Days of Future Past: An Optimization-based Adaptive Bitrate Algorithm over HTTP/3

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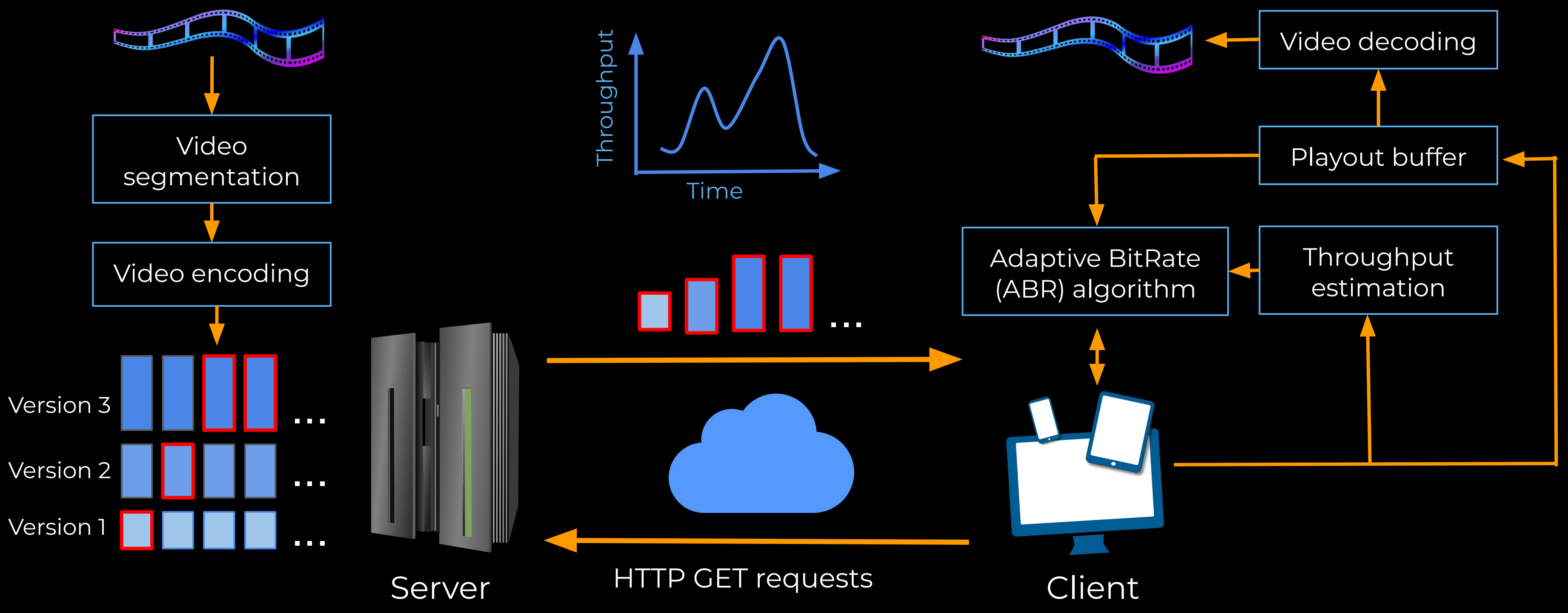
Agenda

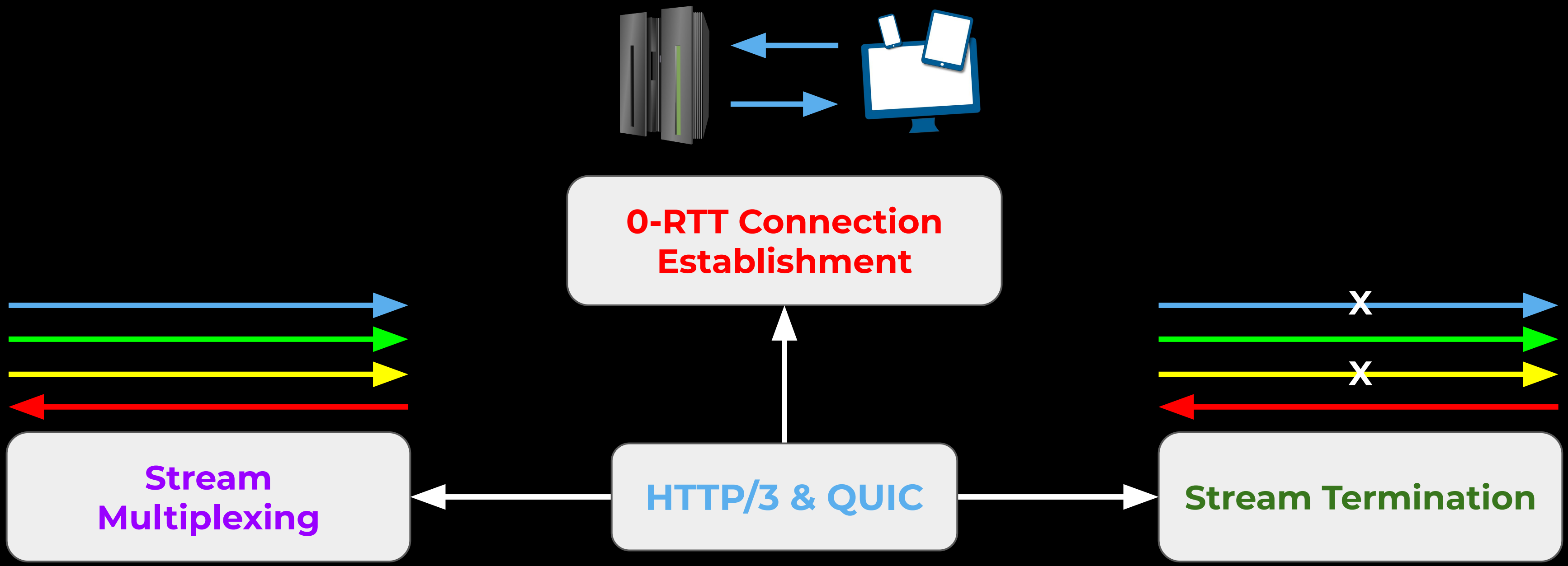
- Introduction
- Motivation
- Proposed method
- Experimental setup
- Results and analysis
- Conclusion

Introduction

Introduction: HAS Schema

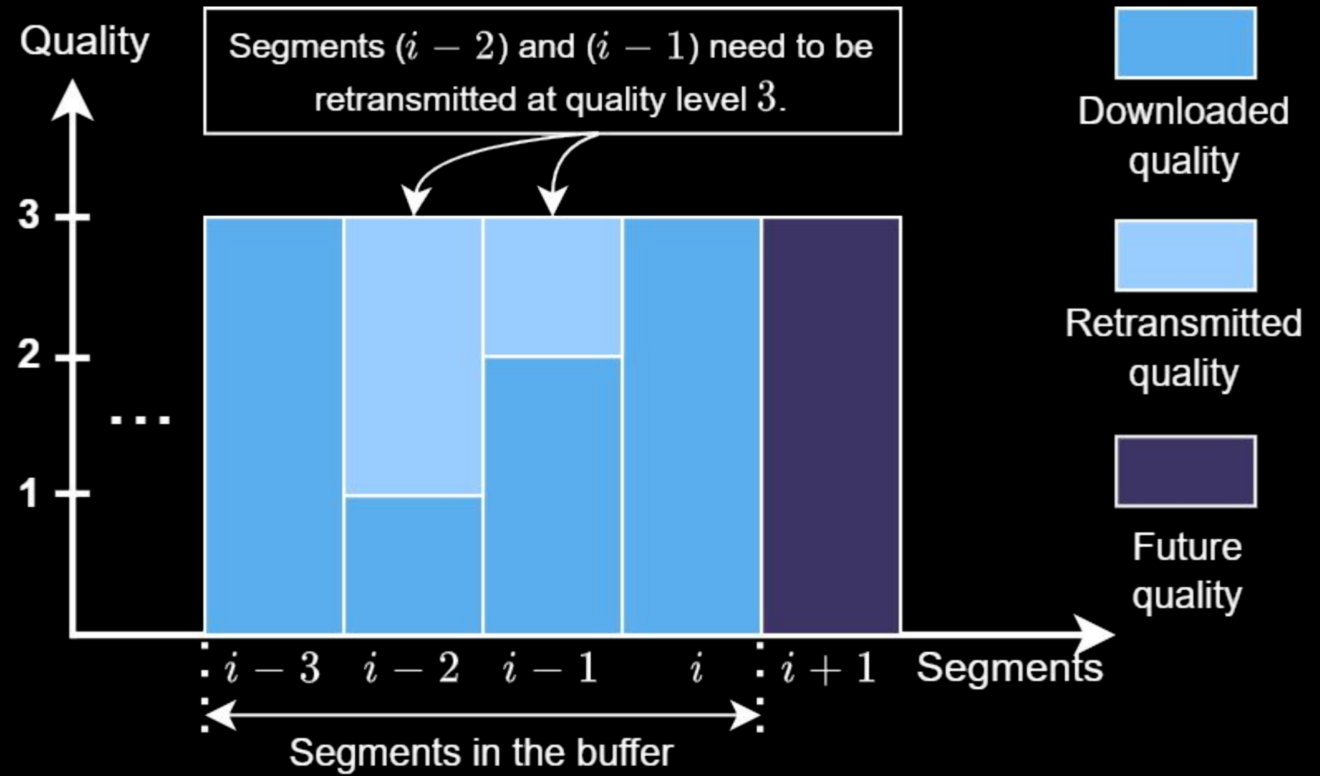


Introduction: HTTP/3 & QUIC



Motivation

Motivation



Quality
Segments $(i-2)$ and $(i-1)$ need to be retransmitted at quality level 3.
3
2
1
...
$i-3$
$i-2$
$i-1$
i
$i+1$
Segments
Segments in the buffer
Downloaded quality
Retransmitted quality
Future quality

Proposed Method

DoFP: An Optimization-based ABR algorithm

- **Mixed Integer Linear Programming (MILP) model** that selects:
  - Bitrate for the next segments;
  - Which segments from the buffer need to be upgraded;
  - Bitrate for these segments.

Par.	$\mathcal{B}$	q_i	$a_{i,j}$	d_i	B_{now}	B_{max}	$S_{i,j}$	t_i	ω
Desc.	Set of indexes of k buffered segments + next one	Quality level of ith segment	Binary variable: 1 → (re-) download ith segment at quality level j;	Deadline to (re-) download ith segment	Current buffer level	(Max.) Buffer size	Size of ith segment with quality level j (kbits)	Assigned throughput to (re-) download ith segment	Available throughput between player and server

DoFP: An Optimization-based ABR algorithm

- **1st constraint** expresses the univocity of the pair (index, quality):

$$\sum_{j=1:\boxed{L}\,\&\,j \geq q_i} a_{i,j} = 1,\ \forall i \in \mathcal{B}$$

Max. quality level

DoFP: An Optimization-based ABR algorithm

- Define the **deadlines** for each segment (where $0 < \alpha < \beta < \gamma < 1, 0 < \mu < 1$):

Seg. length

Safety par.

$$d_{i+1} = \begin{cases} \boxed{\tau} \times (1 - \boxed{\mu}), & \text{if } \alpha \times B_{max} < B_{now} < \beta \times B_{max} \\ B_{now} - \alpha \times B_{max}, & \text{if } \beta \times B_{max} \le B_{now} < \gamma \times B_{max} \\ B_{now} - \beta \times B_{max}, & \text{if } \gamma \times B_{max} \le B_{now} \le B_{max} \end{cases}$$

- **2nd constraint** ensure that the download time is lower than the deadline:

$$\sum_{j=1:L\&\boxed{j>q_i}} a_{i,j} \times S_{i,j} \le d_i \times t_i, \forall i \in \mathcal{B}$$

Not valid for $j=q_i$

DoFP: An Optimization-based ABR algorithm

- **3rd constraint** checks the sum of the assigned throughputs to be at most the total available one:

$$\sum_{i \in \mathcal{B}} t_i \leq \omega$$

No Multiplexing

$$t_i \leq \omega/(k+1) \quad \forall i \in \mathcal{B}$$

With Multiplexing

DoFP: An Optimization-based ABR algorithm

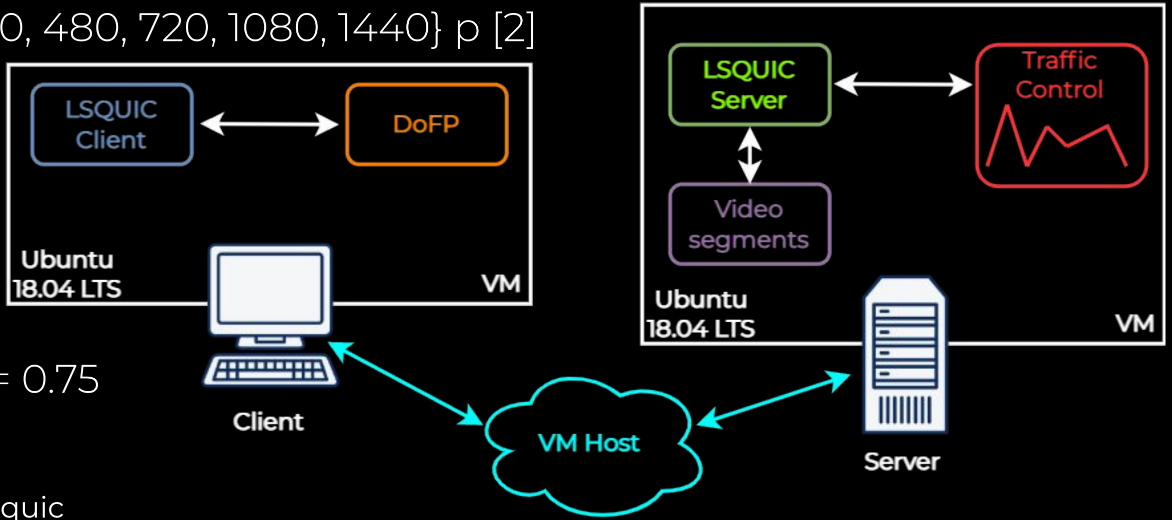
- The **MILP model** is finally introduced as follows:

$$\begin{aligned}
&\mathit{Maximize} && \boxed{j^* + \sum_{i \in \mathcal{B}} \sum_{j=1:L \& j \geq q_i} a_{i,j} \times j} && \textbf{Objective Function} \\
&s.t.: && \boxed{\begin{aligned} & Constraints(1) - (3) \\ & j^* \leq \sum_{j=1:L \& j \geq q_i} a_{i,j} \times j, \forall i \in \mathcal{B} \end{aligned}} && \textbf{Constraints} \\
&var.: && \boxed{a_{i,j} \in \{0, 1\}, t_i \geq 0} && \textbf{Variables}
\end{aligned}$$

Experimental setup

Experimental setup

- HAS + LSQUIC [1] **testbed**
- 5-min **test sequence** (Tears of Steel - begin)
- **Bitrate ladder**: {107, 240, 346, 715, 1347, 2426, 4121} kbps [2]
- **Resolution**: {144, 240, 360, 480, 720, 1080, 1440} p [2]
- Codec: H.264
- Linux **tc (bash script)**
  - **4G** Network **trace**
  - **RTT**: 40 ms
- τ = 4s, B_{max} = 20s
- μ = 0.1, α = 0.25, β = 0.5, γ = 0.75



[1] https://github.com/litespeedtech/lsquic
[2] T. Karagkioules, *et al.*: A Public Dataset for YouTube's Mobile Streaming Client.

Results and analysis

Results and analysis

- **Metrics** considered:
  - Average **quality**: average quality level of the played segments
  - Video **instability**: average quality fluctuation among adjacent segments
  - Number of **switches**: number of segments whose quality is lower than their previous one
  - **Number of stalls**: number of buffer underruns
  - **Stall duration**: total video freeze time
  - **QoE score**: computed via **ITU-T P.1203 mode 0** and its **extension** [3]

[3] https://github.com/Telecommunication-Telemedia-Assessment/itu-p1203-codecextension

Results and analysis

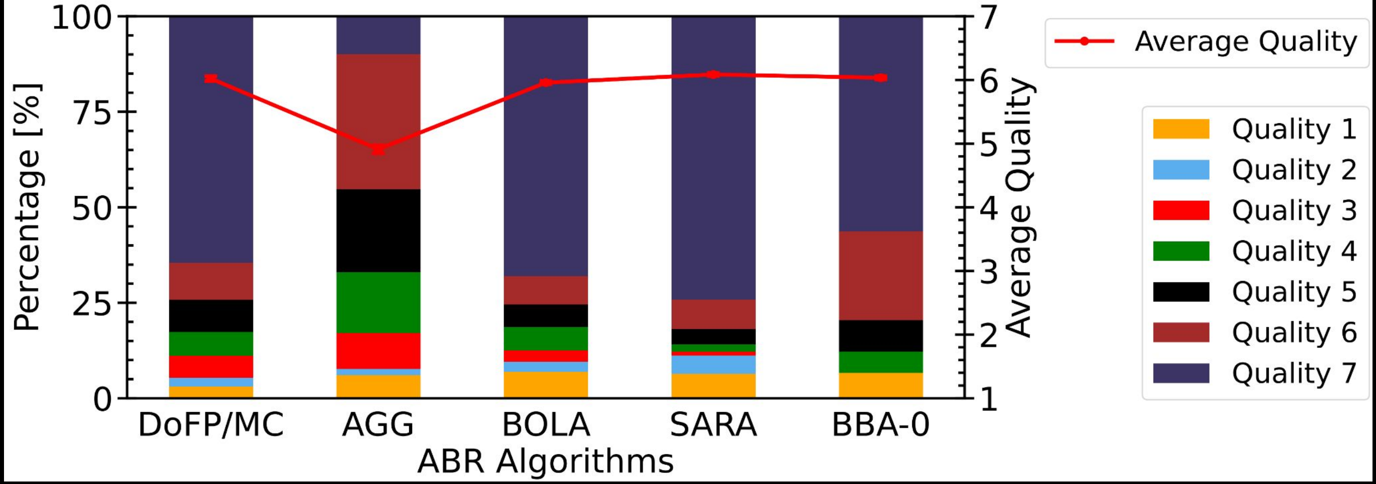
- Results: Comparison among different DoFP versions:
  - **DoFP/B**: next segment, then retransmitted ones seq. in order as in the buffer
  - **DoFP/M**: with **stream multiplexing** feature and concurrent requests
  - **DoFP/C**: with **stream cancellation** feature
  - **DoFP/MC**: with both **stream multiplexing** and **stream cancellation**

	Avg. quality	Video inst.	N. switches	N. stalls	Stall dur. (s)	QoE
DoFP/B	6.12	0.53	8.2	1.8	6.7	3.15
DoFP/M	**6.14**	**0.47**	**7.8**	1.8	6.7	3.25
DoFP/C	6.11	0.48	**7.8**	0.6	1.7	3.36
DoFP/MC	6.02	0.54	10.6	**0.0**	**0.0**	**3.38**

Multiplexing and **cancellation** features **enhance** DoFP **results**

Results and analysis

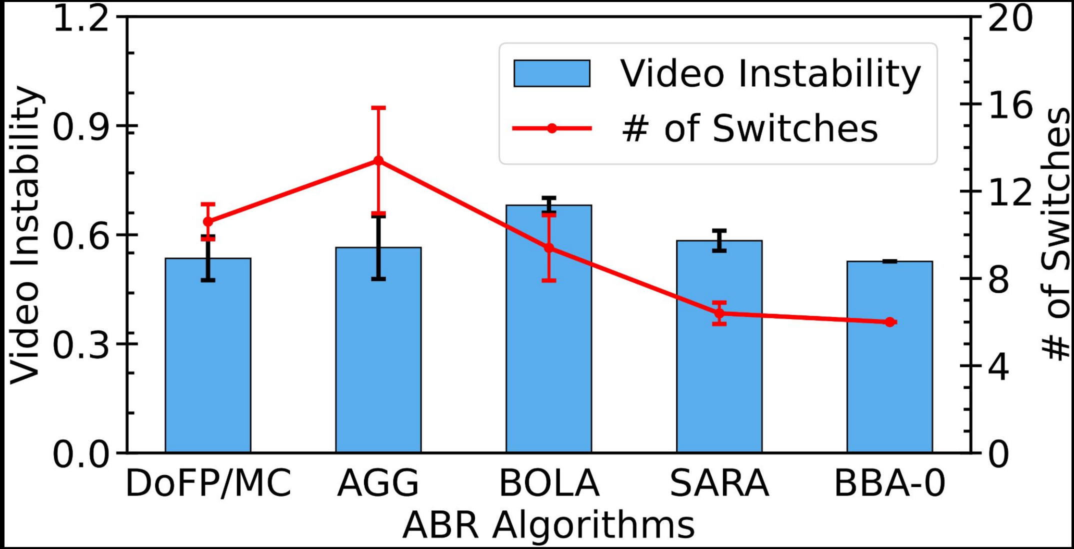
- Results: Comparison with state-of-the-art approaches
  - **SARA** → **DoFP/MC**: **highest %** of **quality 7 seg.** (**74%** → **64%**) and **avg. quality** (**6.12** → **6.02**)
  - **DoFP/MC** → **others**: **lowest %** of **quality 1 seg.** (**3.2%** → **> 6.1%**)



Percentage of quality levels and average quality

Results and analysis

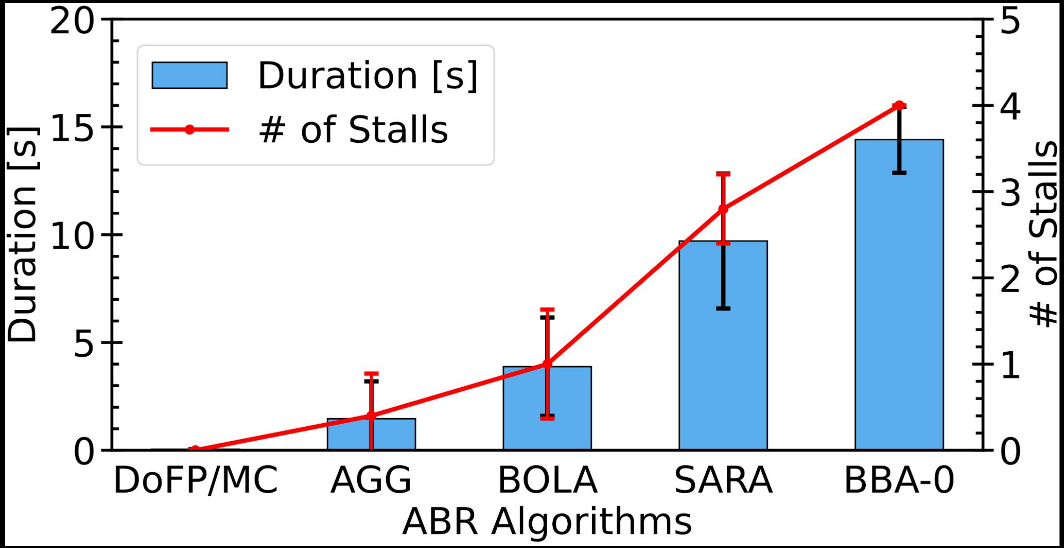
- Results: Comparison with state-of-the-art approaches
  - **BBA-0**: **lowest video instability** (**0.53**); **DoFP/MC**: **second lowest** (**0.54**)
  - **DoFP/MC**: **high # of switches** (**10.6**) → upgrade quality, not eliminate gaps



Number of switches and video Instability

Results and analysis

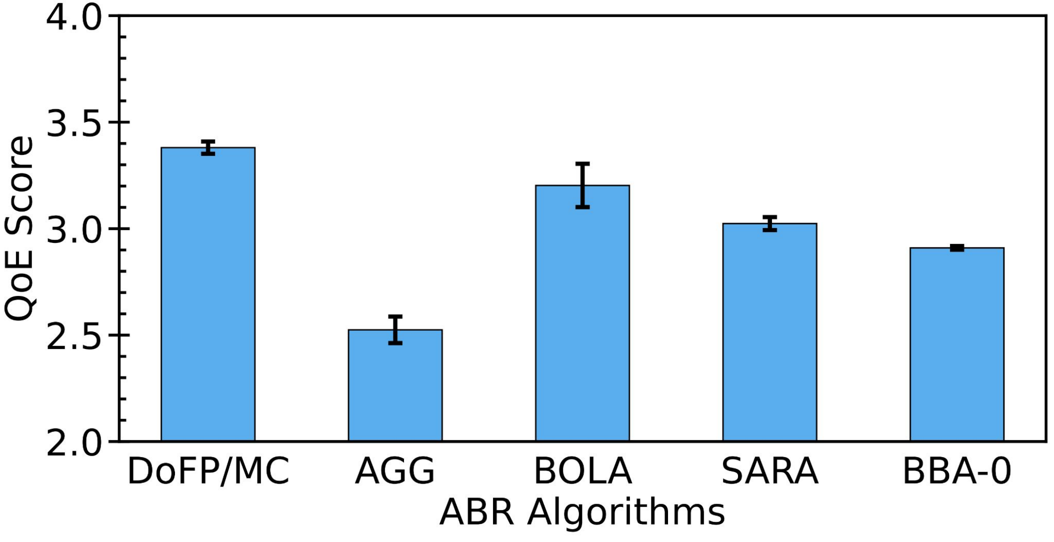
- Results: Comparison with state-of-the-art approaches
  - **DoFP/MC**: **0.0 stalls and 0.0s stall duration**
  - AGG (0.4 - 1.47s), BOLA (1 - 3.88s) → **SARA (2.8 - 9.71s)**, **BBA-0 (4 - 14.41s)**



Number of stalls and stall duration

Results and analysis

- Results: Comparison with state-of-the-art approaches
  - **DoFP/MC**: **best QoE score (3.38)**
  - Up to **33.9%** increment w.r.t the other approaches



QoE scores

Conclusions

Conclusions

- **DoFP(/MC)**: a **MILP model** to provide high QoE (and low stall-probability) through **HTTP/3** and **QUIC features**
- Taking into account **throughput, buffer**, and **quality** of each buffered segment
- The model chooses the **bitrates** for the **next segment** and (if needed) for the **buffered segments** to be re-transmitted
- **DoFP/MC**: **outperforms** the other approaches with the **highest QoE score**
- **Multiplexing** and **cancellation** features **enhance** DoFP **results**
- In the future, investigate the stream priority feature, the impact of DoFP's parameters and different streaming (video sequence, bitrate ladder, segment duration) and network scenarios (bandwidth traces)

Thank you