Prioritized Buffer Control in Two-tier 360 Video Streaming

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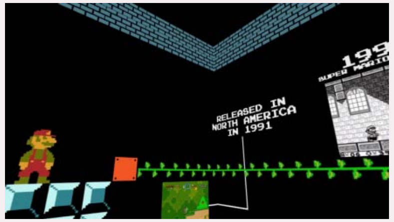
Agenda

- Motivation and Technical Challenges
- Two-Tier 360V Streaming Solution
- Prioritized Buffer Control in Two-Tier 360V Streaming
- System Settings and Evaluations
- Experimental Results
- Conclusions and Future Work

Motivation

Virtual Tour:

Gaming:



Sport:

Show:

Entertainment:

Training:

Technical Challenges

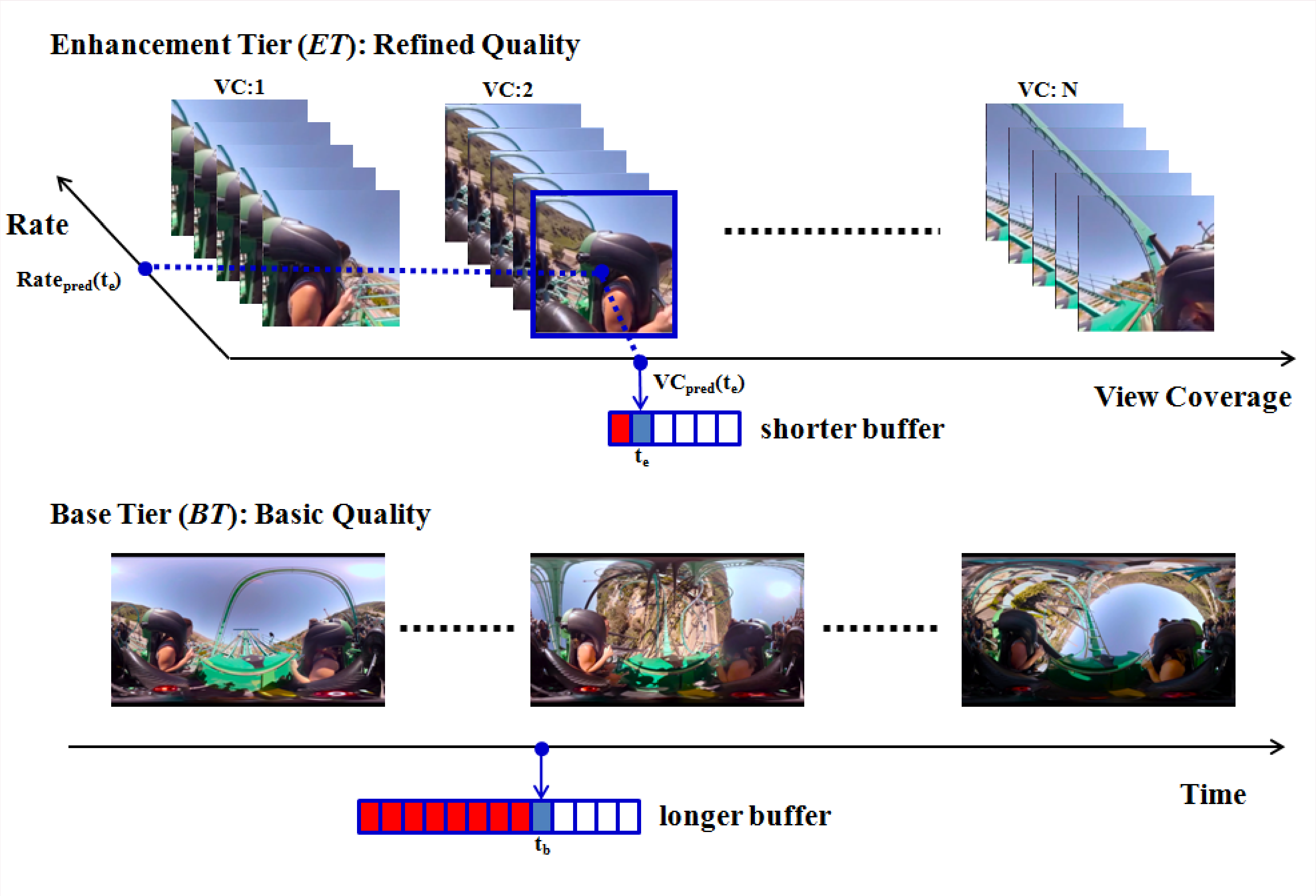
- Challenge 1:
  Bandwidth Requirements

- Challenge 2:
  User View Direction Dynamics

Two-Tier 360V Streaming System

- Base tier streams chunks covering the entire 360 degree view in low quality with a long prefetching buffer.
- Enhancement tier streams chunks covering the predicted FoV with a short prefetching buffer.
- When the predicted FoV is correct and the enhancement tier chunks arrive on time, the viewer sees high quality.
- Otherwise, the viewer sees low quality.

Two-Tier 360V Streaming System



View Prediction
Bandwidth Prediction

REQUEST

RESPONSE

Prioritized Buffer Control

Prioritized Buffer-Based 360 Video Streaming

Prioritized base-tier (BT) downloading to ensure video playback continuity.

If $q^b(t) < q^b_{ref}$, ALWAYS sequentially download base-tier chunks until sufficient

Proportional-Integral (PI) control-based enhancement-tier (ET) downloading to utilize residual bandwidth

Control Signal: $u(k) = K_p\left(q^e\left(t_k^{(s)}\right) - q^e_{ref}\right) + K_I \sum_{t=0}^{t_k^{(s)}} \left(q^e(t) - q^e_{ref}\right)$

Target Request Rate: $\hat{R}(k) = \min\left[(u(k)+1,), \frac{\Delta(k)}{\tau}\right] \cdot \hat{b}(k)$

K_p K_I P-I-controllers

$\langle q^b_{ref}, q^e_{ref}\rangle$ BT and ET target buffer lengths

$\langle q^b(t), q^e(t)\rangle$ BT and ET dynamic buffer lengths

$\hat{b}(k)$ Predicted bandwidth

$\Delta(k)$ Remaining time of chunk k before display deadline

τ Video chunk duration

Prioritized Buffer Control

Prioritized Buffer-Based 360 Video Streaming

$q^e(t)$ *should be determined to balance the system robustness against network variation and the prediction accuracy.*

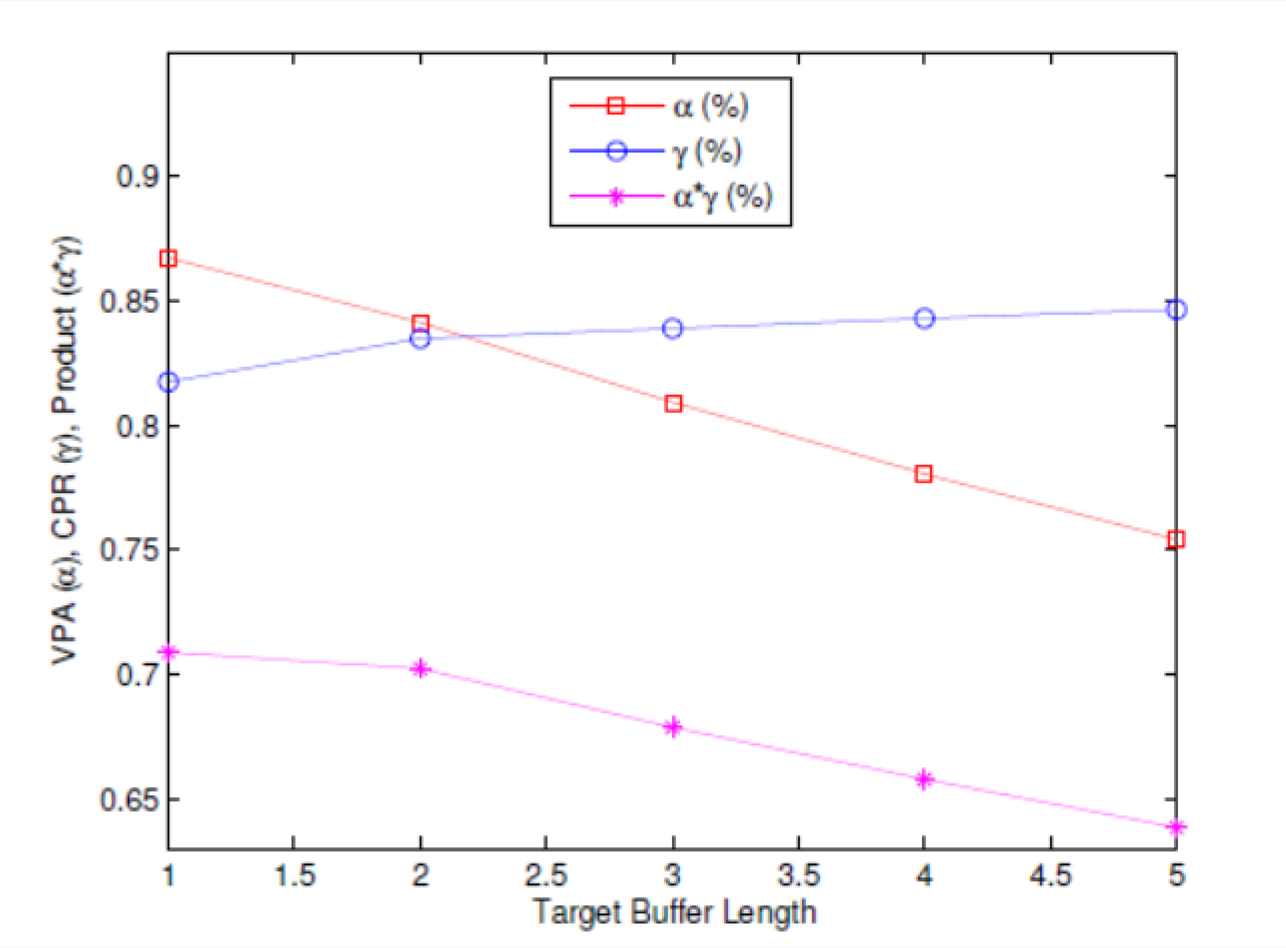
In this work, $q^e(t)$ *is chosen based on video rendering rate metric:*

$$R_{VRR}\left(q^e_{ref}\right) = \frac{R_b}{A_b} + \alpha \cdot \gamma \cdot \frac{R_e}{A_e}$$

R_b	R_e	BT and ET chunk bit-rates
A_b	A_e	BT viewing area (i.e., 360V full scope), ET viewing area (i.e., FoV coverage area)
	α	View Prediction Accuracy (VPA), i.e., the average overlapping ratio between the predicted view coverage and user's actual FOV.)
	γ	Chunk Pass Rate (CPR), i.e., the likelihood that a requested chunk can be delivered before its display deadline.

Prioritized Buffer Control

Prioritized Buffer-Based 360 Video Streaming



The ET target buffer length that maximizes the product of *VPA* and *CPR* should maximize the delivered video rendering rate, and therefore maximize the user end average video quality.

System Settings and Evaluations

Videos:

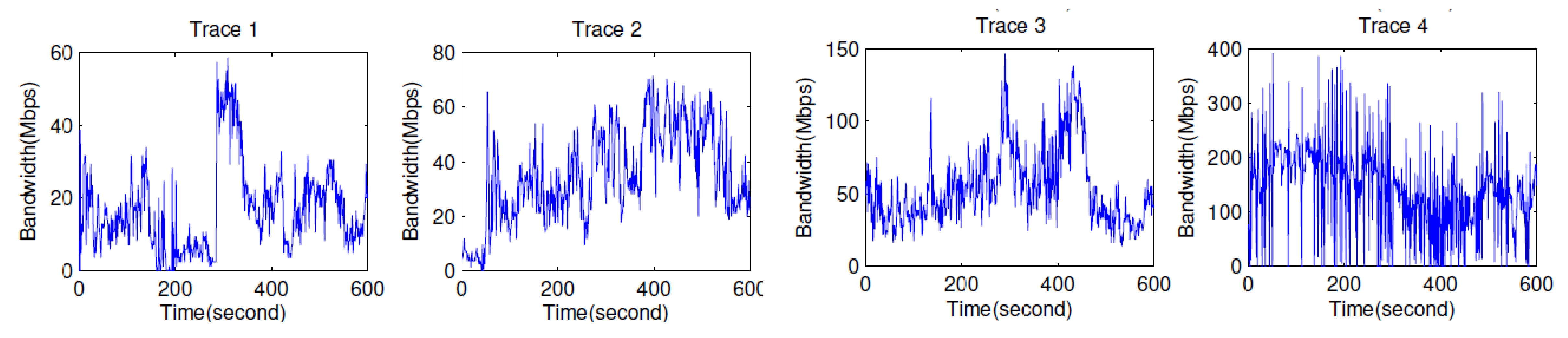
Two test videos are used: “MegaCoster” and “Amsterdam”

Each chunk is horizontally partitioned into 12 overlapping *ET* viewports and vertically partitioned into 3 overlapping *ET* viewports, each covering 120 × 90 degrees.

The *ET* chunks encodes the difference signal between original 360 video and the *BT* low-rate video in three different bitrate settings R_1 , R_2 and R_3.

System Settings and Evaluations

- Network Bandwidth Trace:

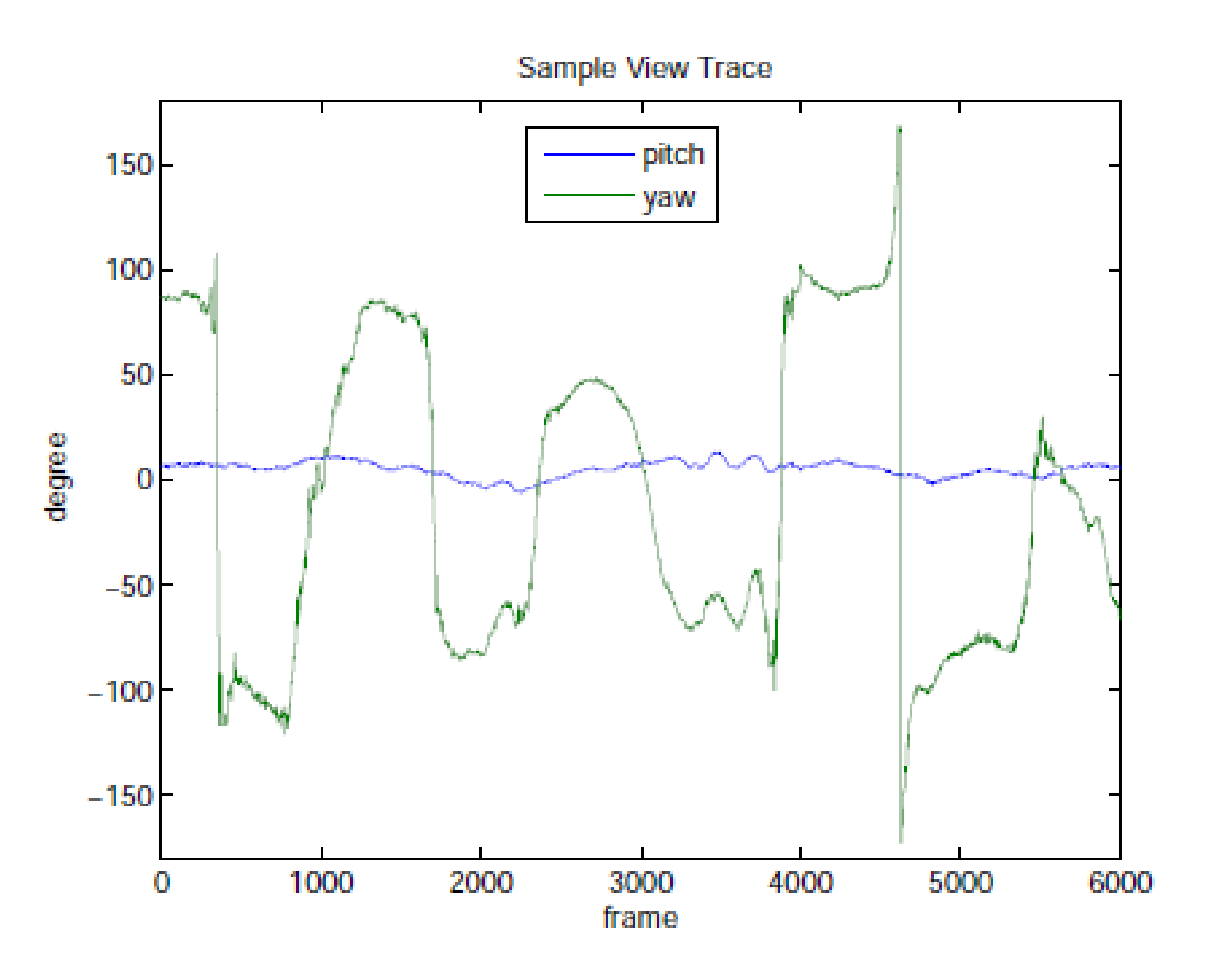


Sample Network Trace. Collected over a 3.5G HSPA[3] cellular network to represent the most typical bandwidth variations in a cellular environment. Scaled up to mimic the 4K-30Hz-8-bit 360 degree video bitrate range (e.g., up to 400 Mbps).

[3] E. Kurdoglu, Y. Liu, Y. Wang, Y. Shi, C. Gu, and J. Lyu. "Real-time Bandwidth Prediction and Rate Adaptation for Video Calls over Cellular Networks," IACM Multimedia Systems Conference, 2016.

System Settings and Evaluations

- View Direction Trace Collection:



Sample View Trace.

Collected From 4 users wearing a Google Cardboard with a Motorola Nexus-6 smart-phone playing our test 360 videos. Motion data (yaw, pitch, roll) captured through head tracker program.

System Settings and Evaluations

- Bandwidth Prediction:

  The sustainable transmission rate for the next chunk set to the average throughput for downloading the last received chunk (from either *BT* or *ET*).

- View Prediction:

  The desired viewport center for the incoming video chunk is linearly predicted based on the past 30 samples collected from the client.

Evaluation Metric

- Delivered Video Rendering Rate (*VRR*)

$$VRR(n) = w_b \cdot R^b(n) + w_f \cdot R^e(n)$$

$R^b(n)$ $R^e(n)$ Delivered *BT* and *ET* bitrate for chunk n

w_b Overlapping portion of the desired FOV and the 360 view decoded from the BT (in our setting, 1/6)

w_f Overlapping portion between the ground-truth FOV per frame and the VC of the downloaded ET chunk.

- Video Freeze Ratio (*VFR*)

The percentage of total time that video buffer underflows (i.e. no bits are available for the user FOV at the display time).

Benchmark Systems

- Benchmark 1 (*BS1: All-360*): simulates the conventional DASH streaming framework, in which videos in the entire 360 view range are pre-encoded using multiple rates.

- Benchmark 2 (*BS1: FoV Streaming*): pre-codes view coverages with the same settings as our enhancement-tier only but coded directly with multiple rates.

Performance Evaluation

Network Trace Solution	1 *BS1*	1 *BS2*	1 TTS	2 *BS1*	2 *BS2*	2 TTS
RollerCoaster	2.8/12%	10.8/27%	7.9/6%	5.9/4%	27.0/10%	21.1/4%
Amsterdam	2.8/12%	10.5/25%	7.7/6%	5.9/4%	27.3/10%	22.3/3%

Network Trace Solution	3 *BS1*	3 *BS2*	3 TTS	4 *BS1*	4 *BS2*	4 TTS
RollerCoaster	9.0/1%	40.2/2%	36.6/0%	23.0/0%	93.1/8%	108.0/0%
Amsterdam	9.0/1%	39.3/2%	36.1/0%	23.0/0%	91.5/7%	106.3/0%

Performance Comparisons: Average Video Rendering Rate (Mbps) / Video Freeze Ratio (%)

- Compared with *BS1*, a 3.7x gain in delivered VRR is achieved on average.
- Much lower video freeze ratio compared with benchmark solutions.
- Demonstrated the potentials and advantages over conventional solutions.

Conclusion and Future Work

- In this work, a two-tier 360V streaming framework with prioritized buffer control is proposed.
- The proposed framework simultaneously handles both network variations and user viewing direction dynamics.
- We plan to further optimize the network and view prediction methodologies and implement the end-to-end system and incorporate perceptual quality evaluation.