

END-TO-END 360° VIDEO STREAMING OVER HTTP/3: ARCHITECTURE AND IMPLEMENTATION

Felipe R. Rosa¹ **Simone Ferlin**^{2,3} **Anna Brunstrom**² **Bruno Kimura**¹

¹Federal University of São Paulo

²Karlstad University

³Red Hat

July 22, 2025

GLOSSARY

1	Introduction	2
2	Background	4
2.1	360° Videos	4
2.2	HTTP/2 and QUIC(HTTP/3)	5
3	Architecture	6
3.1	360°Video Emulator	6
3.2	Operating Modes	7
4	Implementation	8
4.1	DRL-Based ABR	8
4.2	Approaches Used	9
4.3	Network Emulation	10
4.4	Video Processing	11
5	Results and Evaluation	12
5.1	Quality of Experience	12
5.2	Quality of Service	14
6	Conclusion and Future work	15

INTRODUCTION

▶ **Motivation**

- Video on demand accounts for 70% of internet data traffic Ericsson, 2021.
- Immersive videos remain largely unexplored.

▶ **Problem**

- Immersive videos constant interactions via HMD.
- Requires multi-stream.

▶ **Objective**

- This work aims to create an evaluation environment for immersive transmissions.
- Evaluate some solutions.

INTRODUCTION

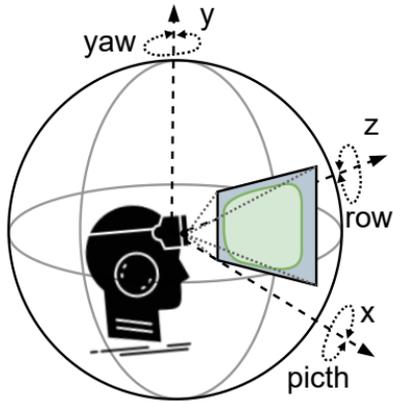
COMPARISON: TRADITIONAL VS 360° VIDEO

Table. Comparison Between Traditional and 360° Videos

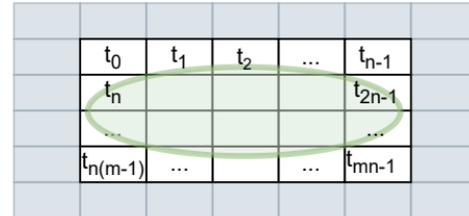
Traditional	360°
Full scene always visible	Scene is partially visible
Static viewport	Dynamic viewport
Wide range of resolutions	Low resolutions not always applicable
Divided into segments	Divided into segments and tiles

BACKGROUND

360° VIDEOS



(a) HMD Movement



(b) FoV and its tiles in viewport $n \times m$

Figure. HMD interaction with a 360° video

BACKGROUND

HTTP/2 AND QUIC(HTTP/3)

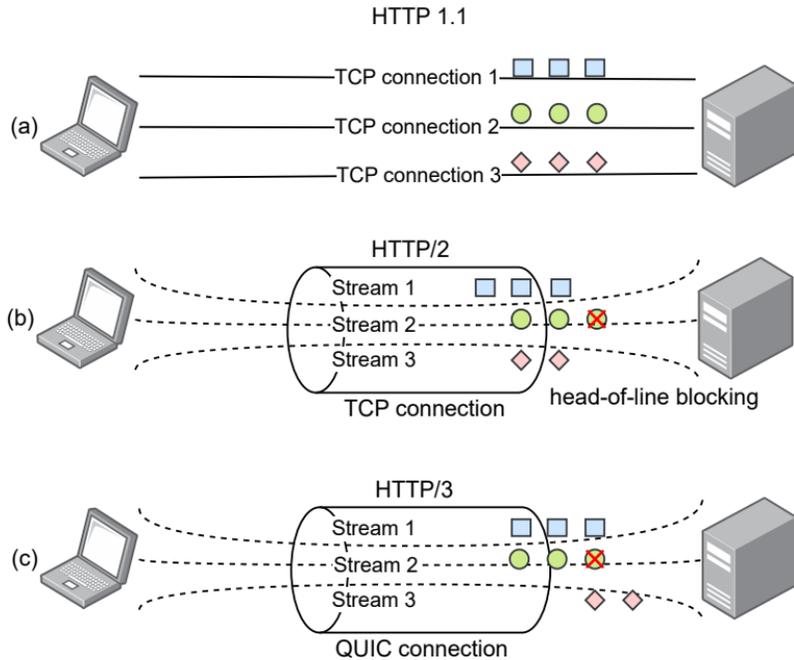


Figure. Stream multiplexing comparison

ARCHITECTURE

360°VIDEO EMULATOR

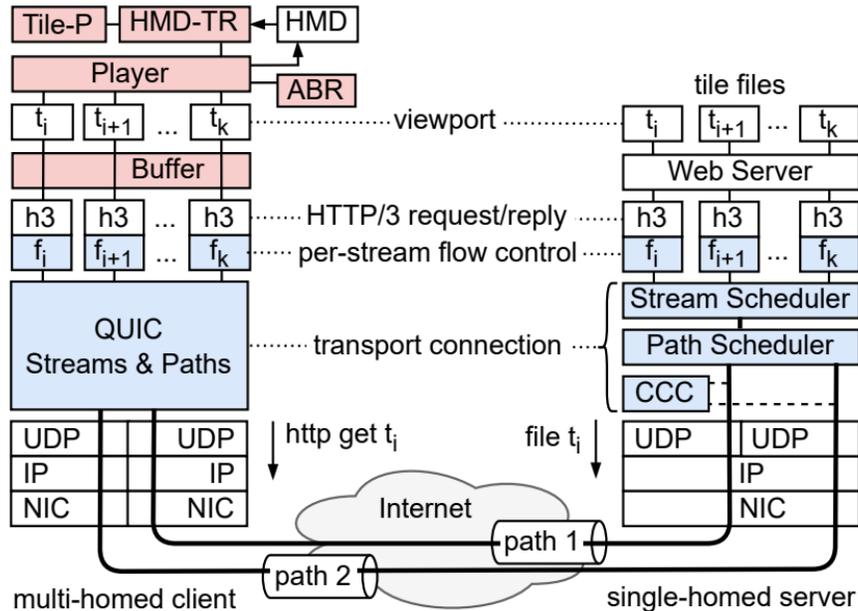


Figure. End-to-end 360° video streaming architecture over HTTP/3. ■ AStream ■ QUIC ■ system.

ARCHITECTURE

OPERATING MODES

▶ Playback

- Blocking (B): Requires all tiles in the FoV.
- Non-Blocking (NB): Requires only central tiles.

▶ Request

- Default: Tiles are requested with equal stream priority.
- Prioritised: Using SA-ECF Rabitsch et al., 2018, streams have different scheduling priorities.

▶ Transmission

- Single-Path (Sp).
- Multi-Path (Mp).
- Sequential tile transmission (single stream) is supported but not evaluated here, focusing on HTTP/3/QUIC's native multi-stream efficiency.

IMPLEMENTATION

DRL-BASED ABR

- ▶ Gelato Patel et al., 2024 is a state-of-the-art ABR based on machine learning. It was adapted for immersive streaming with tile-based delivery.
- ▶ Pre-trained models:
 - Gelato-R: Uses random trace selection during DRL training.
 - Gelato-PS: Employs the Plume-Static strategy to mitigate trace distribution bias.
- ▶ Input data is collected from real-world transmissions on the *puffer* platform
- ▶ Adaptations for immersive streaming:
 - Download size estimation accounts for bitrate, segment duration, and number of tiles in the FoV.
 - Stall quantification includes *tile miss* events

IMPLEMENTATION

APPROACHES USED

Table. 360° video streaming approaches

Solution		MpB	MpNb	MpSaB	MpSaNb	MpSaNbR	SpB	SpNb
Transport	MPQUIC	□	○	△	+	*		
	QUIC						◇	▽
Priority	$P = \{p\}$	□	○				◇	▽
	$P = H \cup L$			△	+	*		
Stream	Default	□	○				◇	▽
	SA-ECF			△	+	*		
Buffer	Blocking	□		△			◇	
	Non-blocking		○		+	*		▽
Quality	$B = ABR()$	□	○	△	+		◇	▽
	$dec(B, \forall L)$					*		

IMPLEMENTATION

NETWORK EMULATION

- ▶ Emulation performed using *mpshell*, a modified version of mahimahi
- ▶ Traces collected from puffer TV¹ (10/2022-10/2023).
- ▶ Traces categorised into 3 throughput groups:
 - Low (< 2.5 Mbps): Below first quartile
 - Medium (2.5-9 Mbps): Second and third quartiles
 - High (> 9 Mbps): Upper quartile
- ▶ Network scenarios:
 - Multi-path: Two network interfaces (high + medium throughput traces)
 - Single-path: Single interface with high throughput trace
 - Emulate heterogeneous environments (WiFi + 5G)
 - Isolate impact of single-path vs multi-path transmission

¹ <https://puffer.stanford.edu/>

IMPLEMENTATION

VIDEO PROCESSING

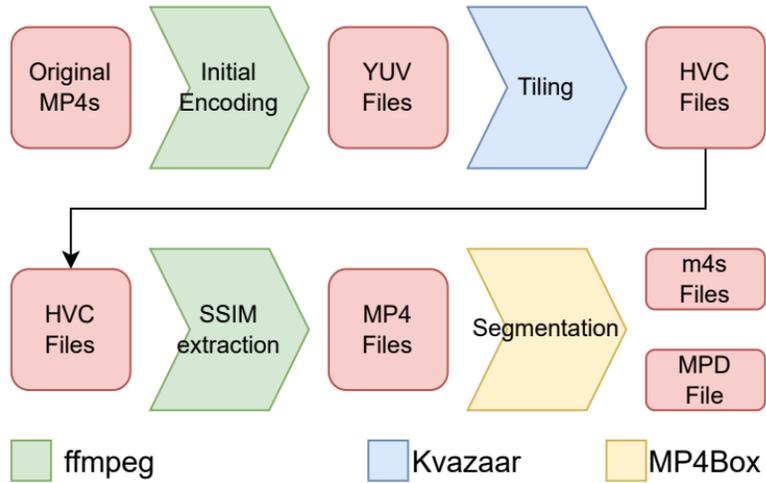
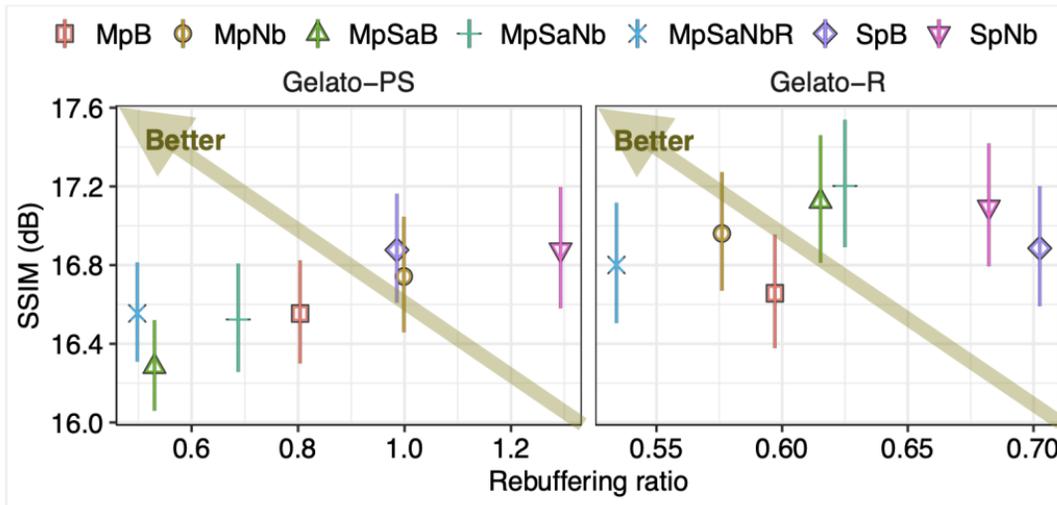


Figure. Video Processing pipeline

RESULTS AND EVALUATION

QUALITY OF EXPERIENCE

Mp: multi-path **Sa:** Sa-ecf **B:** blocking **R:** bitrate reduction
Sp: Single-path **Nb:** non-blocking



(a) SSIM versus number of stalls

RESULTS AND EVALUATION

QUALITY OF EXPERIENCE

Mp: multi-path **Sa:** Sa-ecf **B:** blocking **R:** bitrate reduction
Sp: Single-path **Nb:** non-blocking

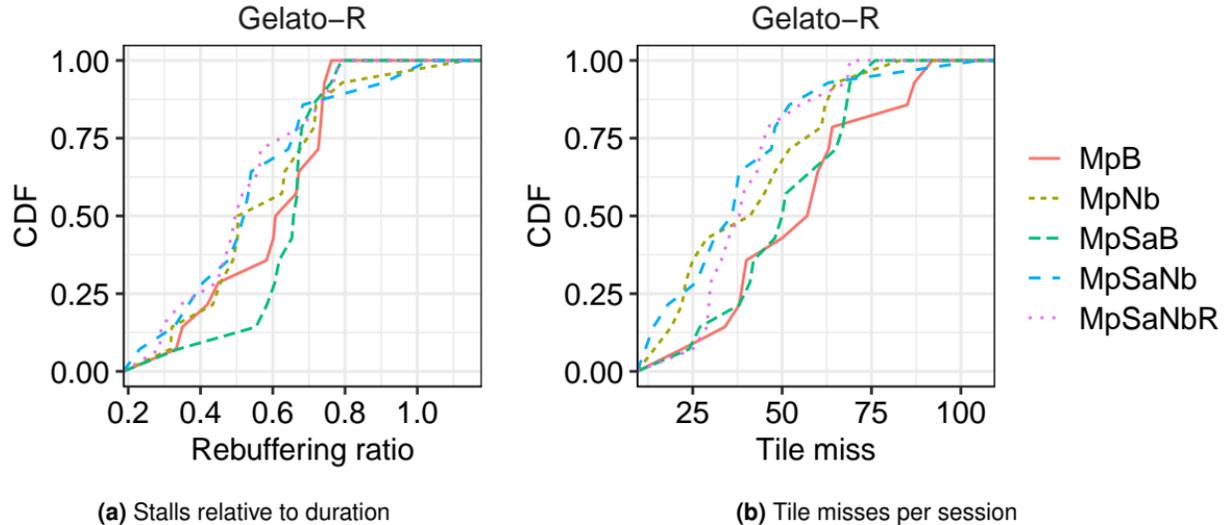
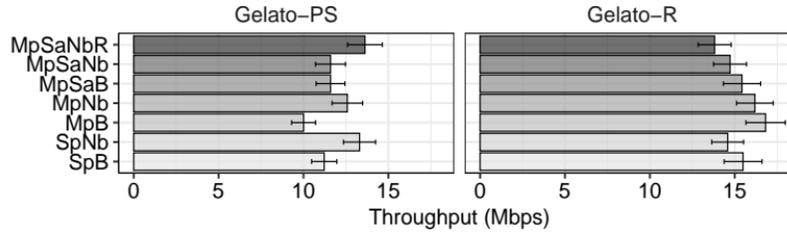


Figure. QoE comparison across scenarios

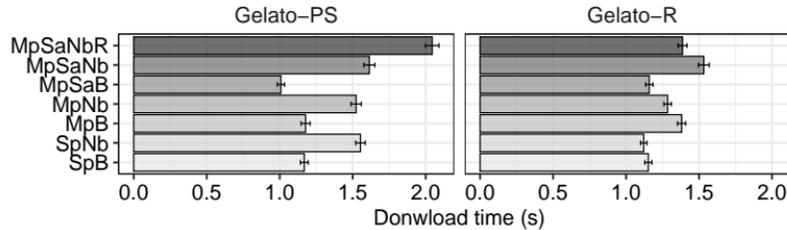
RESULTS AND EVALUATION

QUALITY OF SERVICE

Mp: multi-path **Sa**: Sa-ecf **B**: blocking **R**: bitrate reduction
Sp: Single-path **Nb**: non-blocking



(a) By stream group



(b) By tile stream

Figure. QoS results per ABR and scenario

CONCLUSION AND FUTURE WORK

- ▶ Implemented an end-to-end architecture using state-of-the-art solutions (QUIC/MPQUIC, DRL-ABR, HTTP/3).
- ▶ Demonstrated QoE improvements through multi-path transmission.
- ▶ QoS improvement through multi-stream prioritisation usage.
- ▶ Stalls remain the biggest challenge.
- ▶ Tile-hit based priority.
- ▶ New components: Tile-level ABR, real-time HMD movement predictor.

THE END

END-TO-END 360° VIDEO STREAMING OVER HTTP/3: ARCHITECTURE AND IMPLEMENTATION

Felipe R. Rosa¹ **Simone Ferlin**^{2,3} **Anna Brunstrom**² **Bruno Kimura**¹

¹Federal University of São Paulo

²Karlstad University

³Red Hat

July 22, 2025