Low-Latency Live Video Streaming over Low-Earth-Orbit Satellite Networks

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Abstract

- Video streaming currently dominates Internet traffic with an estimated share of 71% of all mobile data traffic, and it is forecast to increase to 80% in 2028.
- Space-Air-Ground Integrated Networks (SAGINs) are promising to transform future Internet connectivity by merging the capabilities of space, aerial, and terrestrial networks.
- By deploying thousands of low-earth-orbit (LEO) satellites, Starlink provides a low latency and high bandwidth Internet service globally, especially extending connectivity to remote and rural areas.
- While the performance of video-on-demand (VoD) services over Starlink is on par with terrestrial networks, challenges remain in low-latency live video streaming, especially given the dynamic and fluctuating network latency in Starlink networks.

Overview

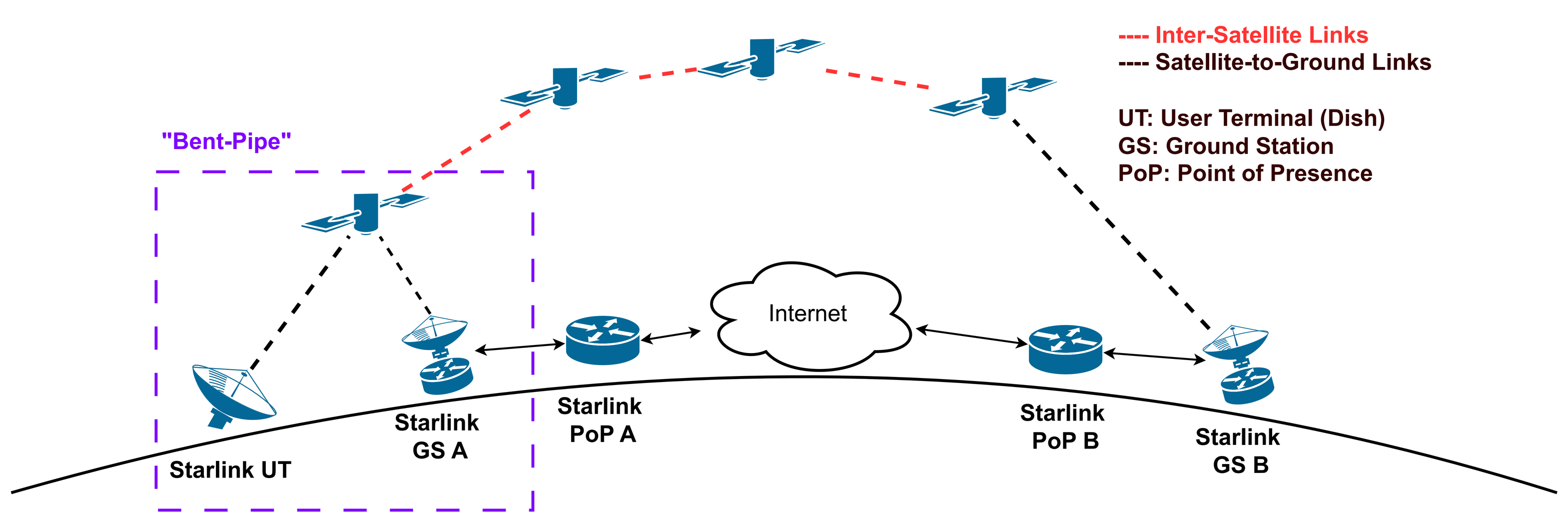


Figure 1. "Bent-Pipe" vs Inter-Satellite Links (ISLs)

- We assessed the performance of Starlink access networks across different protocol layers and geographical locations, taking into account scenarios both with and without ISLs.
- We conducted a latency target-based analysis of three state-of-the-art low-latency live video streaming adaptive bitrate (ABR) algorithms in dash.js over Starlink networks.
- We modeled the low-latency live video streaming problem as an online learning process with contextual multi-armed bandit algorithms and proposed novel ABR algorithms to improve the quality of experience (QoE) of low-latency live video streaming over Starlink networks.
- We implemented an end-to-end prototype of the proposed algorithms with dash.js and evaluated its performance in real Starlink networks.

Starlink Measurement Testbed Setup

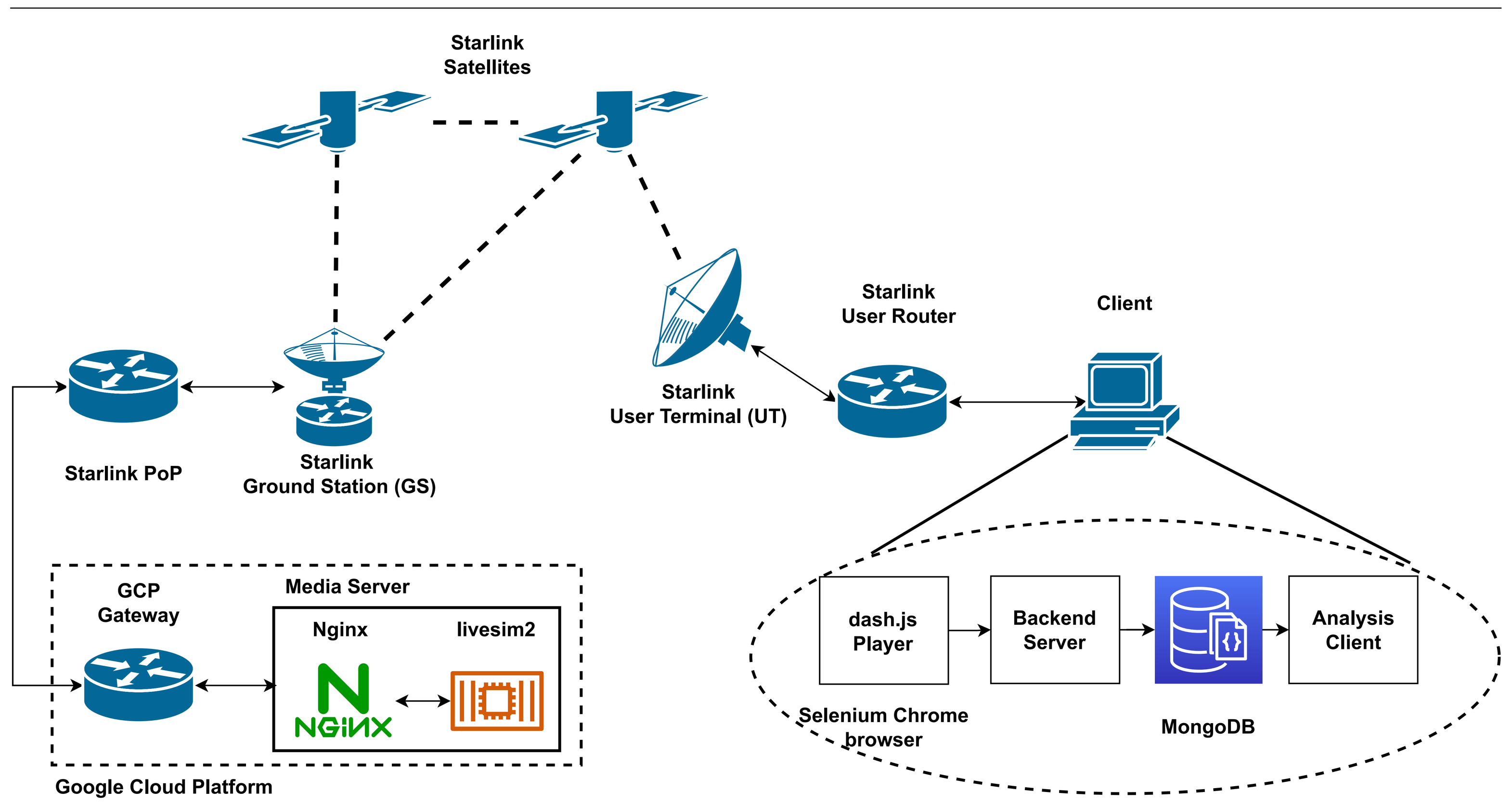


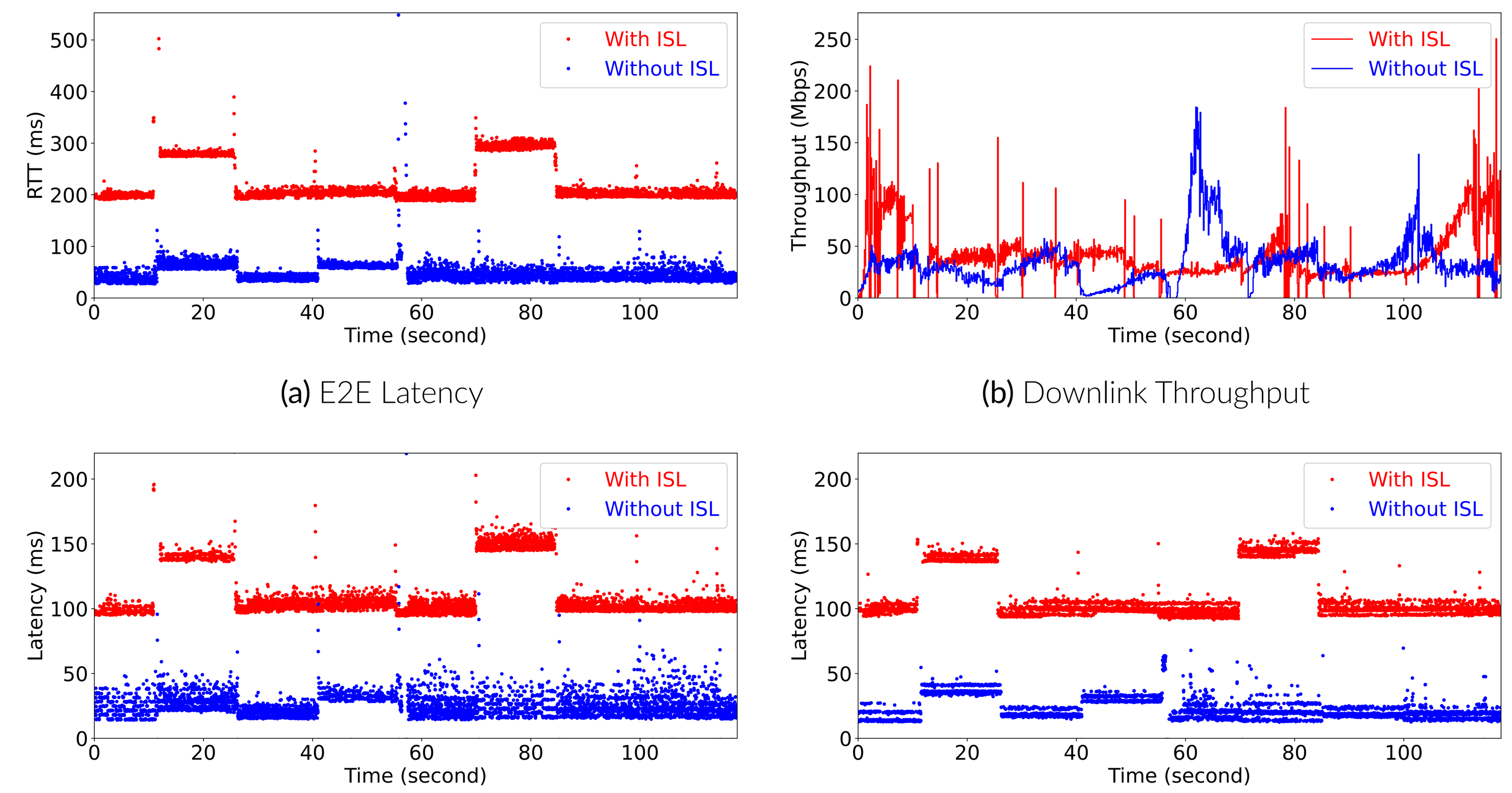
Figure 2. Starlink Measurement Testbed

Experience Starlink near `ECS404`

Come near **`ECS404`** and connect to WiFi SSID **`@starlink`**.

Feel free to **`ping`**, **`mtr`**, **`traceroute`** (**`tracert`** on Windows), speedtest, etc.

Measuring a Low-Earth-Orbit Satellite Network

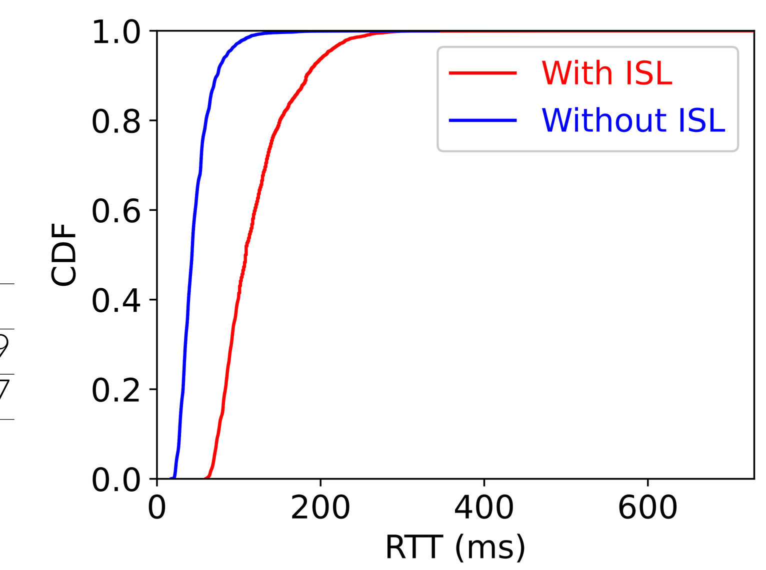


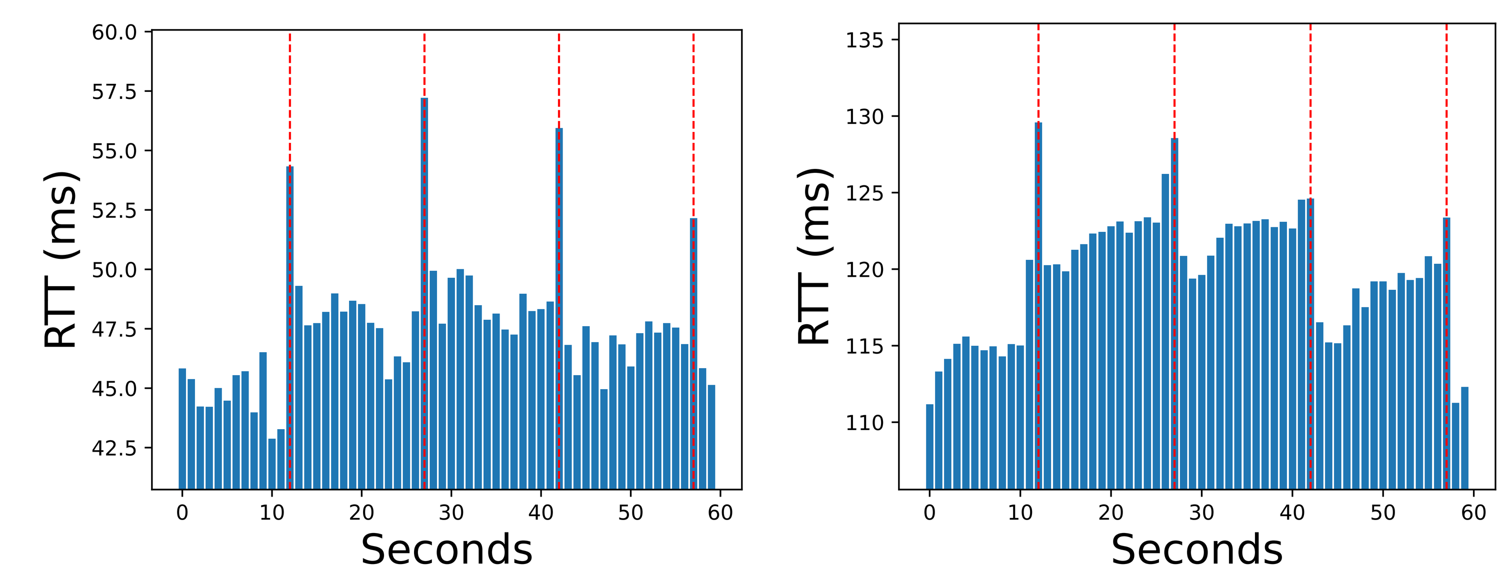
(a) E2E Latency (b) Downlink Throughput (c) Uplink OWD (d) Downlink OWD

Figure 3. Time Synchronized Latency and Throughput

Table 1. Starlink access network latency (ms) to the GS

Starlink Installations	Min	Median	Average	σ
Without ISL	16.7	42.8	47.5	20.9
With ISL	59.1	109.0	119.8	43.7





(a) Avg. RTT without ISL (b) Avg. RTT with ISL

Figure 4. Average RTT to GS at Every Second within a Minute

- SpaceX utilizes a globally time-synchronized scheduler to manage the access network between the UTs and satellites, at the 12th, 27th, 42nd, and 57th seconds of each minute.
- RTT experiences significant fluctuations and is higher than that of conventional Internet.

Table 2. Bitrate ladder of the low-latency live video dataset

Resolution	Frame rate (fps)	Bitrate (Kbps)
1920x1080	50	6000
1920x1080	25	5100
1920x1080	50	4900
1024x576	25	1500
1024x576	25	1200
768x432	25	900
512x288	25	450
480x270	12.5	300

Low-Latency Live Video Streaming over Starlink

Context

When downloading each video segment, the player observes the following context information,

$$b(t) = [\mathrm{L_N}(t), \mathrm{R}(t), \mathrm{X}(t)] \tag{1}$$

where at time t, $\mathrm{L_N}(t)$ is the measured network latency to the media server, $\mathrm{R}(t)$ is the current playback speed, and $\mathrm{X}(t)$ is the estimated network throughput, respectively.

A history $\mathcal{H}^{t-1}$ containing all the previous rewards of the selected arms and their respective contexts up to round $t-1$ can be compiled by the agent before round t. We only consider the history $\mathcal{H}_q^{t-1}$ during the current 15-second timeslot beginning from round q,

$$\mathcal{H}_q^{t-1} = \left\{a(s), r_{a(s)}(s), b(s), s = q, \ldots, t-1\right\} \tag{2}$$

where $a(s)$ denotes the arm played at round s and $r_{a(s)}(s)$ is the reward for arm $a(s)$ at round s, and q is the first round during the current 15-second timeslot.

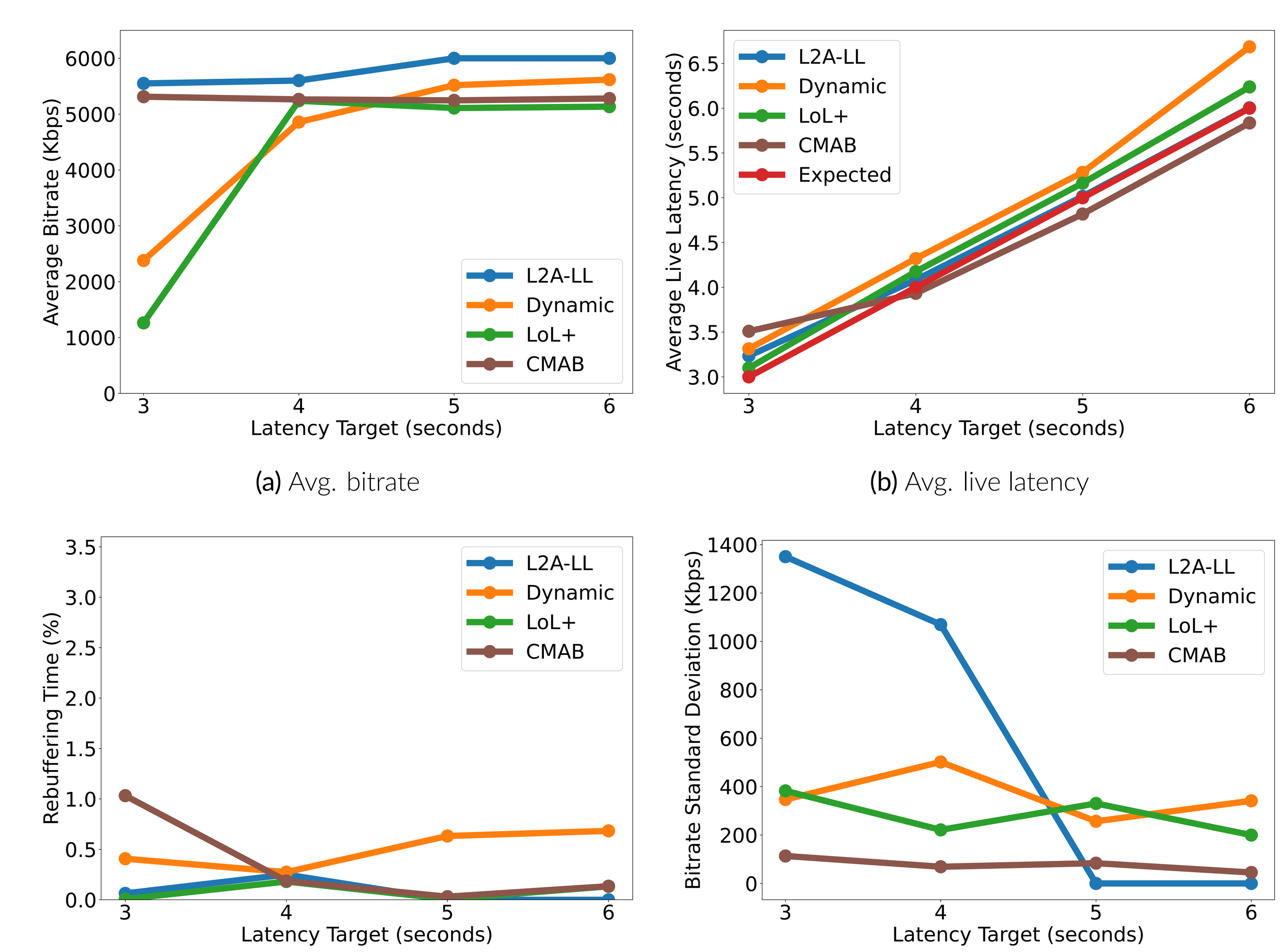
QoE function

$$\mathrm{QoE}(i) = \mathrm{QoE}_{\mathrm{P1203}}(i) * \frac{\mathrm{LL_{target}}}{\mathrm{LL_{current}}(i)} * \frac{\mathrm{B}(i)}{\mathrm{B_{max}}} - \frac{\sum_{j=1}^{C_k} t_j^k}{\sum_{j=1}^{C} t_j}. \tag{3}$$

Playback speed control with satellite handover awareness

- The current buffer level is below the safe threshold, or it is currently within the satellite handover period: slow down the playback speed below 1.0.
- The current buffer level is sufficient, and it is not within the satellite handover period:
  - The live latency is close to the latency target: maintain playback speed at 1.0.
  - The current live latency is lower than the latency target: slow down playback speed.
  - The current live latency is higher than the latency target: speed up playback speed.

Performance evaluation



(a) Avg. bitrate (b) Avg. live latency (c) Rebuffering time (%) (d) Bitrate standard deviation

Figure 5. Performance Evaluation

References

[1] Jinwei Zhao, Jianping Pan, *Low Latency Live Video Streaming over a Low-Earth-Orbit Satellite Network with DASH* Accepted by 2024 ACM 15th Multimedia Systems Conference (MMSys'24)

[2] Jinwei Zhao, Jianping Pan, *QoE-driven Joint Decision-Making for Multipath Adaptive Video Streaming*, Published in 2023 IEEE 42nd Global Communications Conference (GLOBECOM'23)

[3] Jianping Pan, Jinwei Zhao, Cai Lin, *Measuring a Low-Earth-Orbit Satellite Network*, Published in 2023 IEEE 34th Annual International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC'23)