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Enabling High Quality Real-Time Communications with Adaptive Frame-Rate

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Background
Real-Time Communications

Real-Time Communications (RTC) are increasingly popular.

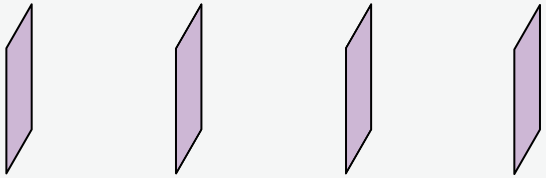
*Slide taken from Salsify [NSDI'18].

Motivation

High-quality RTC

Frame-rate (≥60fps) and *resolution* (≥1080p) increase simultaneously.

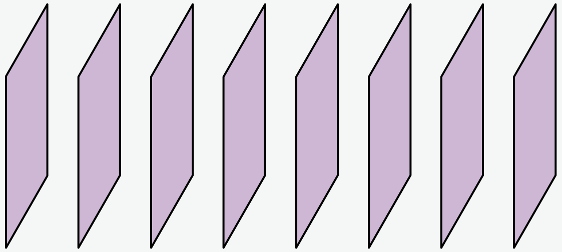
Legacy RTC



240p~720p

5fps~24fps

High-quality RTC



2K~8K

60fps~120fps

Motivation
Latency Variation

Emerging RTC applications asks for extremely low stall ratios!

A 0.3 second stall

*Video source: https://www.youtube.com/watch?v=hfySDsMW8BU

0.1% Stall rate

⇳

Such a 0.3 sec stall happens every 300 secs (5 min)

Motivation
Decoder queue overload

Problem identification: Latency comes from the video client

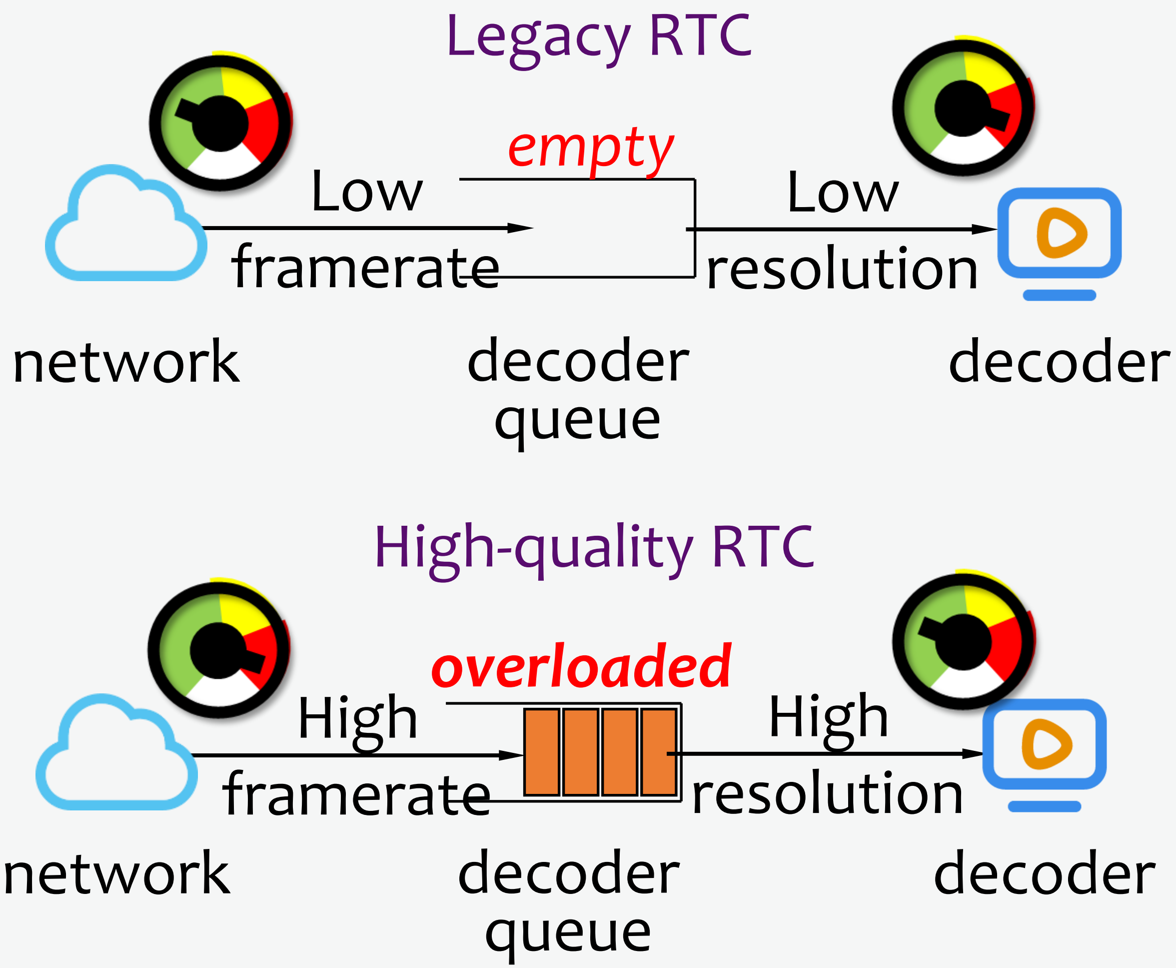
- For cloud gaming with short RTT, the latency at the client device might be unimaginably high.
- Contribute to 57% of end-to-end stutters in Tencent START cloud gaming!

Root cause of a stutter event	
Network	44%
Client device	57%
Server	<1%

Motivation
Decoder queue overload

Problem identification: Increased video quality overloads the video client.

- ➢Decoder queue *between the network and decoder* is not for low latency.
- ➢A queue will be formulated at the client between the application and network stack.



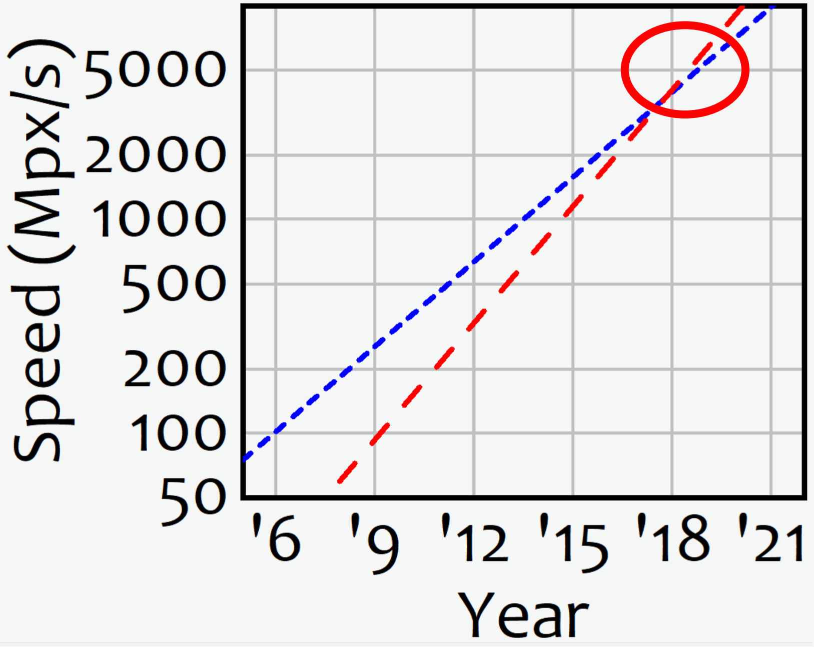
Motivation

Overload is increasingly severe!

Problem identification: Increased video quality overloads the video client.

- Decoder queue *between the network and decoder* is not for low latency.
- More and more common in RTC

Hardware capacity doubles every 27 months

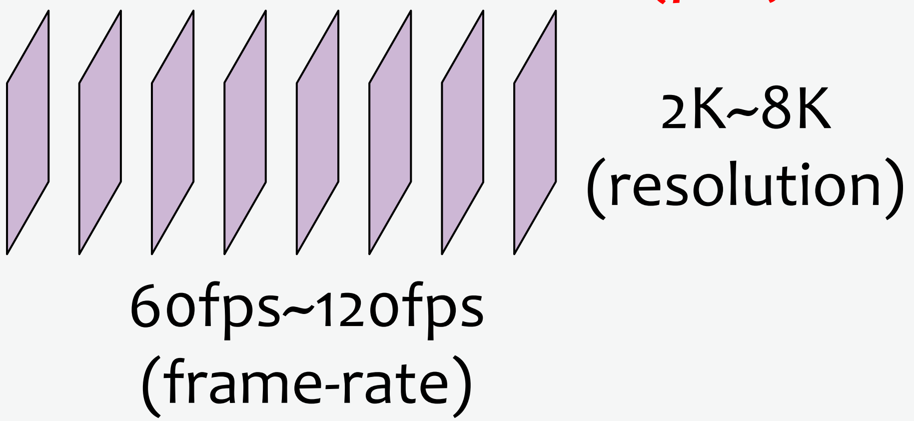


Application demands of Internet video double every 20 months

Design
Adaptive Frame-Rate

Insight: *adapt the frame-rate* to alleviate transient decoder overloads.

- The decoding speed (px/s) depends on the *resolution (px/frame)* and *frame-rate (fps)*.



- Existing work usually *adapt the bit-rate (or resolution)*, which will incur traffic bursts for commercial video codecs.
- We therefore *adapt the frame-rate* to alleviate the overload.

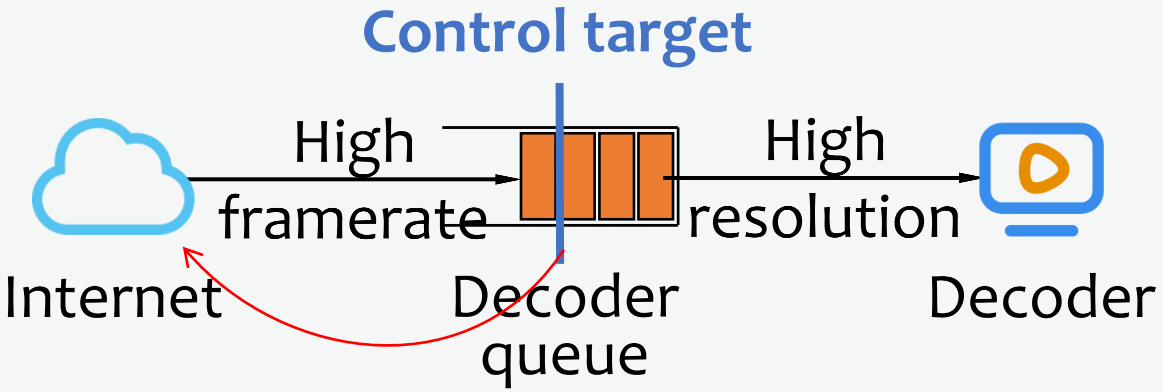
Design
Adaptive Frame-Rate

Insight: *adapt the frame-rate* to alleviate transient decoder overloads.

- The decoding speed (px/s) depends on the *resolution (px/frame)* and *frame-rate (fps)*.

Challenge: achieve an ultra-low queueing delay

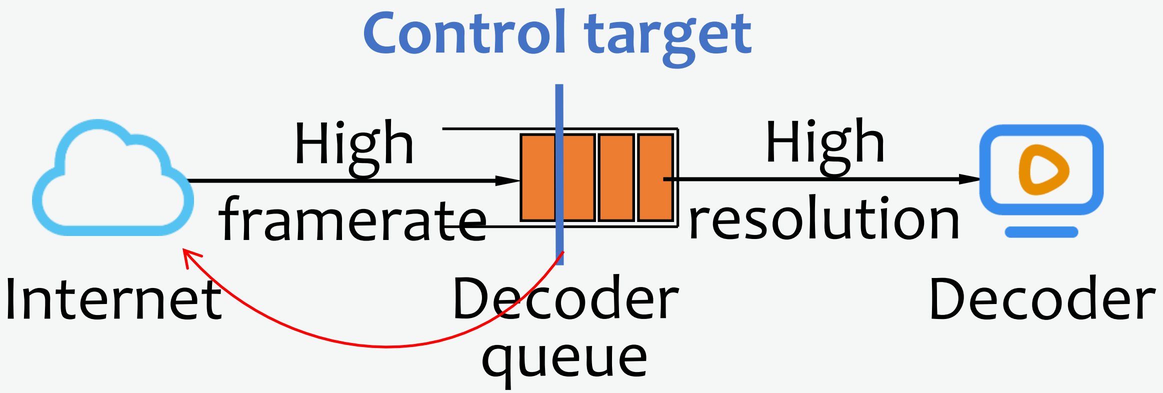
- Existing queue management mechanisms in computer networks *reactively* control the queue length around a target.



Design
Adaptive Frame-Rate

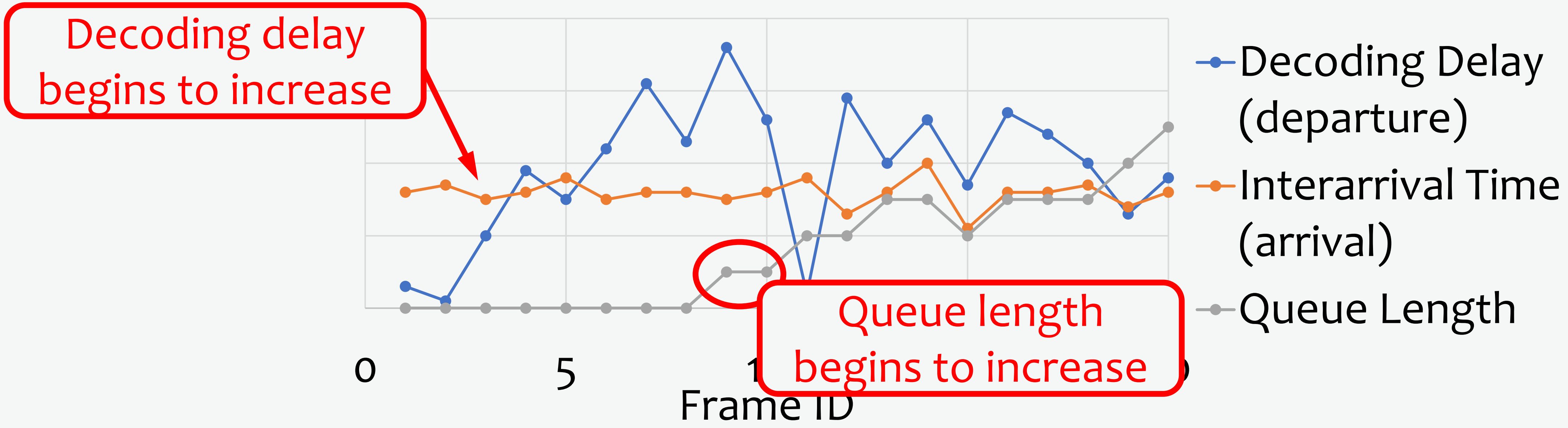
Challenge: achieve an ultra-low queueing delay

- Existing queue management mechanisms in computer networks *reactively* control the queue length around a target.
- Decoder queue is at the granularity of video frames (with an interval of O(10 ms)).
- Even a queue of *one frame* will incur *O(10 ms) delay*.

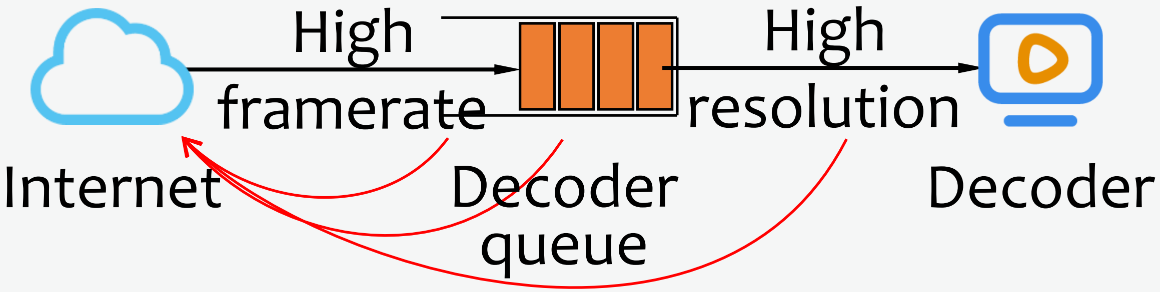


Design
Adaptive Frame-Rate

Solution: *Predictive* frame-rate adaptation.

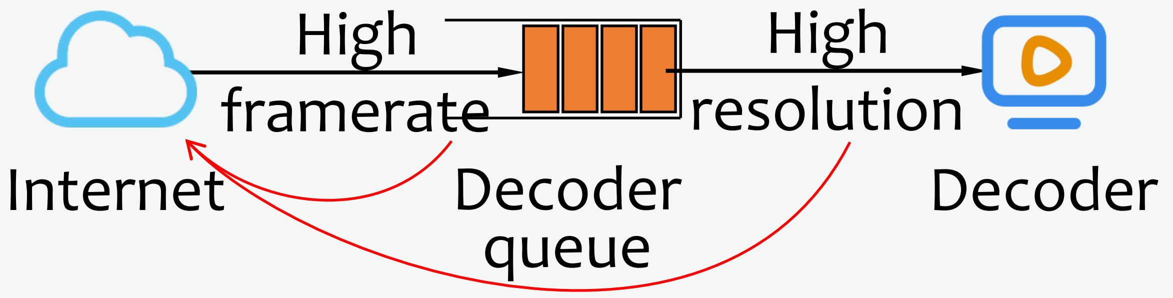


- Predict the queueing delay based on arrivals and departures rather than queue states.



Design
Understanding Queueing Theory

Use Kingman's formula to be aware of both arrivals and departures.



robust to absorb *fluctuation*

$$\mathbb{E}(\tau_{queue}) = \left(\frac{\rho}{1-\rho}\right) \cdot \frac{c_a^2 + c_s^2}{2} \cdot \mu_s$$

adaptive to current decoding speed

$\rho = \frac{arrival\ rate}{departure\ rate}$:

adaptive to rate mismatch *(average)*

Design
Practical Concerns

Various factors can all lead to transient fluctuations.

- Solution: Pattern modelling and matching / filtering

Decoder degradation ➢Frequency downgrades	⇨	Stationary controller (queueing theory)
Burst network arrivals ➢Wireless throttling	⇨	Transient controller (queue length)
Sudden decoder stalls ➢Decoder failure	⇨	Transient controller (head sojourn time)

Please refer to the paper for details!

Evaluation

Experiment Setup

Large-scale trace-driven simulations.

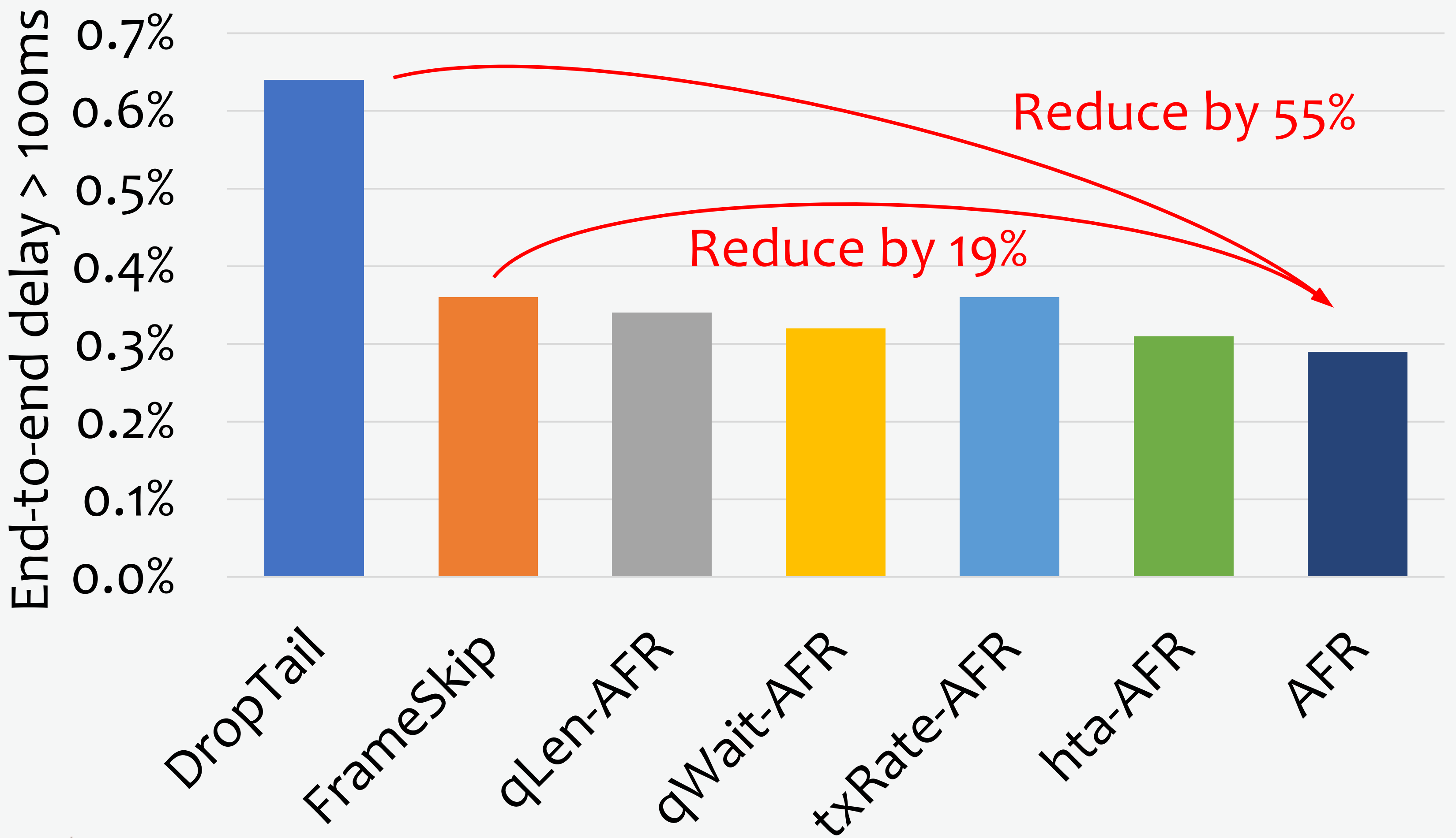
- Simulation traces collected from Tencent START cloud gaming
  - Network RTT, decoding delay, etc.
  - 42k hours (playing time), 38k user sessions.
- Baselines
  - DropTail, FrameSkip [HotEdgeVideo'21]
  - qWait-, qLen-, txRate-based AFR

START云游戏

Evaluation

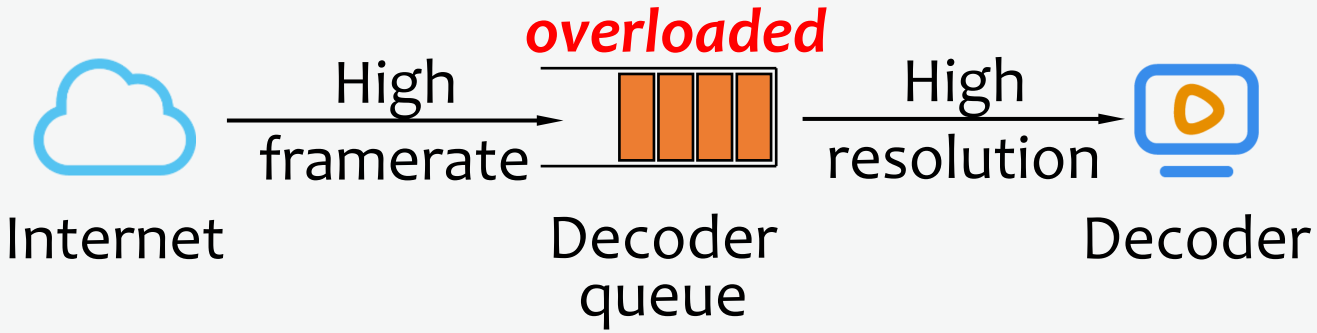
End-to-end Delay Improvement

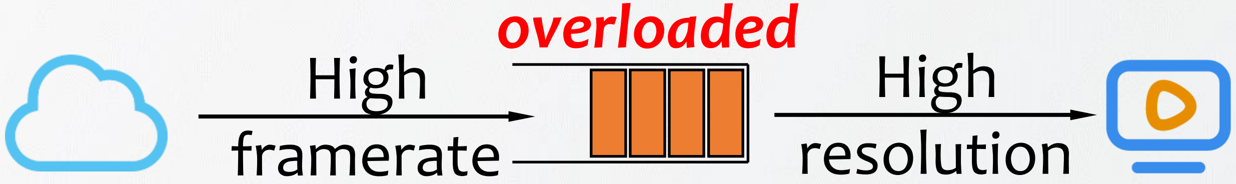
Metric: Ratio of *end-to-end delay > 100 ms* (how we define stutter).



Takeaway

- The *increased video quality* overloads the client decoder queue.
- AFR *adapts the frame-rate based on network / decoder conditions*.
- AFR is *deployable* with current video codec.
- AFR improves the application performance by 34% in production.





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Thank you!

Zili Meng

https://transys.io/afr/