Bitrate Ladder Optimization for Live Video Streaming

Farzad Tashtarian

Department of Information Technology,
University of Klagenfurt

Nov. 18, 2025

Agenda

- An overview of the ATHENA project
- Degree of freedom in video streaming
- ARTEMIS: Adaptive Bitrate Ladder Optimization for Live Video Streaming
- Future research directions

About me

https://www.tashtarian.net/

farzad.tashtarian@aau.at

Farzad Tashtarian

Ph.D. in Computer Engineering,

Postdoctoral Researcher (2021-Present)

University of Klagenfurt, Austria

ATHENA Project

Adaptive Streaming over HTTP and Emerging Networked Multimedia Services

ATHENA

UNIVERSITÄT KLAGENFURT
FAKULTÄT FÜR TECHNISCHE WISSENSCHAFTEN
INSTITUT FÜR INFORMATIONSTECHNOLOGIE

Christian Doppler Forschungsgesellschaft

BITMOVIN
Software to Solve Complex Video Problems

ATHENA Project

ATHENA
Christian Doppler (CD) Laboratory

BITMOVIN

Christian Doppler Forschungsgesellschaft

Adaptive Streaming over HTTP and Emerging Networked Multimedia Services

- **Application/transport layer enhancements**
- **Quality of Experience (QoE) models**
- **Low-latency HAS**
- **Learning-based HAS**

End-to-End Aspects

Content Provisioning

- **Video encoding for HAS**
- **Quality-aware encoding**
- **Learning-based encoding**
- **Multi-codec HAS**

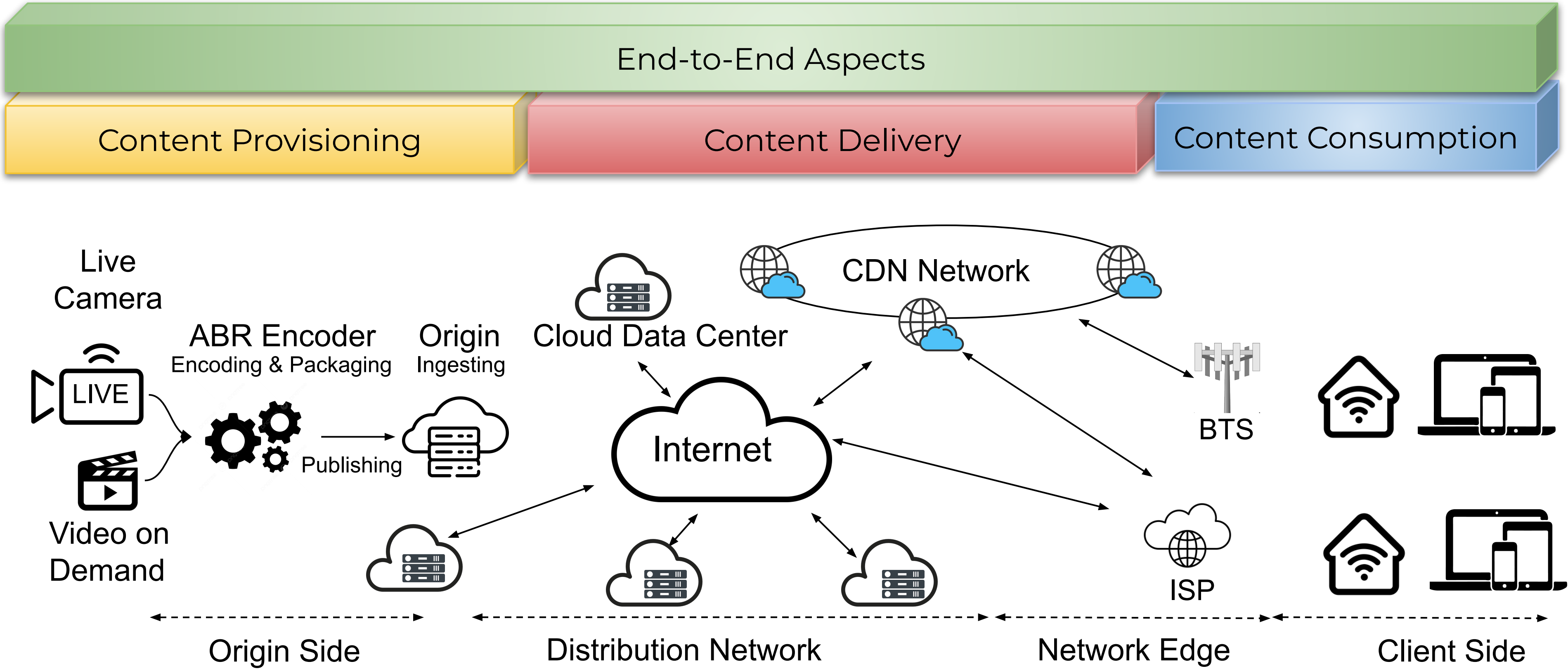
Content Delivery

- **Edge computing**
- **Information CDN/SDN ↔ clients**
- **Netw. assistance for/by clients**
- **Utility evaluation**

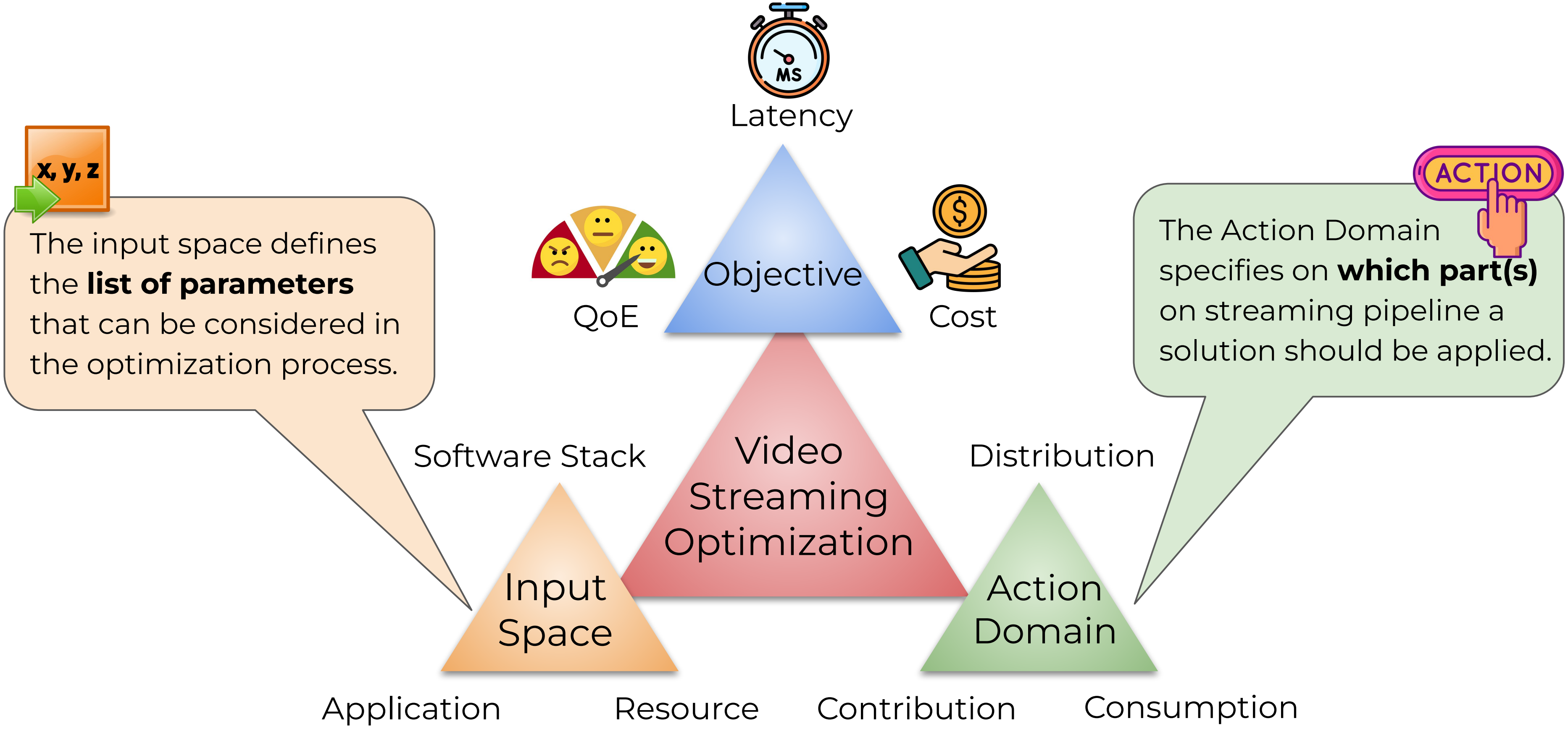
Content Consumption

- **Bitrate adaptation schemes**
- **Playback improvements**
- **Context and user awareness**
- **Quality of Experience (QoE) studies**

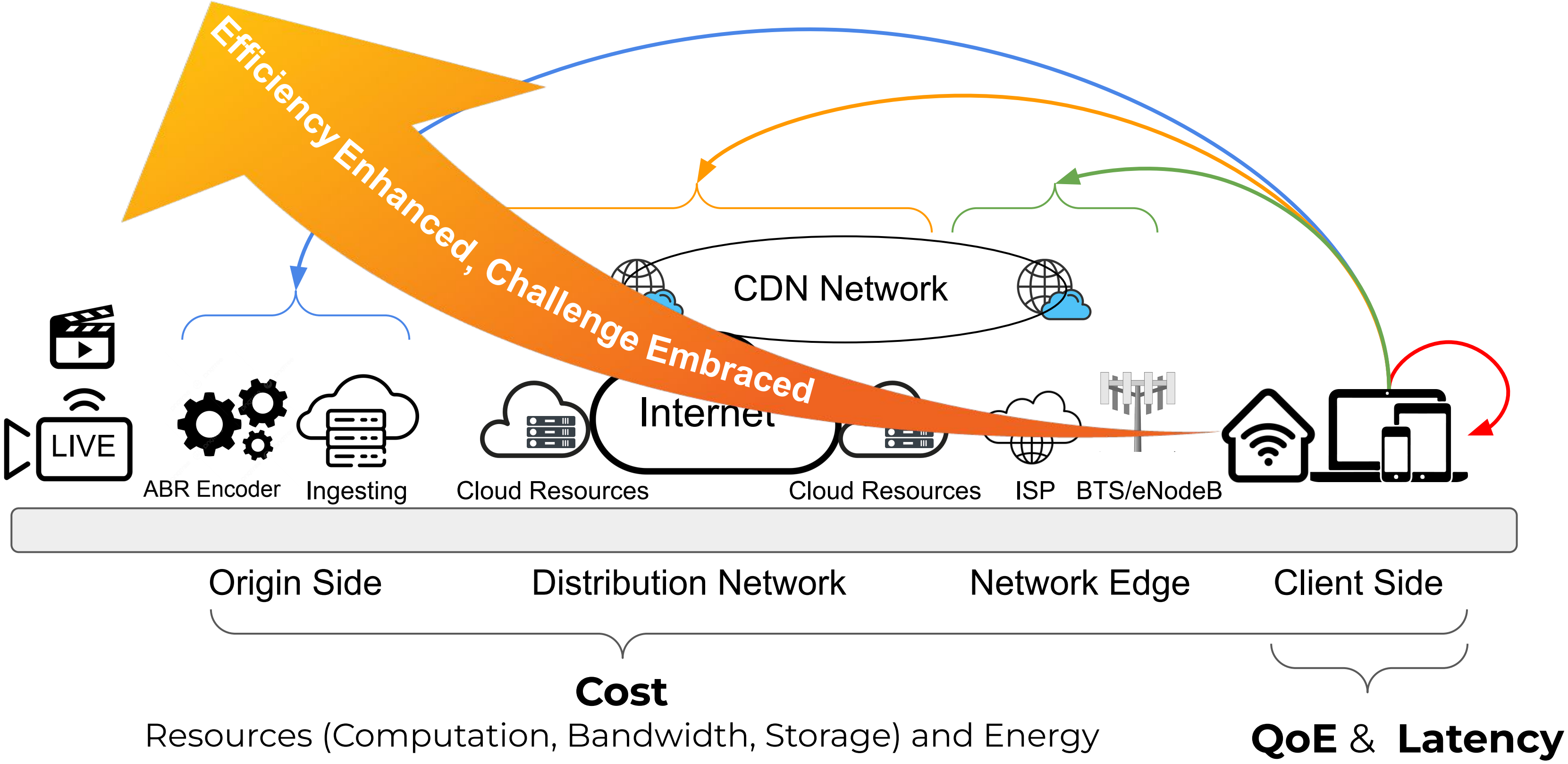
Horizontal View of Video Streaming



Triangle of Video Streaming Optimization



Degree of Freedom in Video Streaming



This paper is included in the
Proceedings of the 21st USENIX Symposium on
Networked Systems Design and Implementation.
April 16–18, 2024 • Santa Clara, CA, USA

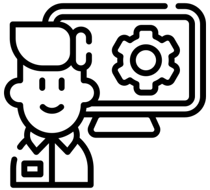
ARTEMIS: Adaptive Bitrate Ladder Optimization for Live Video Streaming

Farzad Tashtarian Abdelhak Bentaleb Hadi Amirpour Sergey Gorinsky

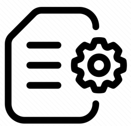
Junchen Jiang Hermann Hellwagner Christian Timmerer

UNIVERSITÄT KLAGENFURT
ATHENA
UNIVERSITÉ Concordia UNIVERSITY
institute IMDEA networks
THE UNIVERSITY OF CHICAGO

Live Video Streaming Pipeline

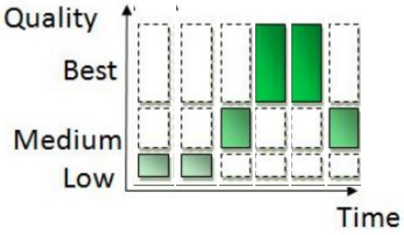


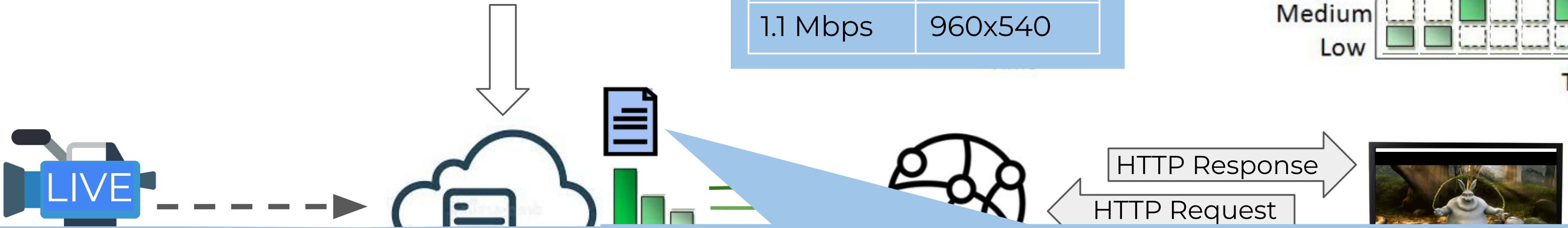
System Admin



Bitrate Ladder

Bitrate	Resolution
5 Mbps	1920x1080
2.8 Mbps	1280x720
1.1 Mbps	960x540

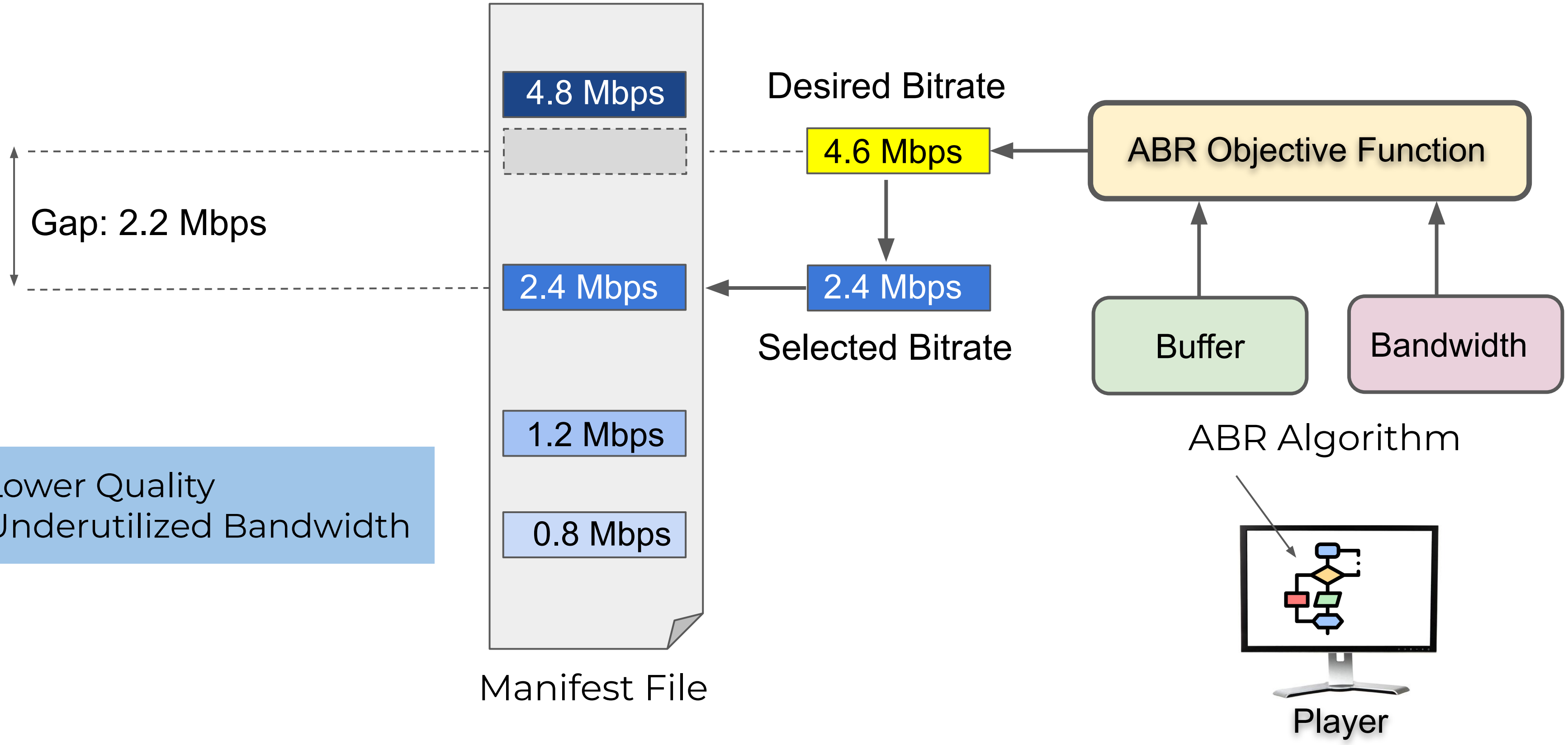




Li

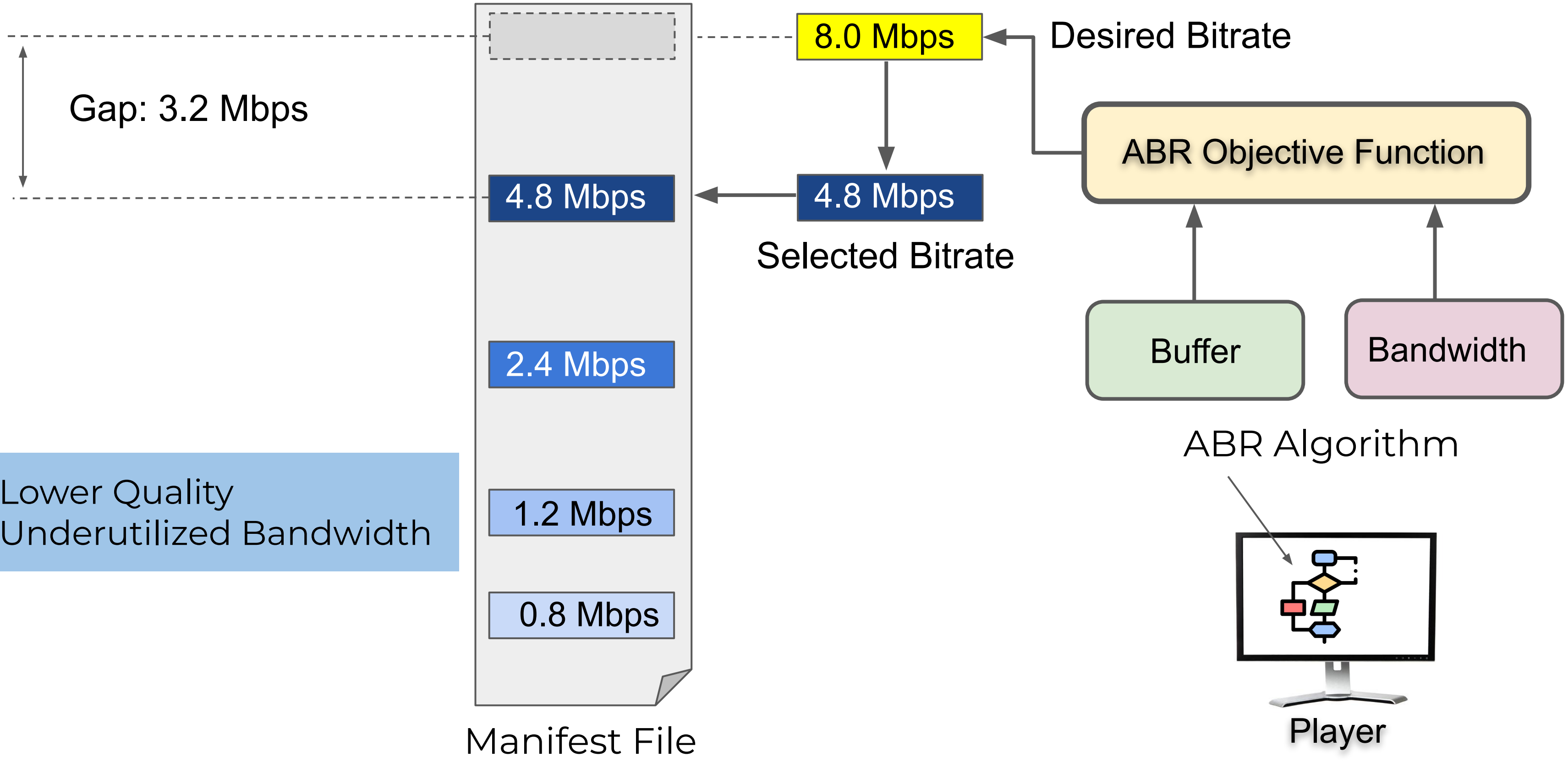
- Fixed bitrate ladder
  - Content-aware, e.g., Netfli
  - Context-aware, e.g., [Lebre
  - Agnostic of the content ai
- Manifest includes representations:
- different versions of the content optimized for various playback conditions, e.g., different bitrates and resolutions

Bitrate Selection by an Adaptive Bitrate (ABR) Algorithm



- Lower Quality
- Underutilized Bandwidth

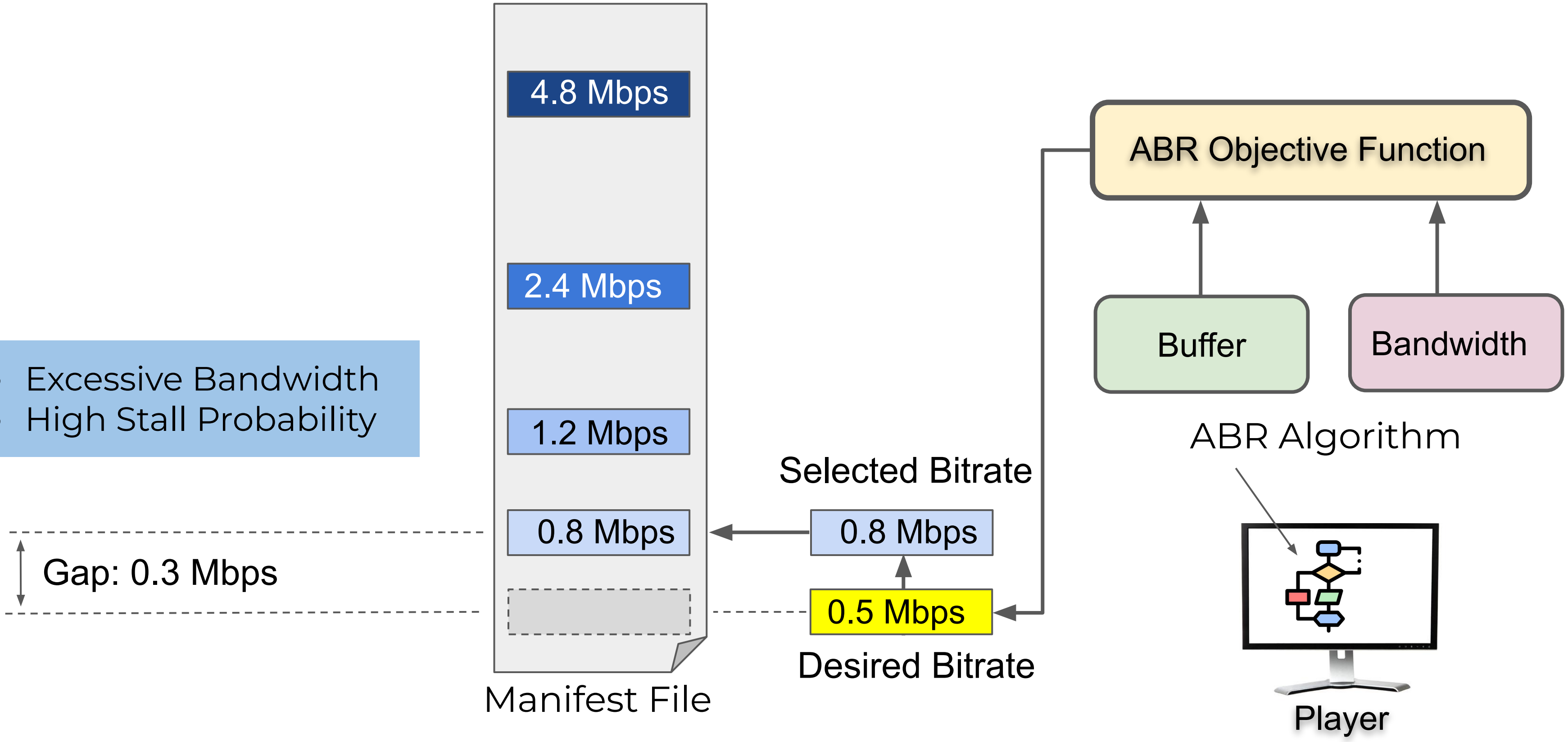
The Highest Bitrate Might be Too Low



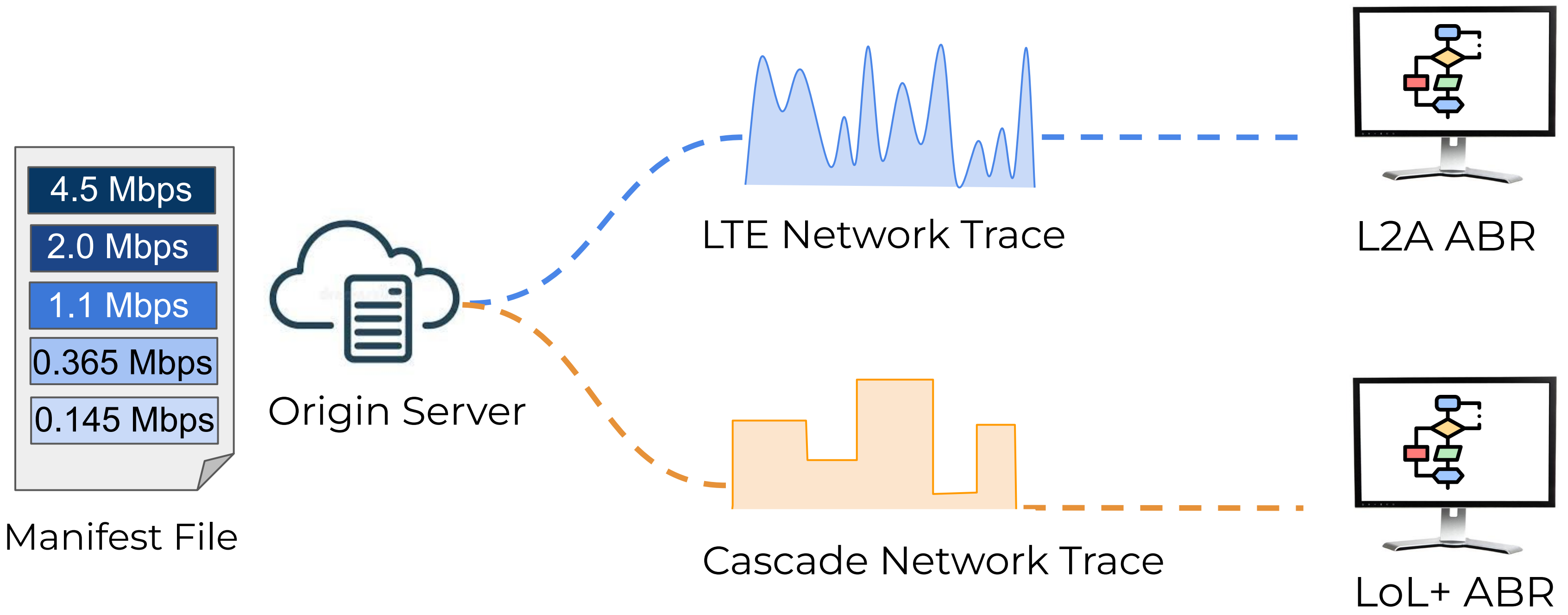
- Lower Quality
- Underutilized Bandwidth

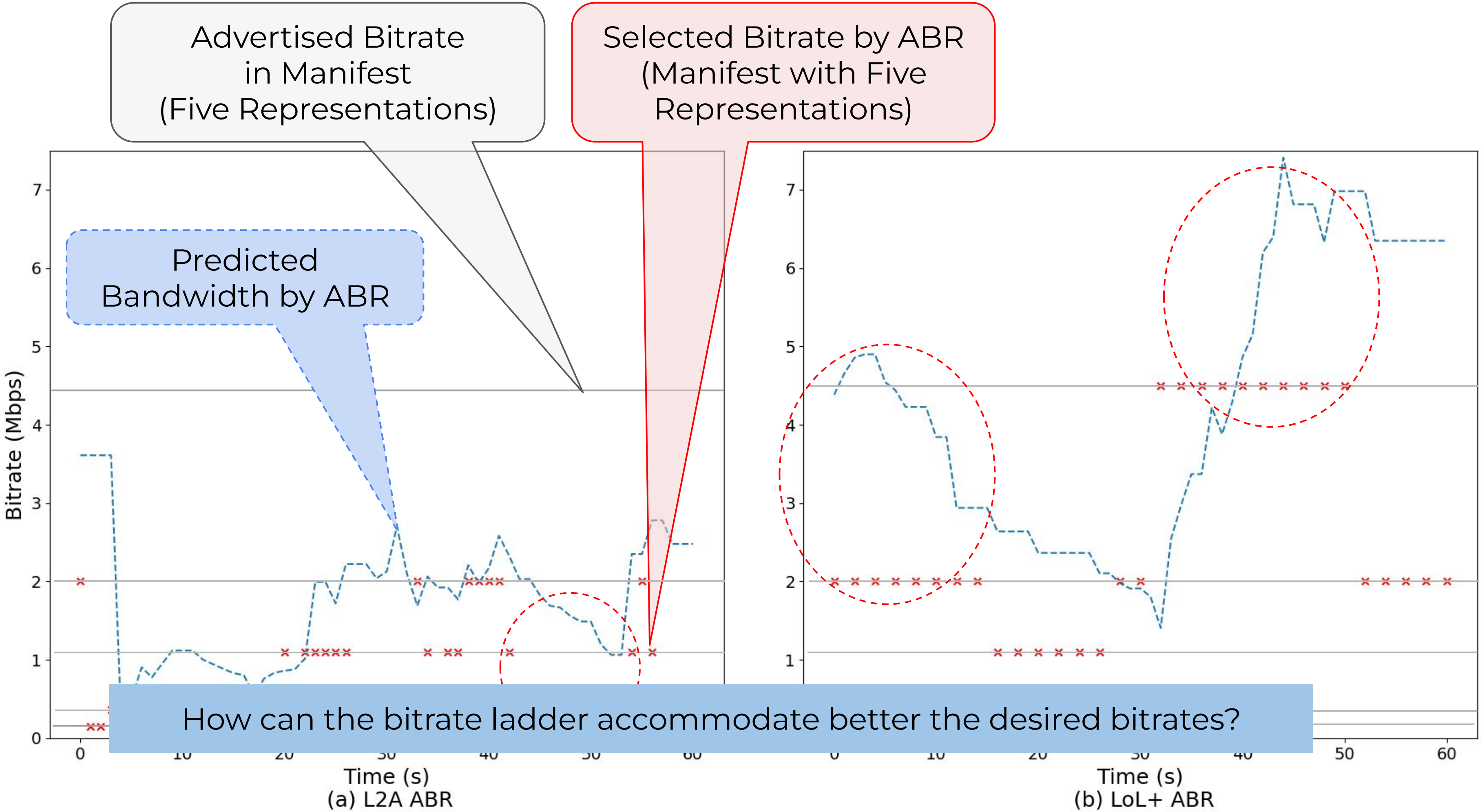
The Lowest Bitrate Might be Too High

- Excessive Bandwidth
- High Stall Probability



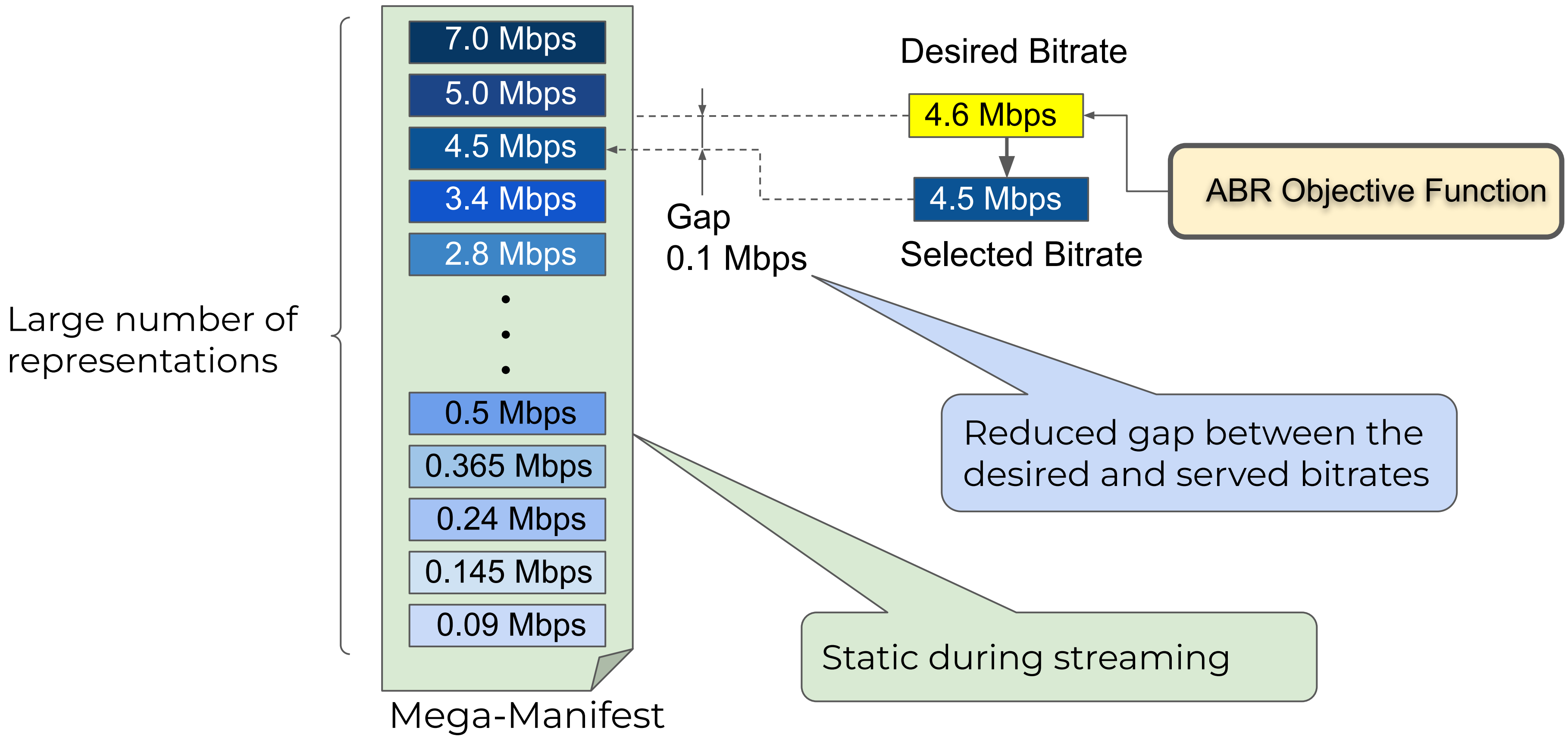
Advertising Five Representations by the Manifest



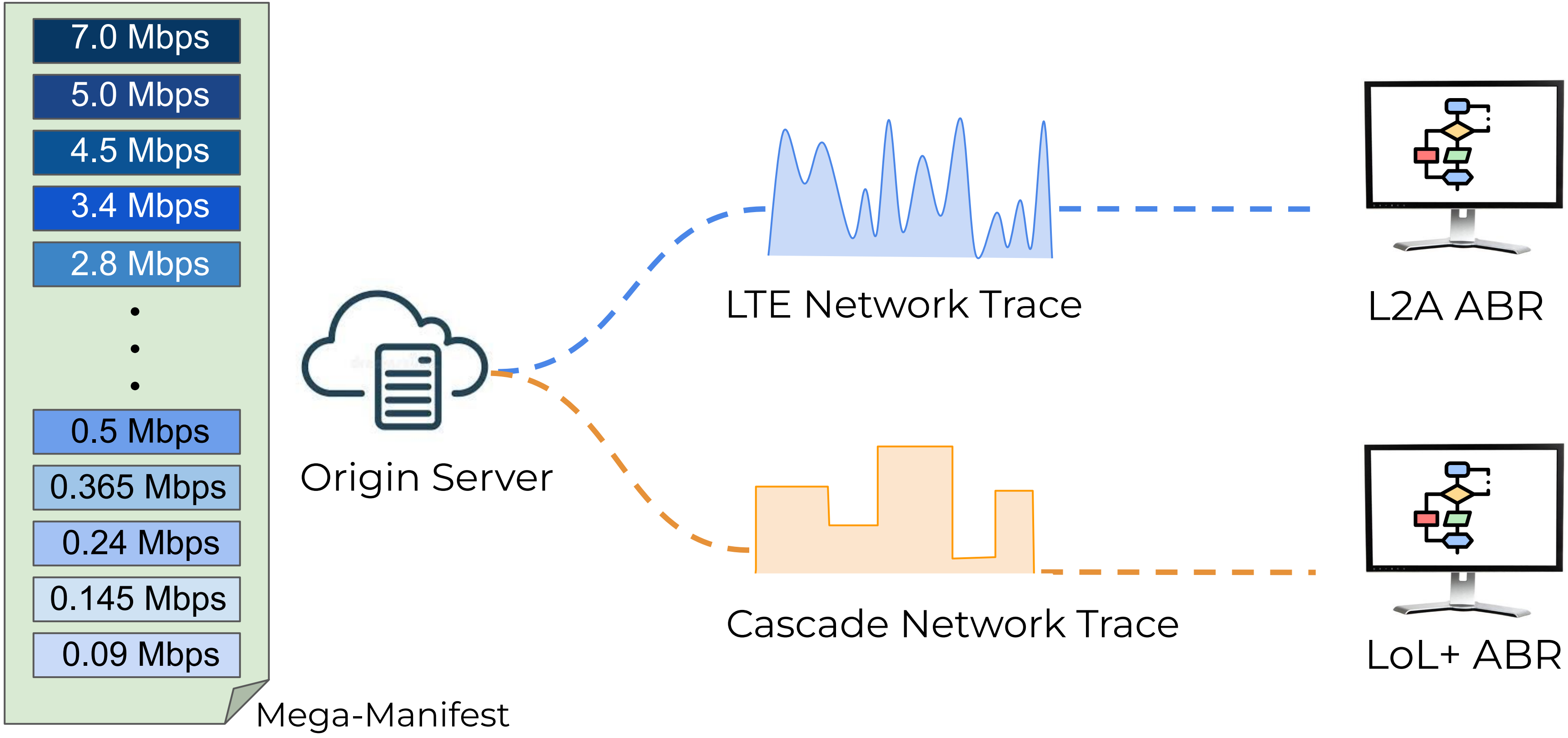


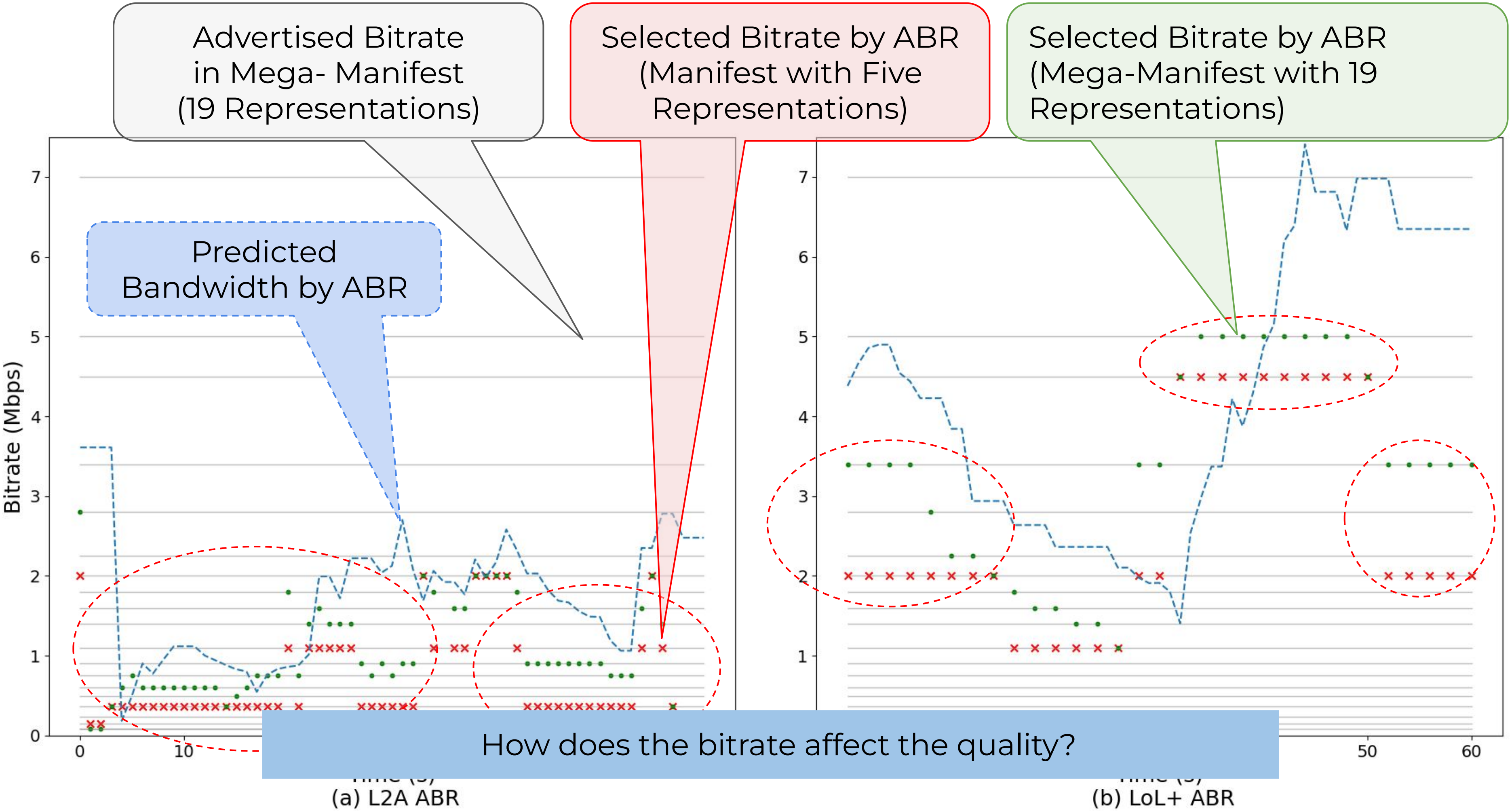
Advertised Bitrate in Manifest (Five Representations)
Selected Bitrate by ABR (Manifest with Five Representations)
Predicted Bandwidth by ABR
Bitrate (Mbps)
Time (s)
(a) L2A ABR
Time (s)
(b) LoL+ ABR
How can the bitrate ladder accommodate better the desired bitrates?

Mega-Manifest for Better Bitrate Alignment



Advertising 19 Representations by the Mega-Manifest

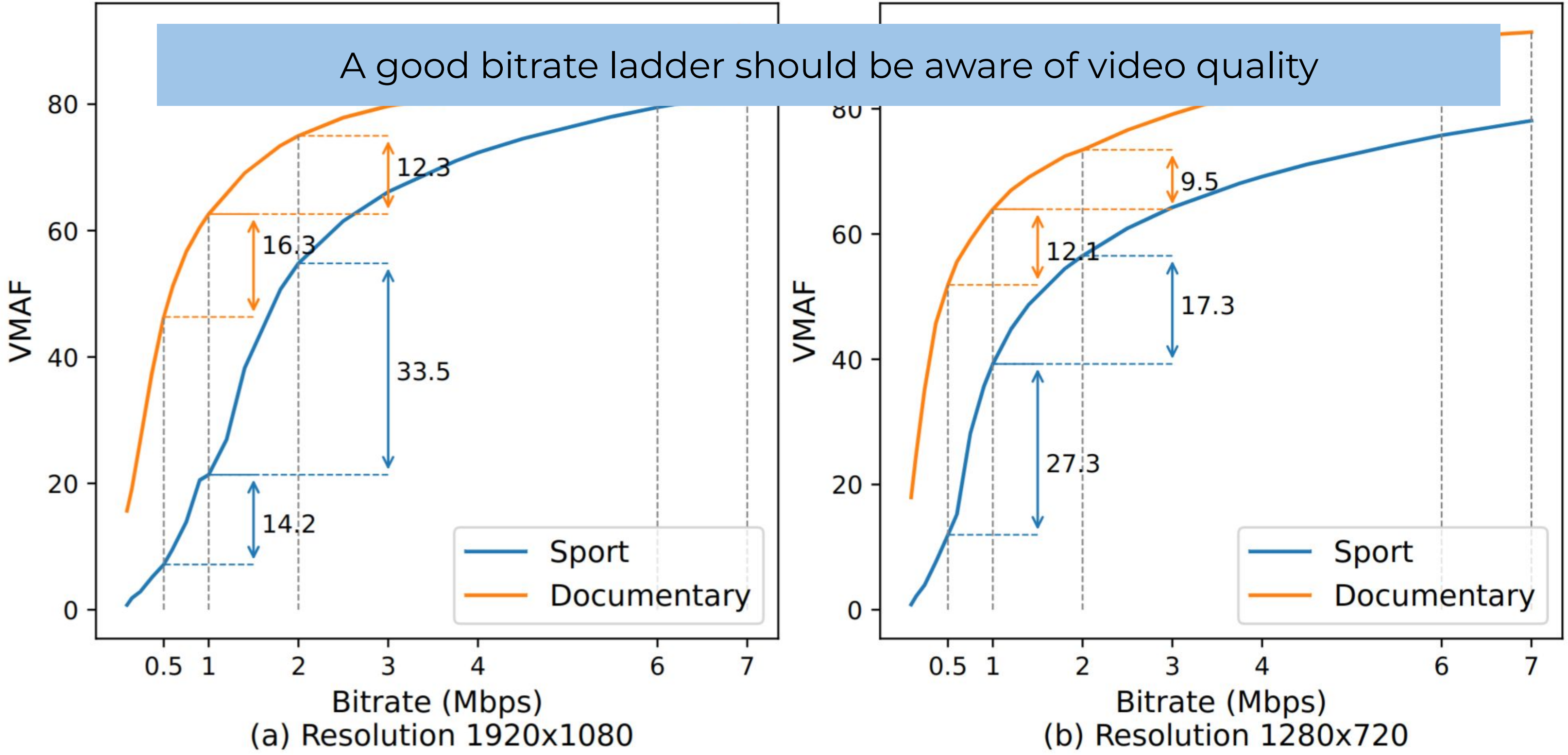




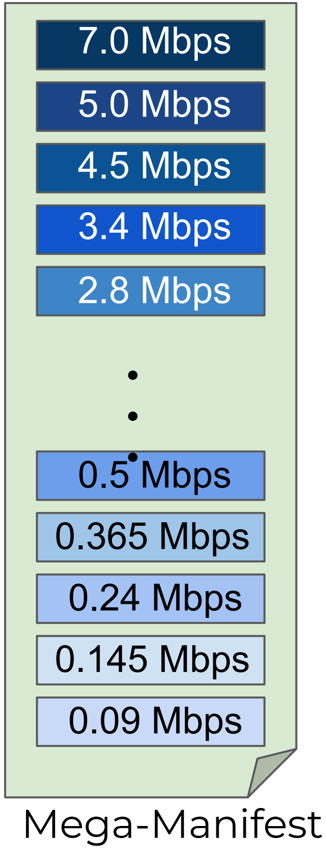
How does the bitrate affect the quality?

Dependence of Video Quality on the Bitrate

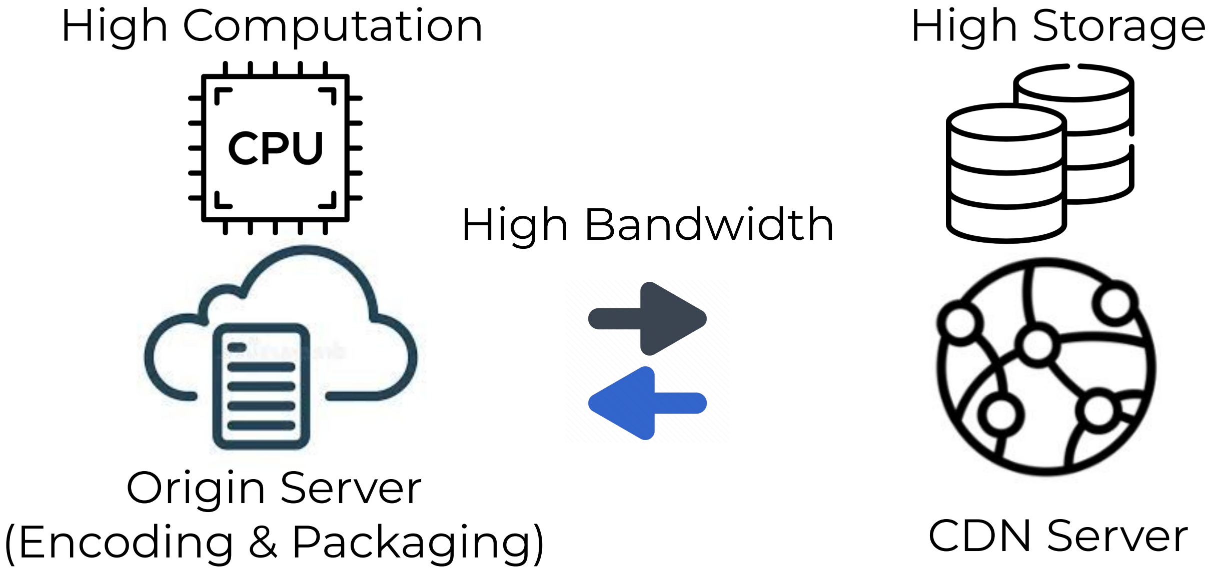
VMAF: Video Multimethod Assessment Fusion



Impact of the Mega-Manifest on the Encoder



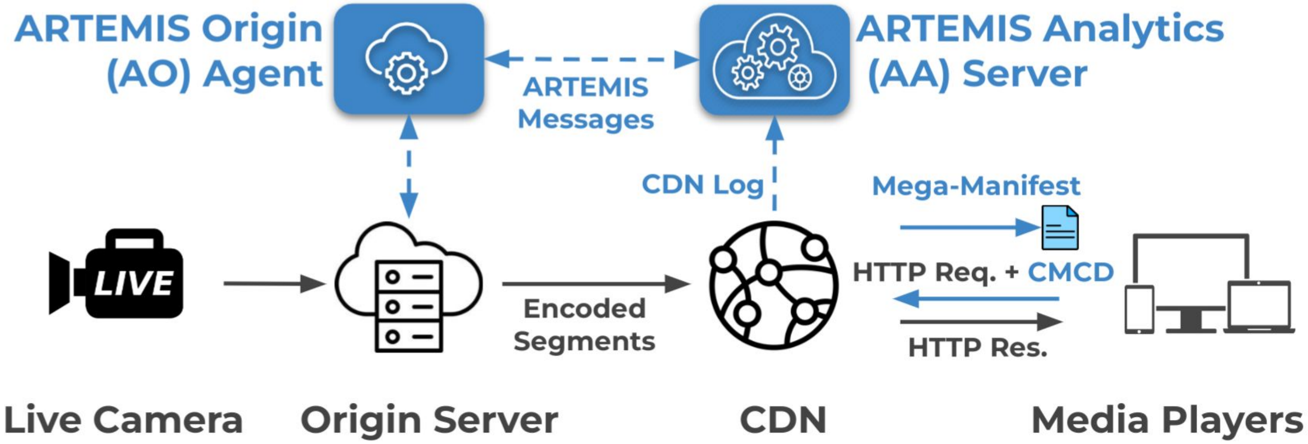
Encoding the content into all representations of the mega-manifest in live streaming **is time-consuming**



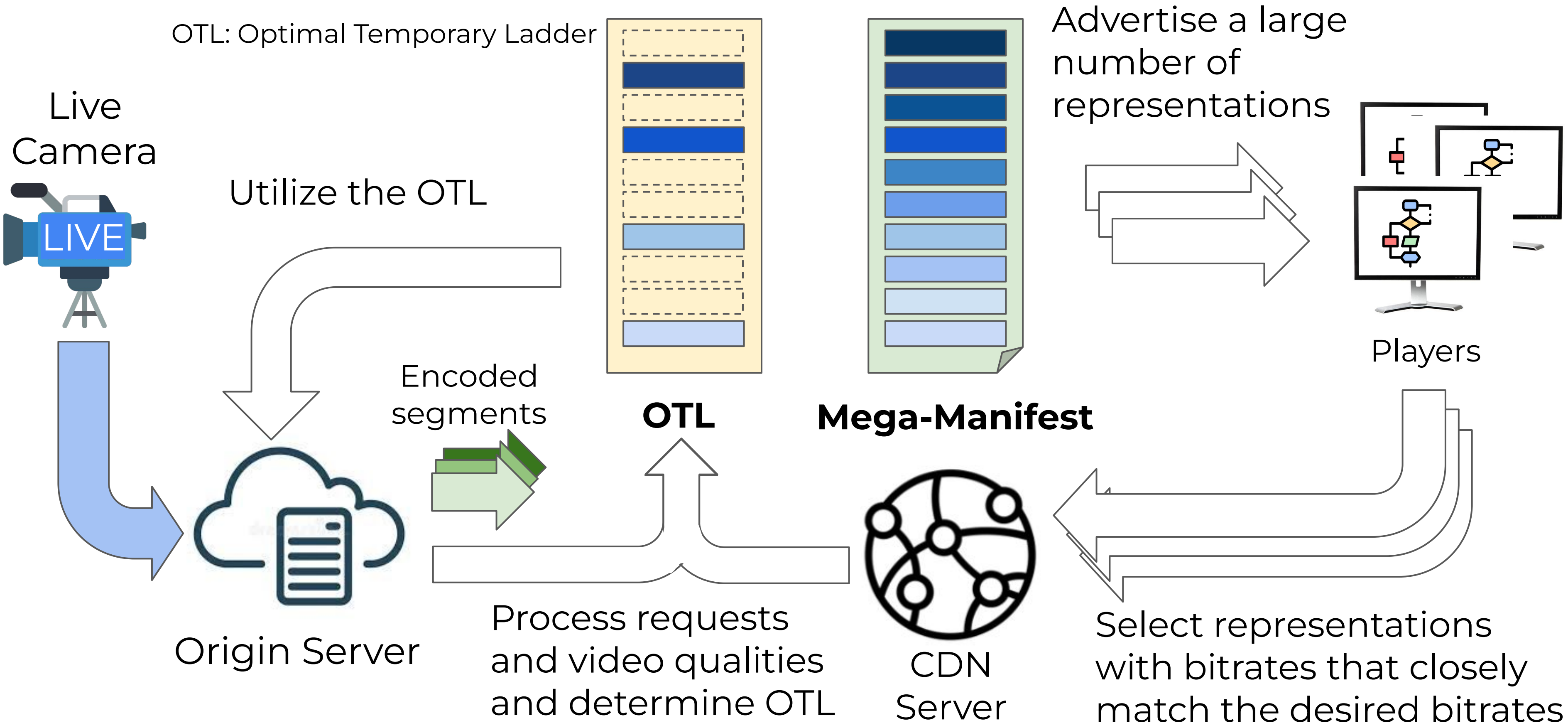
ARTEMIS Aims To:

- Adaptively select an **optimal subset of the mega-manifest representations** by using:
  - ➢ Predicted **quality indicator** as the peak signal-to-noise ratio (PSNR)
  - ➢ Received **CDN logs** containing the selected bitrates and QoE parameters of the players
- Be **end-to-end** and **agnostic** of the player/ABR types
- Operate in a **time-slotted fashion**

ARTEMIS Conceptual Architecture



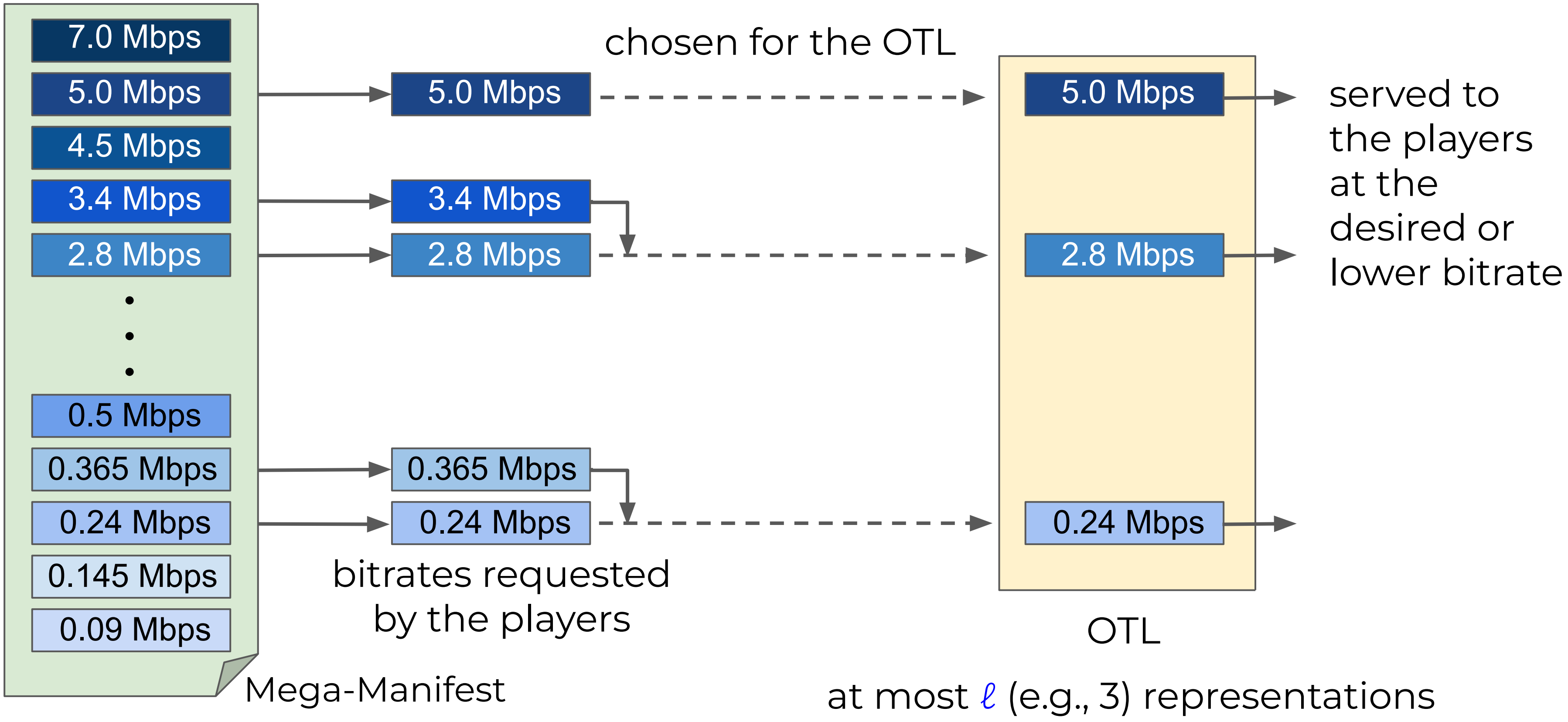
ARTEMIS at a Glance



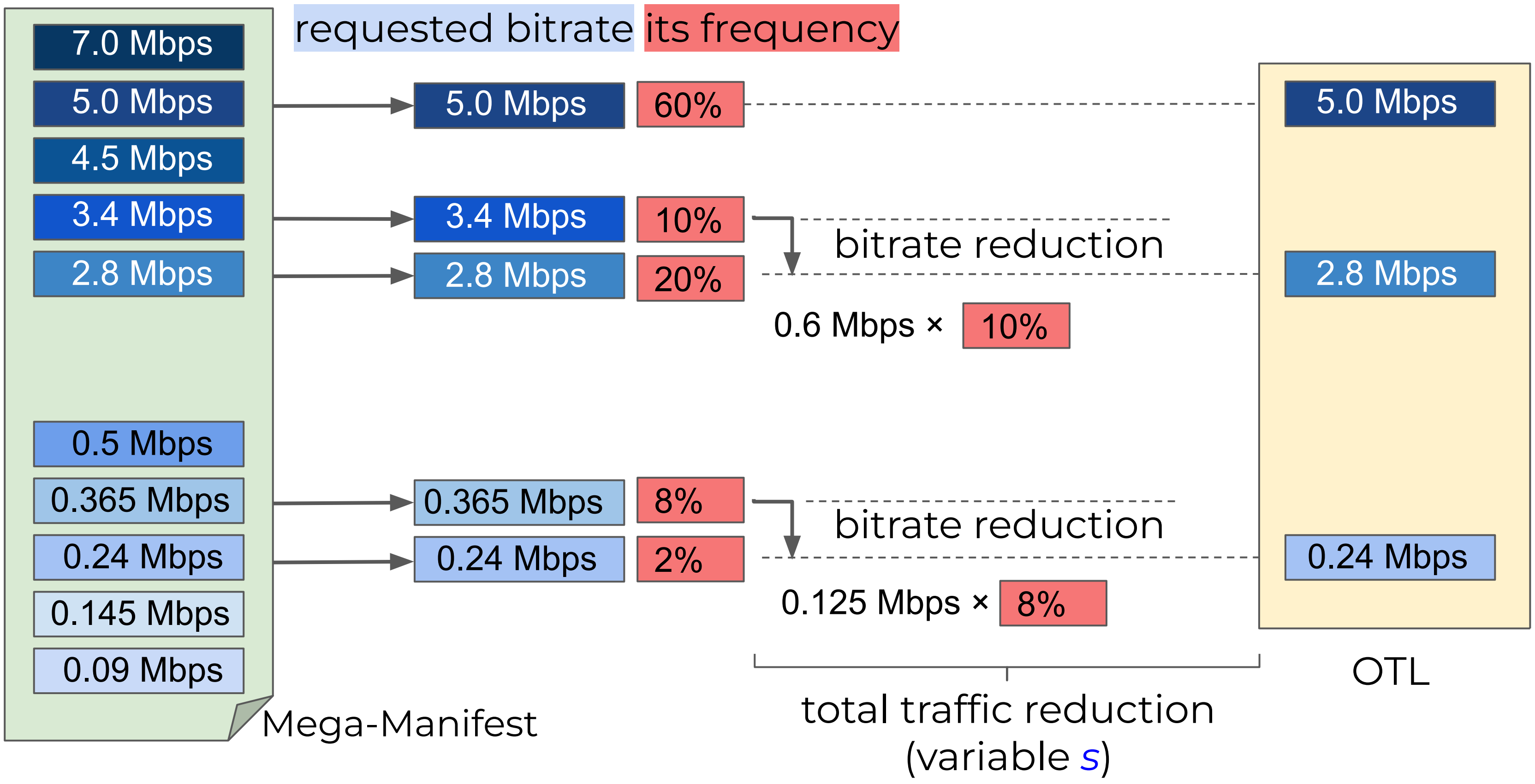
Optimal Temporary Ladder (OTL)

- Cornerstone of ARTEMIS
- **Optimal subset of the mega-manifest** representations utilized by the live encoder
- **Challenges**
  - ➢ How to select the OTL?
  - ➢ Which constraints should the OTL impose?
  - ➢ When should the OTL be updated?

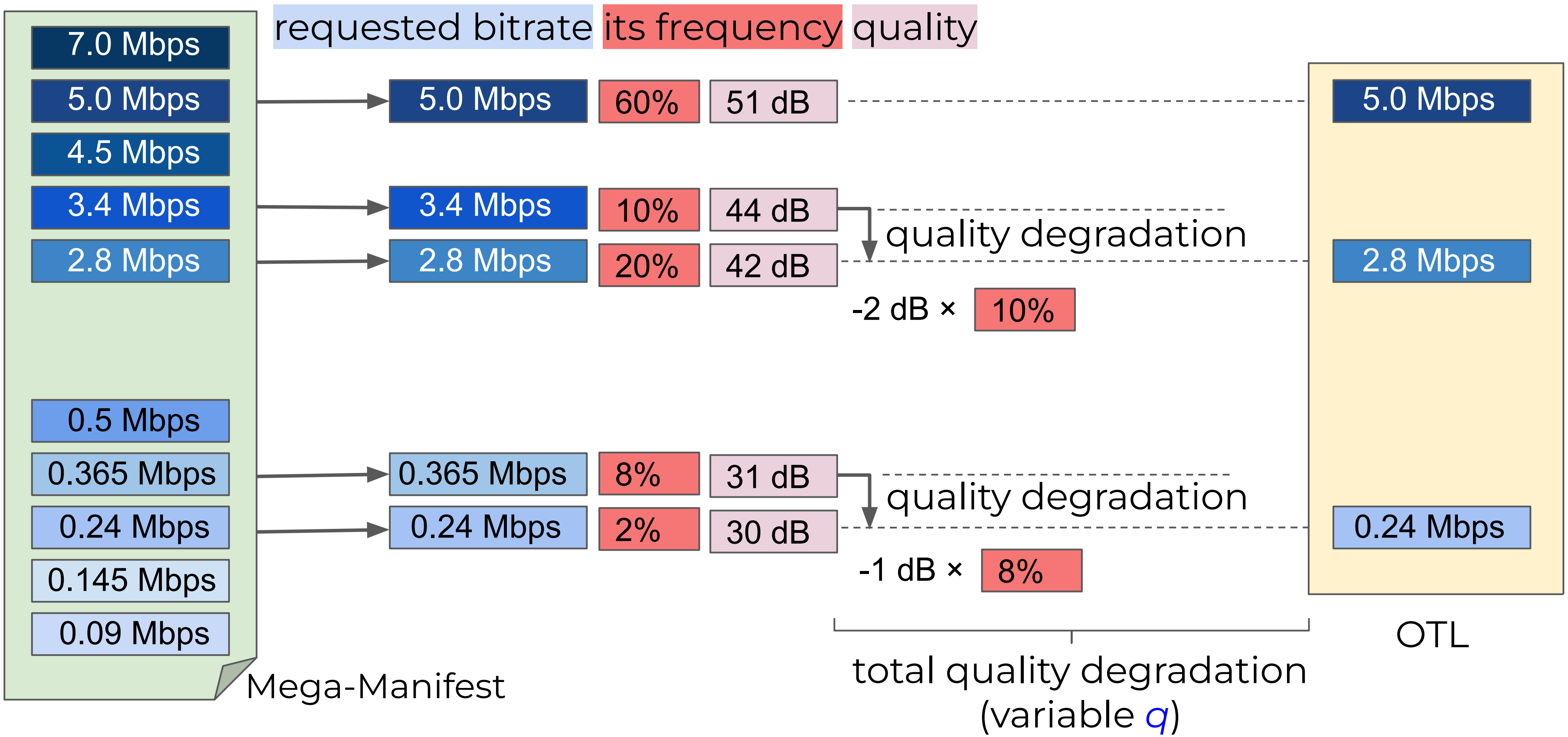
OTL : Maximum Length and Bitrate Reduction



OTL : Traffic Reduction



OTL : Quality Improvement



ARTEMIS MILP model

$$\textit{Maximize:} \quad \alpha \times \frac{q}{Q} + (1-\alpha) \times \frac{s}{S}$$

$$\textit{subject to:} \quad \sum_{j \in B \,\&\, j<i} y_{j,i} + x_i = 1 \quad \forall i \in B,$$

$$\sum_{i \in B \,\&\, j<i} y_{j,i} \leq x_j \times m \quad \forall j \in B$$

$$\sum_{i \in B} x_i \leq \ell.$$

$$\sum_{i \in B} |x_i - \bar{x}_i| \leq \beta,$$

$$q \times \sum_{i \in B} r_i \leq \sum_{i \in B} \sum_{j \in B \,\&\, j<i} r_i \times y_{j,i} \times \left(F(b_j) - F(b_i)\right)$$

$$s \times \sum_{i \in B} r_i \leq \sum_{i \in B} \sum_{j \in B \,\&\, j<i} r_i \times y_{j,i} \times (b_i - b_j)$$

$$\textit{variables:} \quad x_i,\ y_{j,i} \in \{0,1\},\ q \leq 0, \text{ and } s \geq 0$$

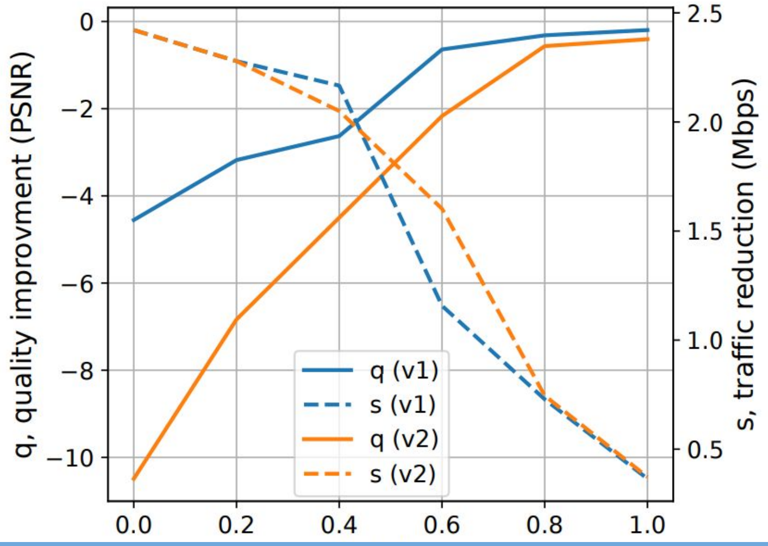
OTL : Computation

Quality improvement

Traffic reductio

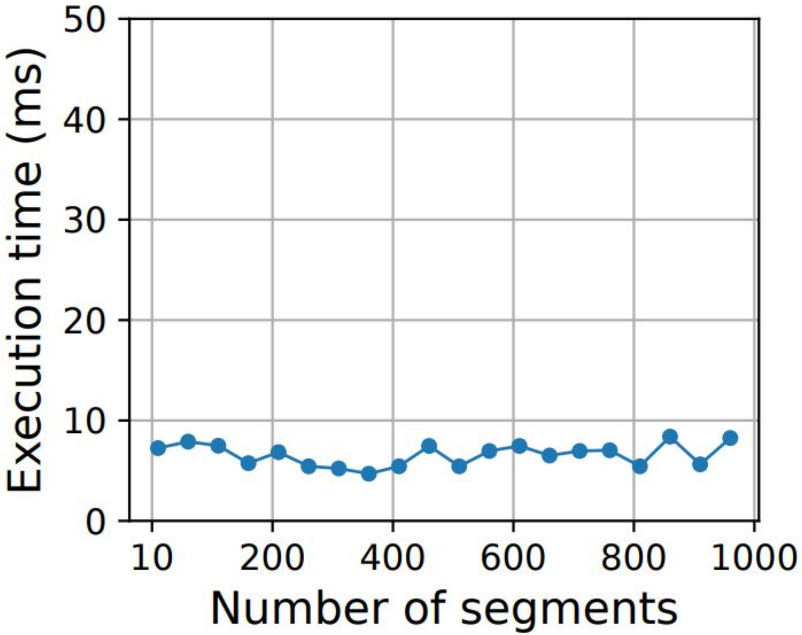
- Objective function: **Maximize** $\alpha \times \frac{q}{Q} + (1-\alpha) \times \frac{s}{S}$
- Parameter α
  - ➤ Relative importance of quality improvement vs. traffic reduction
  - ➤ Computed from the stall information of the players

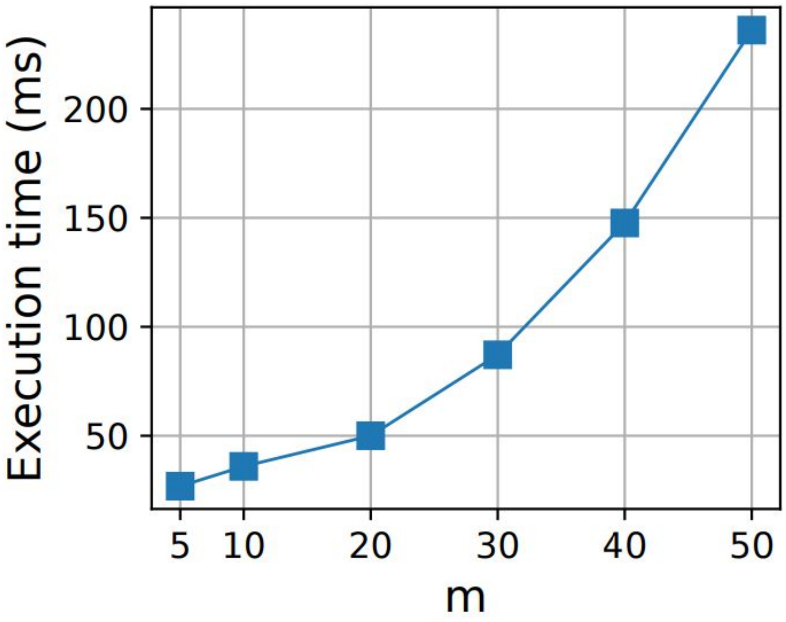
The value of α is selected based on the received stall information from the players in **CMCD**.



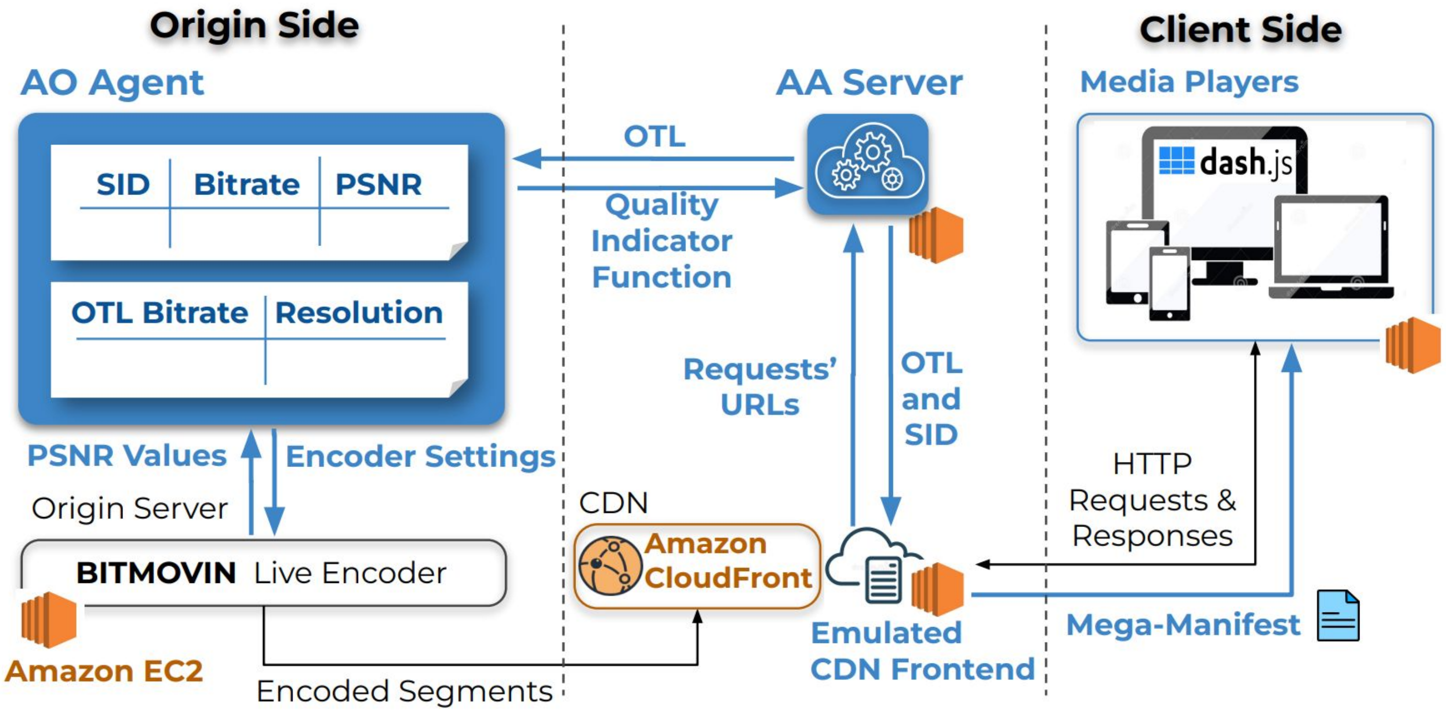
Time complexity of MILP model

➤ Dependent on m, the number of representations in the mega-manifest





Performance Evaluation - Testbed



Evaluation Settings

- Network traces: LTE, AmazonFCC, Cascade-5, and Cascade-20
- Content type: animation, sport, movie, and documentary
- Baselines for ARTEMIS: five static bitrate ladders
- Players: dash.js

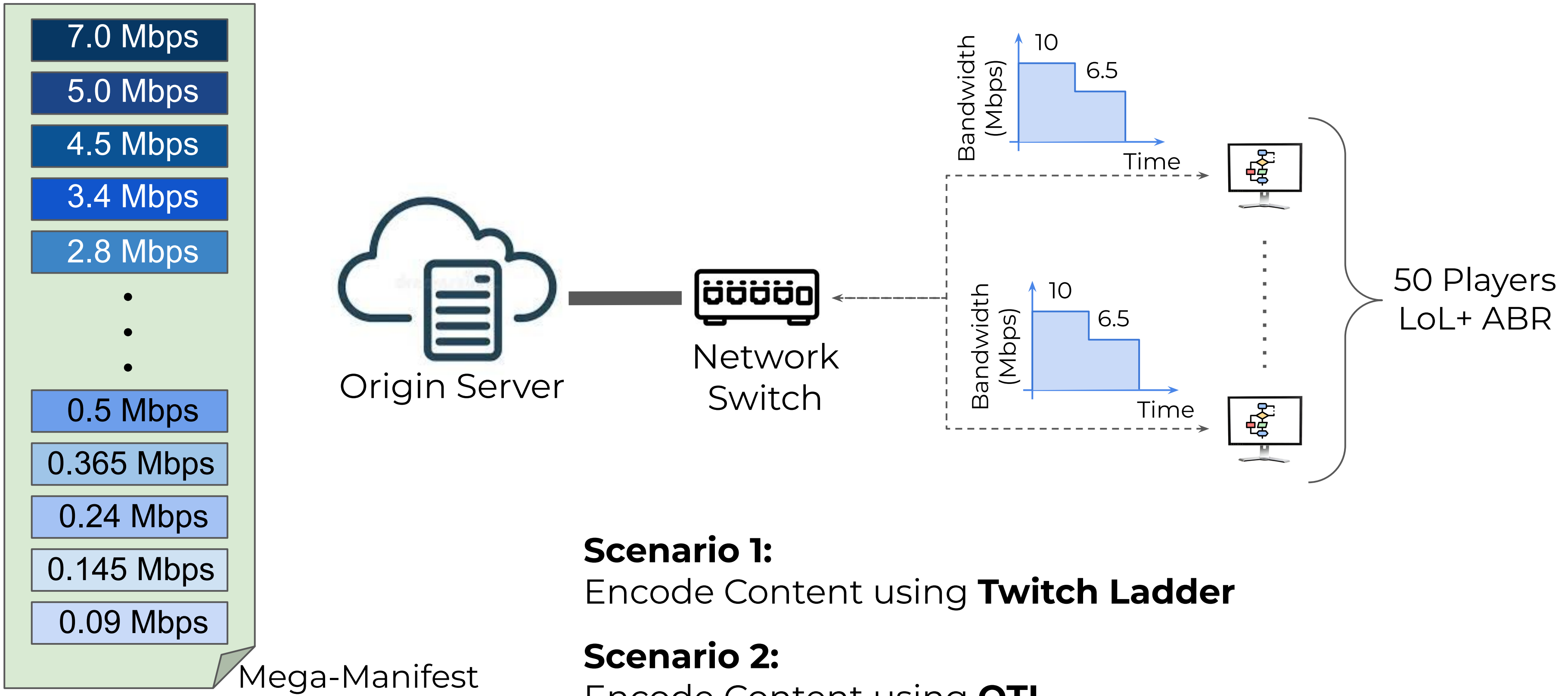
Bitrate Ladder	Length	Min. [Res.@Bitrate]	Max. [Res.@Bitrate]
Theo	4	360p@0.365 Mbps	1080p@4.0 Mbps
Mux	4	360p@0.75 Mbps	1080p@4.5 Mbps
Bitmovin	6	240p@0.145 Mbps	1080p@4.5 Mbps
Pensieve	6	360p@0.365 Mbps	1080p@4.3 Mbps
Twitch	6	360p@0.5 Mbps	1080p@7.0 Mbps
ARTEMIS	29	240p@0.145 Mbps	1080p@7.0 Mbps

Evaluation Settings

- Network traces: LTE, AmazonFCC, Cascade-5, and Cascade-20
- Content type: animation, sport, movie, and documentary
- Baselines for ARTEMIS: five static bitrate ladders
- Players: dash.js

BL \ Res.@Mbps	240p@0.145	240p@0.240	360p@0.365	360p@0.5	360p@0.6	360p@.75	360p@0.9	540p@1.0	480p@1.1	480p@1.2	480p@1.4	720p@1.6	720p@1.8	720p@2.0	720p@2.25	720p@2.5	1080p@2.8	720p@3.0	720p@3.2	720p@3.4	720p@3.75	1080p@4.0	1080p@4.3	1080p@4.5	1080p@5.0	1080p@5.5	1080p@6.0	1080p@6.5	1080p@7.0
Theo			✓					✓								✓						✓							
Bitmovin	✓		✓						✓					✓										✓					
Mux						✓		✓								✓								✓					
Pensieve			✓			✓				✓			✓				✓						✓						
Twitch				✓					✓			✓							✓		✓								✓
ARTEMIS	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

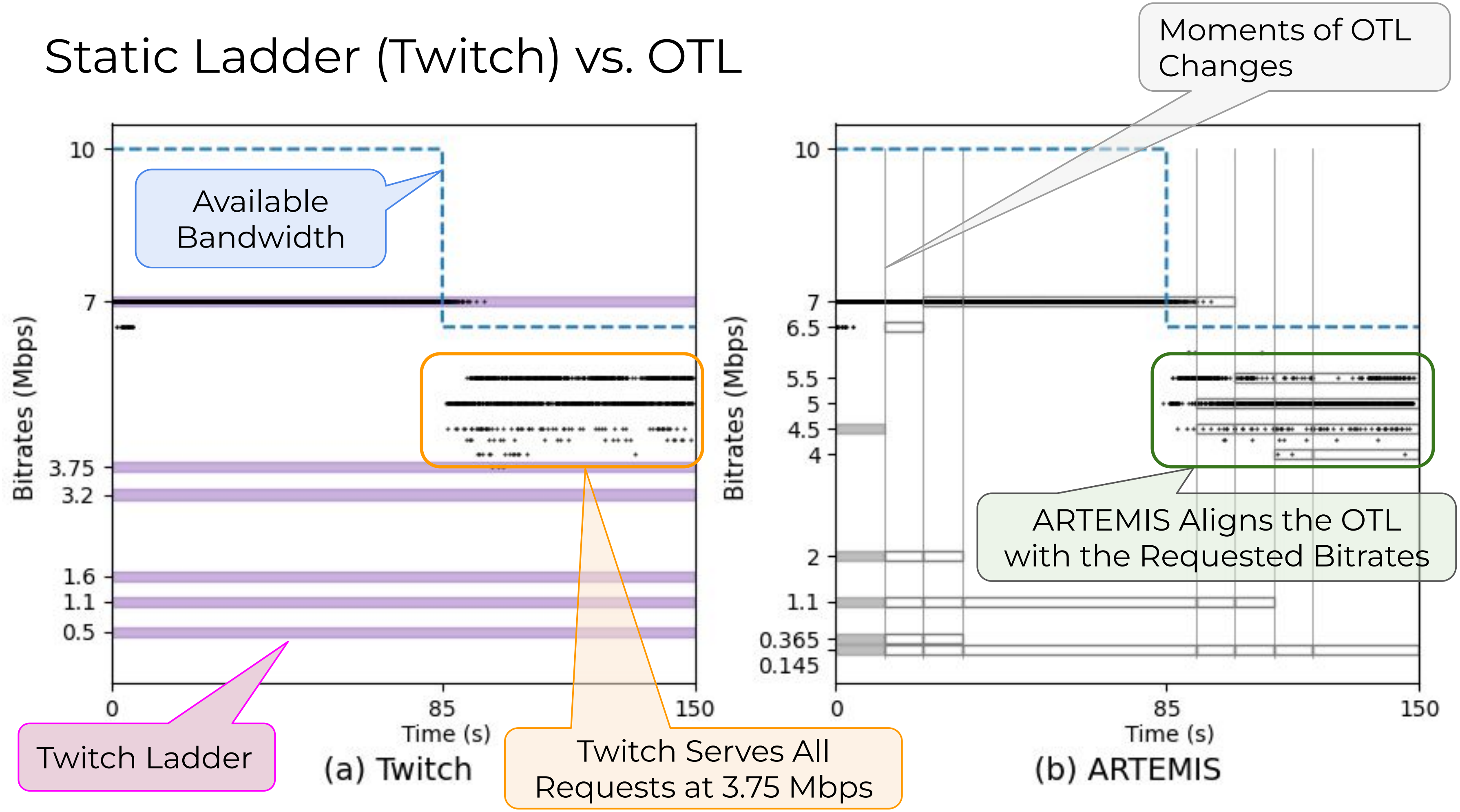
Static Ladder (Twitch) vs. OTL : Experimental Setup



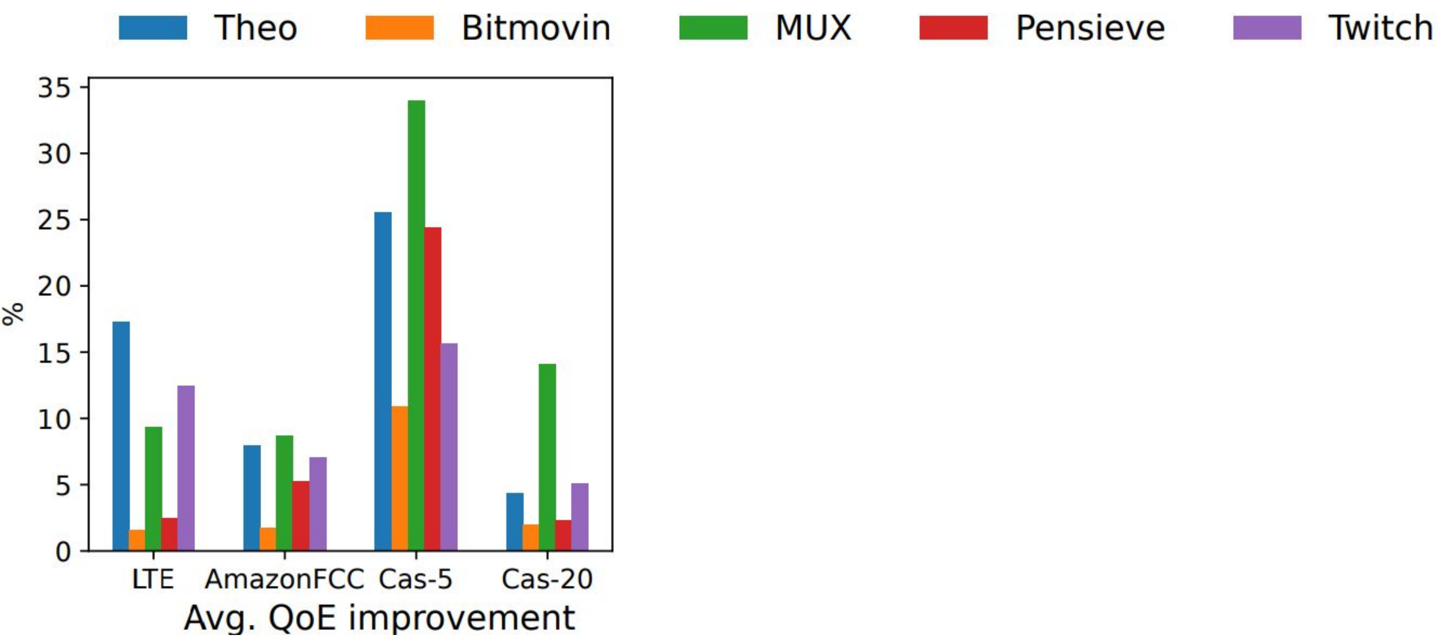
Scenario 1:
Encode Content using **Twitch Ladder**

Scenario 2:
Encode Content using **OTL**

Static Ladder (Twitch) vs. OTL

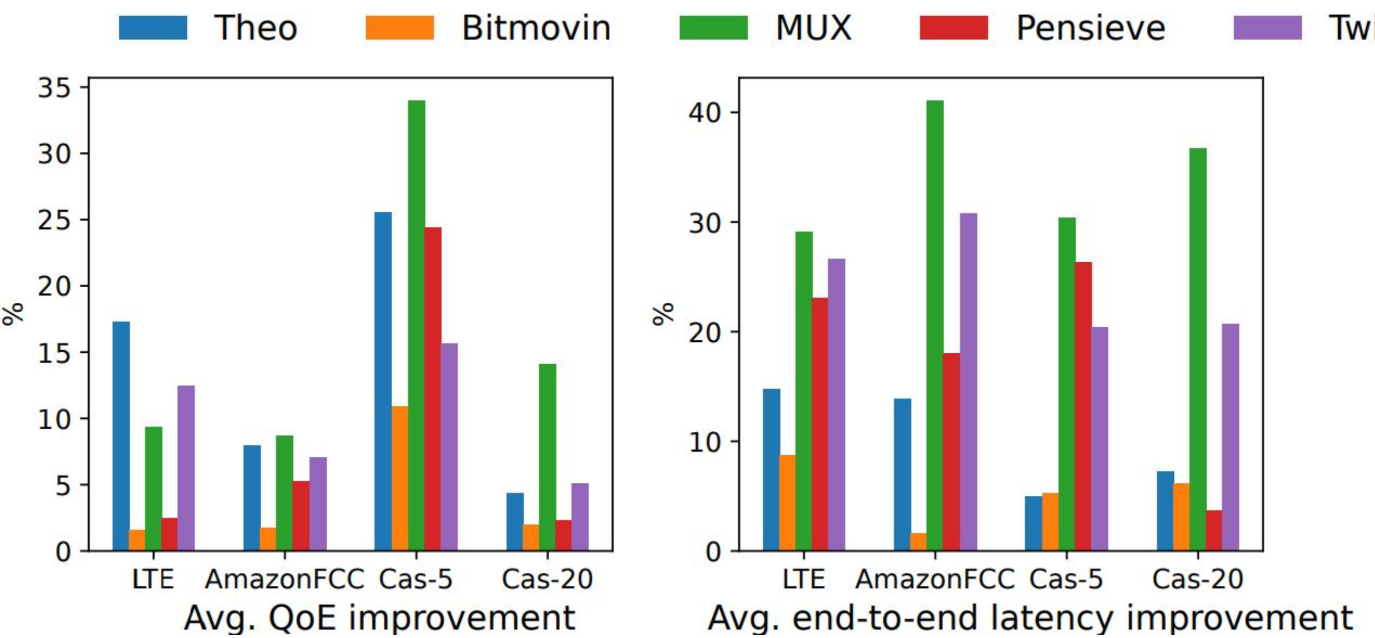


Quality of Experience (QoE) with ARTEMIS vs. Five Static Bitrate Ladders



Average QoE up 11%

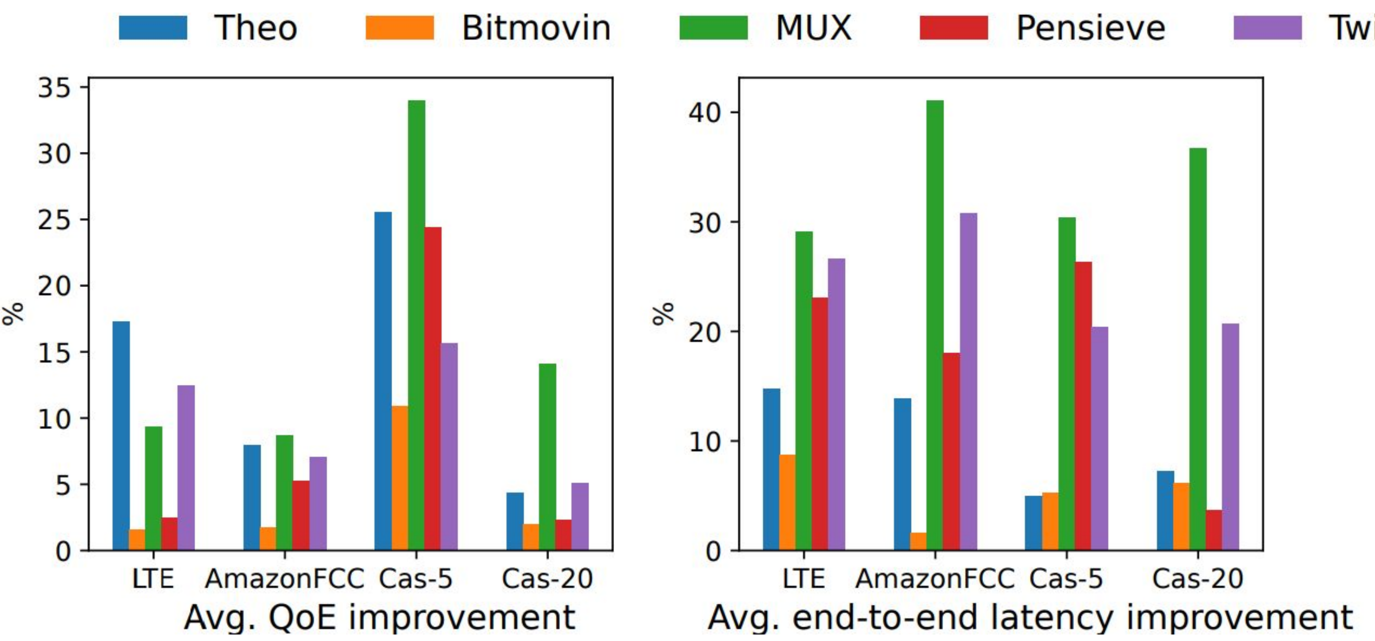
QoE and **Latency** with ARTEMIS vs. Five Static Bitrate Ladders



Average QoE up 11%

Average Latency down 18%

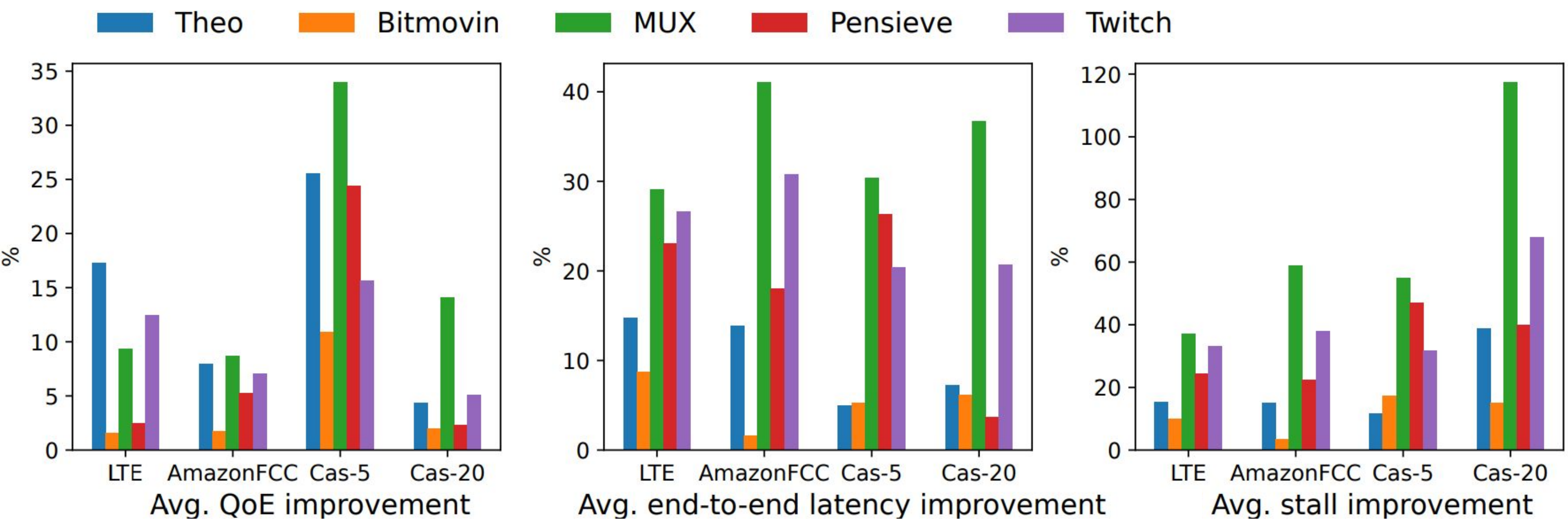
QoE and **Latency** with ARTEMIS vs. Five Static Bitrate Ladders



Average QoE up 11%

Average Latency down 18%

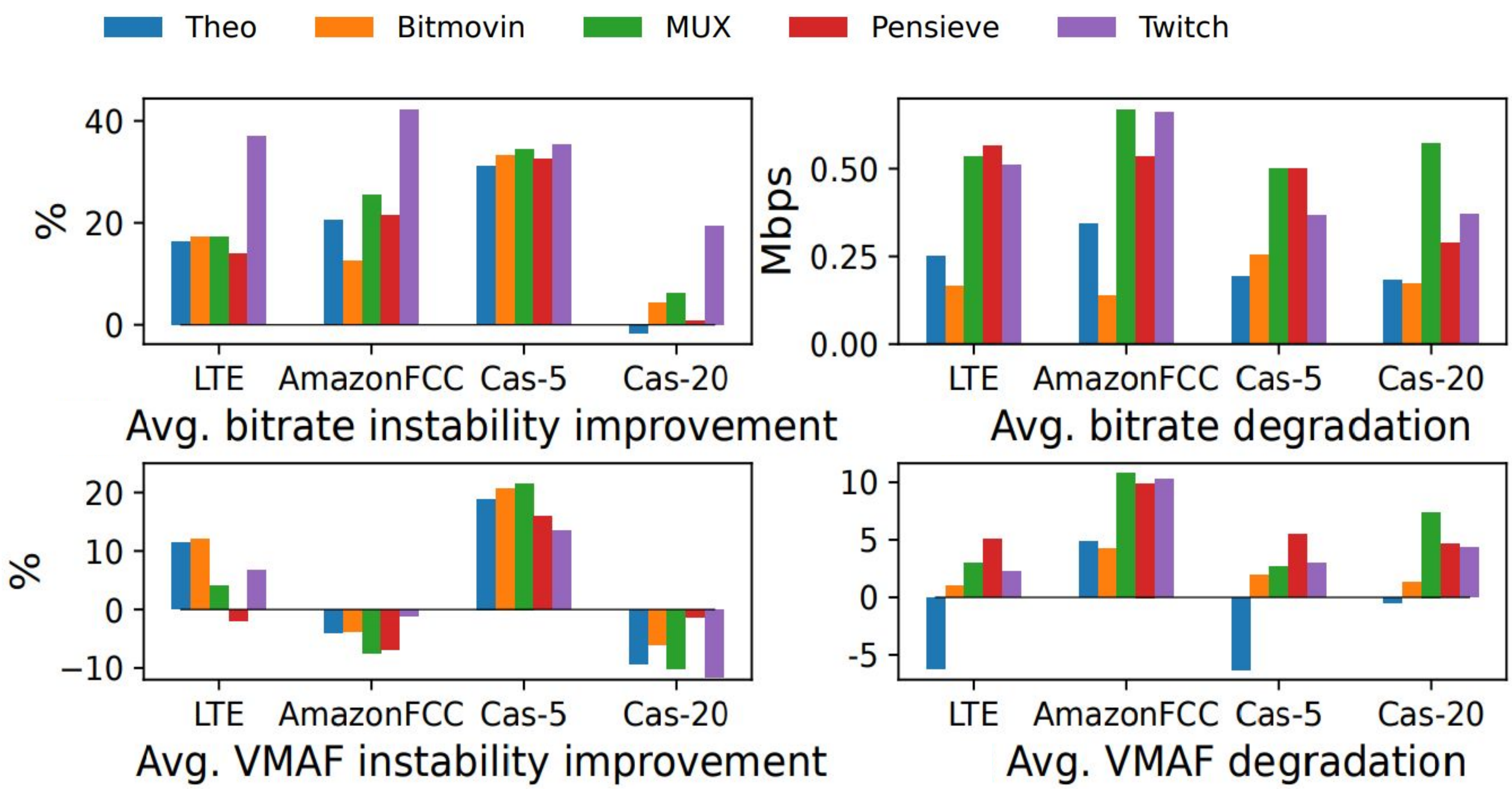
QoE, Latency, and **Stall** with ARTEMIS vs. Five Static Bitrate Ladders



Average QoE up 11%

Average Latency down 18%

Average Stall down 36%


Theo
Bitmovin
MUX
Pensieve
Twitch
%
40
20
0
LTE
AmazonFCC
Cas-5
Cas-20
Avg. bitrate instability improvement
Mbps
0.50
0.25
0.00
LTE
AmazonFCC
Cas-5
Cas-20
Avg. bitrate degradation
%
20
10
0
−10
LTE
AmazonFCC
Cas-5
Cas-20
Avg. VMAF instability improvement
10
5
0
-5
LTE
AmazonFCC
Cas-5
Cas-20
Avg. VMAF degradation

Summary

- **Adaptive bitrate ladder optimization** for live video streaming
  - ➢ Seamless enhancement of the **end-to-end** pipeline
  - ➢ Accounting for the **context** via scalable player feedback
  - ➢ **Content** awareness via PSNR
- **Mega-manifest** to advertise a large number of representations
- **Short dynamic ladder for encoding** the content
  - ➢ An optimal subset of the mega-manifest representations
- Multi-objective **performance improvement**
  - ➢ Reduced **end-to-end** latency and **stall**
  - ➢ Increased **quality of experience**

Bitrate Ladder Optimization for Live Video Streaming

Farzad Tashtarian

Nov. 18, 2025

Thank you so much!

ARTEMIS Algorithm

Algorithm 1 ARTEMIS Algorithm

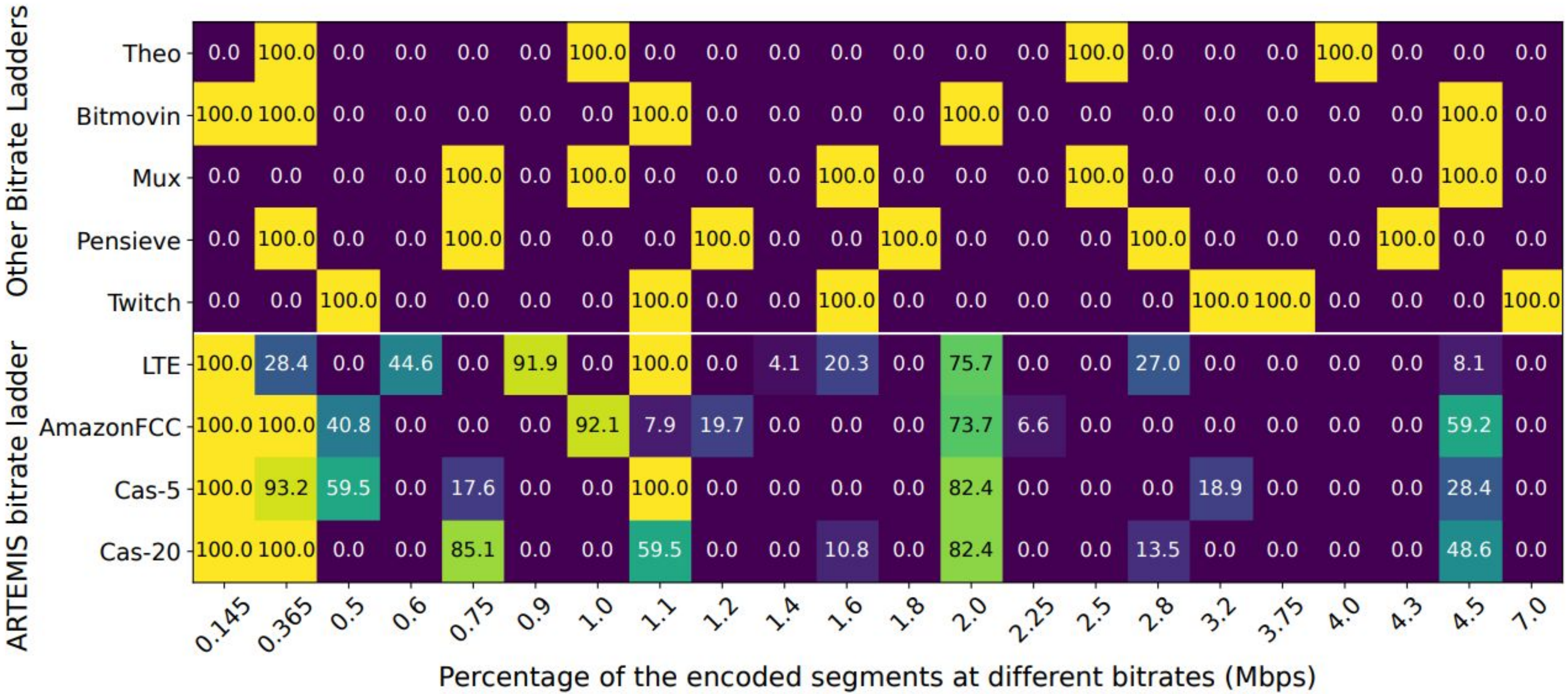
for each time slot **do**
  $R \leftarrow [], T \leftarrow [], F \leftarrow \varnothing, O^* \leftarrow \varnothing$
  while in CI **do** ▷ CI interval starts
    $T, R \leftarrow$ ProcessCDNlogs()
    $F \leftarrow$ QualityFunction()
  end while ▷ OT interval starts
  $\alpha, f_1 \leftarrow$ StallAnalysis(T) ▷ Algorithm 2
  $O, q \leftarrow$ Optimization(α, O^*, R, F)
  if f_1 **then**
    SendOTLtoAOagent(O)
    $O^* \leftarrow O$
  else
    $f_2 \leftarrow$ QualityAnalysis(q, F) ▷ Alg. 3
    if f_2 **then**
      SendOTLtoAOagent(O)
      $O^* \leftarrow O$
    end if
  end if
end for

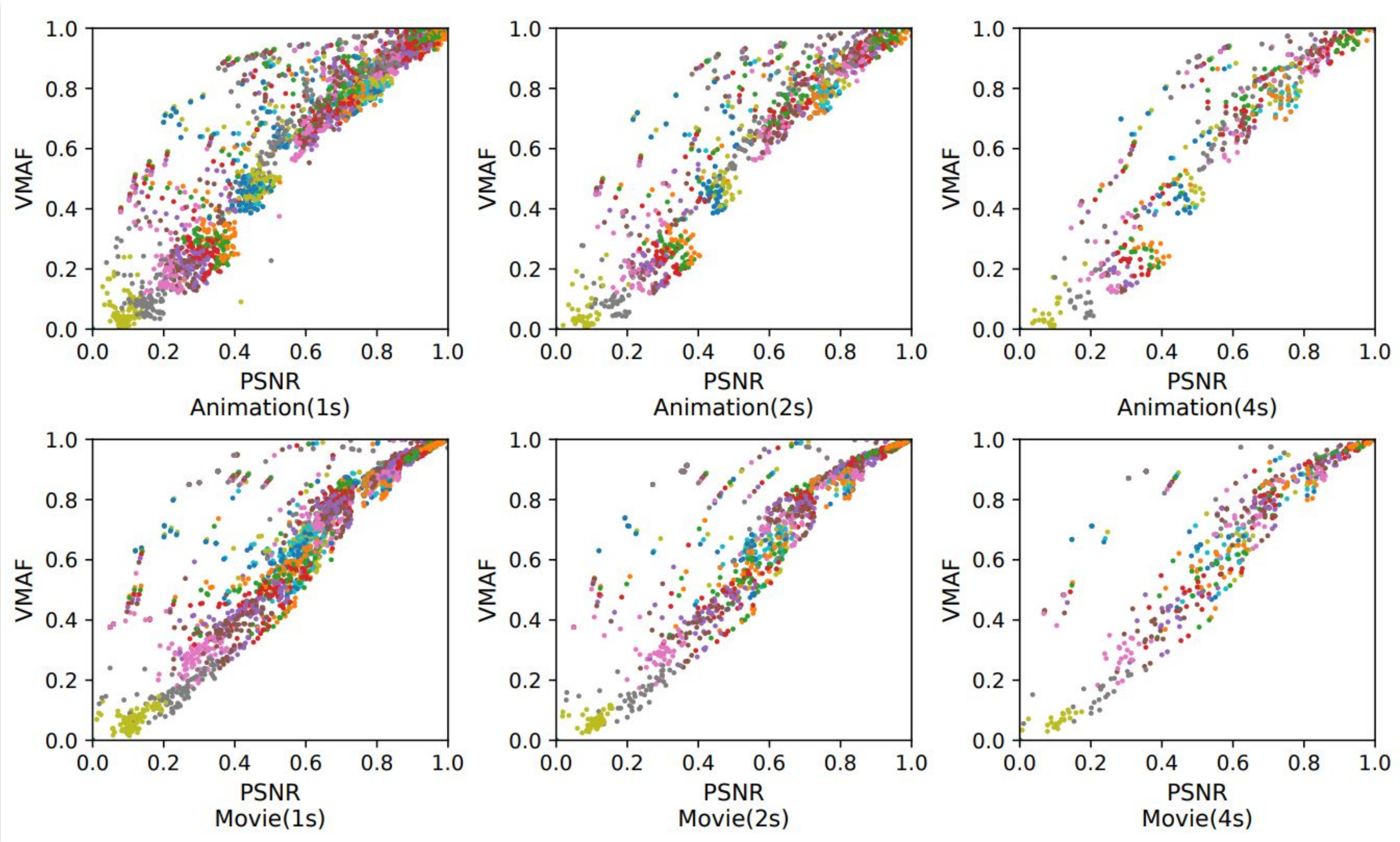
Algorithm 2 StallAnalysis Function

Inputs: LastStall, StallAlpha
function StallAnalysis(T)
  $l^* \leftarrow$ mean(T)
  $\alpha \leftarrow$ SelectAlpha(StallAlpha, l^*)
  $l \leftarrow$ LastStall
  if $l == 0$ **then**
    $t \leftarrow min(1, l^*)$
  else
    $t \leftarrow min(1, \frac{l^* - l}{l})$
  end if
  LastStall $\leftarrow l^*$
  $p \leftarrow$ GenerateRandom(uniform[0,1))
  if $p \leq t$ **then**
    $f \leftarrow$ **True**
  else
    $f \leftarrow$ **False**
  end if
  return α, f
end function

Algorithm 3 QualityAnalysis Function

Inputs: O^*
function QualityAnalysis(q, F)
  $d \leftarrow []$
  for $i \in B$ **do**
    d.append(DiffQuality(b_i,r_i,a_i,F,i))
  end for
  $q^* \leftarrow mean(d)$
  if $q == 0$ **then**
    $t \leftarrow min(1, q^*)$
  else
    $t \leftarrow min(1, \frac{q^* - q}{q})$
  end if
  $p \leftarrow$ GenerateRandom(uniform[0,1))
  if $p \leq t$ **then**
    return True
  else
    return False
  end if
end function


Other Bitrate Ladders
ARTEMIS bitrate ladder
Theo 0.0 100.0 0.0 0.0 0.0 0.0 100.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 100.0 0.0 0.0 0.0 100.0 0.0 0.0 0.0
Bitmovin 100.0 100.0 0.0 0.0 0.0 0.0 0.0 100.0 0.0 0.0 0.0 0.0 100.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 100.0 0.0
Mux 0.0 0.0 0.0 0.0 100.0 0.0 100.0 0.0 0.0 0.0 100.0 0.0 0.0 0.0 100.0 0.0 0.0 0.0 0.0 0.0 100.0 0.0
Pensieve 0.0 100.0 0.0 0.0 100.0 0.0 0.0 0.0 100.0 0.0 0.0 100.0 0.0 0.0 0.0 100.0 0.0 0.0 0.0 100.0 0.0 0.0
Twitch 0.0 0.0 100.0 0.0 0.0 0.0 0.0 100.0 0.0 0.0 100.0 0.0 0.0 0.0 0.0 0.0 100.0 100.0 0.0 0.0 0.0 100.0
LTE 100.0 28.4 0.0 44.6 0.0 91.9 0.0 100.0 0.0 4.1 20.3 0.0 75.7 0.0 0.0 27.0 0.0 0.0 0.0 0.0 8.1 0.0
AmazonFCC 100.0 100.0 40.8 0.0 0.0 0.0 92.1 7.9 19.7 0.0 0.0 0.0 73.7 6.6 0.0 0.0 0.0 0.0 0.0 0.0 59.2 0.0
Cas-5 100.0 93.2 59.5 0.0 17.6 0.0 0.0 100.0 0.0 0.0 0.0 0.0 82.4 0.0 0.0 0.0 18.9 0.0 0.0 0.0 28.4 0.0
Cas-20 100.0 100.0 0.0 0.0 85.1 0.0 0.0 59.5 0.0 0.0 10.8 0.0 82.4 0.0 0.0 13.5 0.0 0.0 0.0 0.0 48.6 0.0
0.145 0.365 0.5 0.6 0.75 0.9 1.0 1.1 1.2 1.4 1.6 1.8 2.0 2.25 2.5 2.8 3.2 3.75 4.0 4.3 4.5 7.0
Percentage of the encoded segments at different bitrates (Mbps)

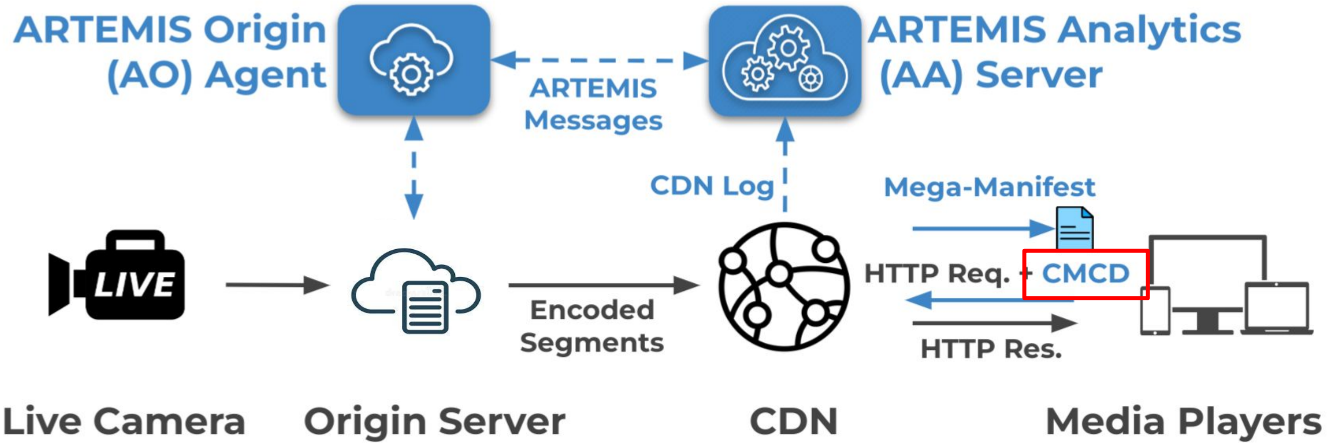

1.0
0.8
0.6
0.4
0.2
0.0
VMAF
0.0 0.2 0.4 0.6 0.8 1.0
PSNR
Animation(1s)
Animation(2s)
Animation(4s)
Movie(1s)
Movie(2s)
Movie(4s)

How to Set α?

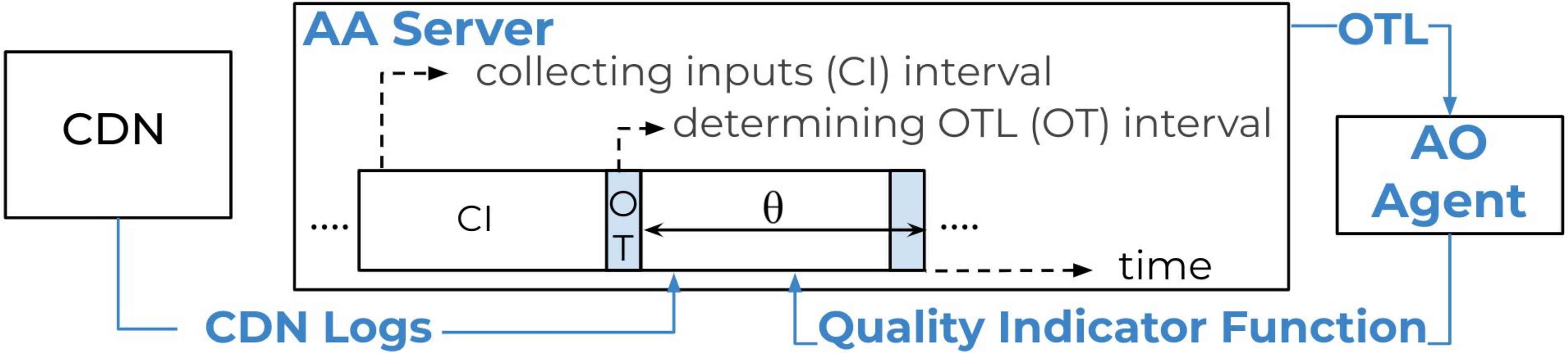
Set α based on the received stall information from the players in CMCD.

StallAlpha={α1:(t1,t2),α2:(t2,t3),...}

StallAlpha={1 : [0,1], 0.9 : [1,2], 0.8 : [2,3], 0.7 : [3,4], 0.6 : [4,5], 0.5 : [5,100]}



Time-slotted Operation by ARTEMIS



When Should OTL be Updated?

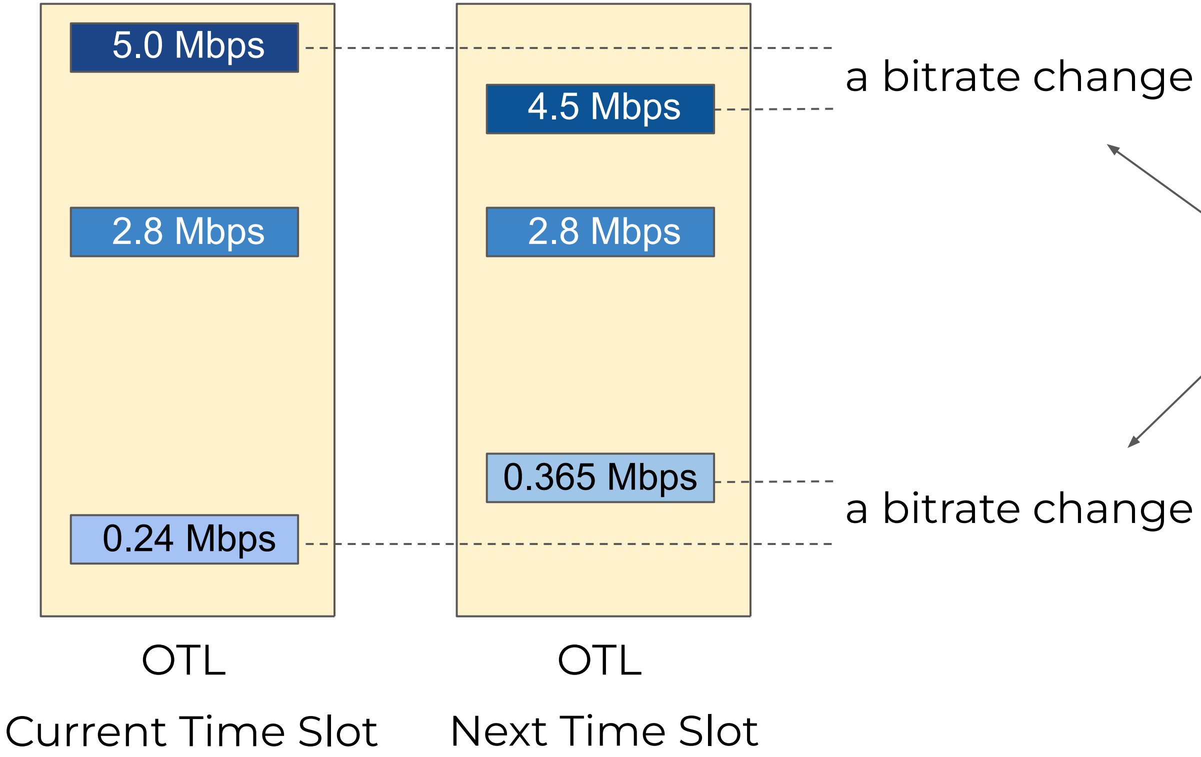
If compared to the previous timeslot, the stall is going up, or the new OTL significantly improves the quality.

if $(rand() \leq P1)$ or $(rand() \leq P2)$ **then**
  Update OTL
end

$L1 \leftarrow$ Mean stall in previous OT
$L2 \leftarrow$ Mean of the current stall
$P1 \leftarrow min(1, L2)$
if $L1 \neq 0$ **then**
  $P1 \leftarrow \min(1, \frac{L2-L1}{L1})$
end

$L1 \leftarrow$ Mean quality impr. by previous OTL
$L2 \leftarrow$ Mean quality impr. by the new OTL
$P2 \leftarrow min(1, L2)$
if $L1 \neq 0$ **then**
  $P2 \leftarrow \min(1, \frac{L2-L1}{L1})$
end

OTL : Changes between Consecutive Time Slots



The number of bitrate changes is at most β (e.g., 2)

Comparing Stall, VMAF, QoE, and **Encoded/Served Bitrate**