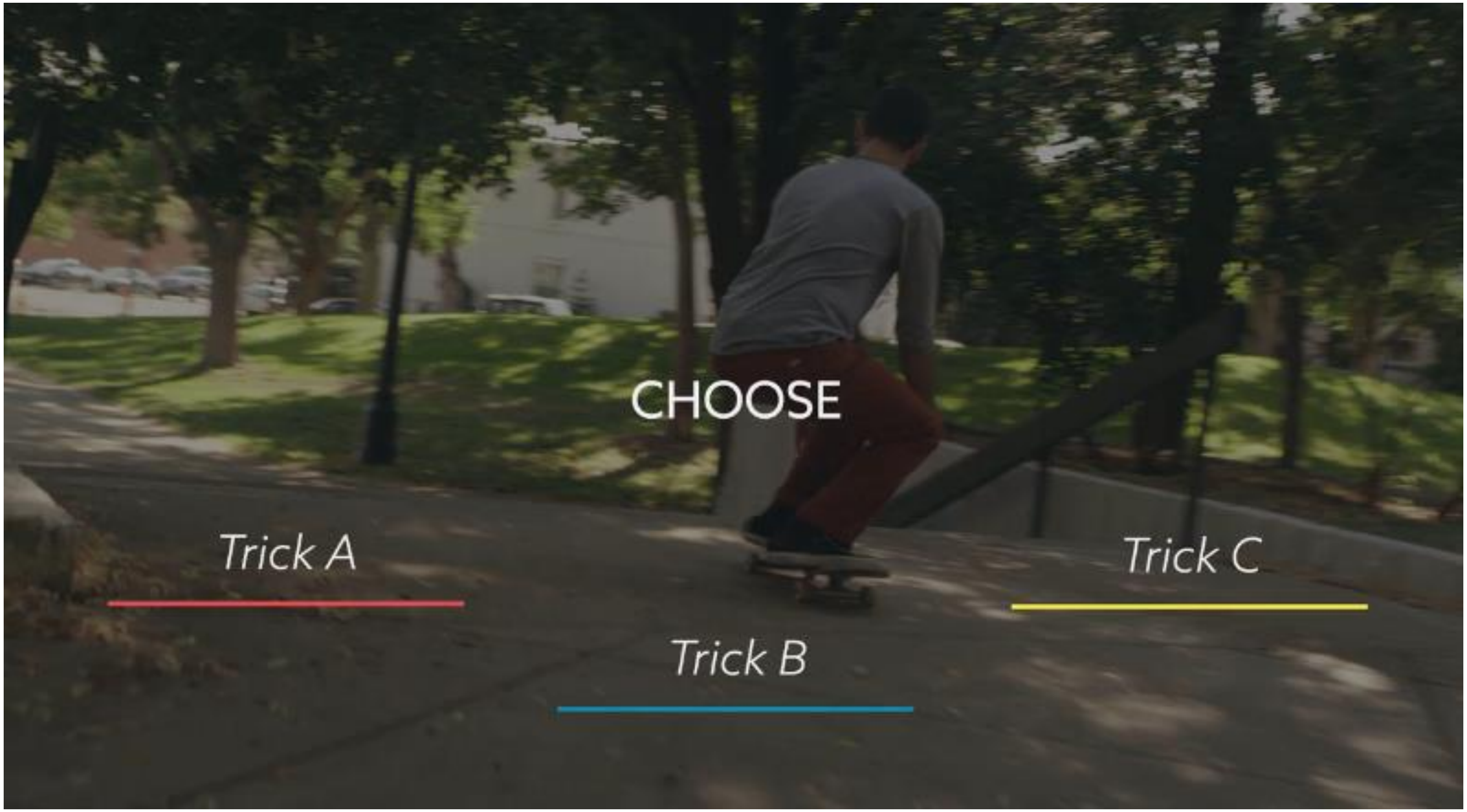

Interactive branched video

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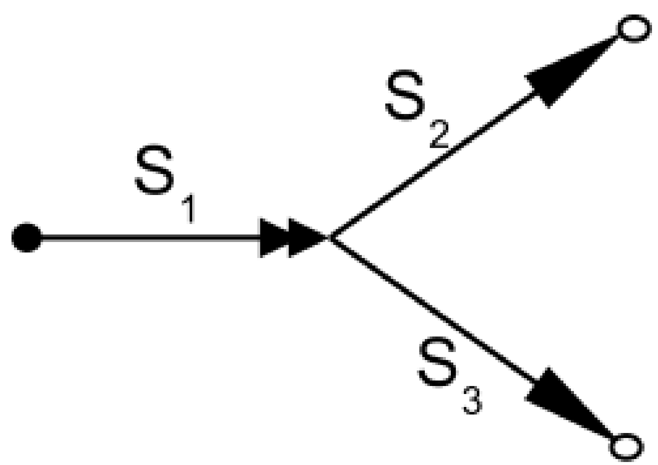
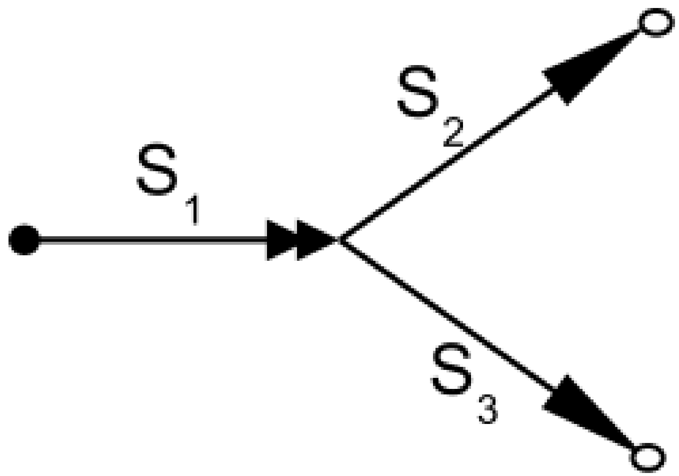


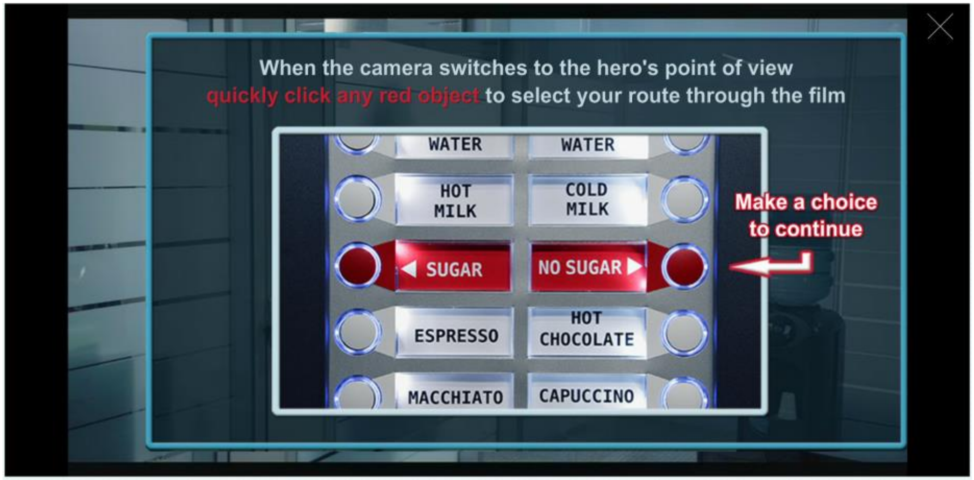
Interactive branched video

- Regardless of interactivity, user experience and user satisfaction is greatly influenced by:
  - Playback stalls and quality fluctuations
  - Current interactive branched players split a video into many sub videos and then link them
- Issues
  - Playback stalls when playing a new video
  - Non-adaptive playback

Contributions

- Our main contributions are (subtopic 2):
  - Propose, implement and evaluate a framework for stall-free branched video streaming over HTTP





Subtopic 1: Proxy-assisted delivery of HAS videos

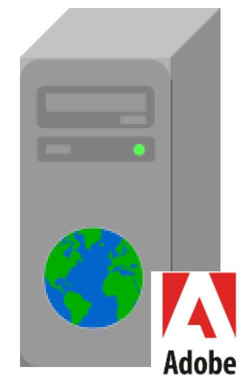
Establishing a baseline client

- At the time, several implementations of HAS players were available

	Player	Container	Open Source
Microsoft Silverlight	Microsoft smooth streaming	Silverlight	✗
NETFLIX	Netflix player	Silverlight	✗
	Apple HLS	QuickTime	✗
	Adobe OSMF	Flash	✓
YouTube	Youtube player	HTML5 /Flash	✗

Establishing a baseline client

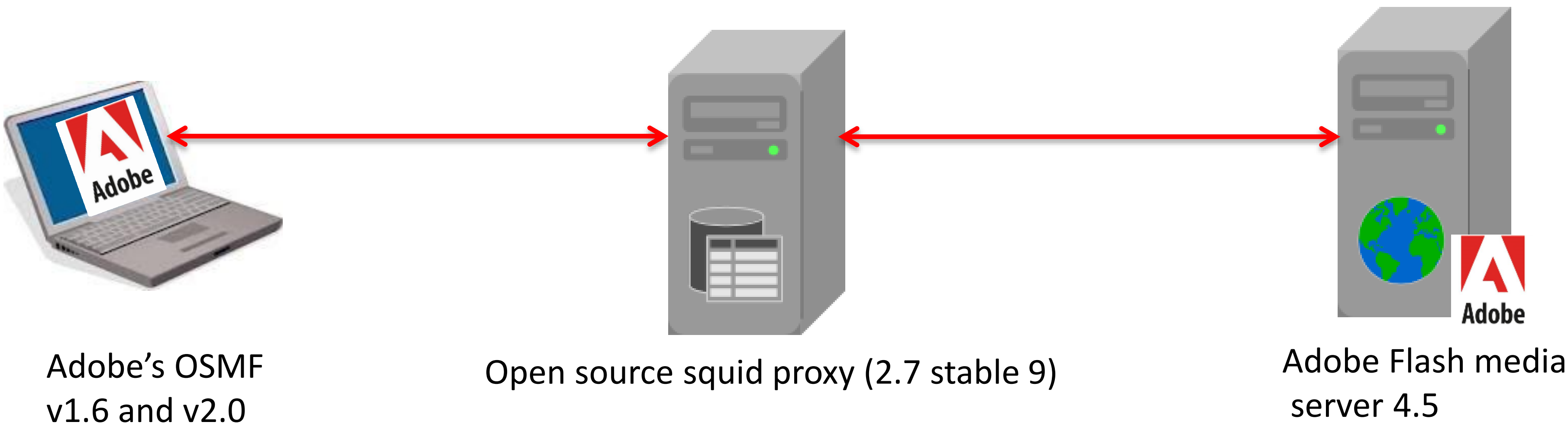
Adobe's OSMF (Open Source Media Framework)
v1.6 and v2.0



Adobe Flash media
server 4.5

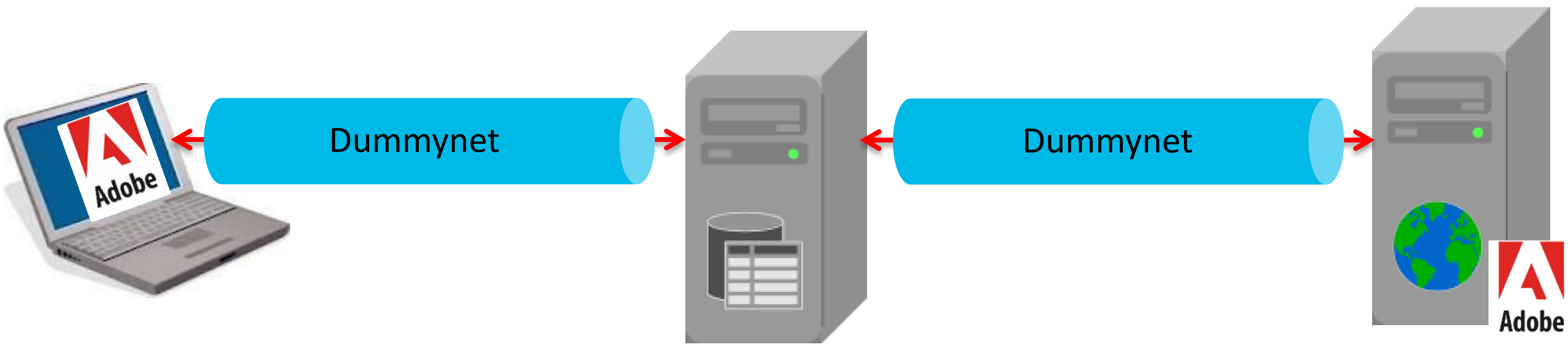
- Instrumented the OSMF client to log internal parameters
  - Buffer occupancy
  - Playback quality
  - Stall occurrences and duration, etc.,

Establishing a baseline proxy



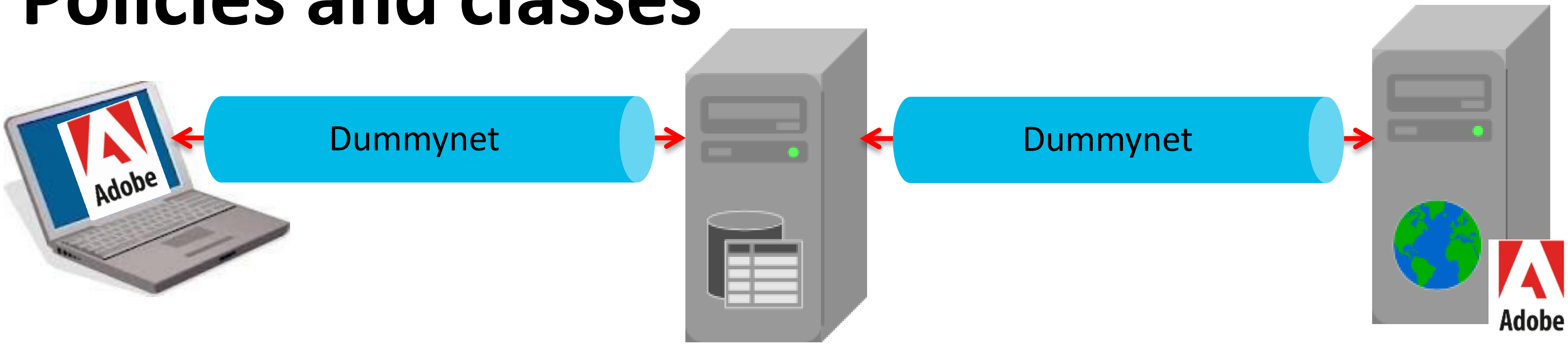
- We use a squid proxy and its default setting as the baseline

Simulating network characteristics



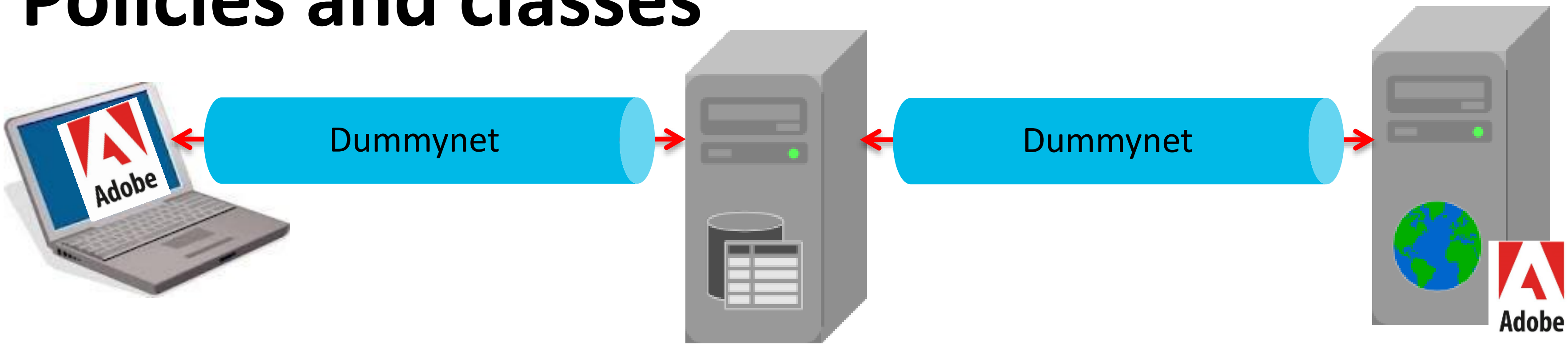
- We use dummynet to simulate varying network characteristic. We evaluate under different,
  - Bandwidths
  - RTTs
  - Packet loss rates
  - Bottleneck location (client-proxy and proxy-server)

Policies and classes



- **Baseline policies**
  - Empty cache

Policies and classes



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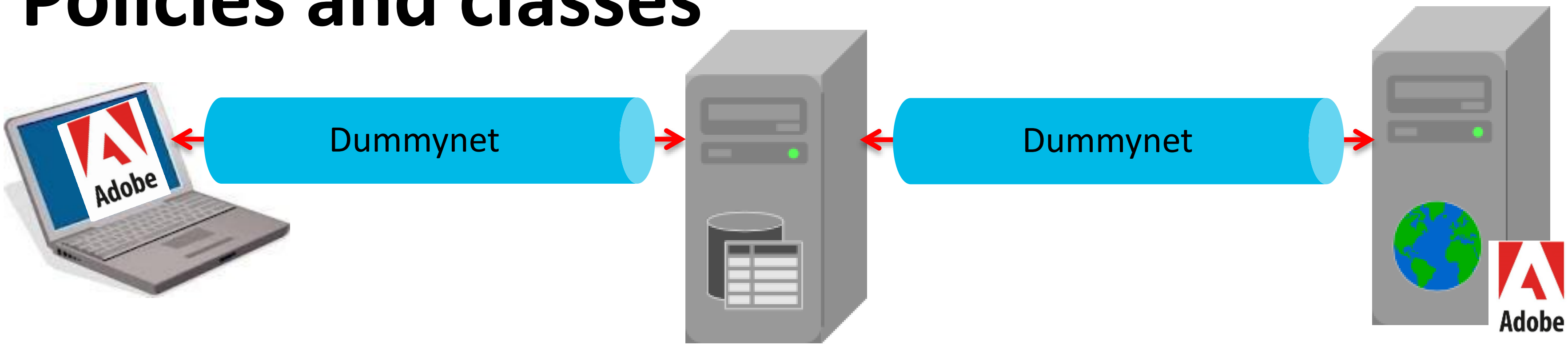

- **Baseline policies**
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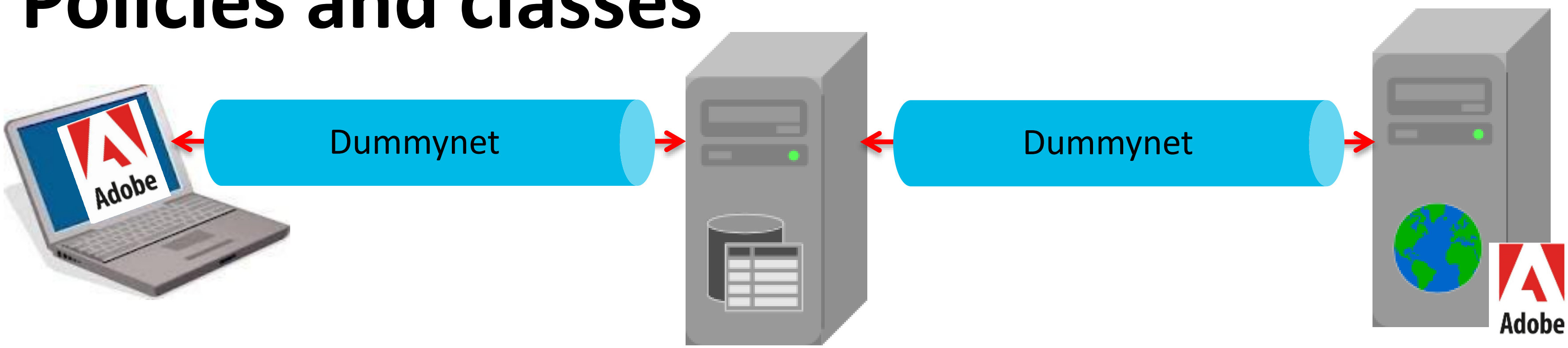
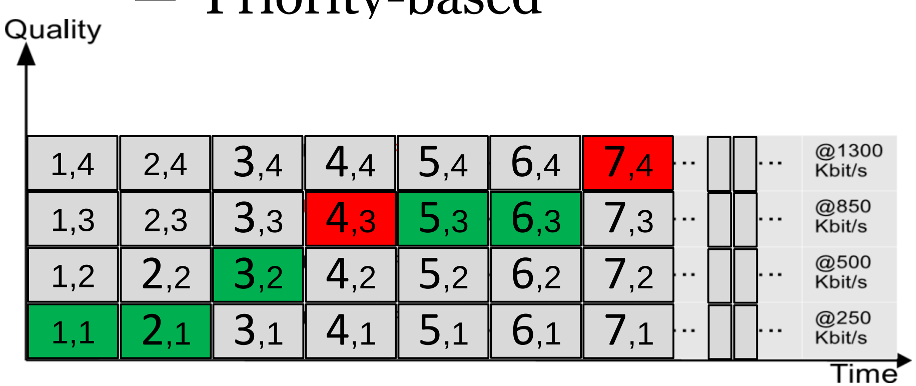
  - Best effort (default, as previous example)

Policies and classes



- **Quality and content-aware prefetching policies**
  - 1-ahead
  - N-ahead
  - Priority-based



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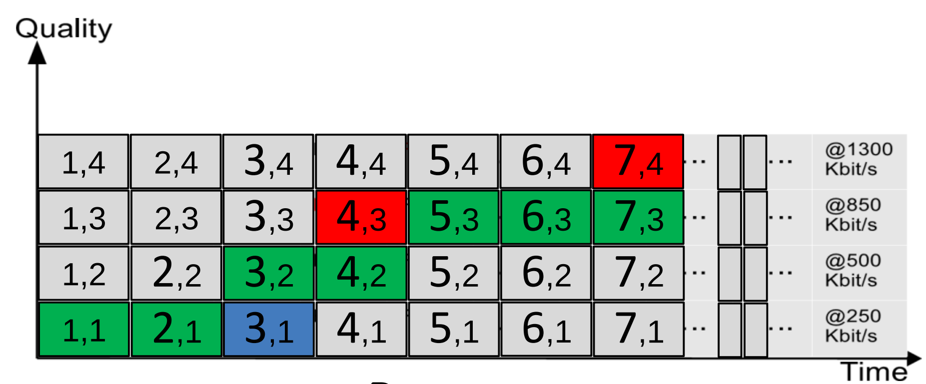
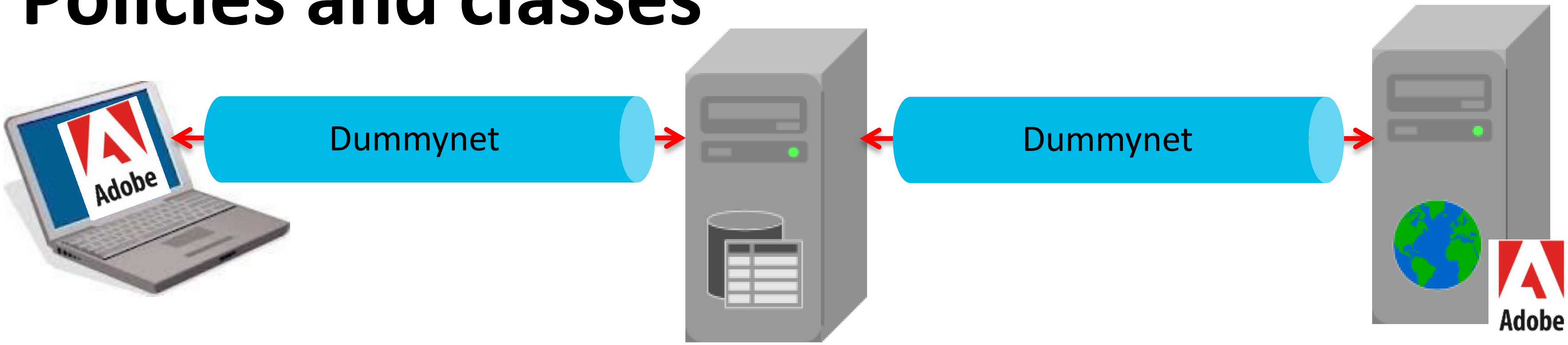


Proxy

Policies and classes



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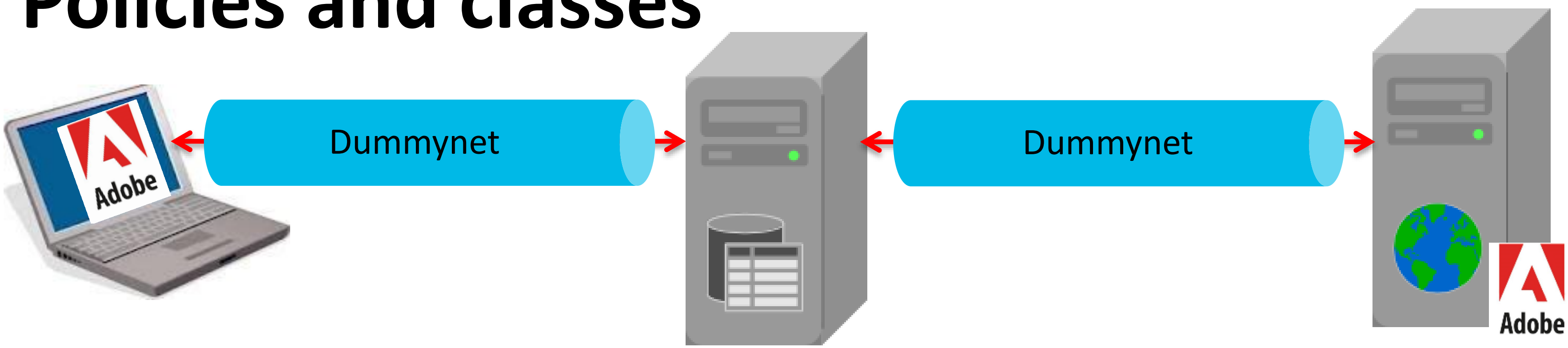
Policies and classes



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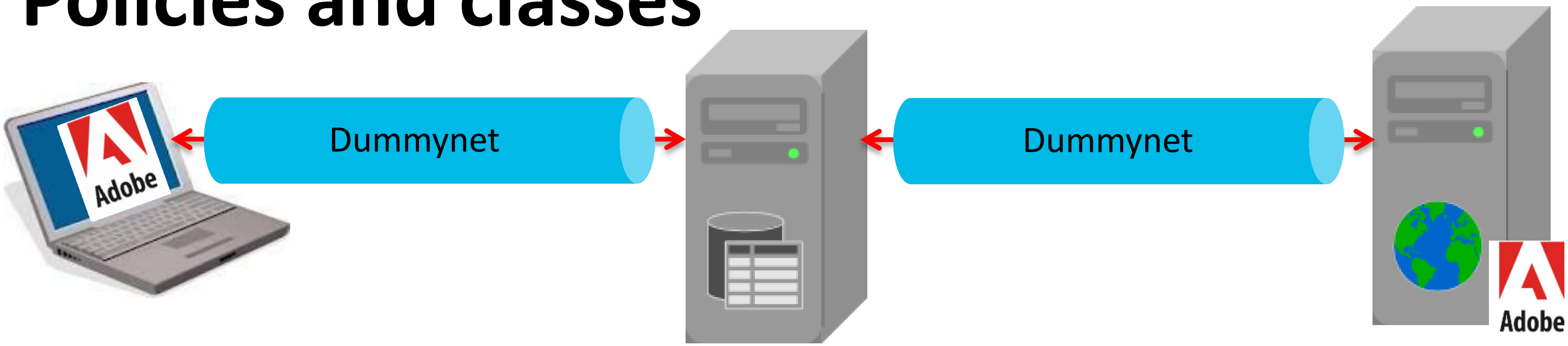
(i) current Q, (ii) ***one Q level below***, (iii) ***one Q level above***, and (iv) no prefetching.

Policies and classes



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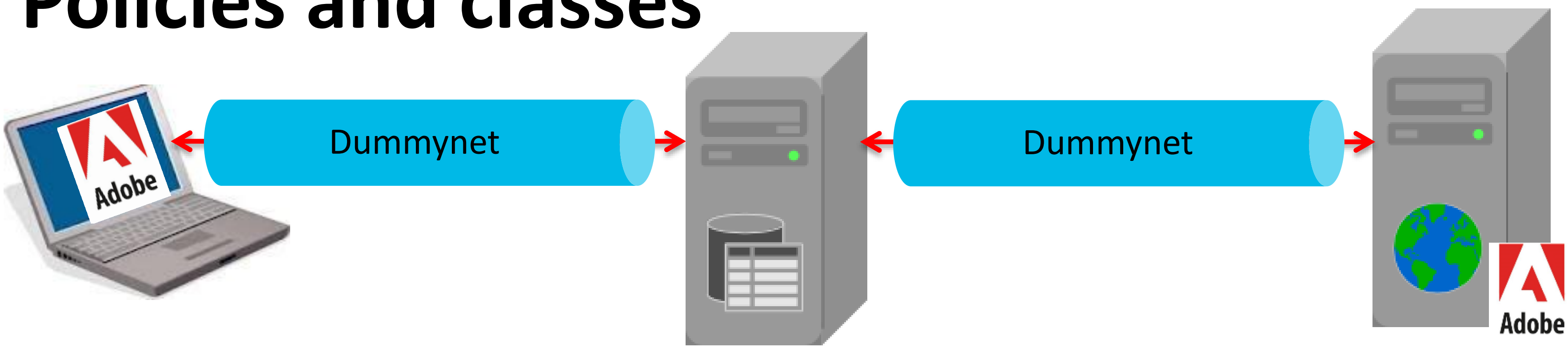

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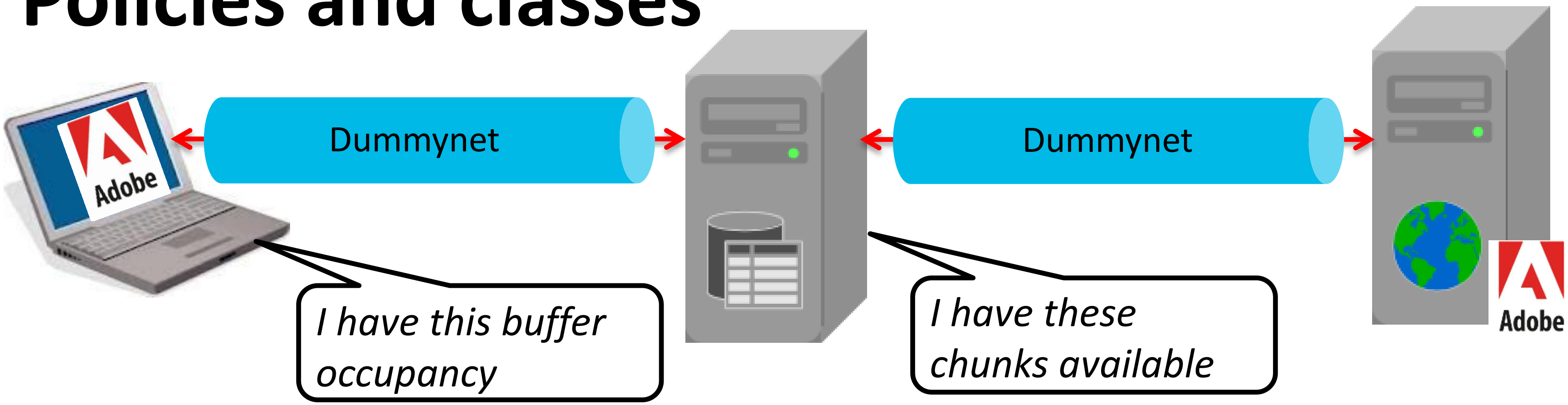

- **Client-proxy cooperation policies**
  - Buffer oblivious (priority-based prefetching)
  - Buffer aware (conservative quality during low buffer conditions)

Policies: overview

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- **Quality and content-aware prefetching policies**
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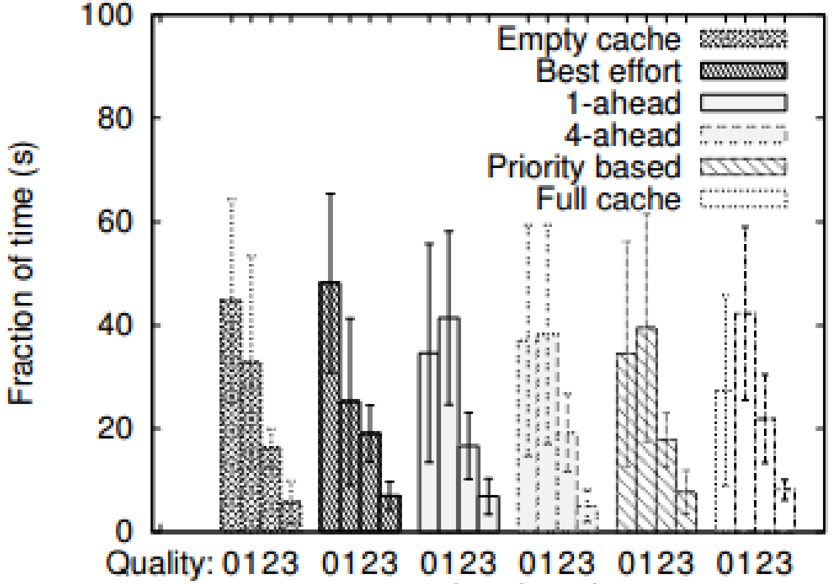
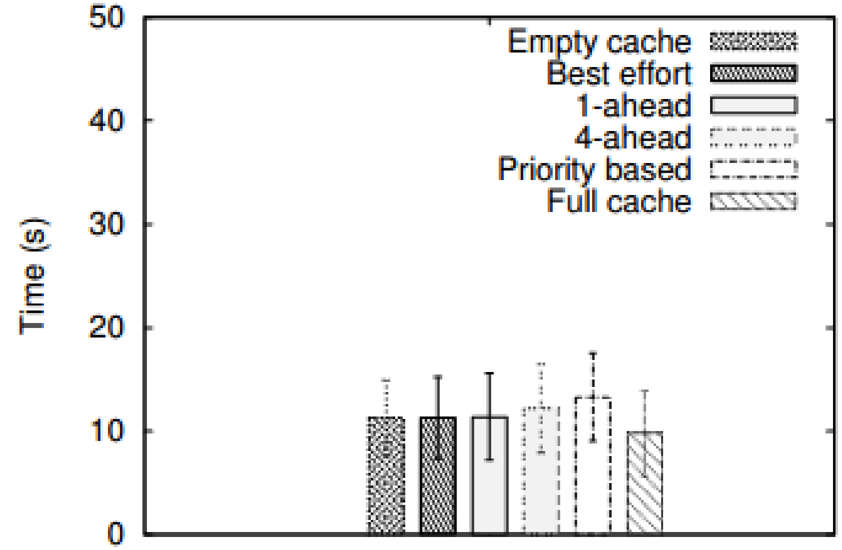
  - Buffer aware (conservative quality during low buffer conditions)

Evaluation: Client-proxy bottleneck

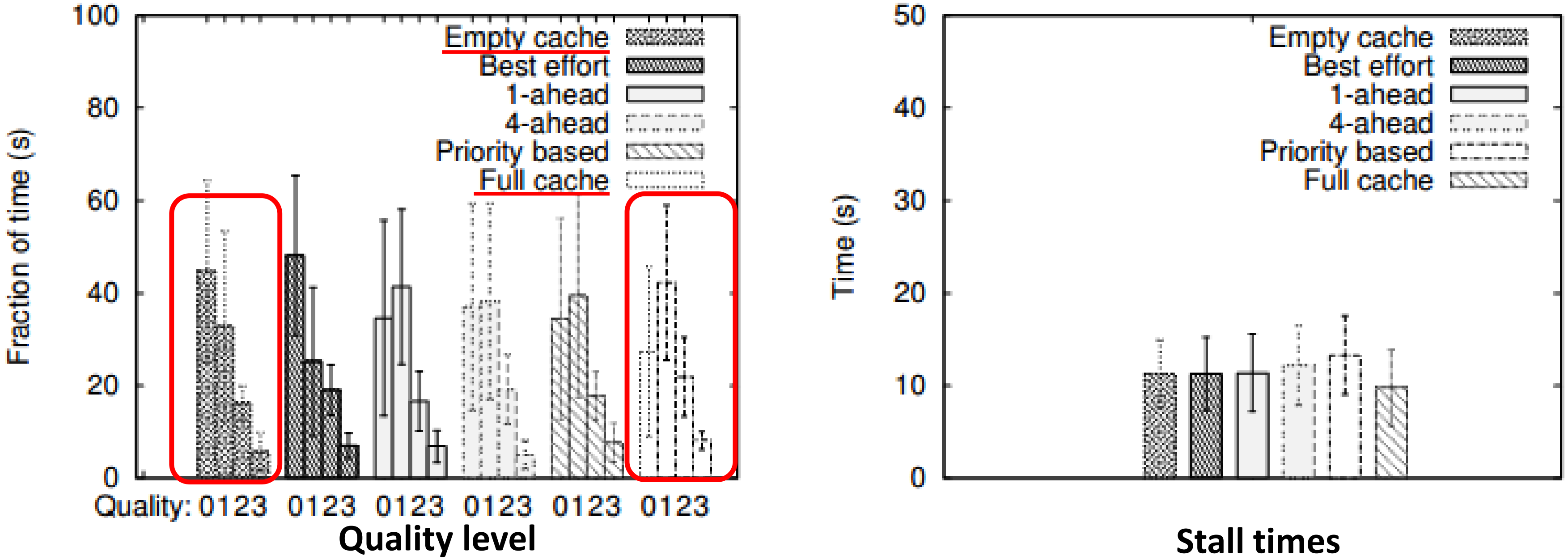


Quality level



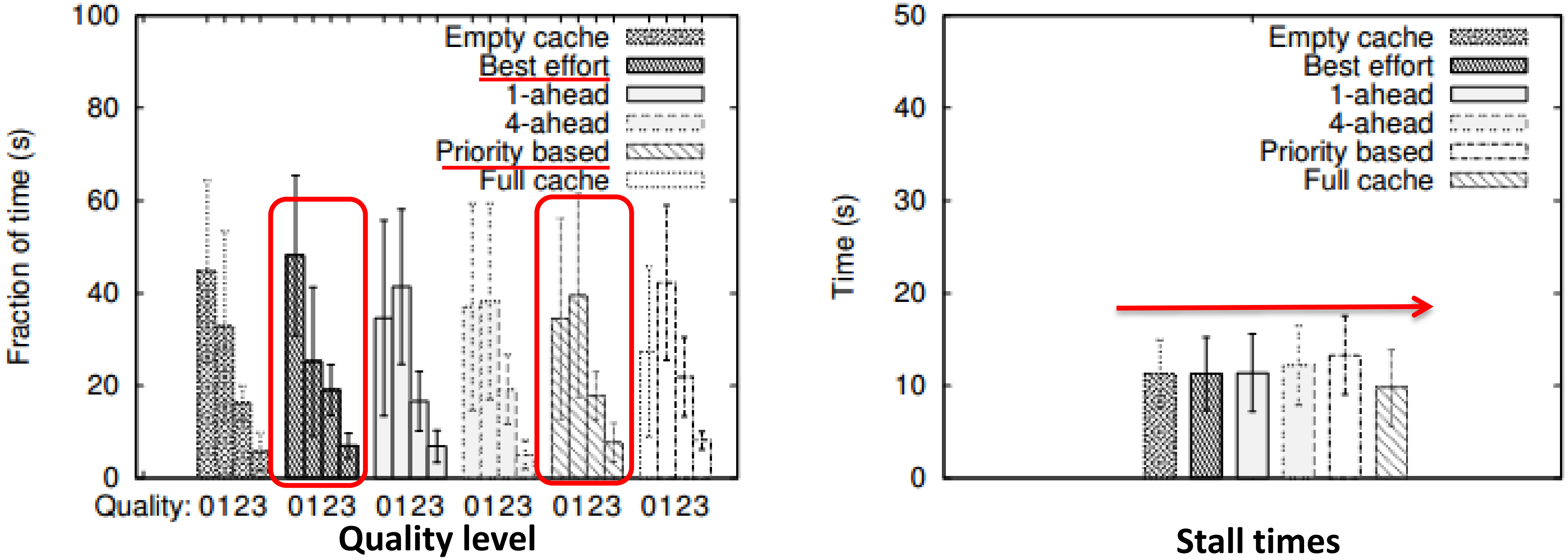
Stall times

Evaluation: Client-proxy bottleneck



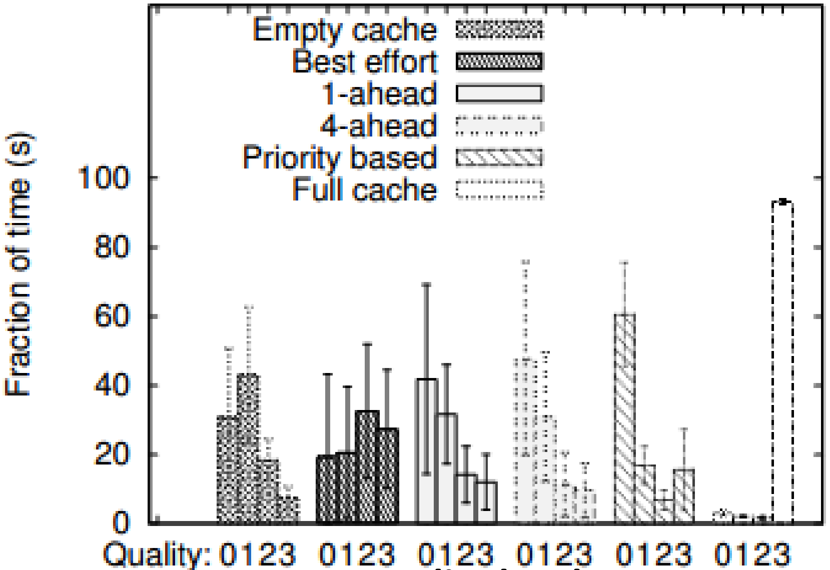
- Proxies provide only limited performance advantages under client-proxy bottleneck

Evaluation: Client-proxy bottleneck

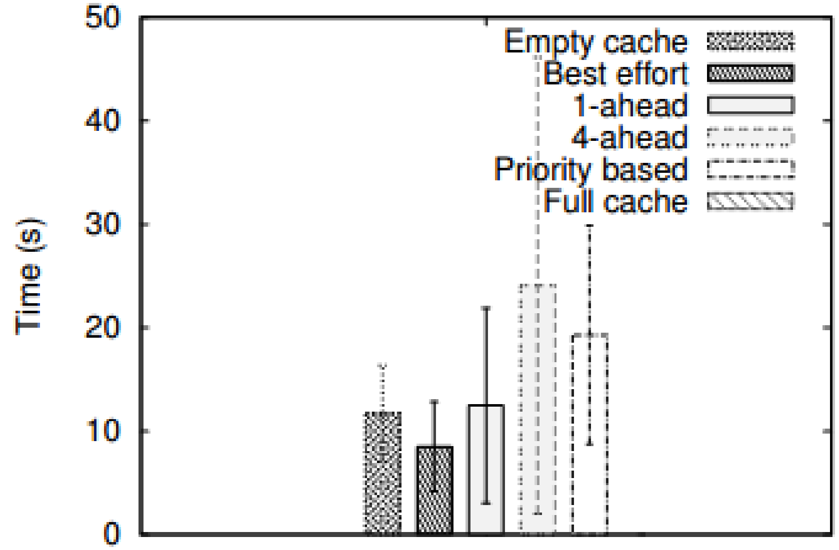


- Proxies provide only limited performance advantages under client-proxy bottleneck
- Some performance improvements with prefetching (but penalty for excessive prefetching)

Evaluation: Proxy-server bottleneck

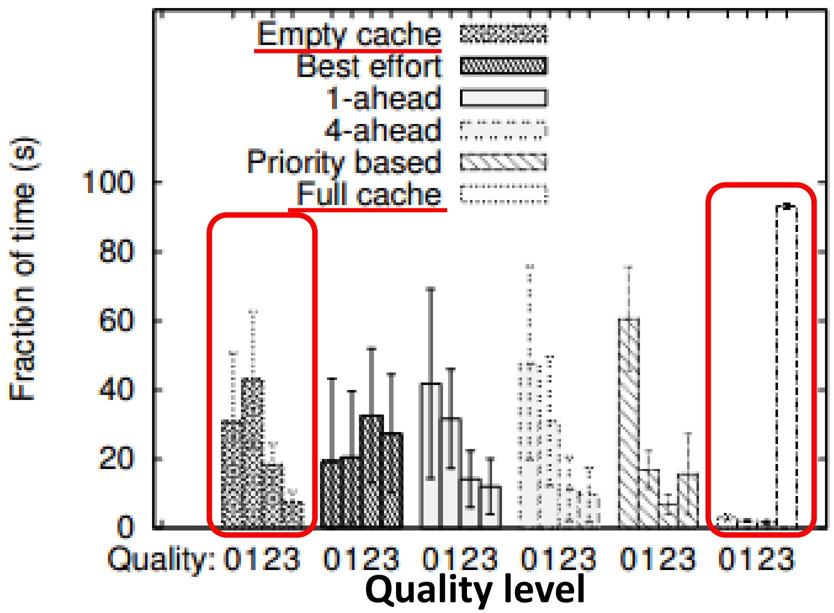


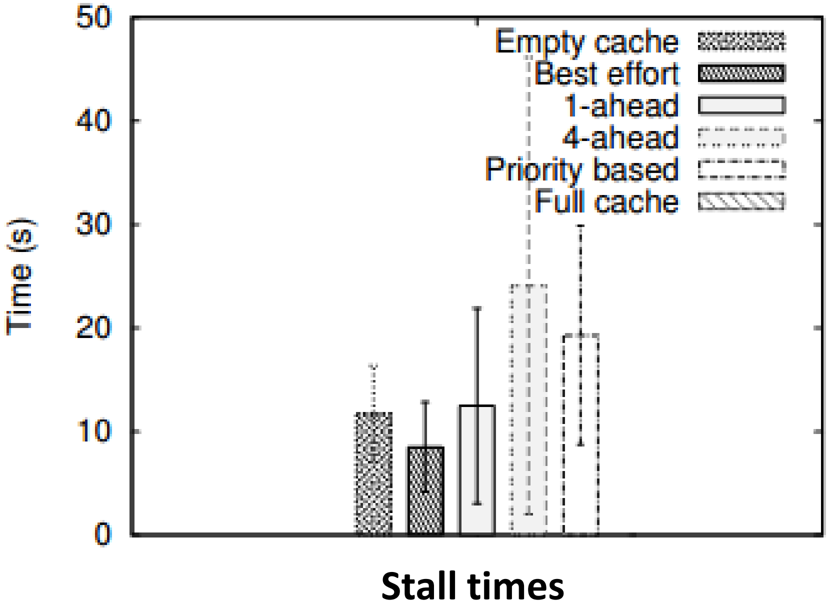
Quality level



Stall times

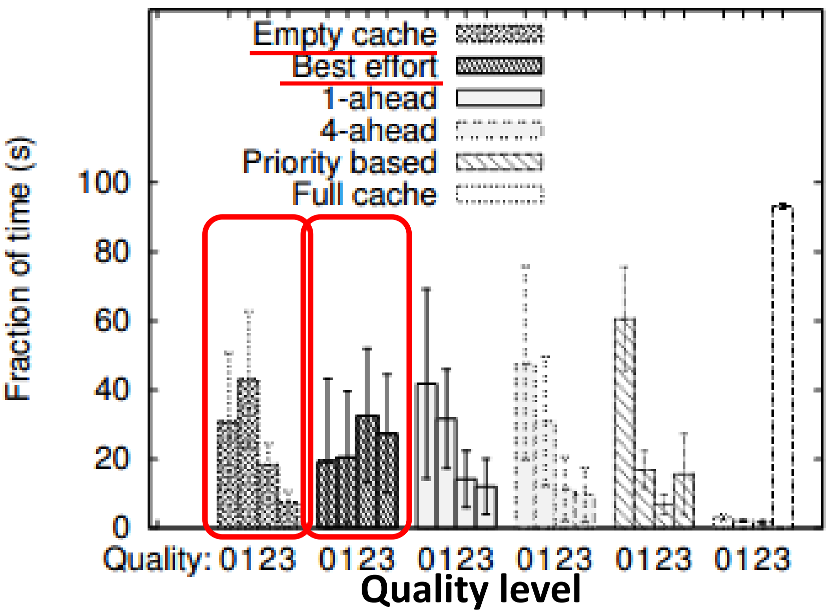
Evaluation: Proxy-server bottleneck

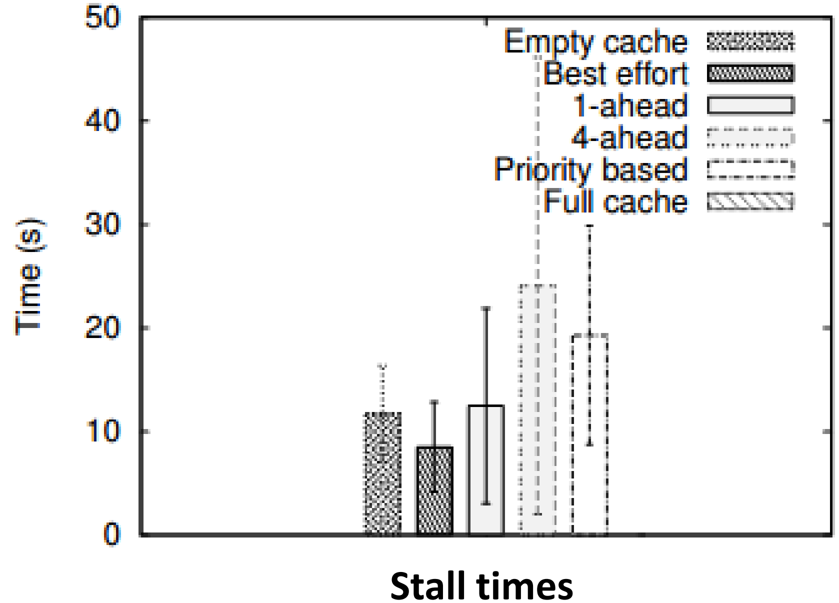




- Large performance potential for proxy caching

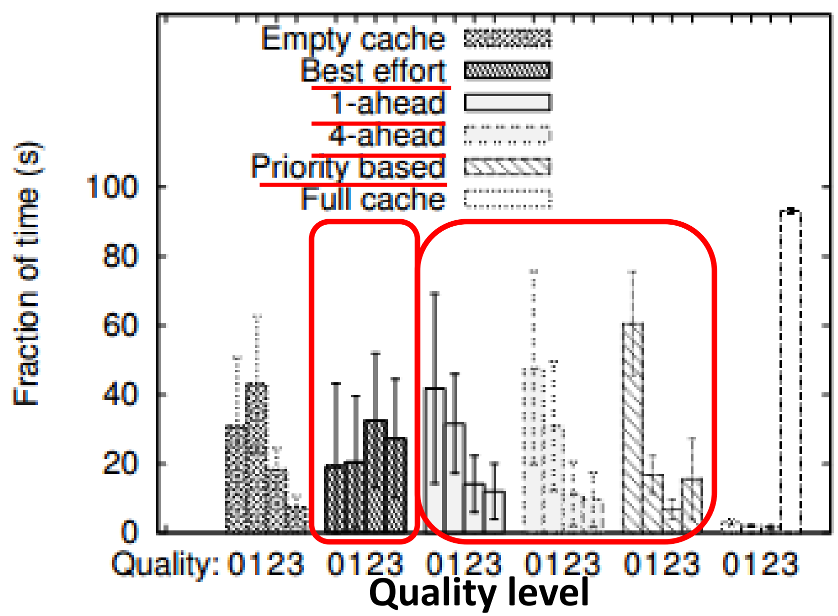
Evaluation: Proxy-server bottleneck

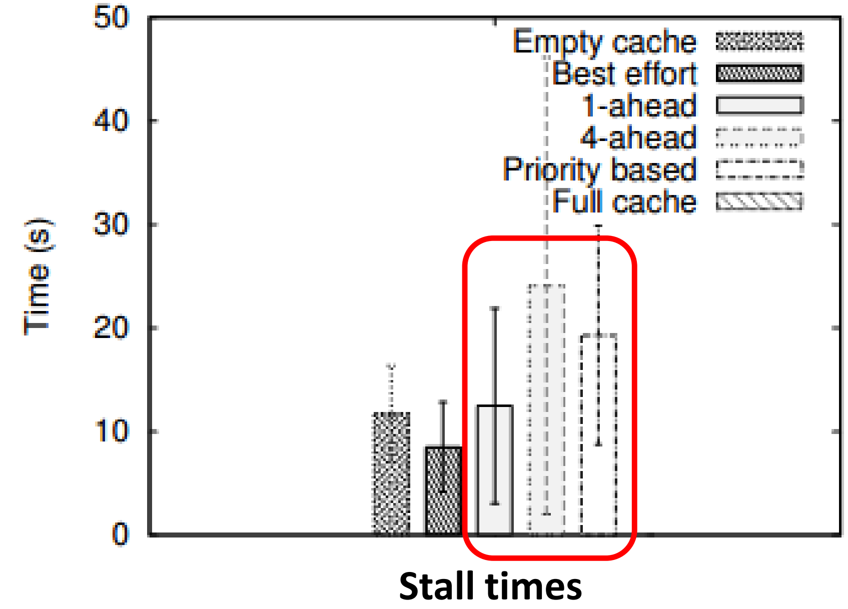




- Large performance potential for proxy caching
- Significant performance improvement with the best effort policy

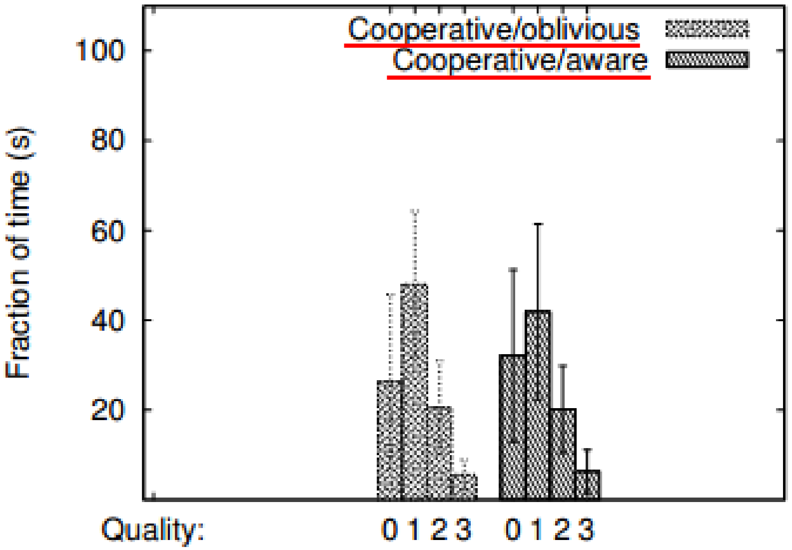
Evaluation: Proxy-server bottleneck

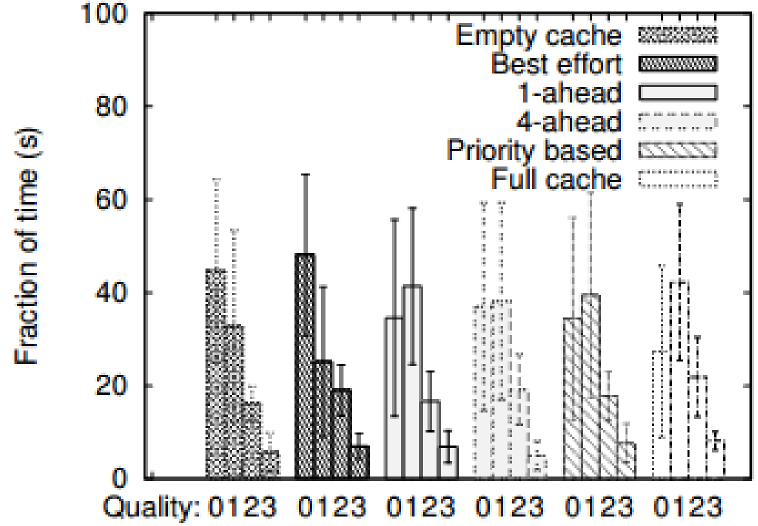




- Large performance potential for proxy caching
- Significant performance improvement with the best effort policy
- Naive prefetching results in penalty. Need for more intelligent prefetching policies (cooperative)

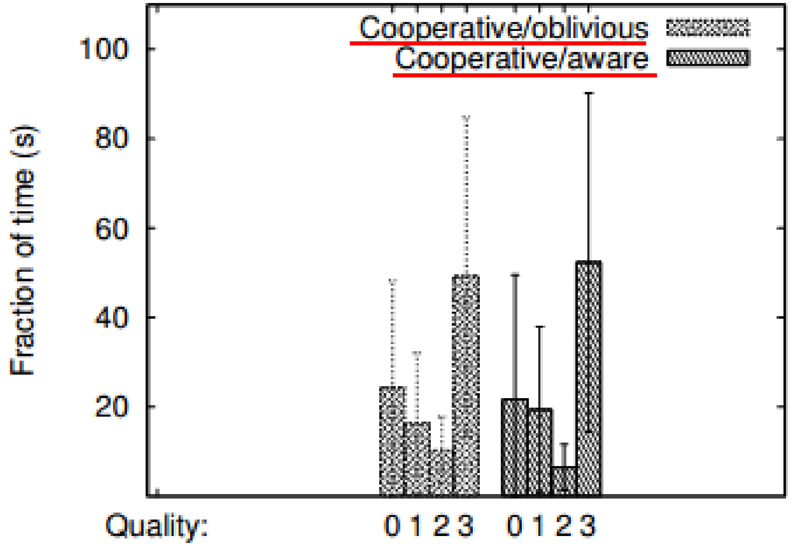
Evaluation: co-operative policies

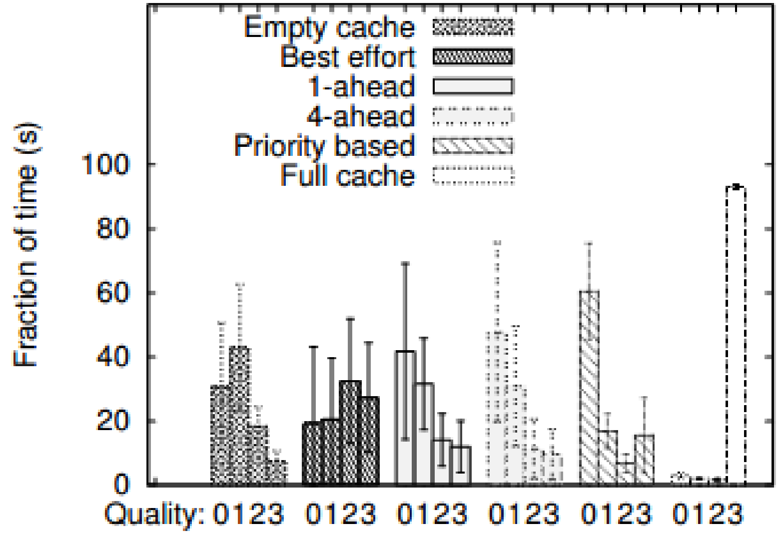




- For client-proxy bottleneck, both policies slightly outperform all baseline and quality-aware prefetching policies (right)

Evaluation: co-operative policies





- For proxy-server bottleneck, both policies vastly outperform all baseline and quality-aware prefetching policies (right)

Proxy-assisted HAS: Conclusions

- Performance impact of HAS-aware proxy policies
  - Baseline policies
  - Quality and content-aware prefetching
  - Client-proxy cooperation

Proxy-assisted HAS: Conclusions

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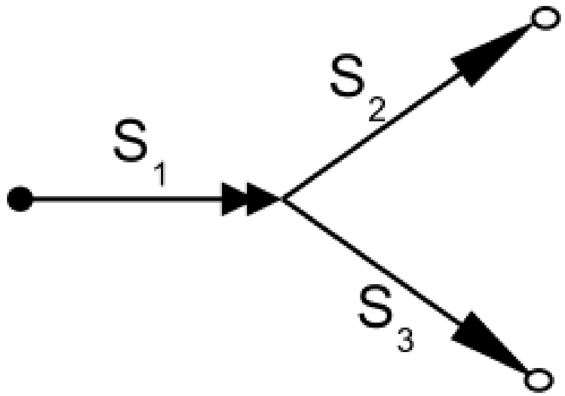
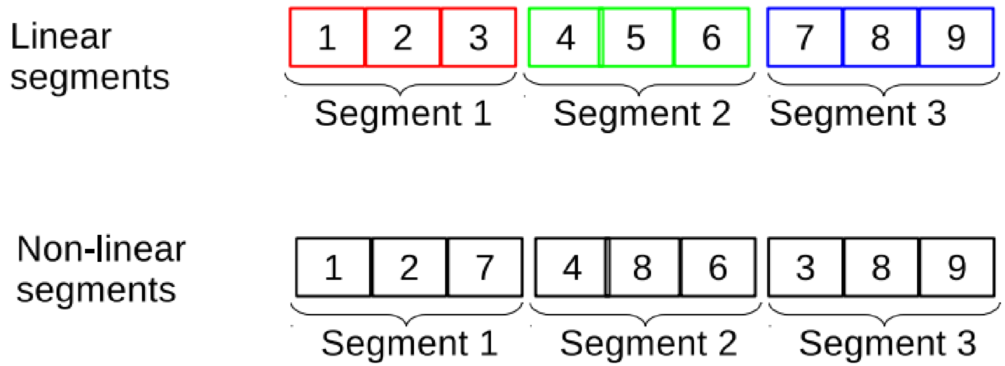
Proxy-assisted HAS: Conclusions

- Performance impact of HAS-aware proxy policies
  - Baseline policies
  - Quality and content-aware prefetching
  - Client-proxy cooperation
- Bottleneck location and network conditions play central roles in which policies are most advantageous
- Proxy design and policy selection is very important

Subtopic 2: Interactive branched videos

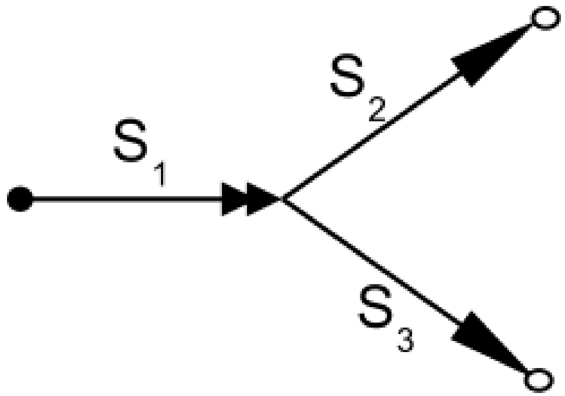
HAS-based interactive branched video

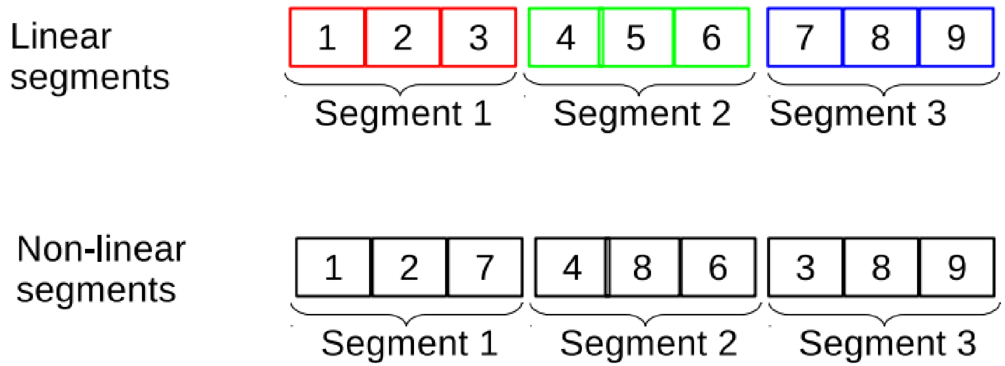




- Branched video and branch points
  - The video can include branch points, with multiple branch choices
  - User selects which segment to play back next

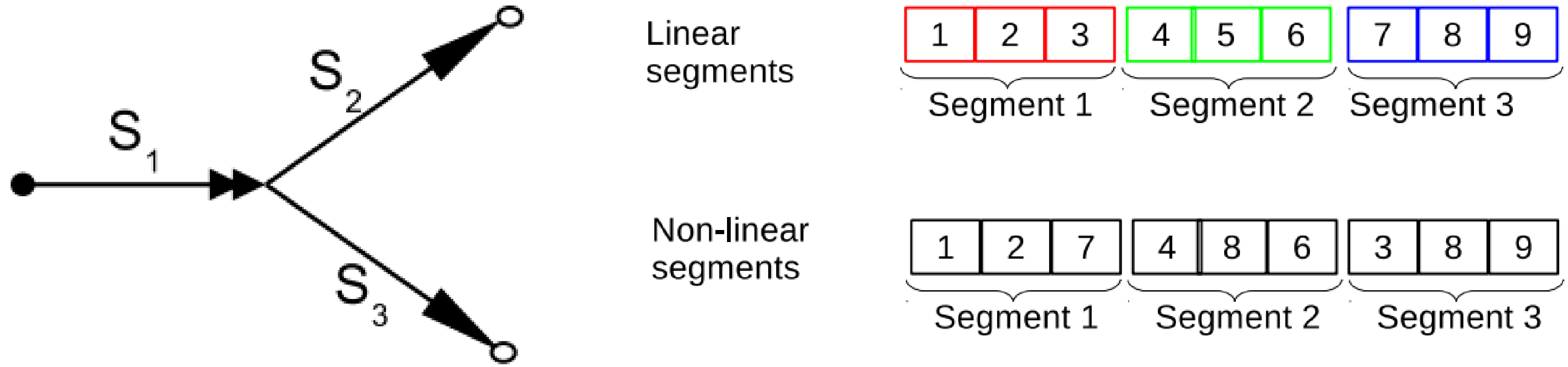
HAS-based interactive branched video





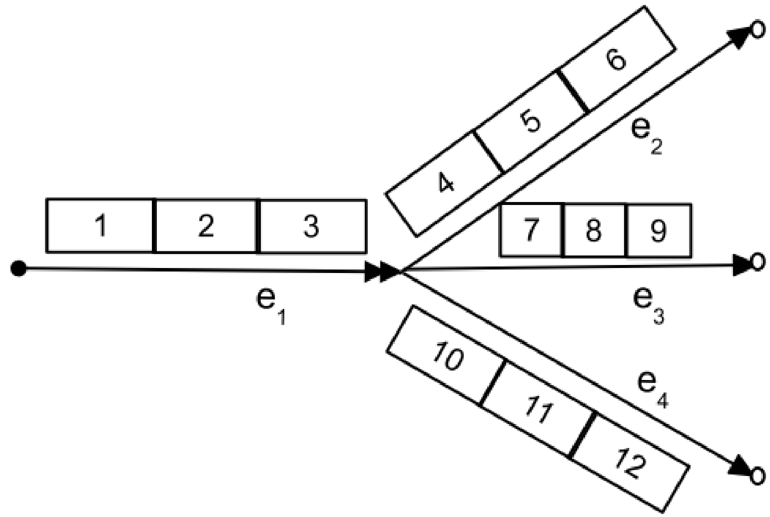
- Branched video and branch points
  - The video can include branch points, with multiple branch choices
  - User selects which segment to play back next
- Our solution: Combine branched video and HAS

HAS-based interactive branched video

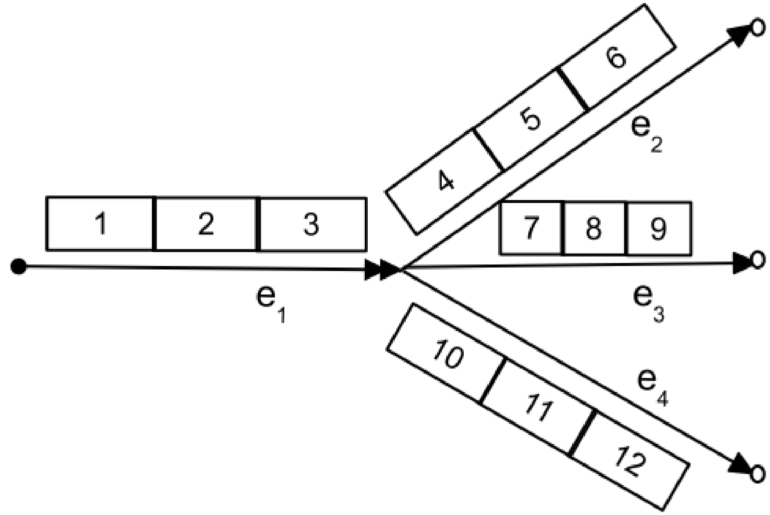


- Branched video and branch points
  - The video can include branch points, with multiple branch choices
  - User selects which segment to play back next
- Our solution: Combine branched video and HAS
- Goal: Seamless playback even if user decision at last possible moment

Problem description and constraints

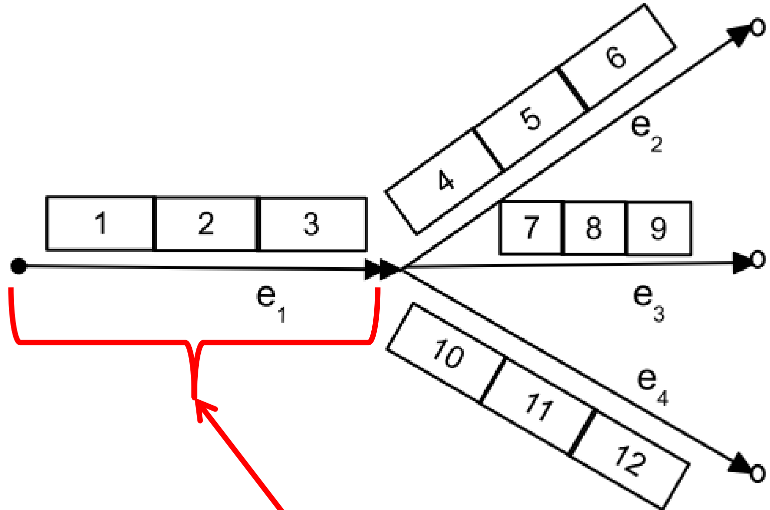


Problem description and constraints



- Problem: Maximize quality, given playback deadlines and bandwidth conditions

Problem description and constraints

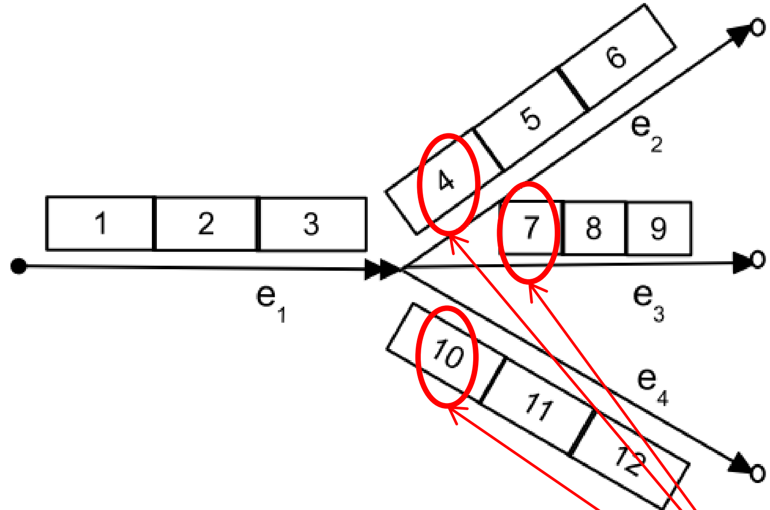


- Objective function:

$$\text{maximize} \sum_{i=1}^{n_e} q_i l_i + \sum_{i=n_e+1}^{n_e+|\mathcal{E}^b|} w_e^b q_i l_i$$

Current segment

Problem description and constraints

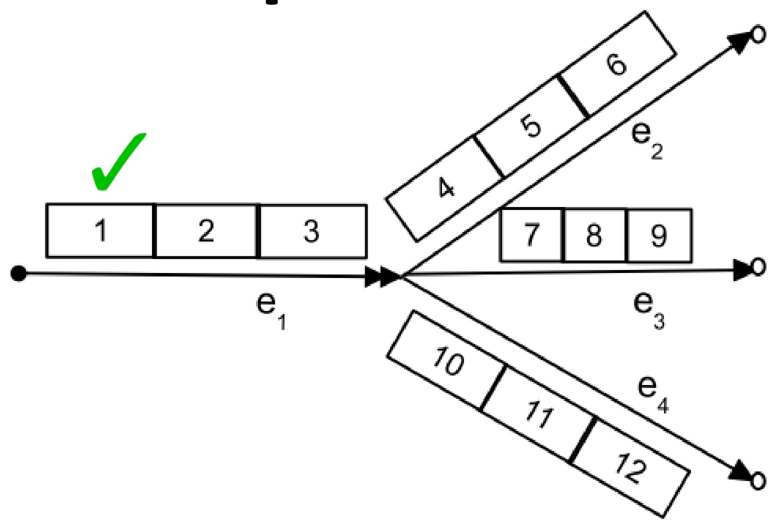


- Objective function:

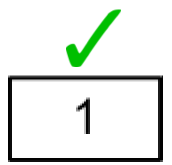
$$\text{maximize} \sum_{i=1}^{n_e} q_i l_i + \sum_{i=n_e+1}^{n_e+|\mathcal{E}^b|} w_e^b q_i l_i$$

Beginning of next segment

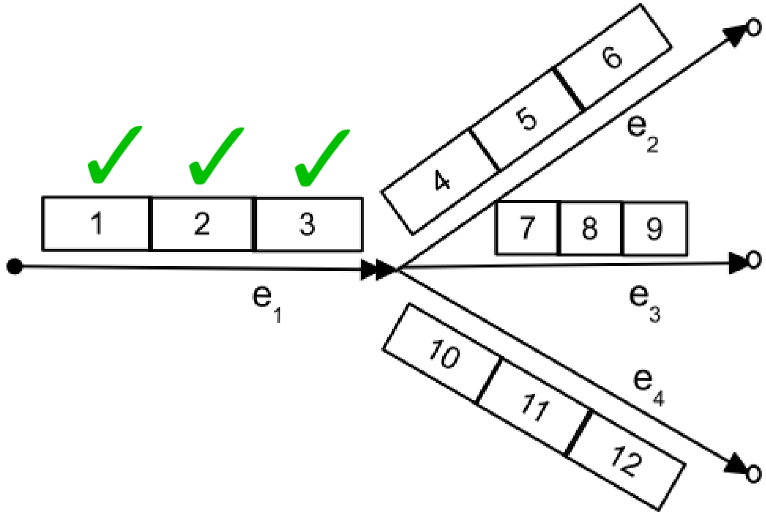
Problem description and constraints



- Download order: round robin (optimal)



Problem description and constraints



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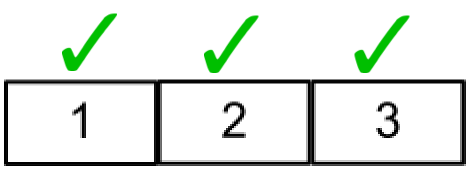
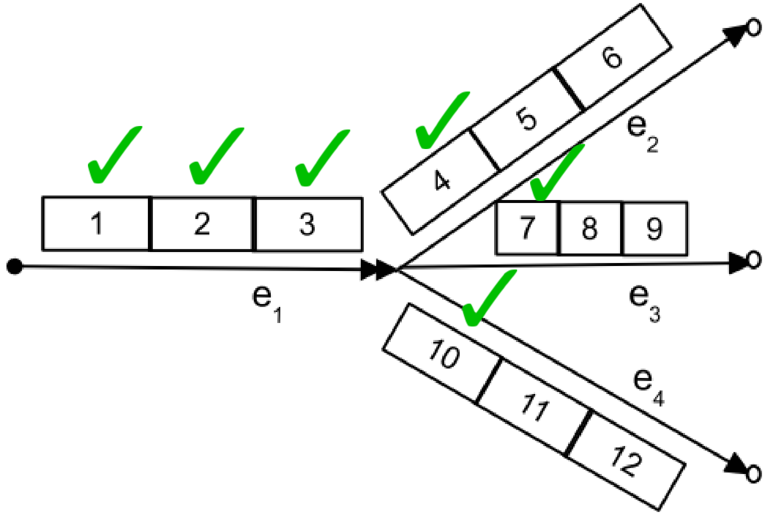
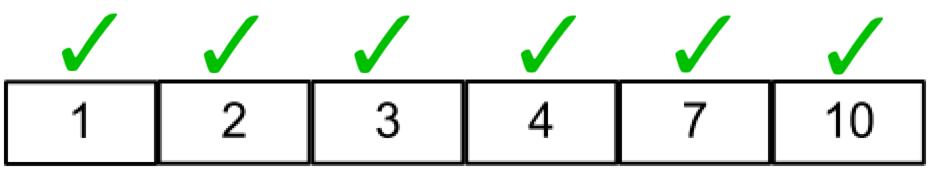


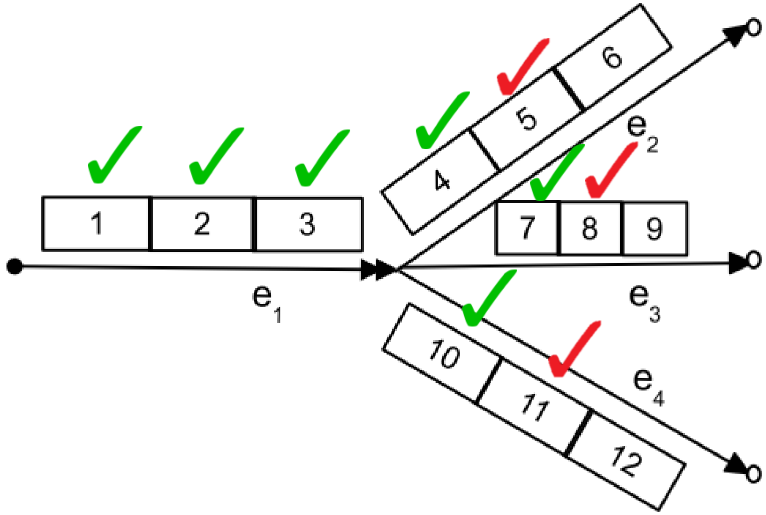
Problem description and constraints



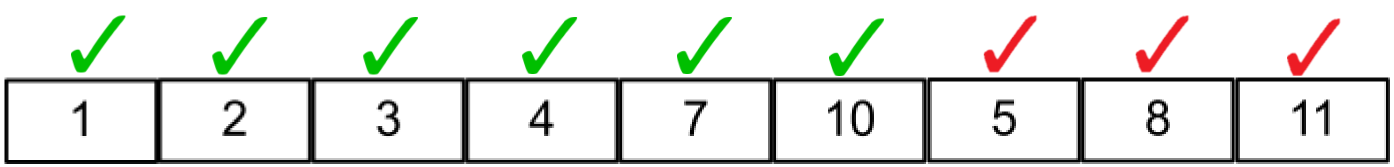
- Download order: round robin (optimal)



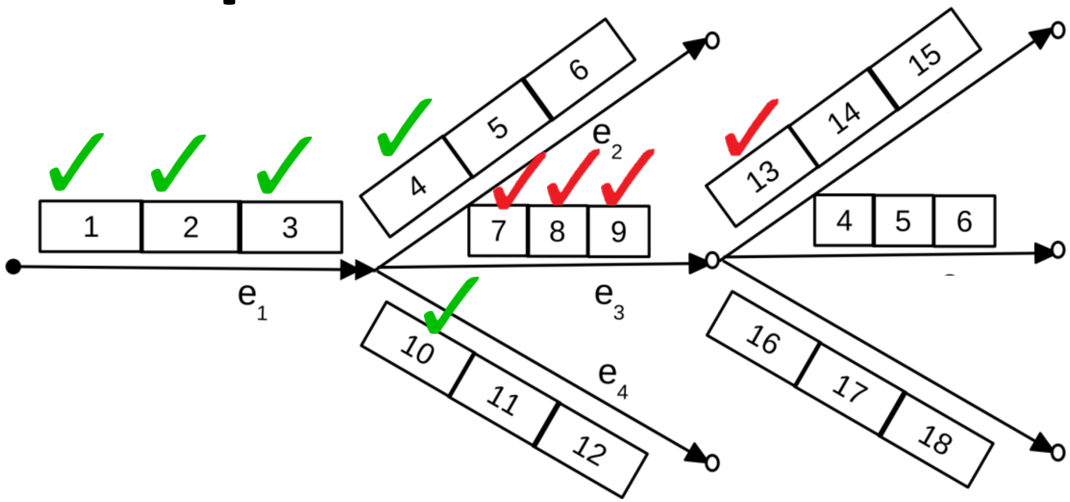
Problem description and constraints



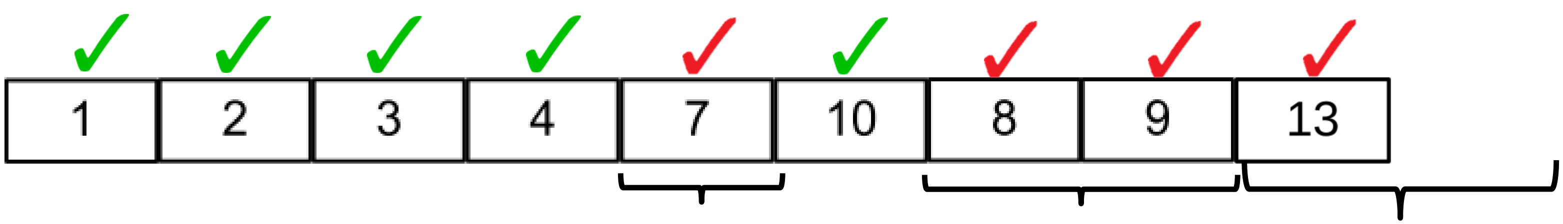
- Download order: round robin (extra workahead)



Problem description and constraints



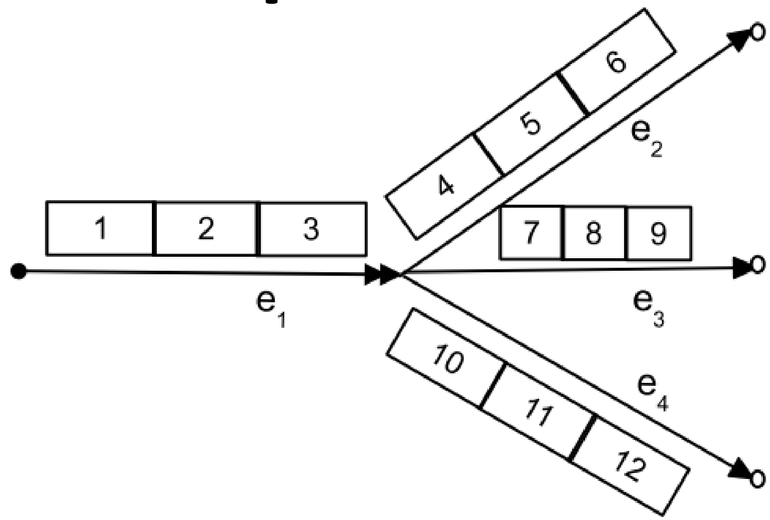
- Once branch point has been traversed, move on to next segment ...



current segment

Next branch

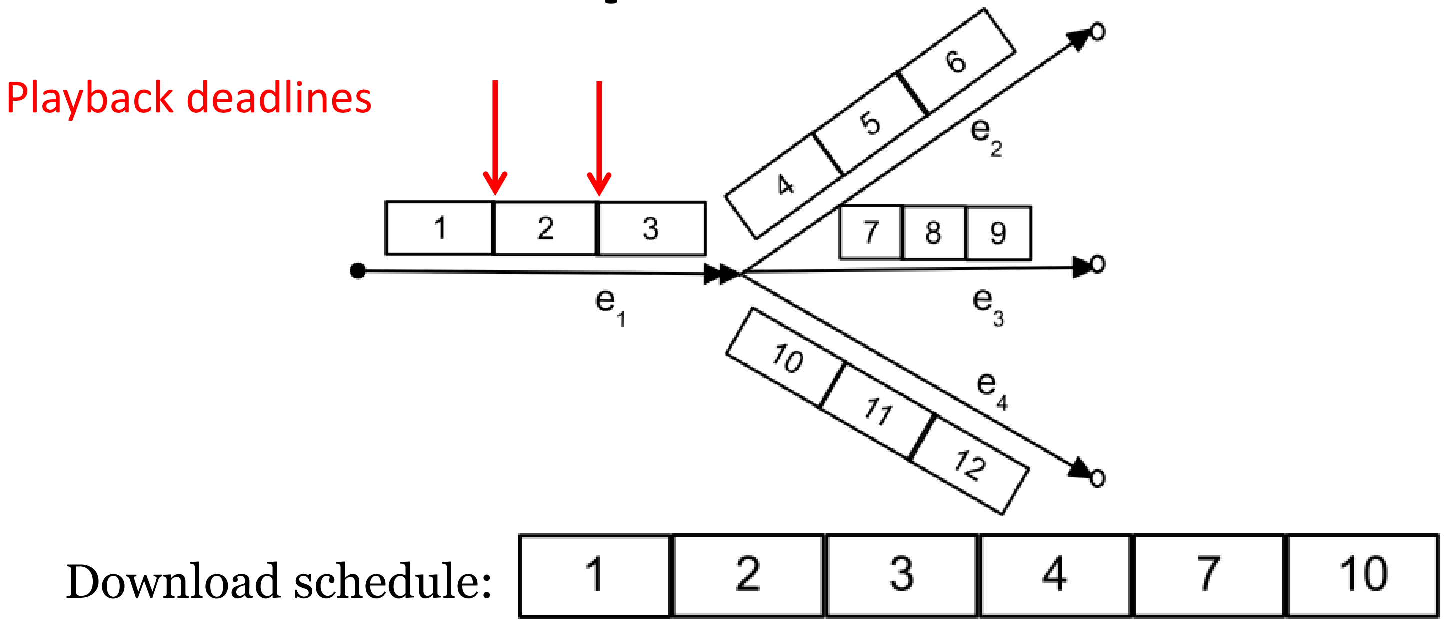
Problem description and constraints



Download schedule:

1	2	3	4	7	10

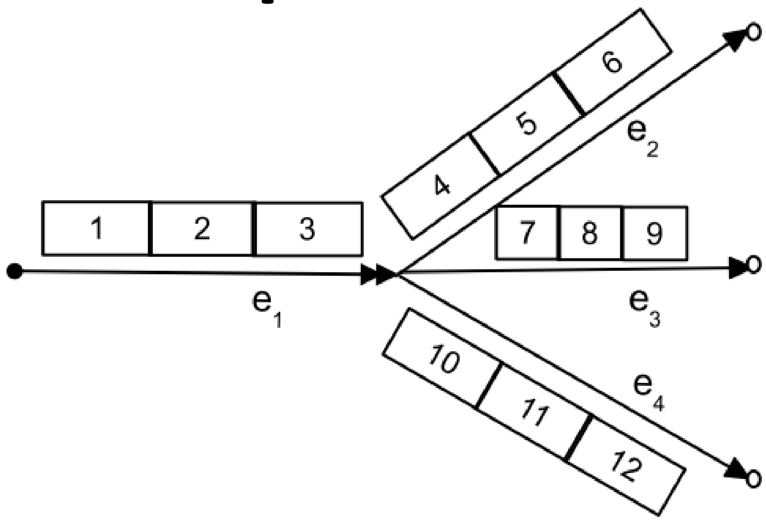
Problem description and constraints



- Playback deadlines:
  - For seamless playback without stalls, eg., chunks 2 and 3,

$$t_i^c \leq t_i^d = \tau + \sum_{j=1}^{i-1} l_j, \quad \text{if } 1 \leq i \leq n_e$$

Problem description and constraints



Download schedule:

1	2	3	4	7	10

Download completion times

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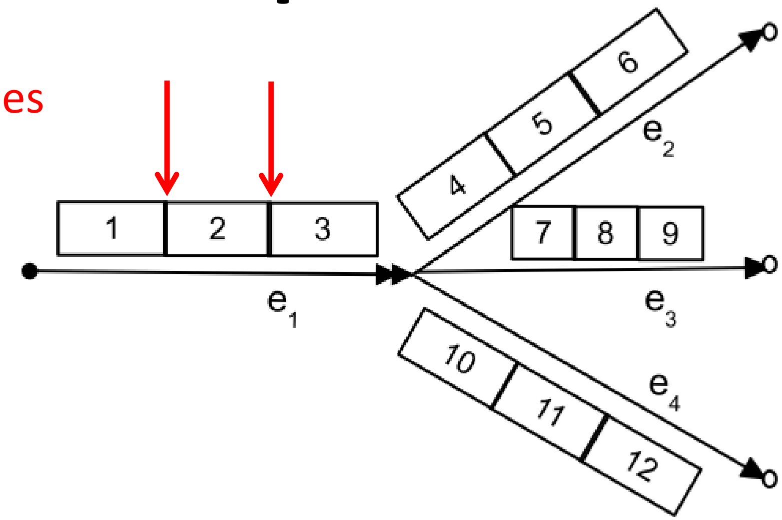
Download completion time

Problem description and constraints

Playback deadlines



Download schedule:

1	2	3	4	7	10

Download completion times

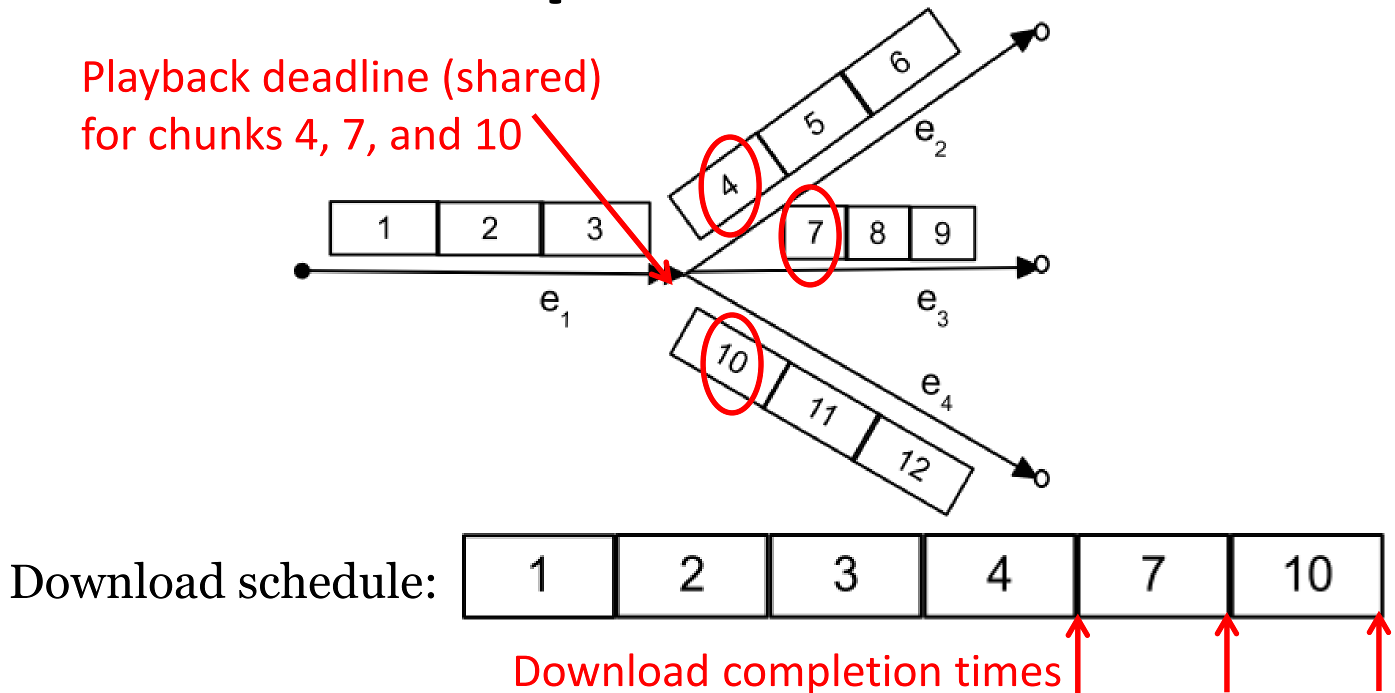
- Playback deadlines:
  - For seamless playback without stalls, eg., chunks 2 and 3,

$$t_i^c \le t_i^d = \tau + \sum_{j=1}^{i-1} l_j, \quad \text{if } 1 \le i \le n_e$$

Time of playback deadline

Download completion time

Problem description and constraints

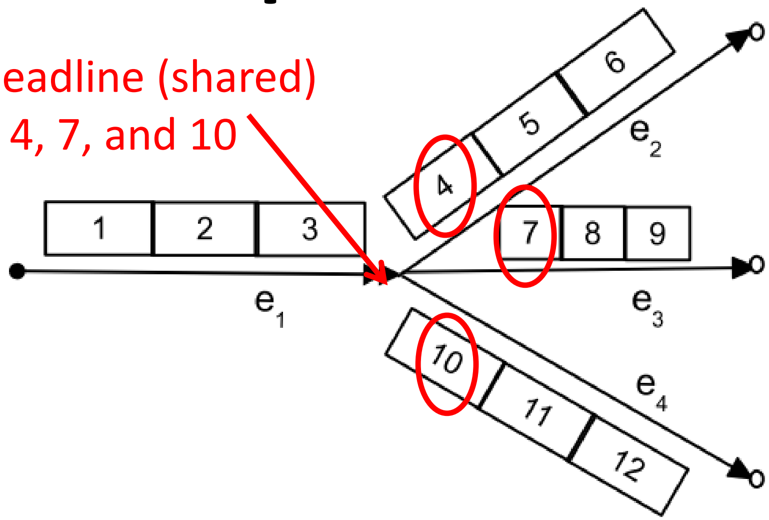


- Playback deadlines:
  - For seamless playback of first chunks in next segment: e.g., 4, 7, and 10

$$t_i^c \leq t_i^d = \tau + \sum_{j=1}^{n_e} l_j , \quad \text{if } n_e < i \leq n_e + |\mathcal{E}^b|$$

Problem description and constraints

Playback deadline (shared)
for chunks 4, 7, and 10



Download schedule:

1	2	3	4	7	10

Download completion times

- Playback deadlines:
  - For seamless playback of first chunks in next segment: e.g., 4, 7, and 10

$$t_i^c \leq t_i^d = \tau + \sum_{j=1}^{n_e} l_j, \quad \text{if } n_e < i \leq n_e + |\mathcal{E}^b|$$

Time at which branch point is reached

Download completion times

Prefetching policies

- At download completion
  - Decide number of chunks to download next (number of connections)
  - Decide quality level of chunks
  - Maximize expected weighted playback

Prefetching policies

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  - Decide number of chunks to download next (number of connections)
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Prefetching policies

- At download completion
  - Decide number of chunks to download next (number of connections)
  - Decide quality level of chunks
  - Maximize expected weighted playback
- Exponential number of candidate schedules
- Our optimized policies restrict the number of candidate schedules to consider
  - Policies differ in number of candidate schedules and how aggressive they are (quality choice)

Comparison between policies

Policy	Connections	Schedules considered	Objective
All schedules	$1 \le c_i \le C^{max}$	Q^M, where $M = n_e + \lvert \xi_b \rvert - m$	-
Optimized non-increasing quality	$1 \le c_i \le C^{max}$	$\binom{M+Q-1}{Q-1}$	$\sum_{i=1}^{n_e} q_i l_i + \sum_{i=n_e+1}^{n_e+\lvert \xi_b \rvert} q_i l_i$
Optimized maintainable quality	$1 \le c_i \le C^{max}$	Q	

- Total number of schedules: Q^M
- Optimized non-increasing quality:
  - Constraint: Qualities of consecutive chunks are non-increasing

Comparison between policies

Policy	Connections	Schedules considered	Objective
All schedules	$1 \leq c_i \leq C^{max}$	Q^M, where $M = n_e + \vert \xi_b \vert - m$	-
Optimized non-increasing quality	$1 \leq c_i \leq C^{max}$	$\binom{M+Q-1}{Q-1}$	$\sum_{i=1}^{n_e} q_i l_i + \sum_{i=n_e+1}^{n_e+\vert \xi_b \vert} q_i l_i$
Optimized maintainable quality	$1 \leq c_i \leq C^{max}$	Q	

- Total number of schedules: Q^M
- Optimized non-increasing quality:
  - Constraint: Qualities of consecutive chunks are non-increasing
- Optimized maintainable quality:
  - Constraint: Chosen quality must be sustainable

Comparison between policies

Policy	Connections	Schedules considered	Objective
Single connection	1	Q	$\sum_{i=1}^{n_e} q_i l_i + \sum_{i=n_e+1}^{n_e+\lvert\xi_b\rvert} q_i l_i$

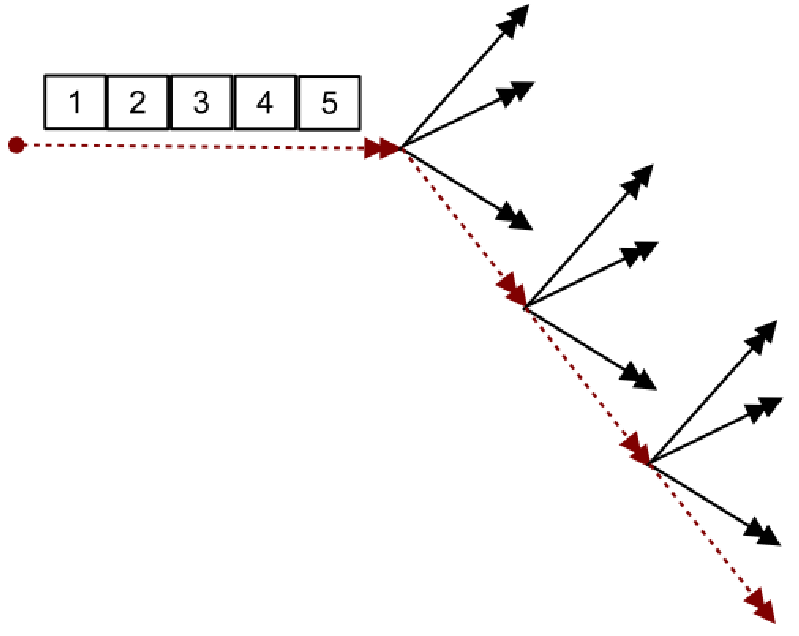
- Single connection: baseline comparing to policies which do not use multiple connections

Comparison between policies

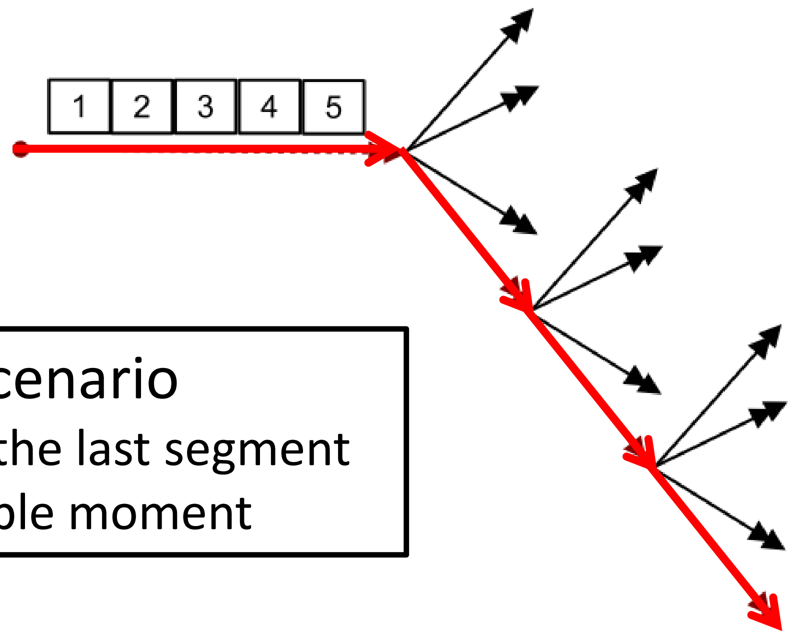
Policy	Connections	Schedules considered	Objective
Single connection	1	Q	$\sum_{i=1}^{n_e} q_i l_i + \sum_{i=n_e+1}^{n_e+\lvert\xi_b\rvert} q_i l_i$

- Single connection: baseline comparing to policies which do not use multiple connections
- Naïve: benchmark to regular branched video players

Test scenario

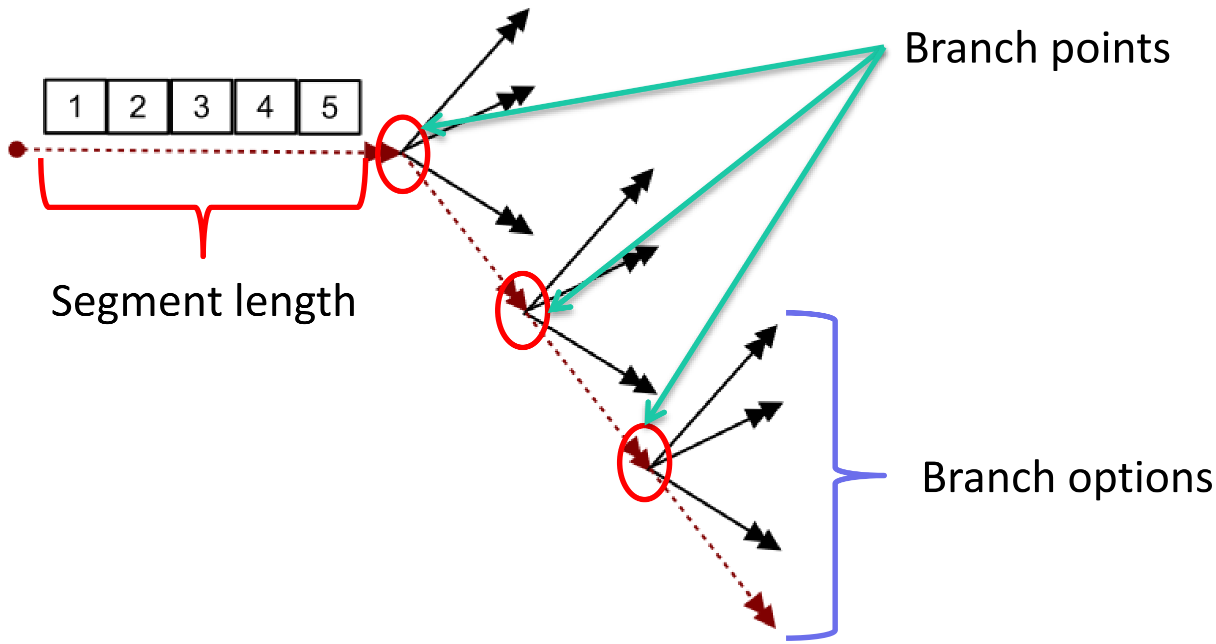


Test scenario



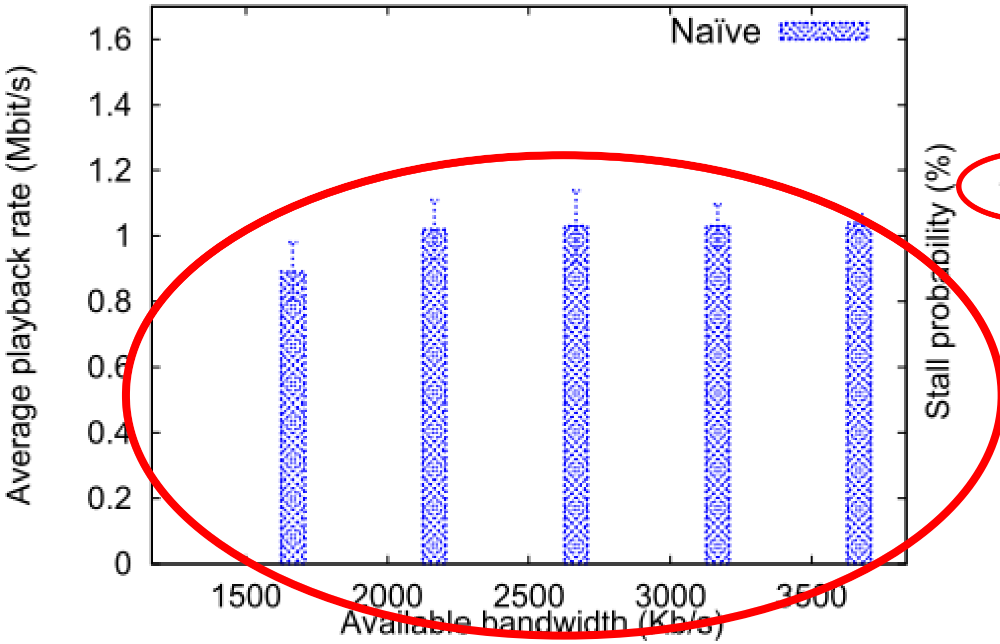
Worst case scenario
- always pick the last segment
- at last possible moment

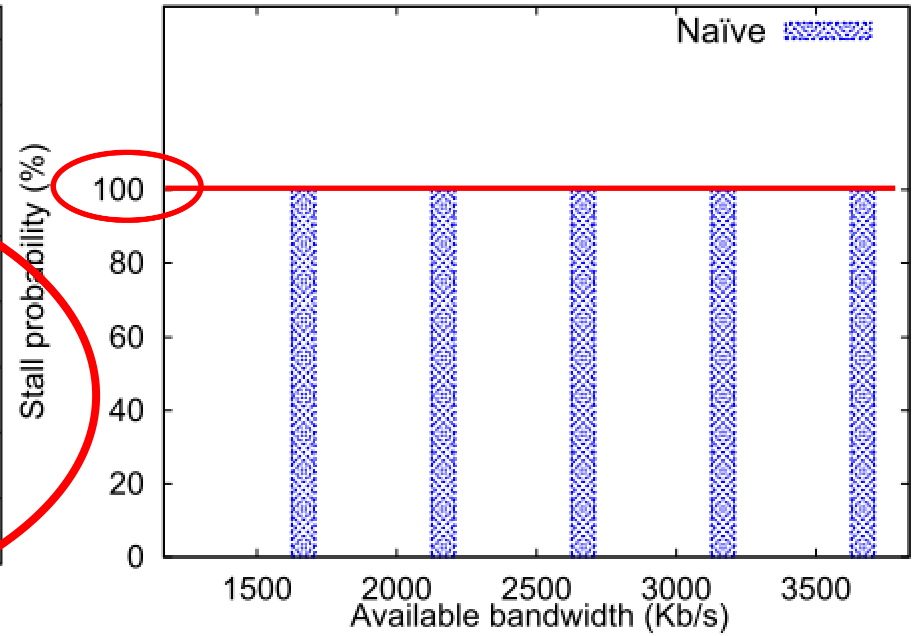
Test scenario



- Default scenario:
  - Segment length: 5
  - Branch options per branch point: 4
  - Branch points: 3

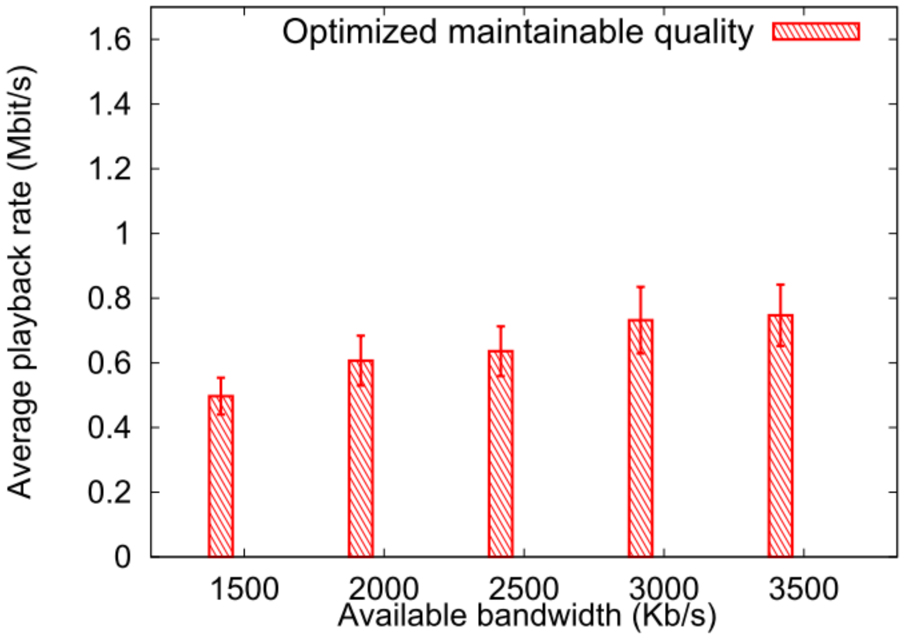
Policy comparison

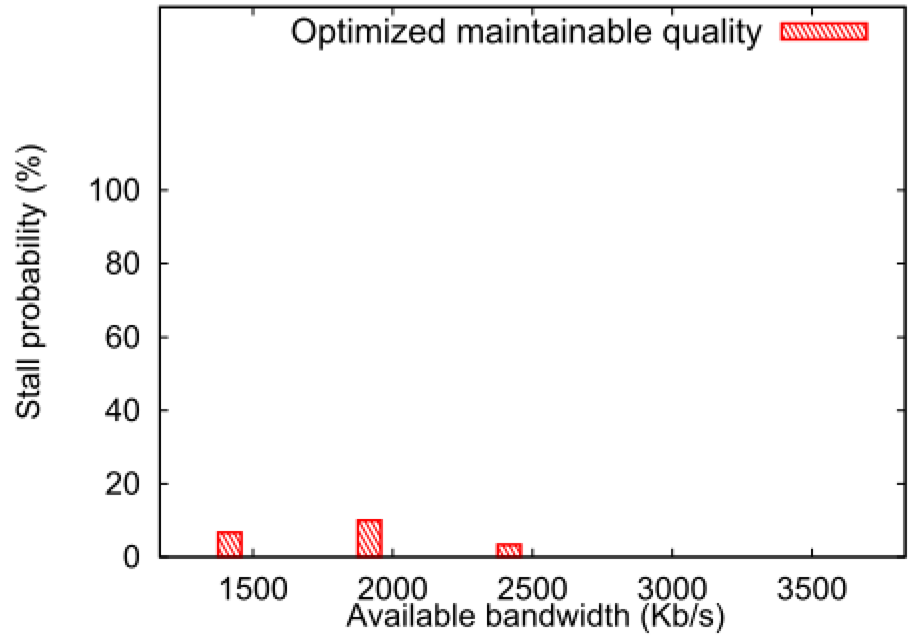




- Naïve policy: does not perform prefetching
  - Stalls at every branch point
  - Note: High playback rate is misleading on its own

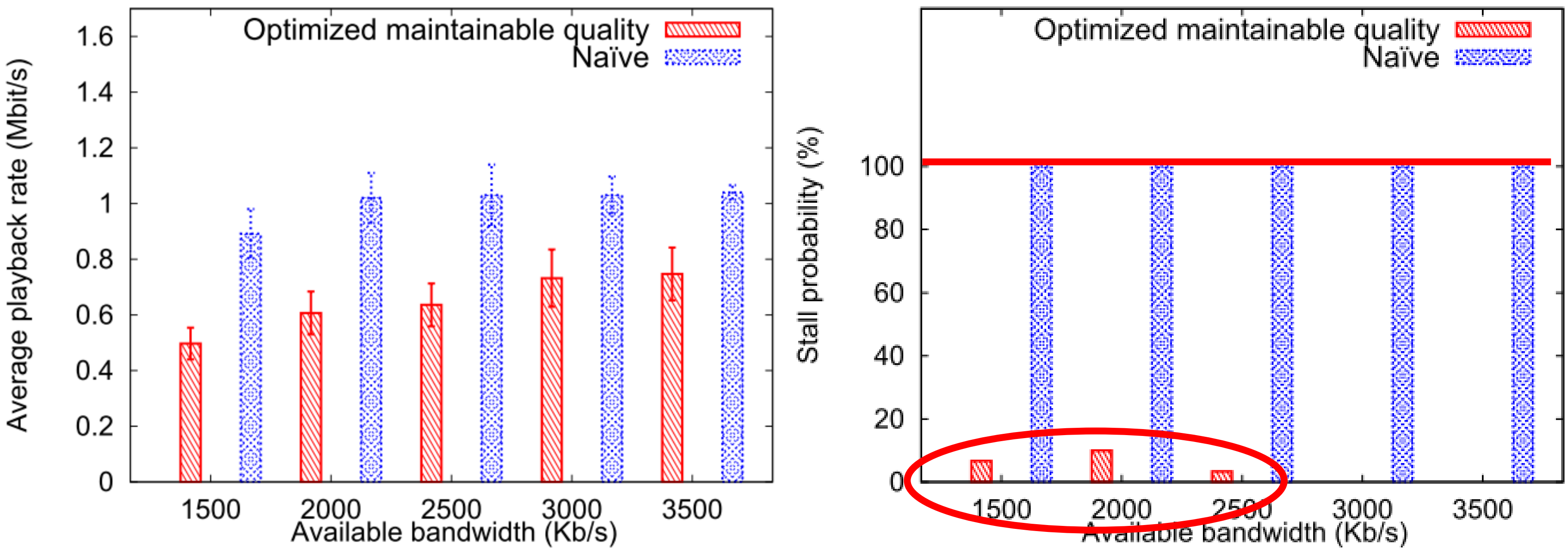
Policy comparison





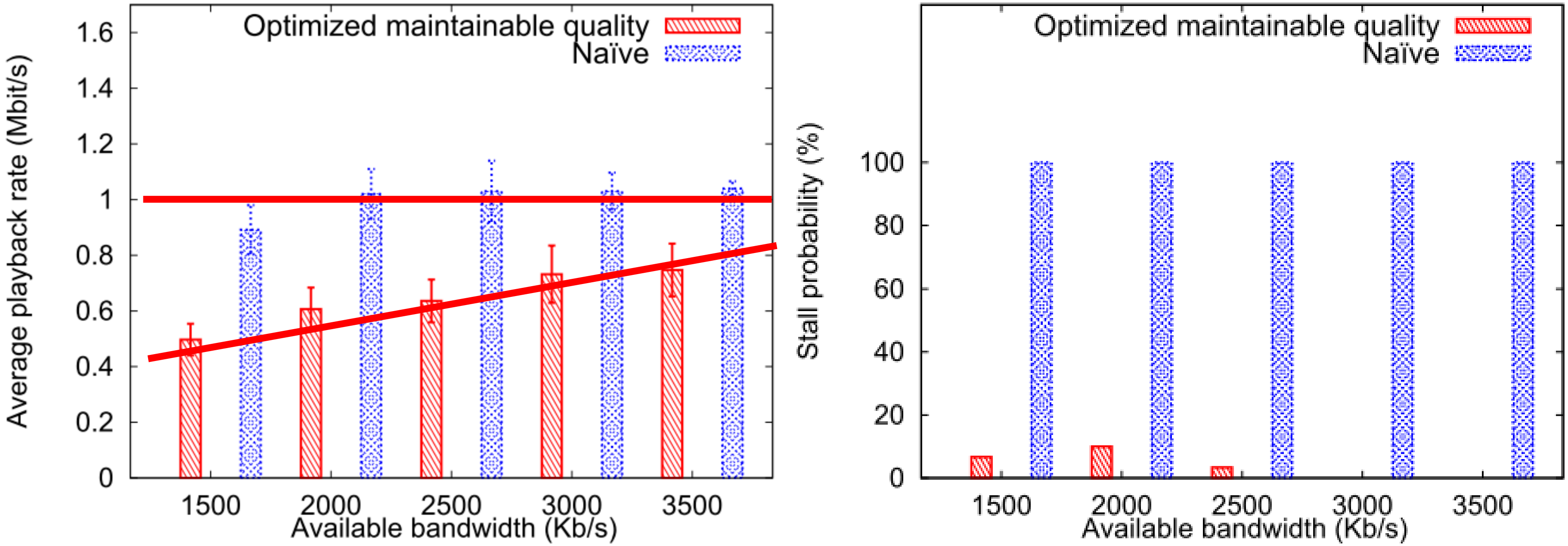
- *Optimized maintainable quality* provides best tradeoff

Policy comparison



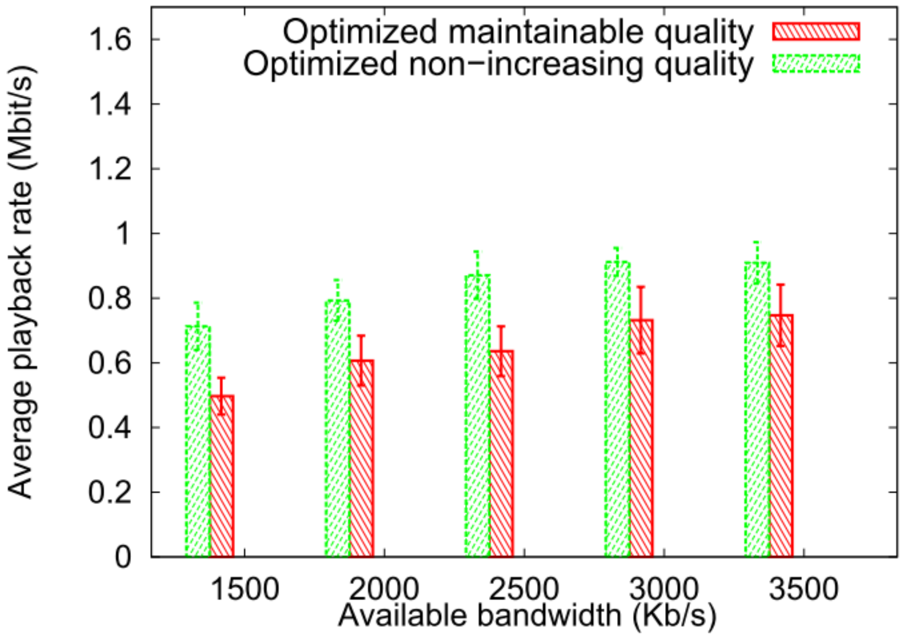
- *Optimized maintainable quality* provides best tradeoff
  - Much lower stall probability

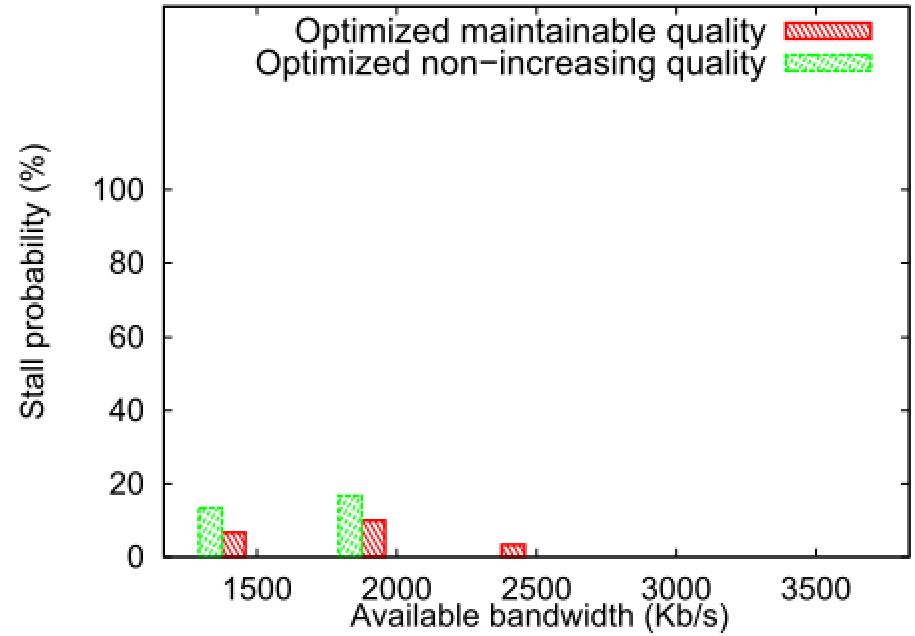
Policy comparison



- *Optimized maintainable quality* provides best tradeoff
  - Much lower stall probability
  - Tradeoff is somewhat lower playback quality

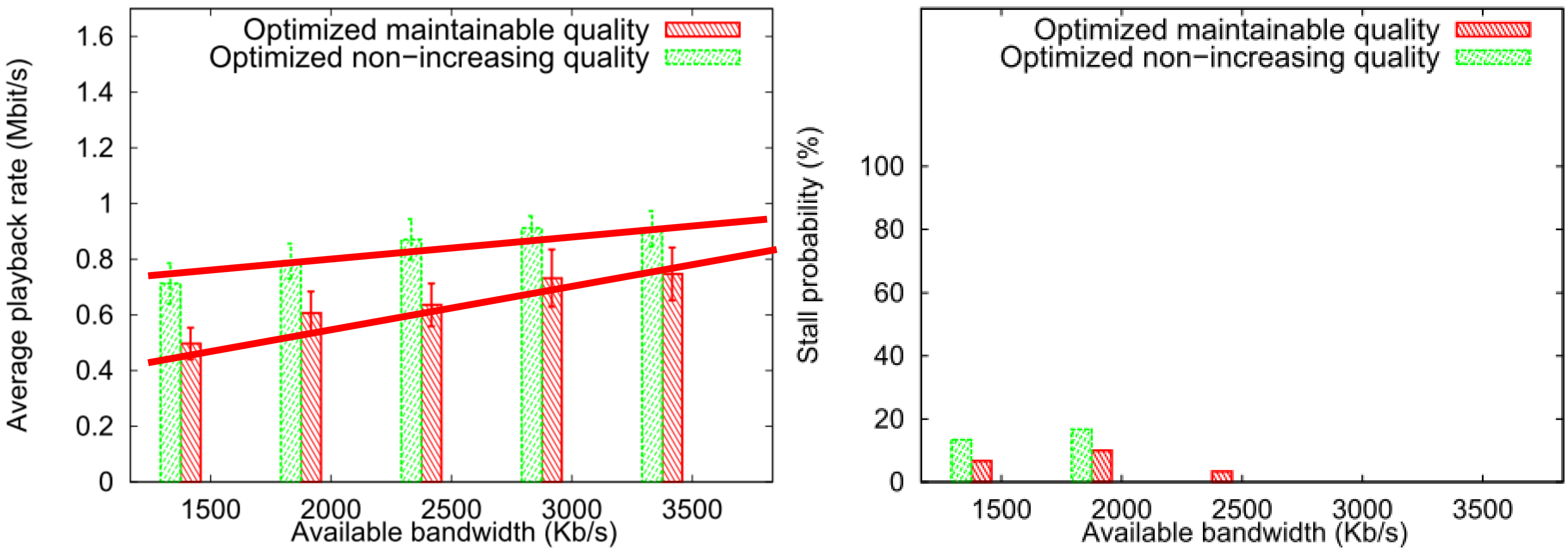
Policy comparison





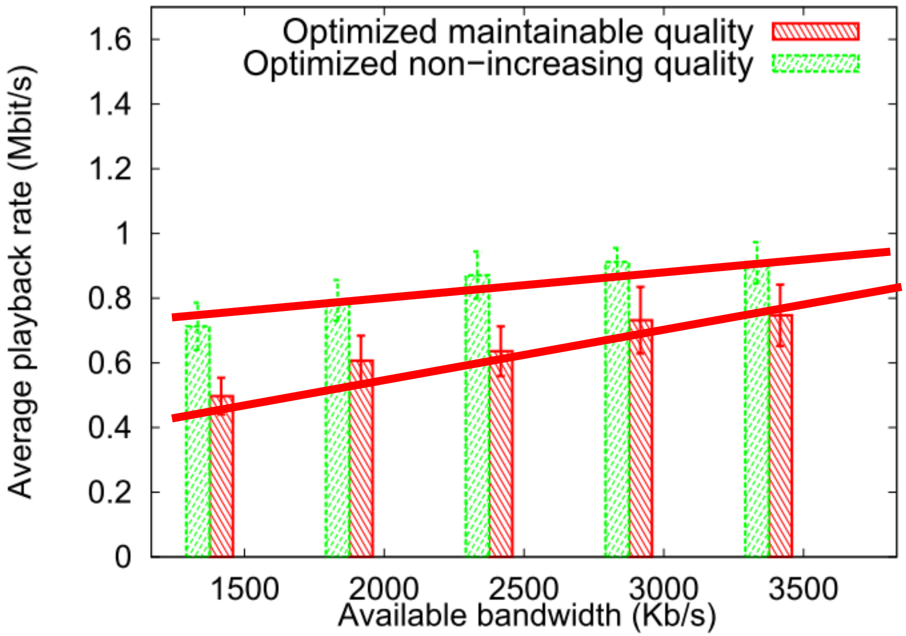
- *Optimized non-increasing quality* is aggressive
  - Higher playback rate
  - More stalls

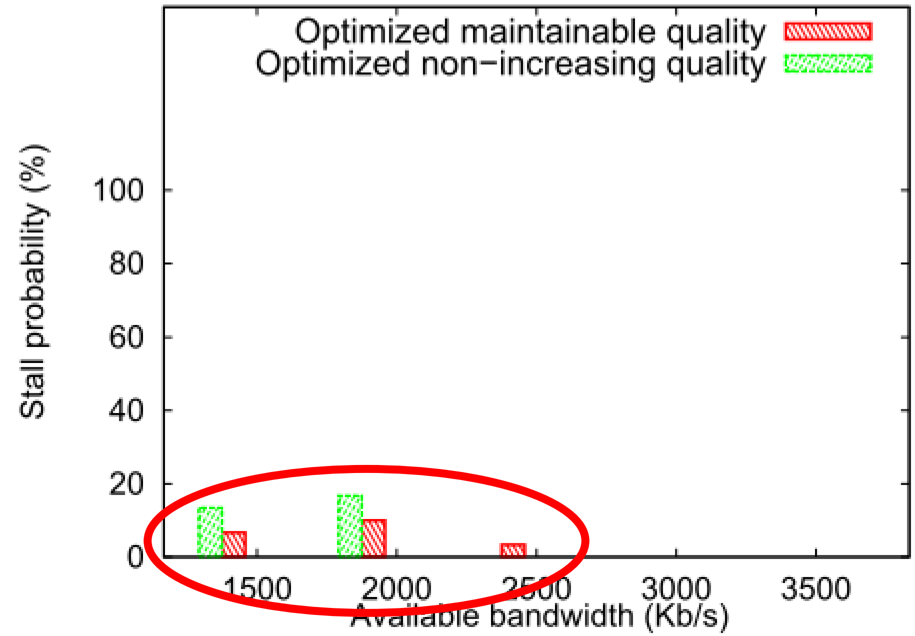
Policy comparison



- *Optimized non-increasing quality* is aggressive
  - Higher playback rate
  - More stalls

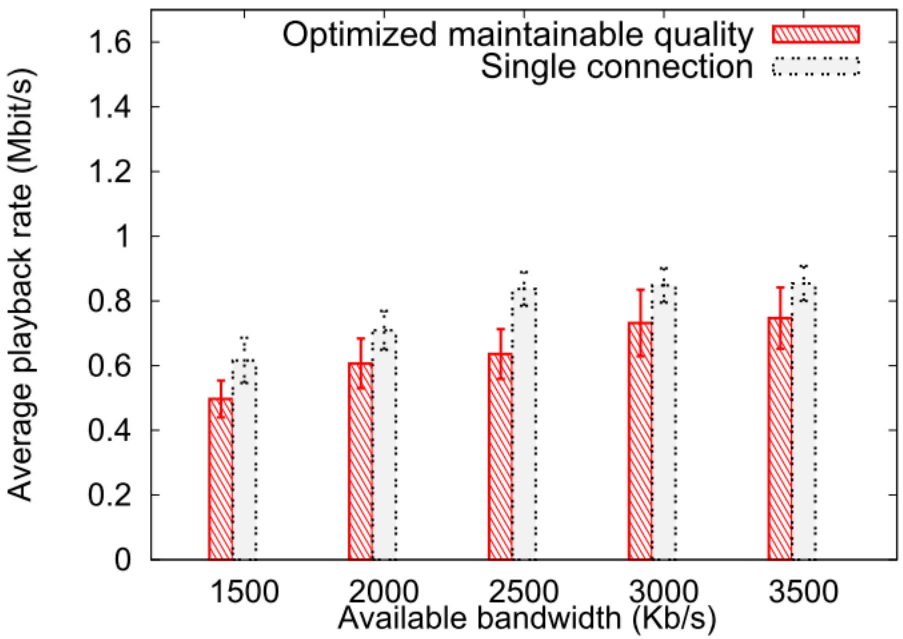
Policy comparison

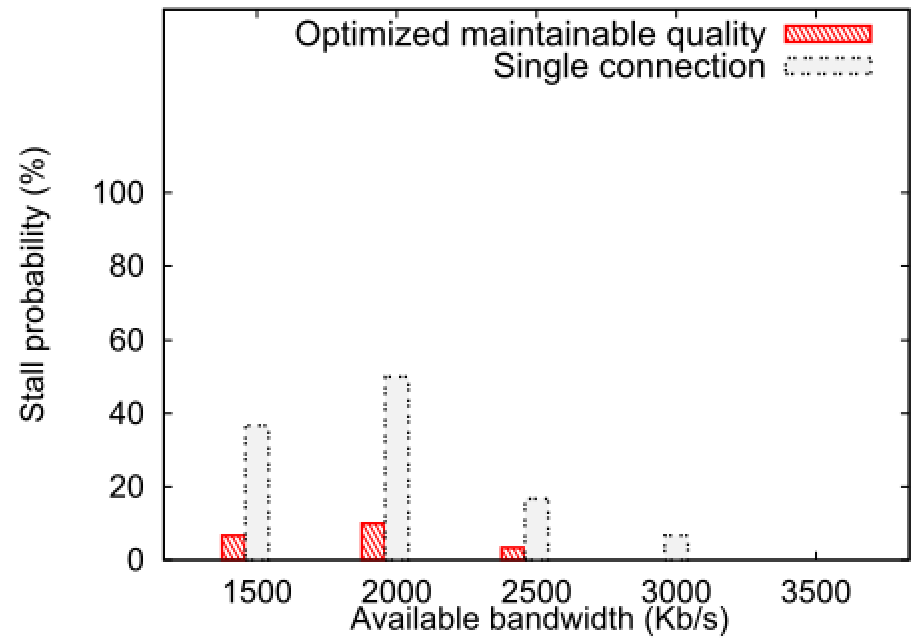




- *Optimized non-increasing quality* is aggressive
  - Higher playback rate
  - More stalls

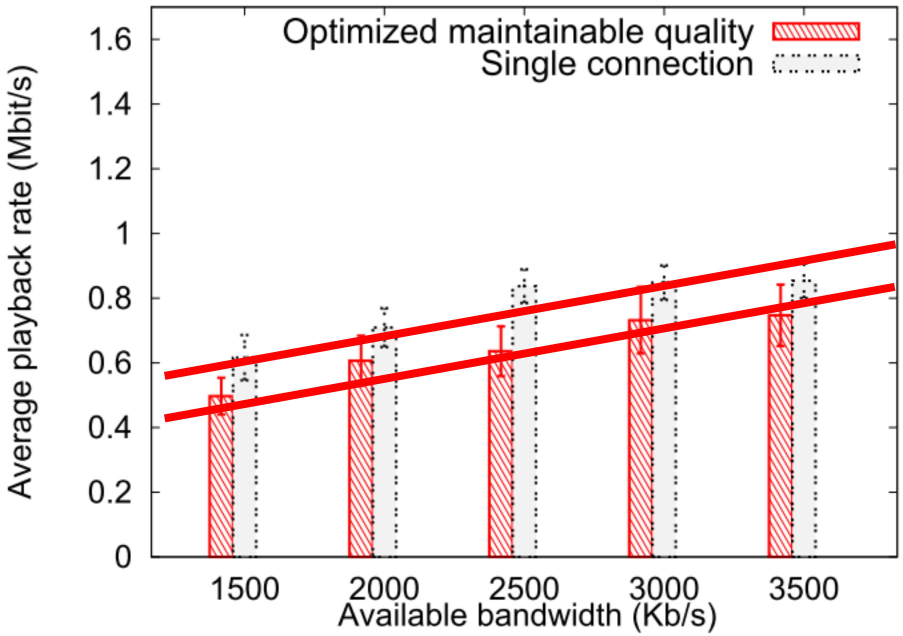
Policy comparison

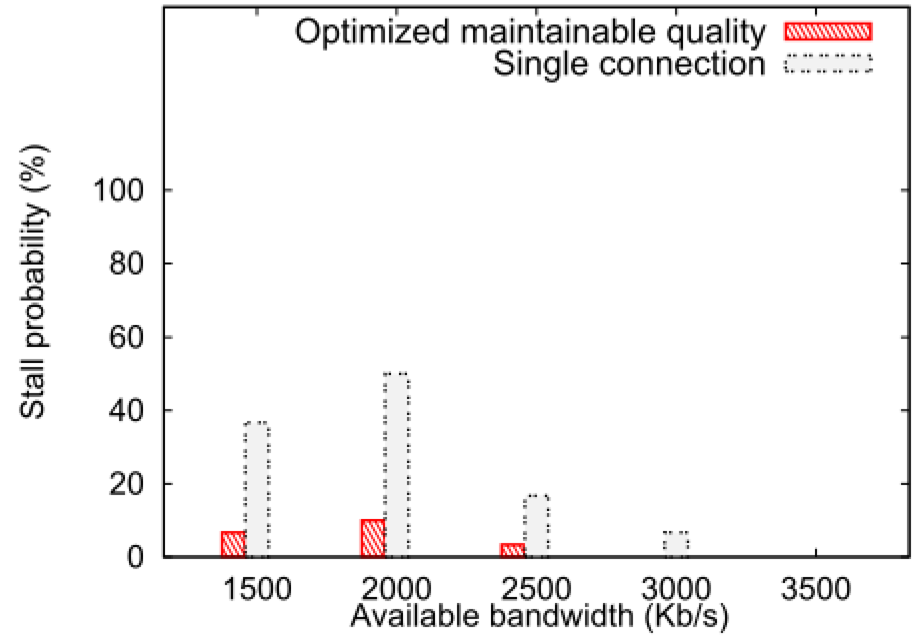




- *Single connection* does not use parallel connections
  - Good (slightly higher) playback rate
  - Much more stalls

Policy comparison





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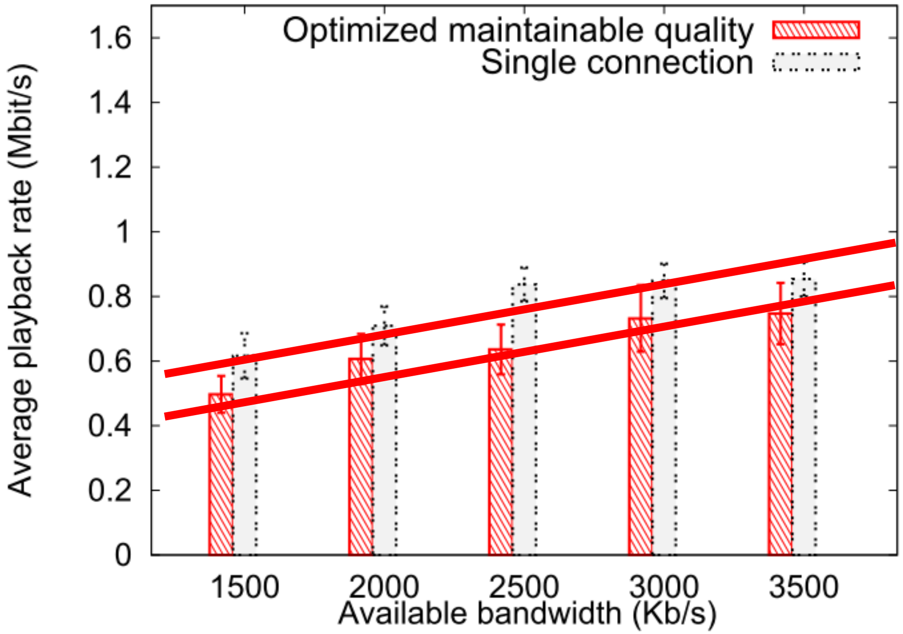

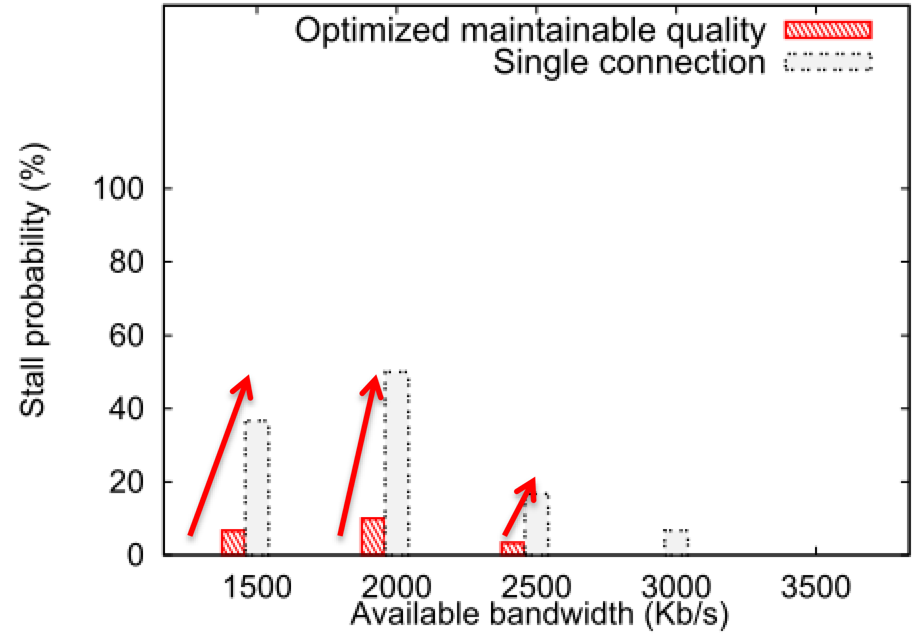

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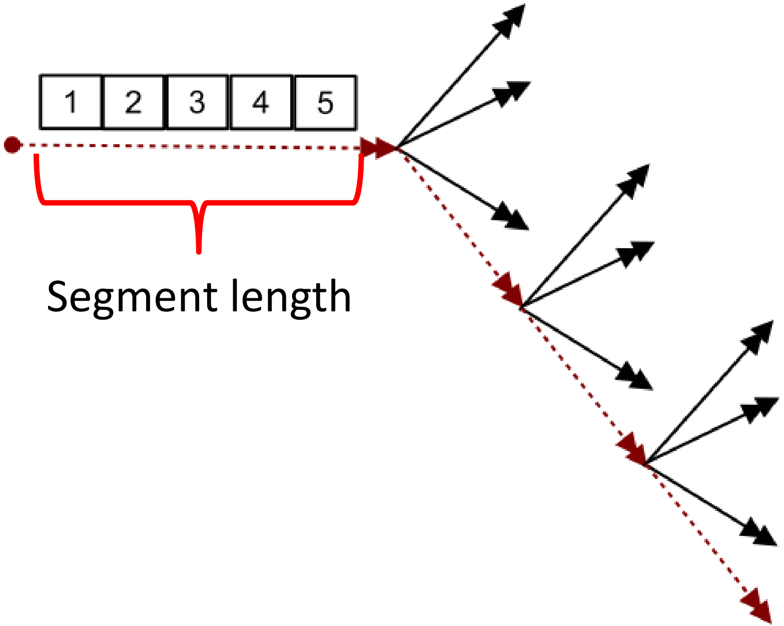
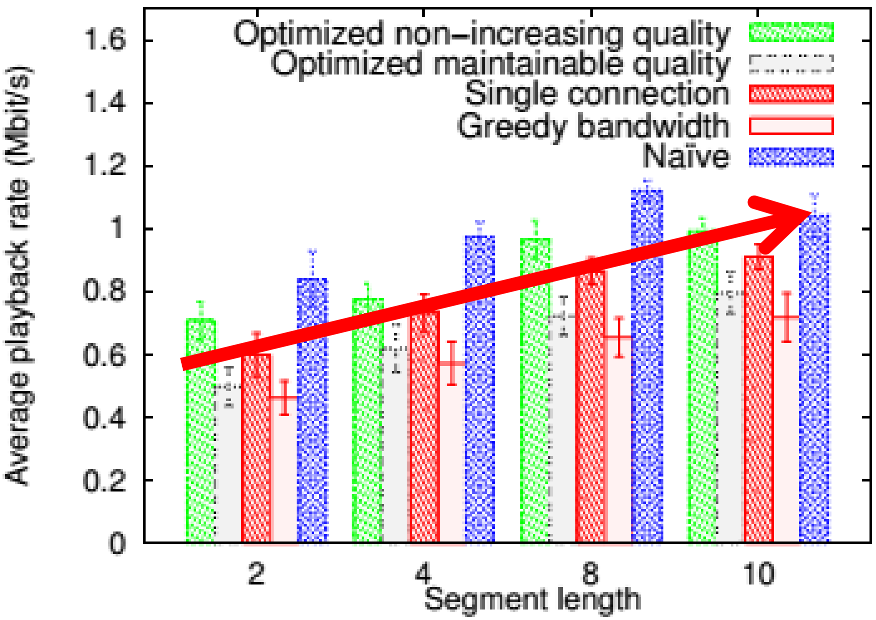
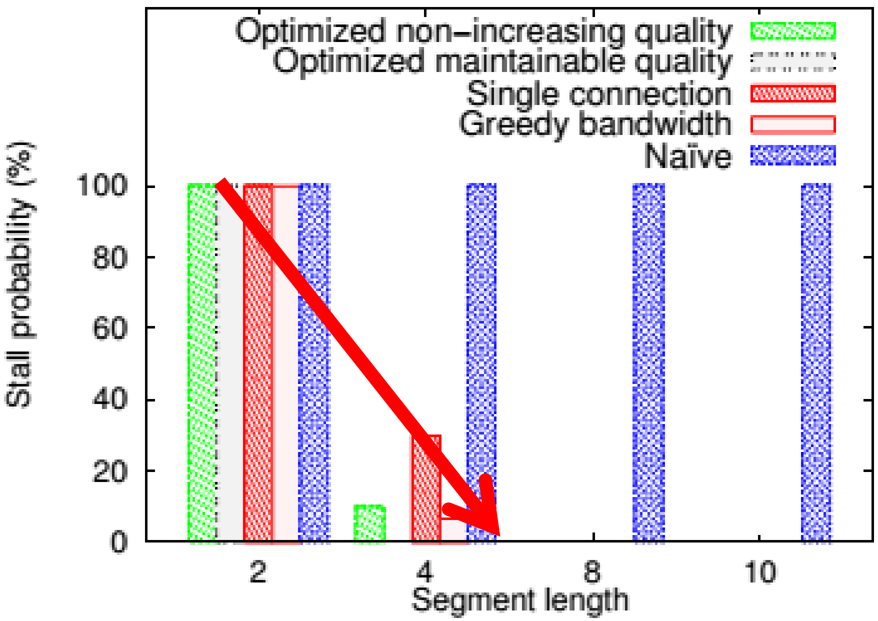
Impact of segment lengths



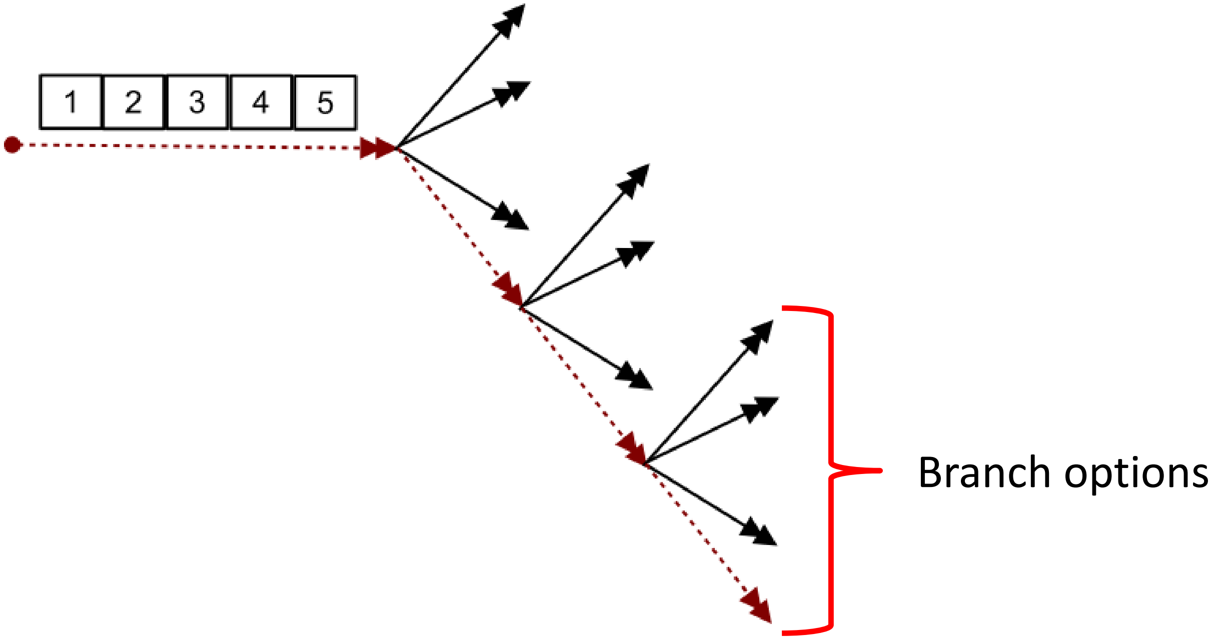
Impact of segment lengths



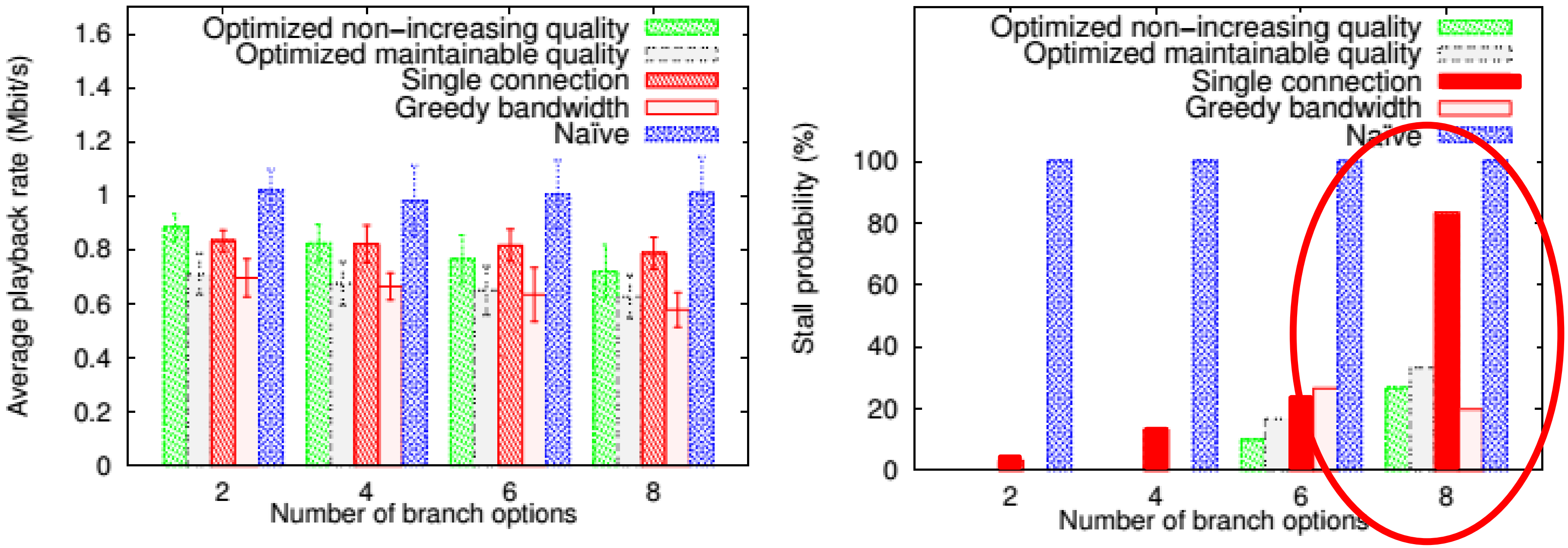


- Quality increases with more chunks per segment
- Very many stalls if segments are too short

Impact of branch options



Impact of branch options



- Stalls frequent when too many branch options
  - Single connection struggles the most

HAS-based branched video: Conclusion

- Designed and implemented branched video player that achieve seamless branched streaming
- Designed optimized policies that maximize playback quality while ensuring sufficient workahead
- Evaluation shows that solution effectively adapt to varying conditions

Our interactive branched video implementation can be downloaded from:
http://www.ida.liu.se/~nikca89/papers/mm14.html

Summary

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- In this thesis, we have:
  - Evaluated the performance impact of proxy caches on HAS clients
  - Designed and evaluated collaborative policies between HAS clients and proxy caches

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- In this thesis, we have:
  - Evaluated the performance impact of proxy caches on HAS clients
  - Designed and evaluated collaborative policies between HAS clients and proxy caches
  - Proposed, designed, implemented and evaluated stall-free HAS-based branched streaming

Works presented were in collaboration with …

- Patrik Bergström (Linköping University, Sweden)
- Niklas Carlsson (Linköping University, Sweden)
- Derek Eager (University of Saskatchewan, Canada)
- Anirban Mahanti (NICTA, Australia)
- Nahid Shahmehri (Linköping University, Sweden)

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NICTA

Papers in this thesis

- V. Krishnamoorthi, N. Carlsson, D. Eager, A. Mahanti, and N. Shahmehri, **Quality-adaptive Prefetching for Interactive Branched Video using HTTP-based Adaptive Streaming.** *In Proc. ACM Multimedia*, Nov. 2014.
- V. Krishnamoorthi, N. Carlsson, D. Eager, A. Mahanti, and N. Shahmehri, **Helping Hand or Hidden Hurdle: Proxy-assisted HTTP-based Adaptive Streaming Performance**. *In Proc. IEEE MASCOTS*, Aug. 2013.
- V. Krishnamoorthi, P. Bergström, N. Carlsson, D. Eager, A. Mahanti, and N. Shahmehri, **Empowering the Creative User: Personalized HTTP-based Adaptive Streaming of Multi-path Non-linear Video**, *In Proc. ACM SIGCOMM Workshop on Future Human-Centric Multimedia Networking (FhMN)*, Aug. 2013.

Efficient and Adaptive Content Delivery of Linear and Interactive Branched Videos

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