Packet Video Workshop

San Jose, December, 2013

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Optimal Adaptation Trajectories for Block-Request Adaptive Video Streaming

Outline

- Motivation
- Problem formulation
- Approach
- Evaluation

Adaptive Video Streaming

- Cisco forecast: video will be 80 % - 90 % of total consumer traffic in 2017
- Huge heterogeneity of terminal devices
  - Screen sizes, screen resolutions, CPU power, battery capacity
- Huge heterogeneity of network conditions
  - Throughput from 10 kbps to 10 Mbps and more
  - Packet loss rate from 0 to 10 % and more
  - Latency from 1 ms to 1 s and more

Adaptation necessary

Adaptive Video Streaming

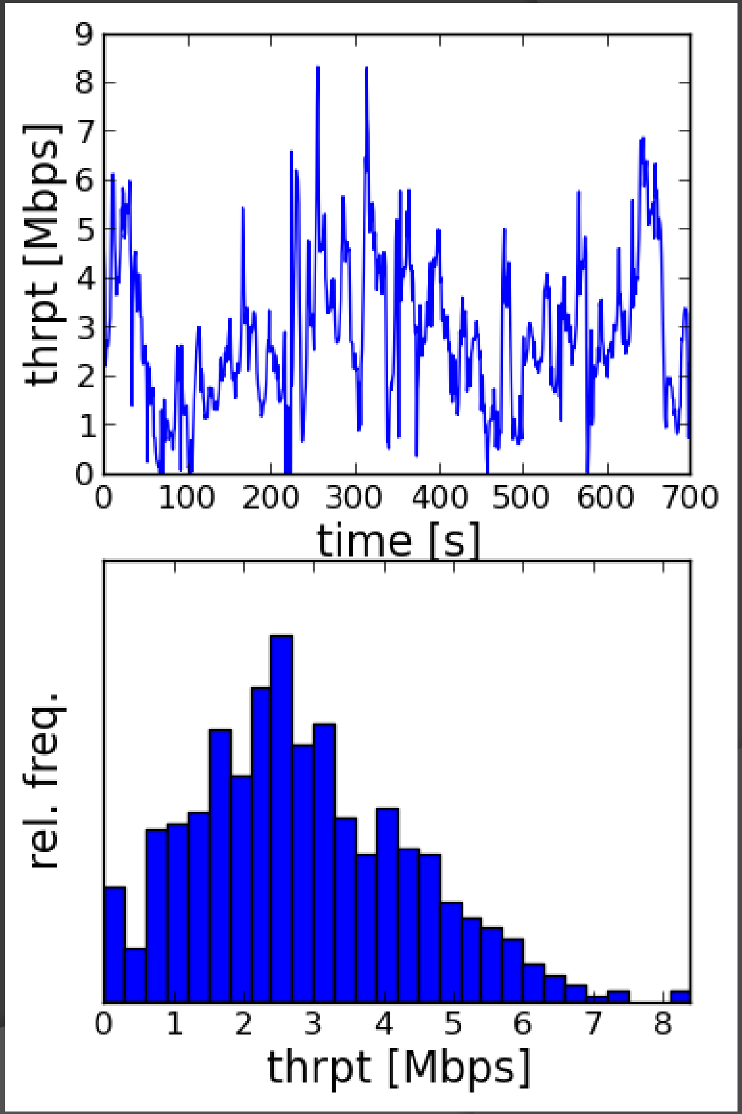
- Network conditions change dynamically
  - Cross-traffic
  - Mobility
    - Outdoor/indoor, overground/underground
    - Changing distance to base station
    - Changing environment geometry
- Continuous dynamic adaptation required, e.g.,
  - Adaptation of video bit-rate
  - Adaptation of other encoding parameters
    - Example: GOP size to loss rate
    - …

State-of-the-Art

- Block-request adaptive streaming
  - Stateless server, e.g., HTTP
  - Client requests chunks of video data
  - Chunk representation selected dynamically
    - Based on network conditions, etc.
- Standards: MPEG-DASH, HLS (draft), etc.
- Popular commercial implementations
  - Microsoft SmoothStreaming (proprietary)
  - Apple QuickTime, iOS (HLS)
  - Adobe HTTP Dynamic Streaming (proprietary)

Adaptation strategies

- Adaptation strategy is essential for QoE
- Challenge: random throughput, high variance (esp. wireless networks)
- Conflicting objectives
  - Avoid underruns
  - Max. average media bit-rate
  - Min. quality jumps
  - Min. start-up delay



Problem: How to evaluate adaptation strategies?

- Compare to predefined requirements
  - No predefined requirements: best-effort
  - User's expectations depend on many factors
    - Age, affinity to technology, viewing context, etc.
- Compare to state-of-the-art solution
  - No widely accepted state-of-the-art clients/benchmarks
- Compare to optimum
  - Calculate optimal adaptation trajectories for given network conditions

Approach

Approach and application

- Calculate optimal adaptation trajectories, given
  - Throughput over time
  - Segment size and representation information
- Application scenario I
  - Record clients throughput over time
  - Calculate optimum and compare
  - Difficulty: client might introduce delays between requests
    → Potential loss of optimality
- Application scenario II
  - Rerun continuous TCP flow under same conditions
  - Calculate optimum and compare
  - Multiple runs to account for randomness

Further applications

- Evaluate influence of various factors on achievable performance
- Influence of video parameters
  - Number and bit-rates of representations
  - Segment duration
  - …
- Influence of network parameters
  - QoS: Throughput, packet loss, latency
  - MAC strategy
  - TCP flavor
  - …

Optimality metric

- Ultimate goal: optimize QoE
- Factors that influence QoE
  - Re-buffering duration and distribution over time
  - Average quality over chunks, minimum quality
  - Number of quality switches and distrib. over time
  - Start-up delay
- No unifying QoE metric exists so far
- Our optimization objectives and constraints
  - No re-buffering
  - Maximum average video bit-rate
  - Minimum number of switches
  - Start-up delay is configuration parameter

} two step approach (Maximum average video bit-rate, Minimum number of switches)

Step 1: Average bit-rate maximization

- Given
  - Throughput over time $V(t)$
  - Desired start-up delay
- Objective: maximize average video bit-rate
- Additional constraint: no buffer underruns

$i = 1, \ldots, n$ - segments
$j = 1, \ldots, m$ - representations
S_{ij} - segment size
D_i - playback deadline
x_{ij} - download i from j

$$
\begin{aligned}
\textbf{(OP1)} \quad & \max \quad \sum_{i=1}^{n} \sum_{j=1}^{m} S_{ij} x_{ij} \\
& \text{s.t.} \quad \sum_{j=1}^{m} x_{ij} \geq 1 \qquad \text{for all } i = 1, \ldots, n \\
& \qquad \sum_{i=1}^{k} \sum_{j=1}^{m} S_{ij} x_{ij} \leq V(D_k) \qquad \text{for all } k = 1, \ldots, n
\end{aligned}
$$

- MCNKP
- NP-hard
- Pseudo-polyn.
- Solution: seconds (Gurobi)

Step 2: Quality switches minimization

- Given: as in step 1 plus optimal average quality V^*
- Objective: minimize number of switches
- Constraint: same as step 1 plus average quality equal to optimum

$i = 1, \ldots, n$ - segments
$j = 1, \ldots, m$ - representations
S_{ij} - segment size
D_i - playback deadline
x_{ij} - download i from j
V^* - optimum val. of (OP1)

$$(\mathbf{OP2}) \quad \min \quad \frac{1}{2}\sum_{i=1}^{n-1}\sum_{j=1}^{m}\left(x_{ij} - x_{i+1,j}\right)^2$$

$$\text{s.t.} \quad \sum_{j=1}^{m} x_{ij} \geq 1 \qquad \text{for all } i = 1, \ldots, n$$

$$\sum_{i=1}^{k}\sum_{j=1}^{m} S_{ij}x_{ij} \leq V(D_k) \qquad \text{for all } k = 1, \ldots, n$$

$$\sum_{i=1}^{n}\sum_{j=1}^{m} S_{ij}x_{ij} \geq V^*$$

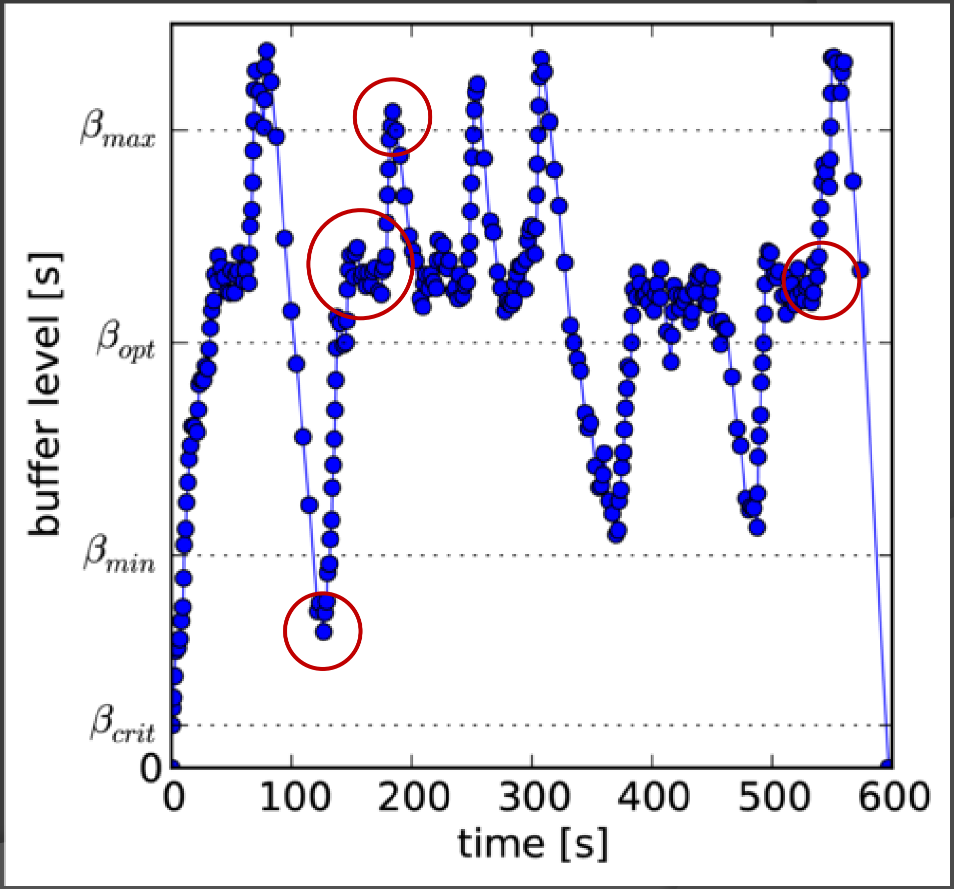
- Quadratic MCNKP
- Solution: minutes (Gurobi)

Evaluation

Previous work: adaptation strategy

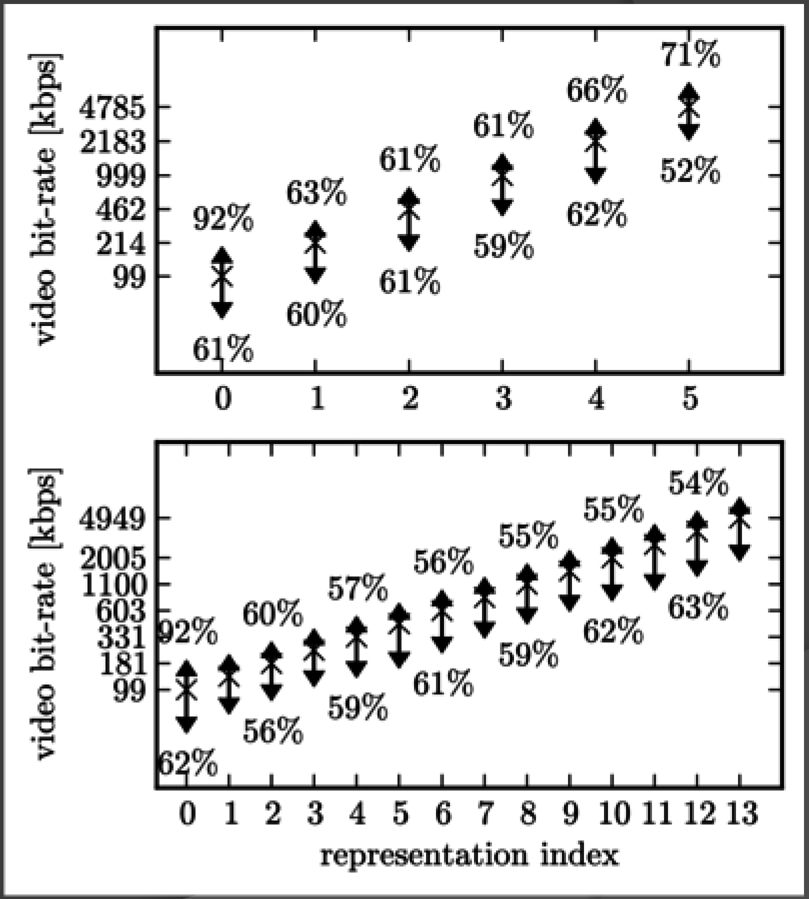
- DASH does not specify adaptation strategy
- Developed own algorithm (impl. as plugin for VLC)

- $\beta < \beta_{min} \wedge \beta' < 0 \quad \Rightarrow \searrow$
- $\beta > \beta_{max} \wedge \beta' > 0$
  - $r^{\uparrow} < \alpha\rho \quad \Rightarrow \nearrow$
  - $r^{\uparrow} \geq \alpha\rho \quad \Rightarrow \wr$
- $\beta > \beta_{opt} \wedge r^{\uparrow} \geq \alpha\rho \quad \Rightarrow \wr$
- $\beta < \beta_{crit} \quad \Rightarrow \downarrow\downarrow$
- + aggressive at start-up
- + some additional tweaks
- In total: 10 parameters



Video used for evaluation

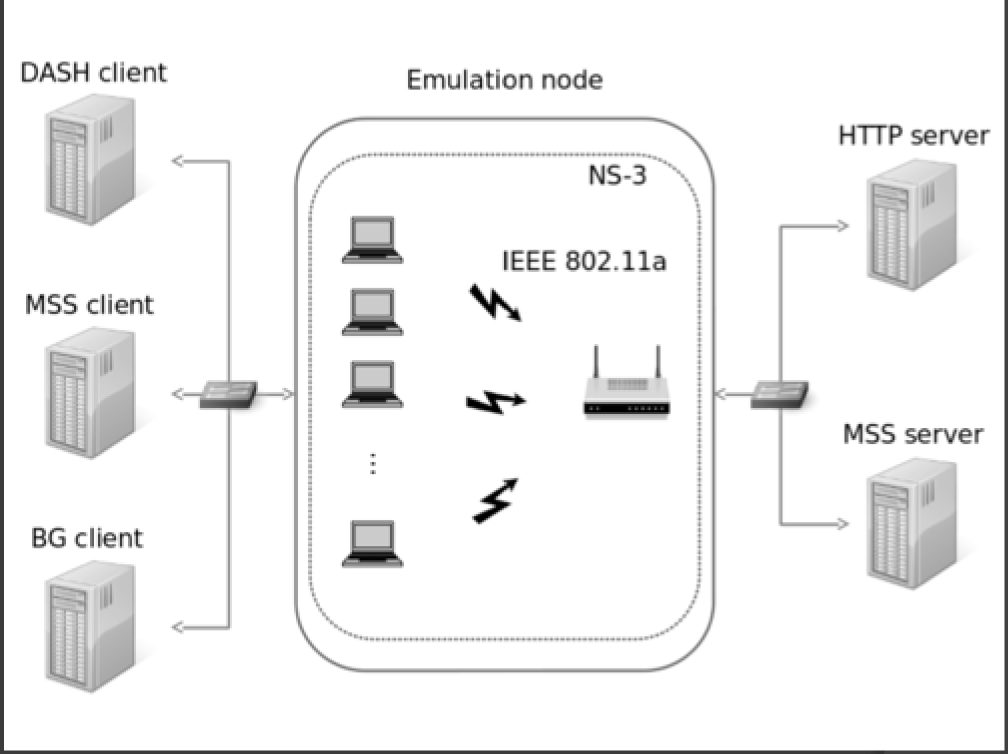
- Big Buck Bunny (animated)
  - 598 seconds
- Encoded in 6 and 14 representations
  - 299 segments, 2 sec. each
  - Bit-rates logarithmically from 100 kbps to 5 Mbps
  - Kept bit-rates fluctuations low
  - 2 manifests and container formats: DASH and MSS
- Low fluctuation amplitude is important if segment size not known in advance



(Note the log y-axis)

Evaluation setting

- 802.11a model based on BOWL indoor testbed (7 stations)
- Max. TCP throughput: 1.4, 1.7, 19, 19, 21, 21, 21 Mbps
- Second slowest selected for video traffic

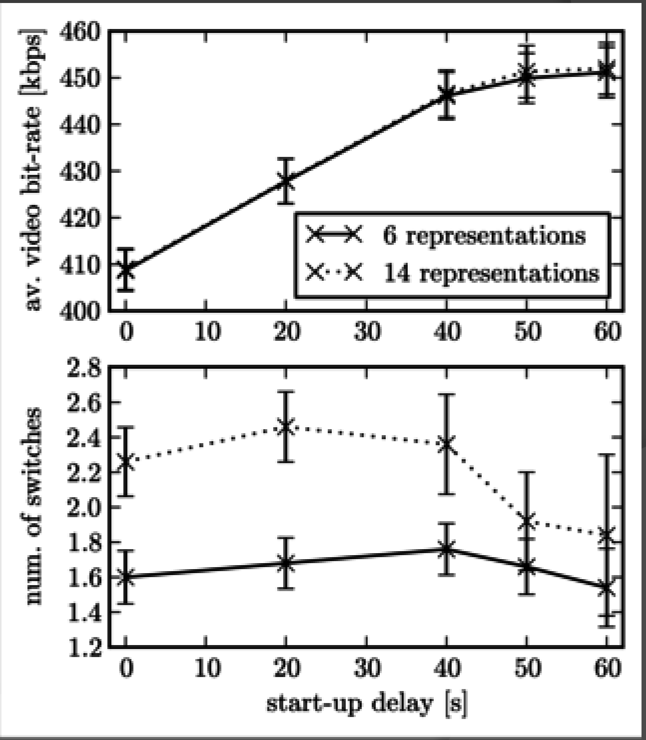


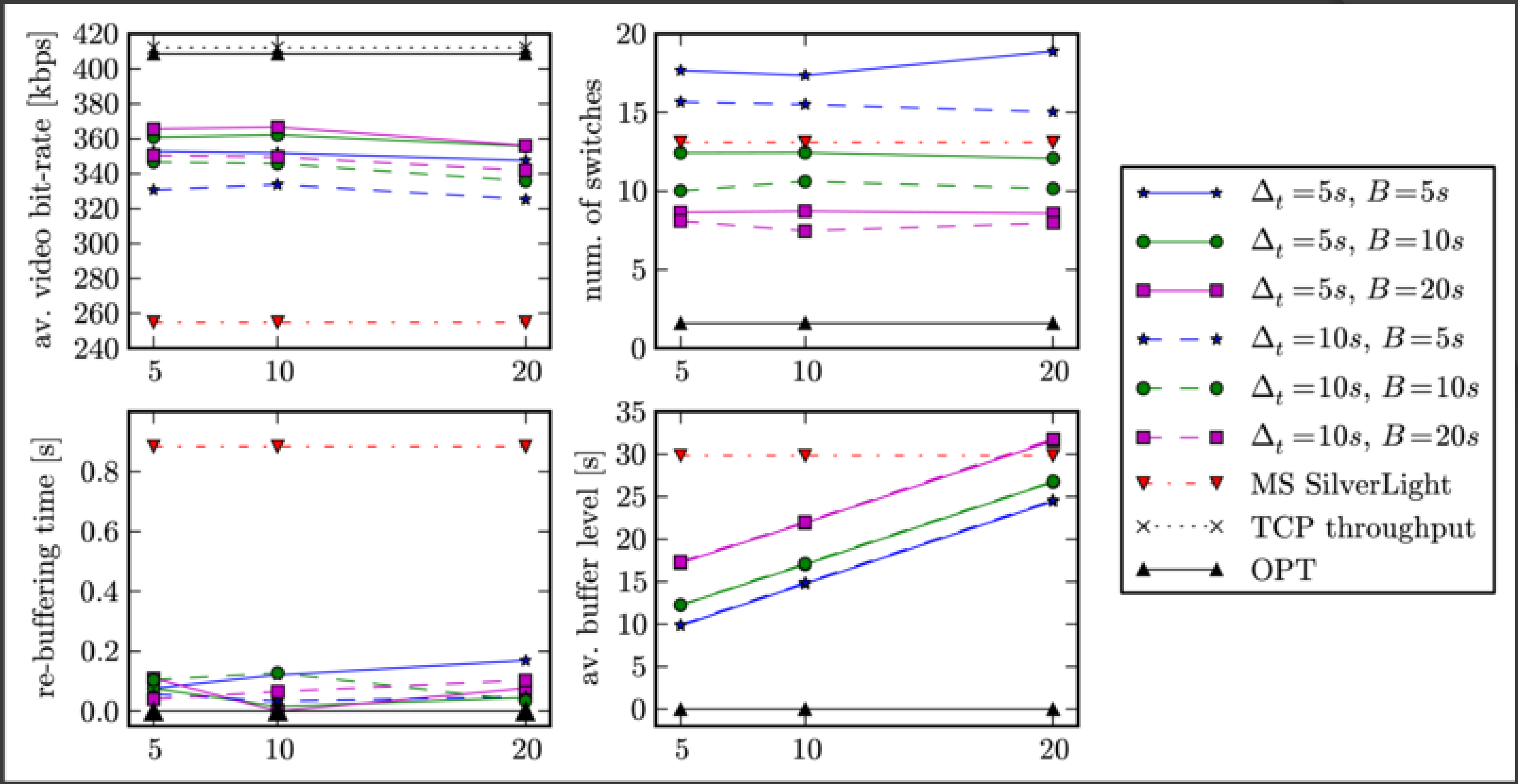
- 14 synthetic HTTP clients as cross-traffic (Pries et al.)
  - 2 on each wireless station
  - Detailed model: experimentally fitted distributions for
    - User activity, main object sizes, secondary object sizes, inter-object intervals, etc.

Results: influence of video parameters

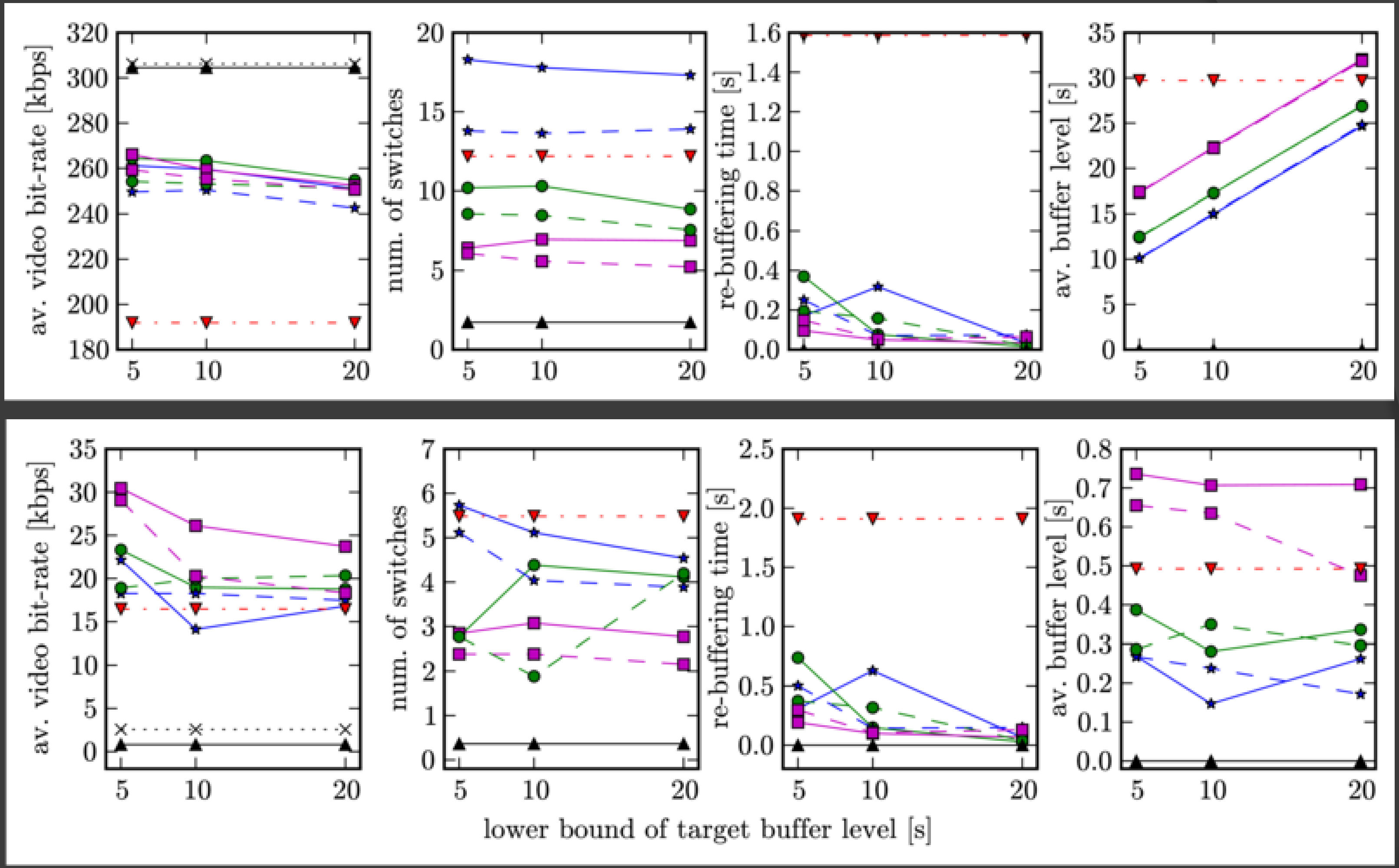
- Influence of number of video representations
- Influence of start-up delay

- 6 representations sufficient
- Num. switches surprisingly low (here: upper bounds)
- Start-up delay has little influence
  - Approx. 12 % for 60 s





- OPT utilize almost 100% of TCP's fair share
- OPT has 0 re-buffering, very little switches, almost 0 buffer level
- DASH av. video bit-rate: 78% to 90% of OPT, MSS: 62%
- Num. of switches, re-buffering: DASH is better or comparable
- DASH has lower avg. buffer level → better for live content
- Good DASH configuration: $\beta_{min} = 10s,\ B = 20s,\ \Delta_t = 5s$



- Two clients on same wireless stations (backgr. as before)
- Differences between two clients, averaged over runs
- Good fairness w.r.t. avg. bit-rate, re-buffering, buffer level
- Medium fairness w.r.t. number of switches

Conclusion

- Optimal adaptation trajectories allow to
  - Benchmark adaptation strategies
  - Study influence of network and video parameters
- Potential extensions
  - Optimize w.r.t. QoE metric, once available
- Evaluation
  - DASH comparable or better in studied setting
  - DASH achieves 78% to 90% of optimum

THE END

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