Adaptive Video Streaming and Cloud Gaming

What's beyond CSC 461/561 Multimedia Systems

Instructor: Prof. Jianping Pan

Jinwei (Clark) Zhao

2023/09/07

University of Victoria

Course Outline

https://heat.csc.uvic.ca/coview/course/2023091/CSC461
https://heat.csc.uvic.ca/coview/course/2023091/CSC561

Microsoft Teams for class communication
Download and login with your Netlink ID

Location:	Classes Start:	Classes End:	Days of week:	Hours of day:	Instructor:
CLE A224	2023-09-06	2023-12-04	MTh	11:30-12:50	Jianping Pan

Term Schedule

Tentative schedule is as follows:

Assignment/Midterm Exams/Project	Weight	Assigned Date	Due Date
Assignment 1	5%	Sep 22	Sep 29
Midterm Exam 1	15%	Oct 5	Oct 5
Midterm Exam 2	15%	Nov 2	Nov 2
Midterm Exam 3	15%	Dec 4	Dec 4
Project	50%		TBD

Grading

Coursework	Weight (out of 100%)
Written Assignment	5%
Midterm Exams	45%
Project	50%

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About me

- Final year MSc student in Computer Science at UVic, advised by Dr. Jianping Pan
- Email: clarkzjw@uvic.ca
- https://pan.uvic.ca/~clarkzjw/

- Current research interests:
  - Adaptive video streaming
  - QUIC and its multipath extension
  - Multimedia system performance over Starlink

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My own work and involved

- QoE-driven Joint Decision-Making for Multipath Adaptive Video Streaming
  - *Jinwei Zhao, Jianping Pan*
  - Accepted by IEEE Globecom 2023

- Measuring a Low-Earth-Orbit Satellite Network
  - *Jianping Pan, Jinwei Zhao, Lin Cai*
  - Accepted by IEEE PIMRC 2023, https://arxiv.org/abs/2307.06863

- Measuring NVIDIA GeForce NOW Cloud Gaming over Starlink
  - Provided mentorship to a first year undergraduate student via VKURA internship this summer, guiding a measurement study focused on evaluating the performance of cloud gaming (NVIDIA GeForce NOW) over the Starlink network.

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Today’s Topics

What’s beyond the course and what you can do in course projects or future graduate studies

Introduction to

- Measurement of Cloud Gaming over Starlink
  - VKURA internship project by a first year undergraduate student this summer
- Adaptive Video Streaming
  - My MSc research topic

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About Multimedia and Multimedia Systems

What is “media”?

Information represented in different formats

- text
- graphics
- image

Discrete media: time independent

- animation
- audio
- video

Continuous media: time dependent

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About Multimedia and Multimedia Systems

Multimedia: a form of communication that uses a combination of different content forms such as writing, audio, images, animations, or video into a single interactive presentation, in contrast to traditional mass media, such as printed material or audio recordings, which features little to no interaction between users.

Multimedia system: the generation, manipulation, storage, presentation, and communication of multimedia information

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(Digital and Networked) Multimedia Systems

- Leveraging interconnected systems to present, share and interact with diverse multimedia content.
- Example multimedia systems:
  - Video conferencing (Zoom, Google Meet…)
  - Video-on-demand services (YouTube, Netflix…)
  - Live streaming (YouTube, Twitch…)
  - Online games (Steam, Epic Games…)
  - Cloud gaming (Nvidia GeForce NOW, Xbox Cloud Gaming…)
  - Virtual reality (Meta Quest, Apple Vision Pro…)
  - Social media (Twitter/X, Instagram…)
  - …

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Multimedia and Computer Science

- To computer science researchers, multimedia consists of a wide variety of topics:

1. **Multimedia processing and coding**:

audio/image/video compression, multimedia content analysis, computer vision, etc.

2. **Multimedia system support and networking**:

network protocols, operating systems, quality of service (QoS), databases, etc.

3. **Multimedia tools, end-systems and applications**:

user interfaces, multimedia system integration and interactivity, etc.

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Multimedia and Computer Science

Reputable multimedia conferences and journals

- ACM Multimedia (MM)
- ACM Multimedia Systems Conference (MMSys)
- Conference on Computer Vision and Pattern Recognition (CVPR)
- International Conference on Computer Vision (ICCV)

- IEEE Transactions on Multimedia (ToM)
- ACM Transactions on Multimedia Computing, Communications, and Applications (TOMM)
- …

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About Multimedia Systems

Objectives

To understand the fundamental issues and problems in the representation, manipulation and delivery of multimedia content such as images, audio and video, particularly in a networked environment

Prerequisite

CSC 360 Operating Systems

CSC 361 Computer Networks

Today's Topics

Introduction to

- Measurement of Cloud Gaming over Starlink
  - VKURA internship project by a first year undergraduate student this summer
- Adaptive Video Streaming
  - My MSc research topic

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Analyzing the Performance of Cloud Gaming over Low-Earth Orbit Satellite Networks

By Pouria Tolouei

Supervised by Dr. Jianping Pan
Mentored by Jinwei Zhao
Supported by the Valerie Kuehne Undergraduate Research Awards (VKURA)

1. Introduction
2. Methods
3. Results
4. Discussion/Conclusion
5. Possible Future Work

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About Starlink

Operated by SpaceX, with the goal of providing high-speed and low-latency Internet access globally, especially to underserved and remote areas.

As of May 2023, Starlink has more than 1.5 million subscribers [1].

As of August 2023, Starlink consists of over 5,000 mass-produced small satellites in low Earth orbit (LEO), which communicate with designated ground transceivers.

In total, nearly 12,000 satellites are planned to be deployed, with a possible later extension to 42,000 [2].

A detailed introduction about Starlink:

How does Starlink Satellite Internet Work? | Branch Education

https://www.youtube.com/watch?v=qs2QcycggWU

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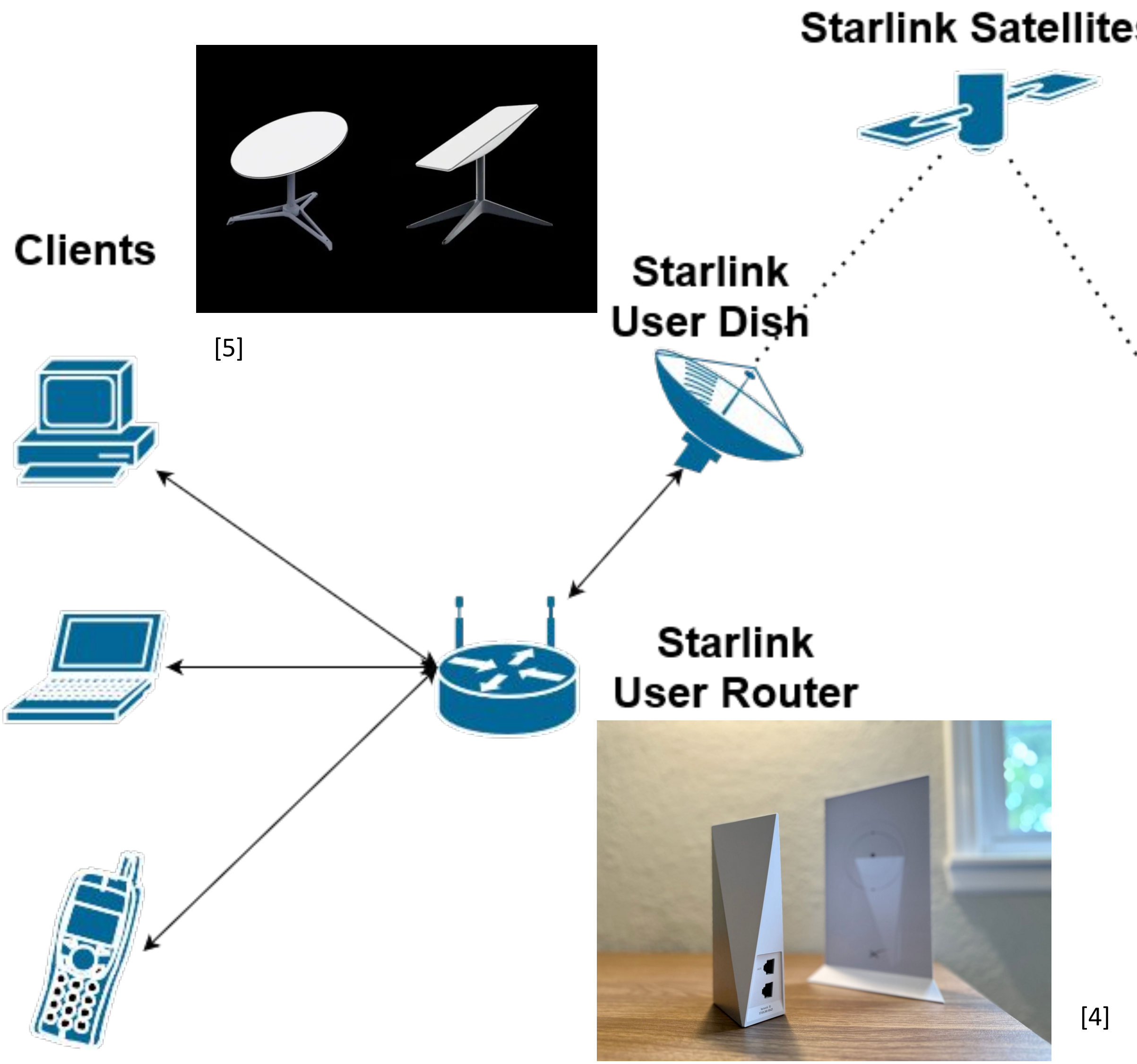
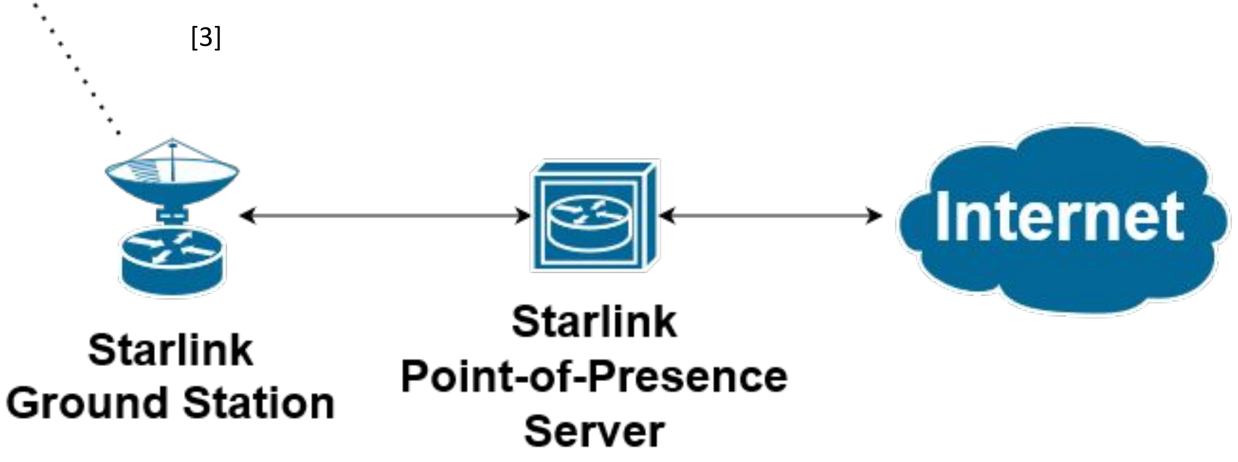
[1] https://twitter.com/Starlink/status/1654673695007457280
[2] https://en.wikipedia.org/wiki/Starlink

A simplified Starlink topology





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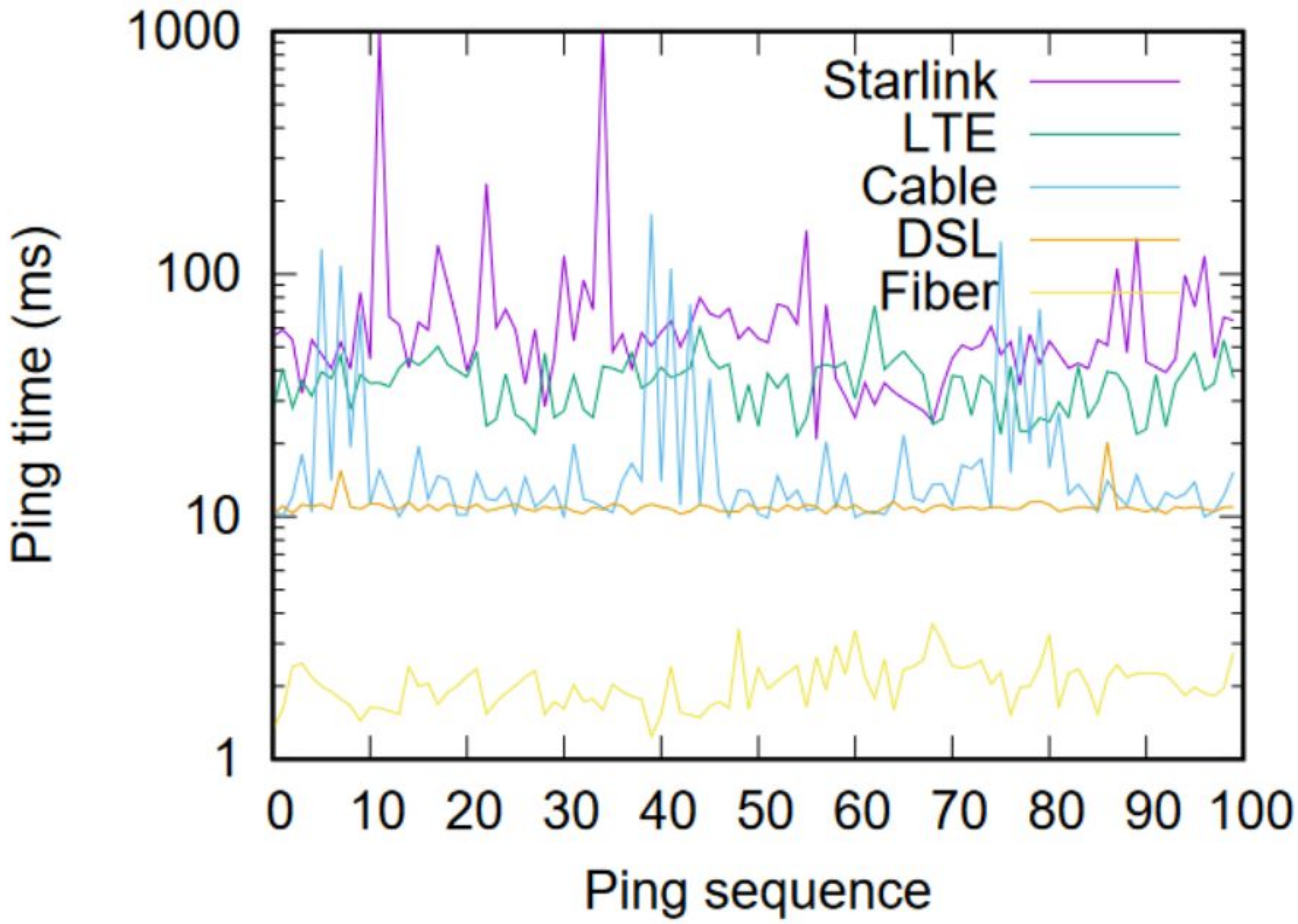
[3] https://www.reddit.com/r/Starlink/comments/pbfpvs/starlink_is_coming_to_turkey_these_are_starlink/
[4] https://www.starlinkhardware.com/new-starlink-router-spotted-3-things-you-want-to-know/
[5] https://starlinkmag.com/types-of-starlink-dish-antenna/

Comparison with terrestrial ISPs



RTT from user dish to gateway:

- Highly fluctuating
- Higher than fiber, DSL or cable,
- Comparable to LTE
- Significantly better than traditional satellite ISPs (e.g. Intelsat)
  - minRTT ~700ms

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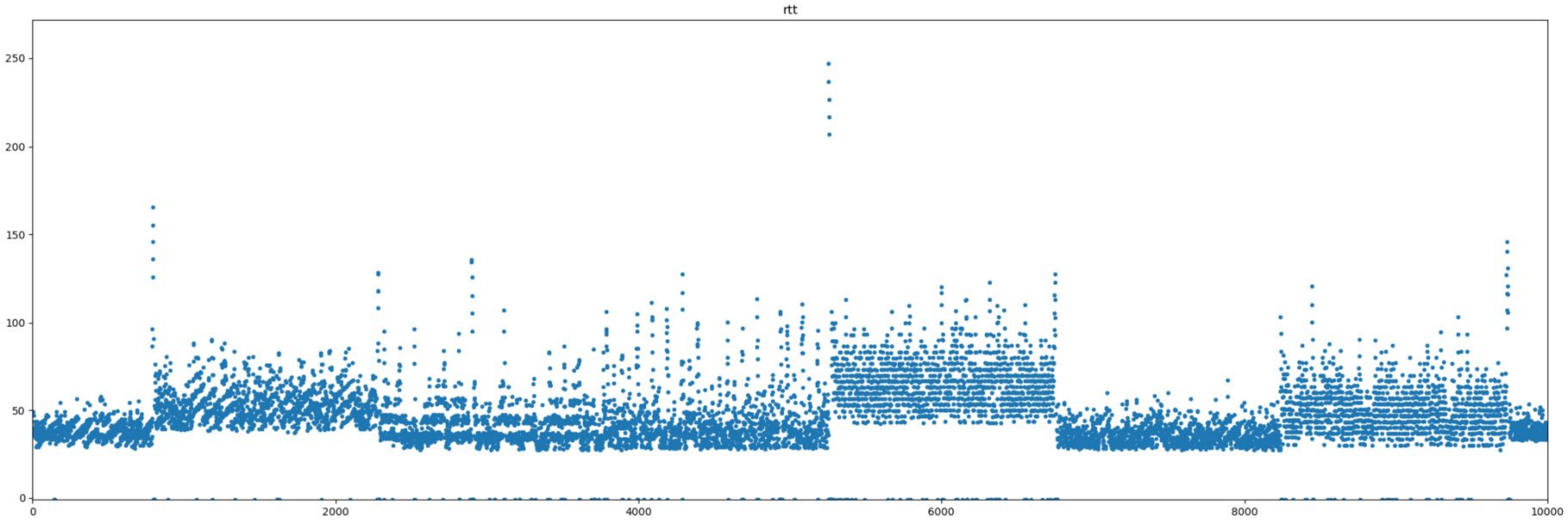
[6] https://arxiv.org/pdf/2307.06863.pdf

Unique pattern: frequent and predictable satellite handover



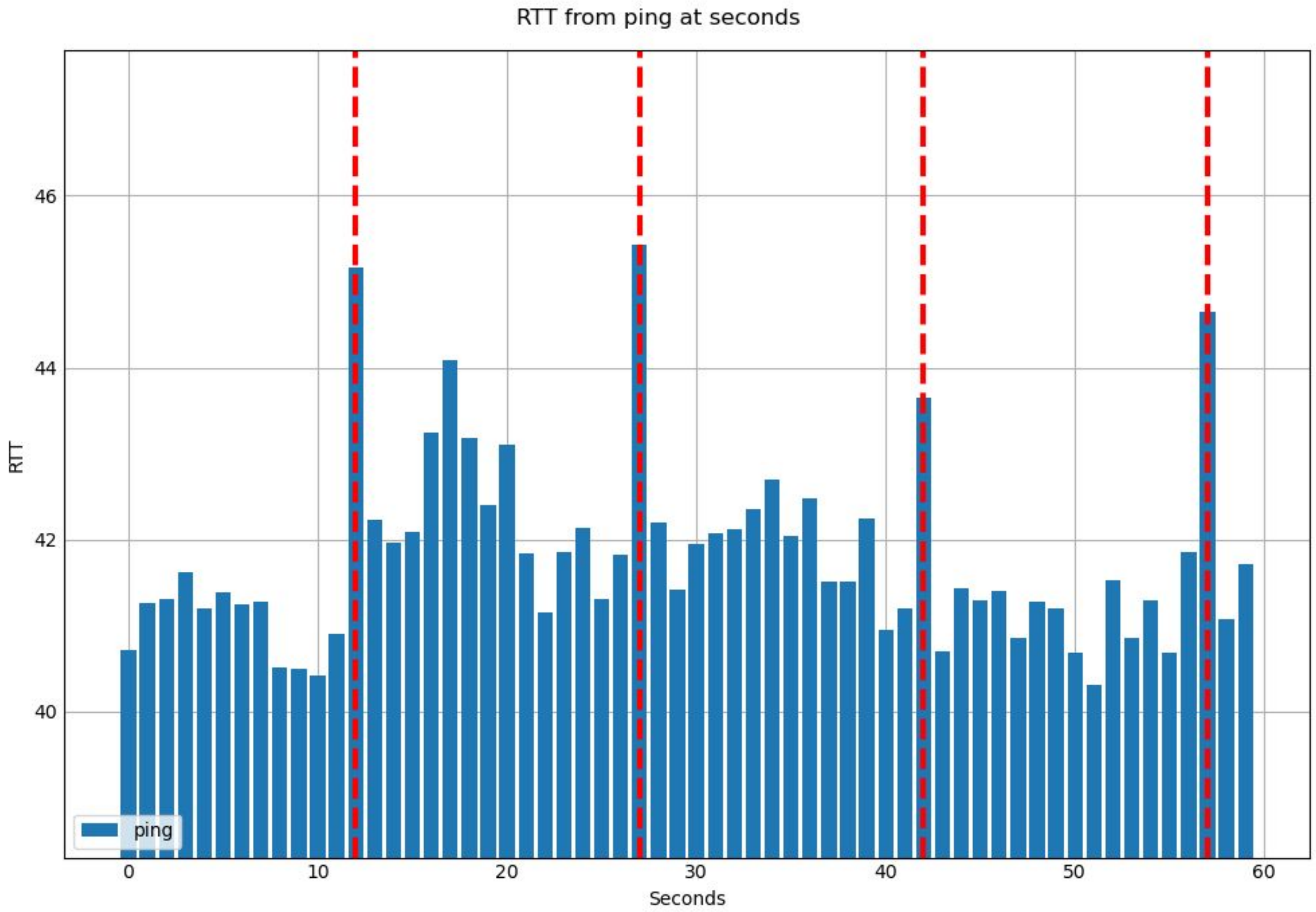
Ping every 10ms

Frequent handover:
The nature of LEO satellite networks

1. unique latency pattern every 15 seconds

https://starlink.sx

Unique pattern: frequent and predictable satellite handover



Starlink satellite handover occurs at synchronized 12, 27, 42, 57 second after each minute

Questions

How does the fast changing latency of Starlink affect the cloud gaming performance?

- Challenging for interactive applications
- Cloud gaming can be especially challenging as it is a remote system

A case study

Nvidia GeForce NOW

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Methods (Setup)

- Three Starlink dishes located in Victoria, Vancouver and Ottawa, each connected with a mini PC
- Platform: GeForce NOW Cloud Gaming on Chrome
  - Game play setting
    - Fixed at 1080p 60 FPS
    - “Adjust for Poor Network” disabled
  - Victoria/Vancouver: US West Server   Ottawa: US South Server
- Game: Rocket League

- mini PC Hardware:
  - OS: Ubuntu 22.04.2
  - CPU: Intel(R) Celeron(R) N5095A @ 2.00GHz
  - GPU: Jasper Lake [UHD Graphics]
  - RAM: 8 GB
  - Virtual Display

- Connection to network via Gigabit Ethernet
  - Telus Fibre and Starlink
  - * Only one scenario used Wi-Fi (Telus vs. Telus Different Network)

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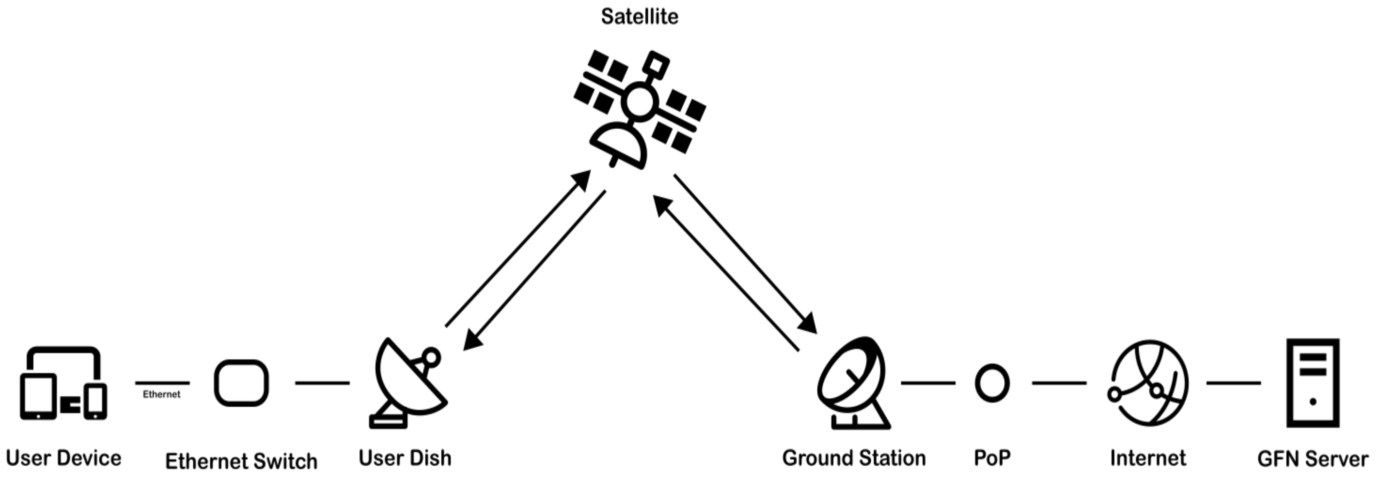
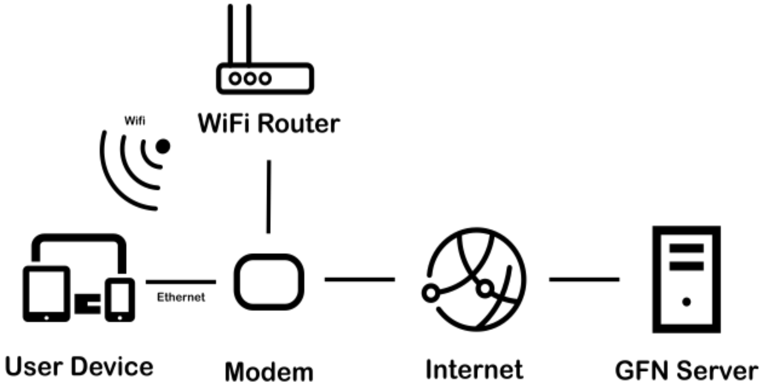
Methods (Setup)

Starlink Network Topology



Telus Fibre Network Topology



Methods (Testing Scenario)

- Two systems each joined their own independent private match and played simultaneously
- Gameplay and data collection was handled by an automated Python script

- 48 rounds (2 minutes gameplay/round) throughout a day (Only Monday to Thursday)
  - 12 rounds at 9:00 a.m (morning)
  - 12 rounds at 1:00 p.m (afternoon)
  - 12 rounds at 5:00 p.m (evening)
  - 12 rounds at 9:00 p.m (night)

- Each day a different scenario
  - Victoria Telus Fibre vs. Victoria Telus Fibre (same network)
  - Victoria Telus Fibre vs. Victoria Telus Fibre (different network)
  - Victoria Starlink vs. Victoria Telus Fibre
  - Victoria Starlink vs. Victoria Starlink (same dish, same PoP (point of presence))
  - Victoria Starlink vs. Vancouver Starlink (different dish, same PoP)
  - Victoria Starlink vs. Ottawa Starlink (different dish, different PoP)

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Methods (Measurements)

- Collected (GFN Network Stats Overlay)
  - Ping (ms)
  - Packet Loss (# of packets)
  - Used and Available Bandwidth (Mbps)
  - Resolution
  - Stream FPS

- Measured
  - Input latency (ms)
  - * Approximated using screenshots

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Methods (Measurements)

- Method for measuring input latency
  - Press the key (virtually) to boost the car forward every 1 second
  - Record the keystroke timestamp (input time)
  - Observe a pixel in the car exhaust and look for a red color change
    - Using screenshots
    - Each screenshot has an average latency of 53 ms
  - Record the color change timestamp (action time)
  - Subtract the two timestamps to get input latency

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Results (Summary)

		Ping (ms) (mean)	Input Latency (ms) (mean)	Round Packet Loss (mean)	Round Packet Loss (%) (mean)	Available Bandwidth (Mbps) (mean)	Used Bandwidth (Mbps) (mean)
Victoria Telus vs. Victoria Telus (Same)	Victoria Telus 1	31.42	72.89	62.27	0.025%	82.33	19.18
	Victoria Telus 2	31.21	74.61	62.10	0.025%	81.86	19.34
Victoria Telus vs. Victoria Telus (Different)	Victoria Telus 1	31.51	72.00	0.40	0.000%	83.75	19.27
	Victoria Telus 2	42.65	91.72	447.125	0.179%	57.95	18.03
Victoria Starlink vs. Victoria Telus	Victoria Starlink	**67.04**	**116.92**	**460.04**	**0.184%**	56.87	15.89
	Victoria Telus	**31.41**	**74.64**	**16.88**	**0.007%**	82.80	19.22
Victoria Starlink vs. Victoria Starlink	Victoria Starlink 1	70.26	121.68	730.75	0.292%	46.75	15.17
	Victoria Starlink 2	70.41	121.56	862.04	0.345%	46.54	15.19
Victoria Starlink vs. Vancouver Starlink	Victoria Starlink	67.44	116.95	608.60	0.243%	57.30	16.02
	Vancouver Starlink	65.88	118.32	727.04	0.291%	61.60	16.29
Victoria Starlink vs. Ottawa Starlink	Victoria Starlink	**65.29**	**117.24**	**745.54**	**0.298%**	59.78	17.43
	Ottawa Starlink	**60.57**	**106.84**	**597.60**	**0.239%**	51.49	13.85

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Results (Summary)

		Ping (ms) (SD)	Input Latency (ms) (SD)	Round Packet Loss (SD)	Round Packet Loss (%) (SD)	Available Bandwidth (Mbps) (SD)	Used Bandwidth (Mbps) (SD)
Victoria Telus vs. Victoria Telus (Same)	Victoria Telus 1	1.53	25.50	177.72	0.071%	12.78	1.73
	Victoria Telus 2	1.52	28.61	185.86	0.074%	12.54	1.69
Victoria Telus vs. Victoria Telus (Different)	Victoria Telus 1	1.40	20.09	2.60	0.001%	12.16	1.55
	Victoria Telus 2	8.87	39.37	107.91	0.043%	12.82	3.03
Victoria Starlink vs. Victoria Telus	Victoria Starlink	**26.50**	**84.68**	**435.34**	**0.174%**	18.50	4.91
	Victoria Telus	**1.61**	**25.15**	**48.42**	**0.019%**	12.85	1.61
Victoria Starlink vs. Victoria Starlink	Victoria Starlink 1	27.93	87.10	641.52	0.257%	14.20	4.88
	Victoria Starlink 2	29.05	97.66	925.39	0.370%	14.12	4.97
Victoria Starlink vs. Vancouver Starlink	Victoria Starlink	28.09	76.52	401.52	0.161%	17.40	4.98
	Vancouver Starlink	20.68	91.47	419.68	0.168%	21.58	4.91
Victoria Starlink vs. Ottawa Starlink	Victoria Starlink	21.27	82.65	590.57	0.236%	16.09	4.11
	Ottawa Starlink	21.35	82.22	296.46	0.119%	24.37	5.06

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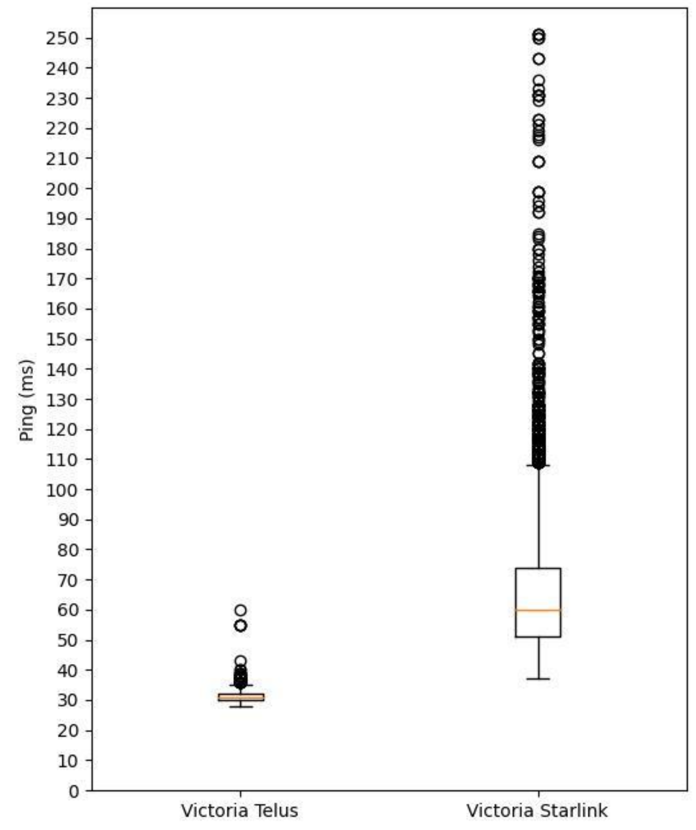
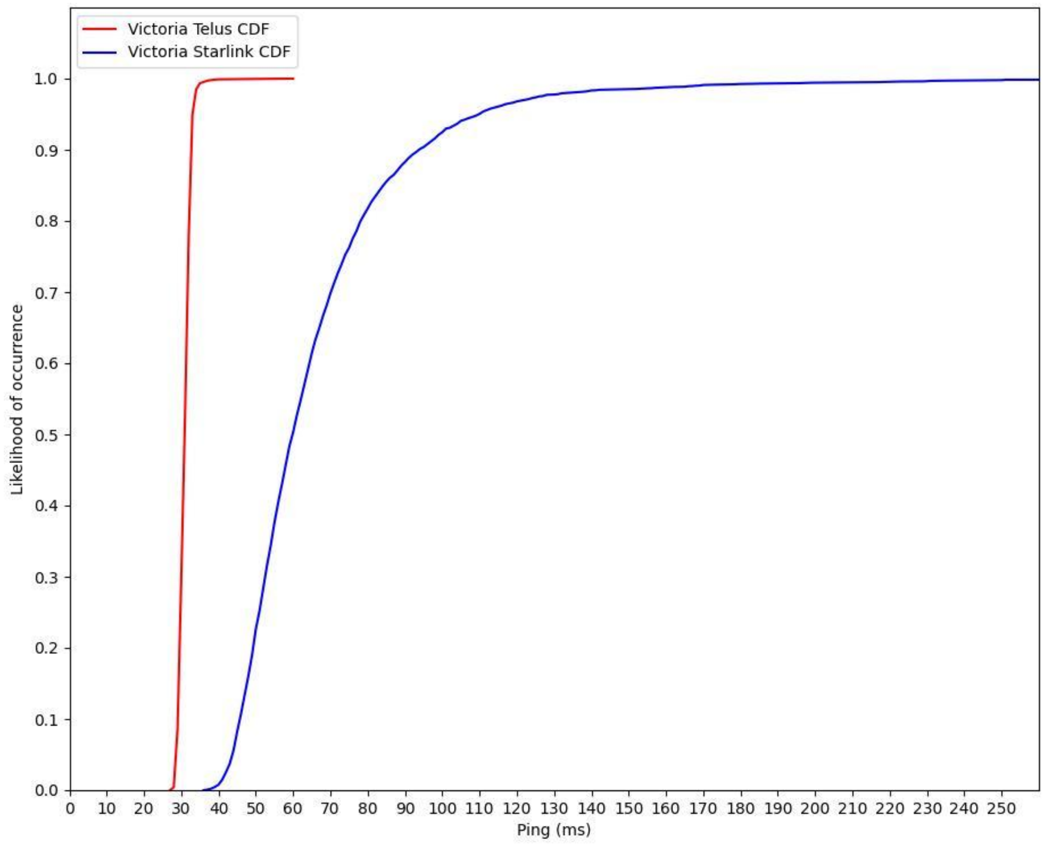
Results (Ping: Victoria Starlink vs. Victoria Telus)

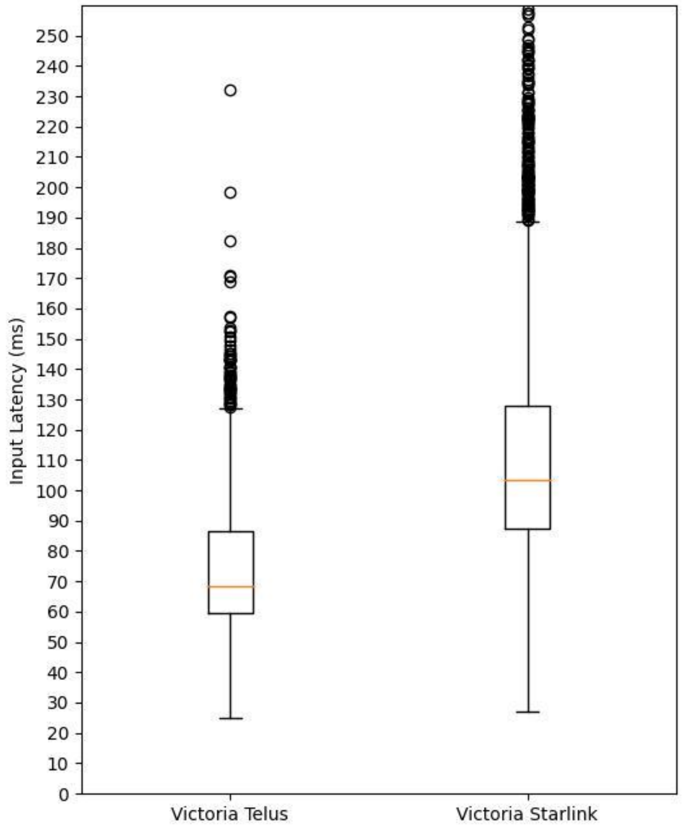


Ping (ms)

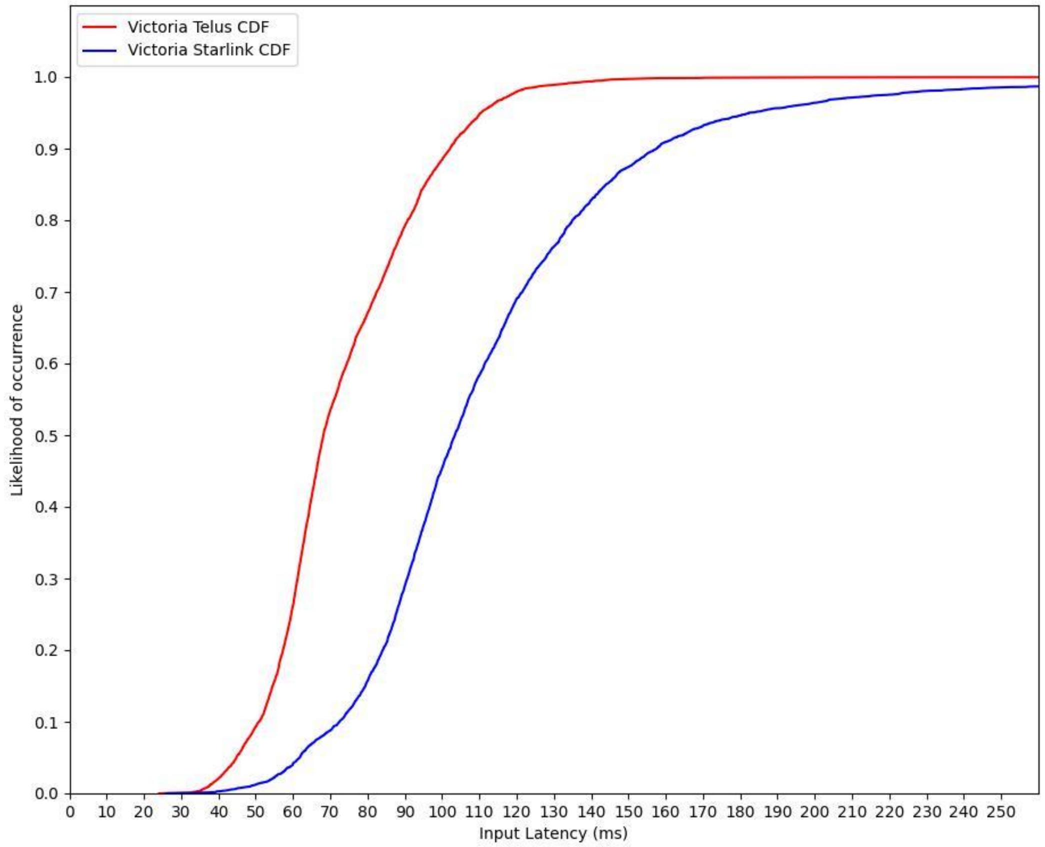


CDF

Results (Input Latency: Victoria Starlink vs. Victoria Telus)



Input latency (ms)



CDF

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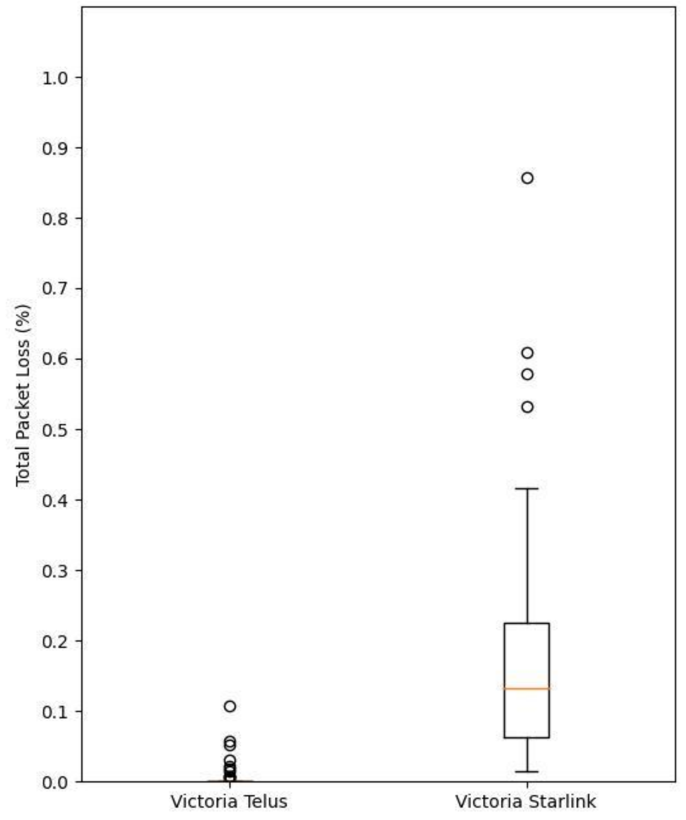
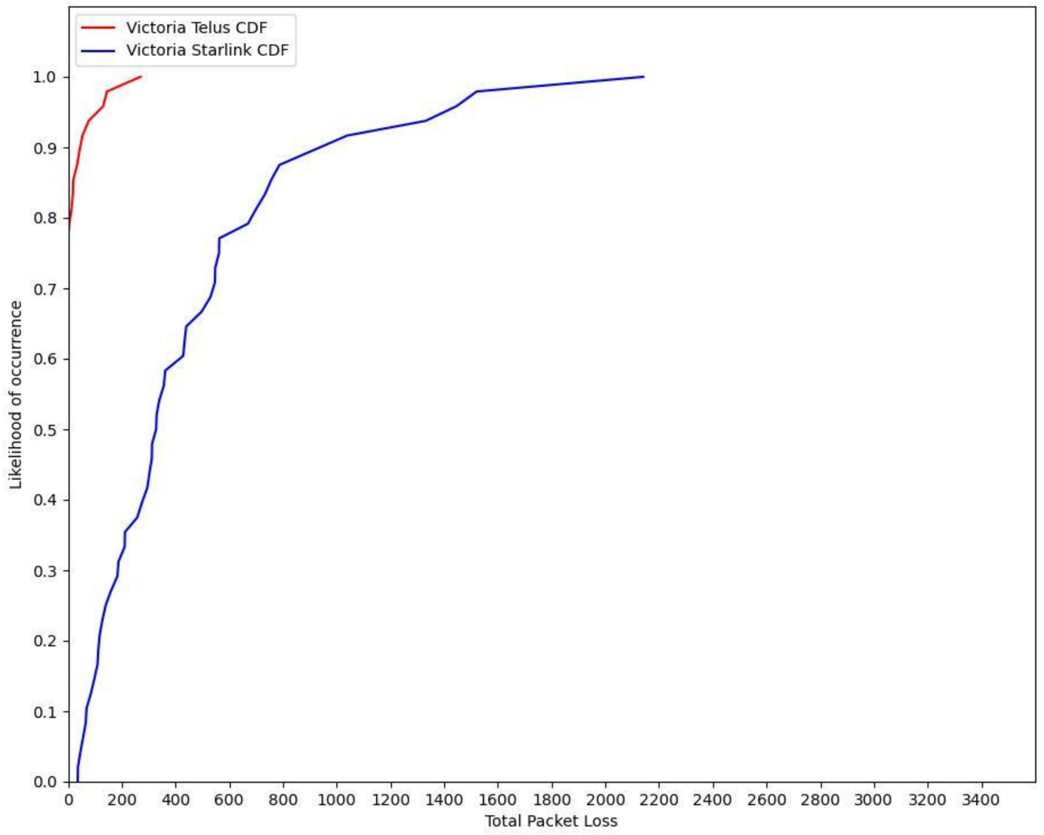
Results (Packet Loss: Victoria Starlink vs. Victoria Telus)





Total packet loss (%)

CDF

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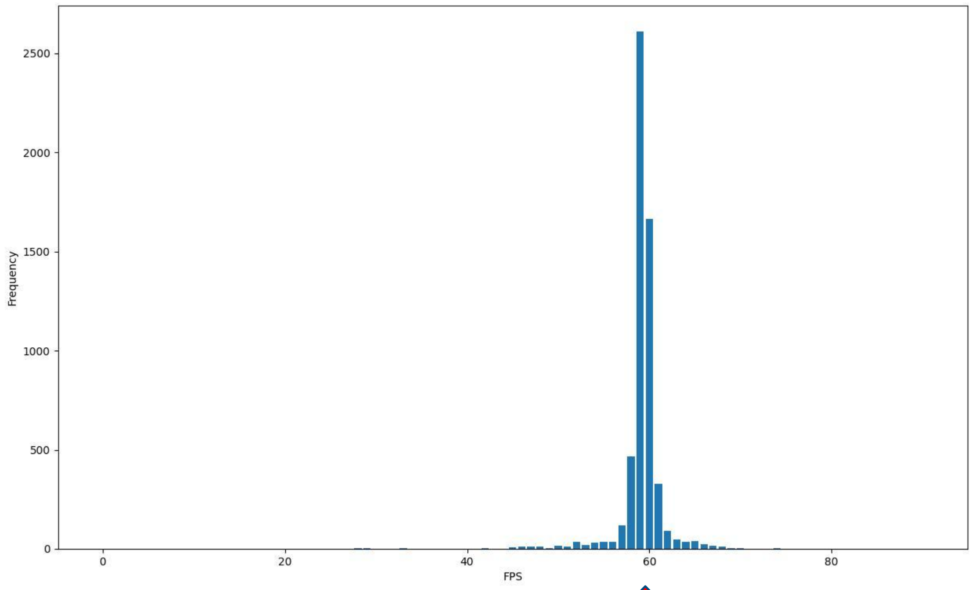
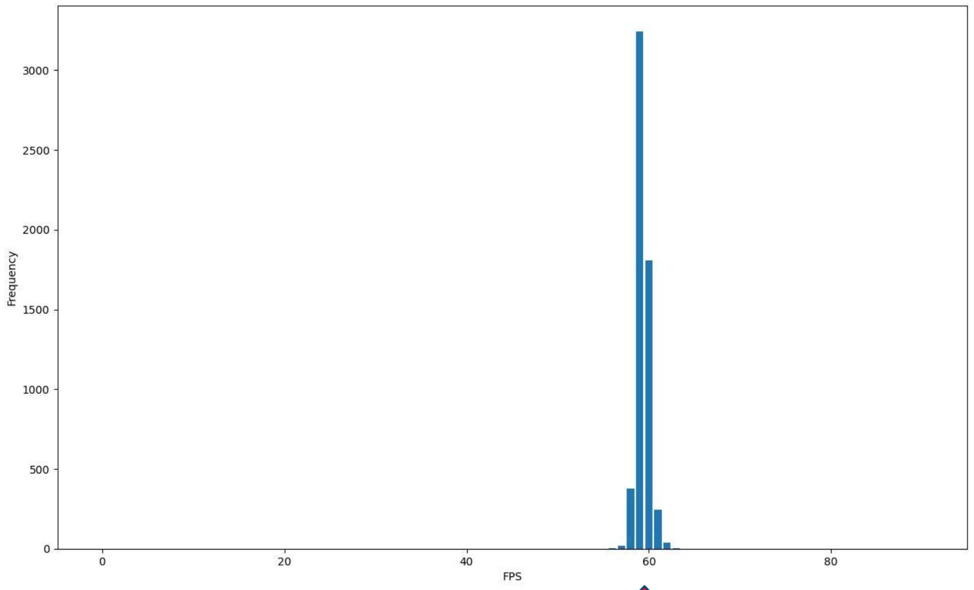
Results (Stream Quality in FPS: Victoria Starlink vs. Victoria Telus)

Victoria Starlink



60 FPS

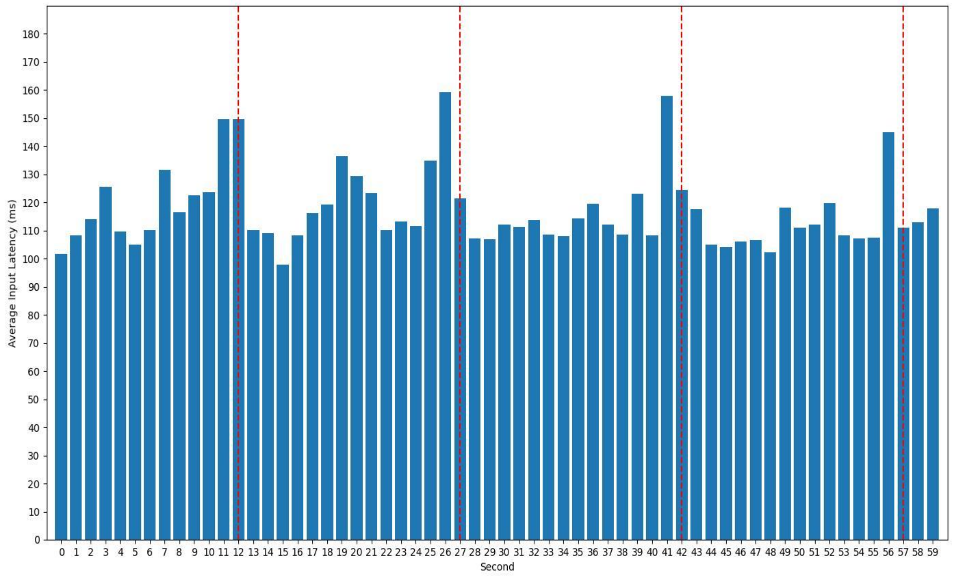
Victoria Telus



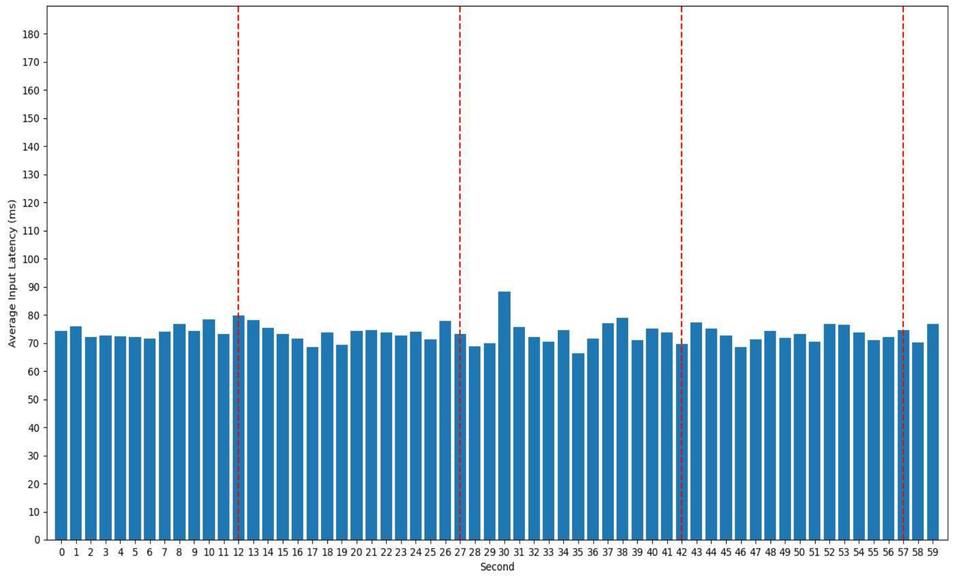
60 FPS

Results (Average Input Latency at Seconds: Victoria Starlink vs. Victoria Telus)

Victoria Starlink

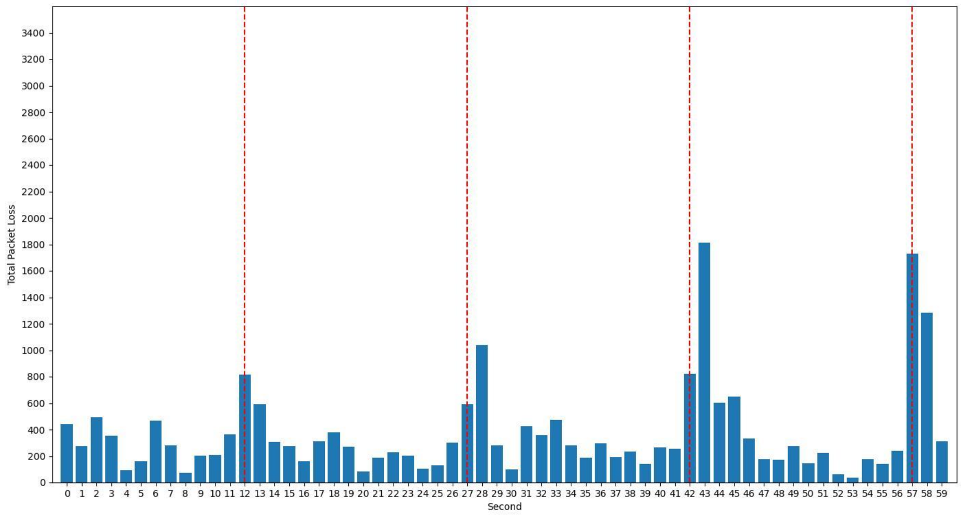


Victoria Telus

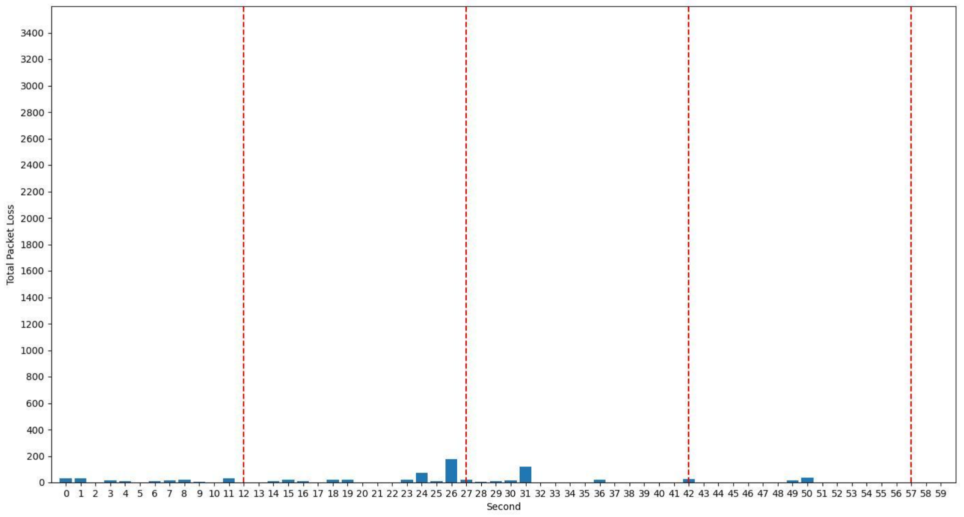


Results (Total Packet Loss at Seconds: Victoria Starlink vs. Victoria Telus)

Victoria Starlink



Victoria Telus



Full report

Link:

https://tinyurl.com/gfn-starlink

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Discussion/Conclusion

- Similar Starlink performance across the locations
- Higher/faster changing latency, less stable bandwidth, and more packet loss on Starlink
  - → More input lag and stutters
  - Identified causes:
    - Communication with distant and moving satellites before connecting to PoP
      - Nature of the connection to enable wider coverage (especially rural)
    - Frequent and brute force satellite handoffs (12-27-42-57)
      - Effective but not efficient
      - Services (such as GeForce Now) can take advantage of this

- Stream Quality and FPS seems relatively stable (at least based on stats)
  - Bandwidth doesn't seem to be much of an issue
  - Video streaming bitrate adaptation could still be happening (requires video analysis)

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Possible Future Work

- Design a solution to take advantage of the predictable satellite handovers
- Use application layer codec design to smooth out packet loss introduced by 15s handover
- Focus on stream quality and video analysis
- Enable "Adjust for Poor Network" and measure the performance of Nvidia's adaptive cloud gaming video streaming algorithms
  - Cloud gaming eventually is interactive adaptive video streaming (next topic)
- Test on the GeForce NOW desktop clients instead of web version
  - Desktop clients have more client logs and metrics available
- Comparison with other cloud gaming platforms (Xbox Cloud Gaming, etc.)
- Test games with more multiplayer interaction

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Possible Future Work (Starlink related)

- Starlink for indigenous communities
  - https://www.cbc.ca/news/canada/saskatchewan/spacex-s-starlink-rural-community-1.6690957
- Improvement on Starlink laser Inter-Satellite Links (ISLs)
  - Better network routing algorithms, etc.
- Reverse engineering physical layer properties
  - Software defined radios, signal patterns, etc.
- Network protocols and applications
  - TCP performance-enhancing proxies (PEPs)
  - QUIC
  - Congestion control
  - Low latency multimedia streaming
- Try out Starlink network near ECS404
  - Wi-Fi SSID: @starlink

If you are interested in further investigation and research, talk to Prof. Pan about course project ideas

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Adaptive Video Streaming and Cloud Gaming

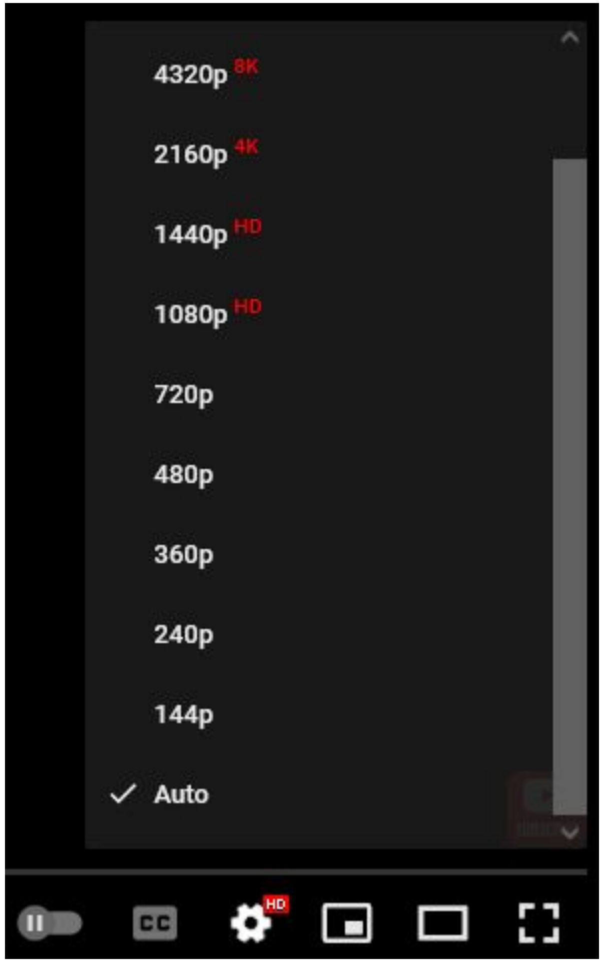
What's beyond CSC 461/561 Multimedia Systems

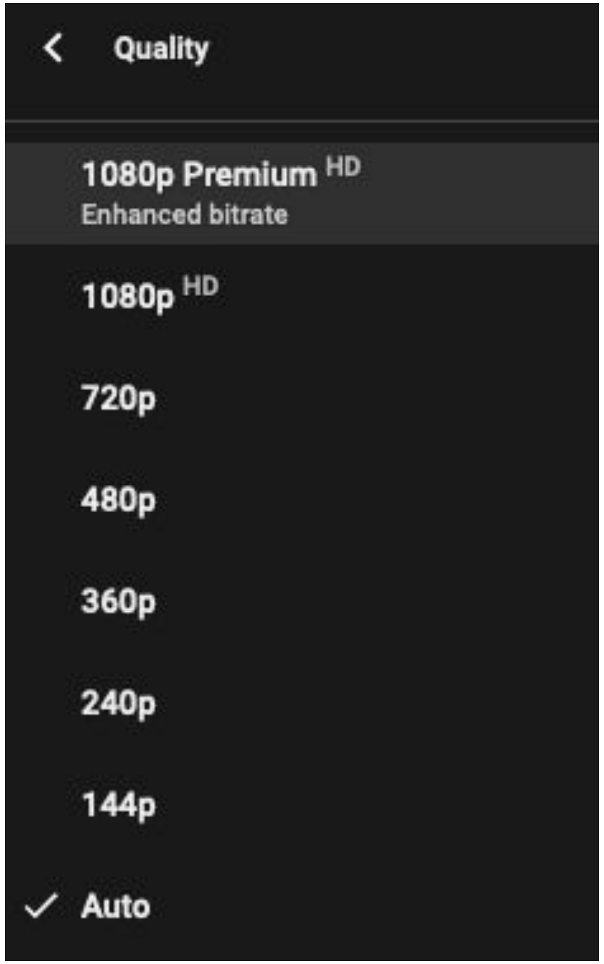
Part 2

Jinwei (Clark) Zhao

2023/09/07

The challenges for adaptive algorithms





Example

Resolution	Video bitrate
1080p Premium	5782 kbps
1080p	986 kbps

Using the yt-dlp [1] tool:

```
yt-dlp -F https://www.youtube.com/watch?v=xxxx
```

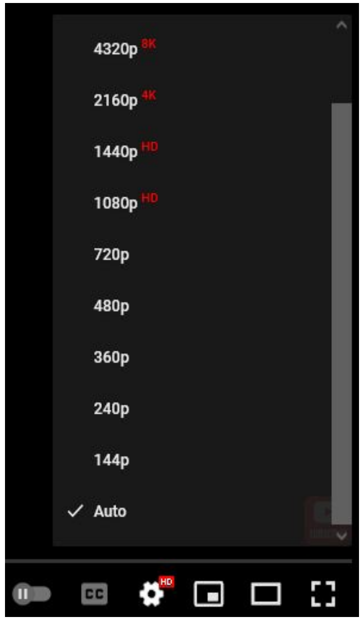
Auto: Adaptive video bitrate algorithms

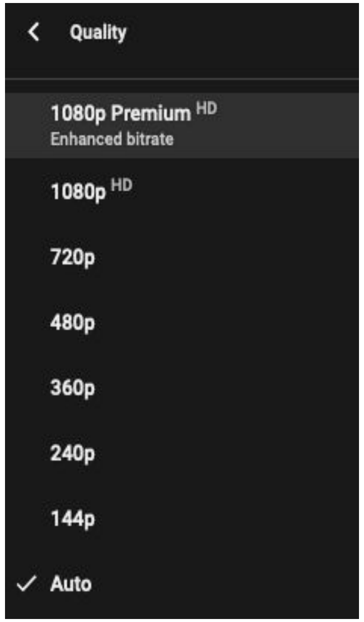
[1] https://github.com/yt-dlp/yt-dlp

The challenges for adaptive algorithms

Delivering high-quality videos to end-users, considering:

- Different computing capabilities (CPU and GPU) of streaming devices
  - Smart phones, desktop computers, laptops, tablets, TV or even cars…
- Different networking conditions (It changes while you’re watching)
  - DSL, Cable, Fiber, 3G/4G/5G, Satellite/Starlink…
- User’s expectations
  - High quality, less rebuffering, start playback as quickly as possible…





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Video streaming protocols

Almost Dead

- HTTP Dynamic Streaming by Adobe
- Smooth Streaming by Microsoft

Widely used nowadays

- HTTP Live Streaming (HLS) by Apple
- Dynamic Adaptive Streaming over HTTP (DASH)
    - First adaptive bitrate HTTP-based streaming solution that is an international standard
    - Transport layer protocol: TCP

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The core ideas of DASH

- Split the content into a sequence of small segments, each segment contains a short interval of playback time (usually 2-10 seconds) of content that is potentially many hours in duration, such as a movie
- The content is encoded at a variety of different resolutions and bitrates (720p, 1080p, 4K), i.e., alternative segments encoded at different bitrates covering aligned short intervals of playback time, these information are stored in a media presentation description (MPD) file.
- While the content is being played back by an DASH client, the client uses a bitrate adaptation (ABR) algorithm to automatically select the segment with the highest bitrate possible that can be downloaded in time for playback without causing stalls or rebuffering events in the playback.
- DASH is codec-agnostic (H.264, H.265, VP9…)

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Every title has many files

- **Video tracks**
  - VP9
  - HDR
  - H264
    - 5800 kbps
    - 560 kbps
    - 175 kbps
  - AV1
- **Audio tracks**
  - AAC 5.1
  - 2.0
    - 64 kbps
      - English
      - Korean
      - French
    - 96 kbps

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What happens when we click play?

Netflix client

1. Where can I download this title?

AWS

Netflix Control Plane

2. nearest CDN server and a list of available quality levels (MPD file)

3. First segment at 8Mbps please?

Netflix Data Plane (Content Server)

All around the world

4. Constantly makes ABR decisions based on previous statistic and future bandwidth prediction

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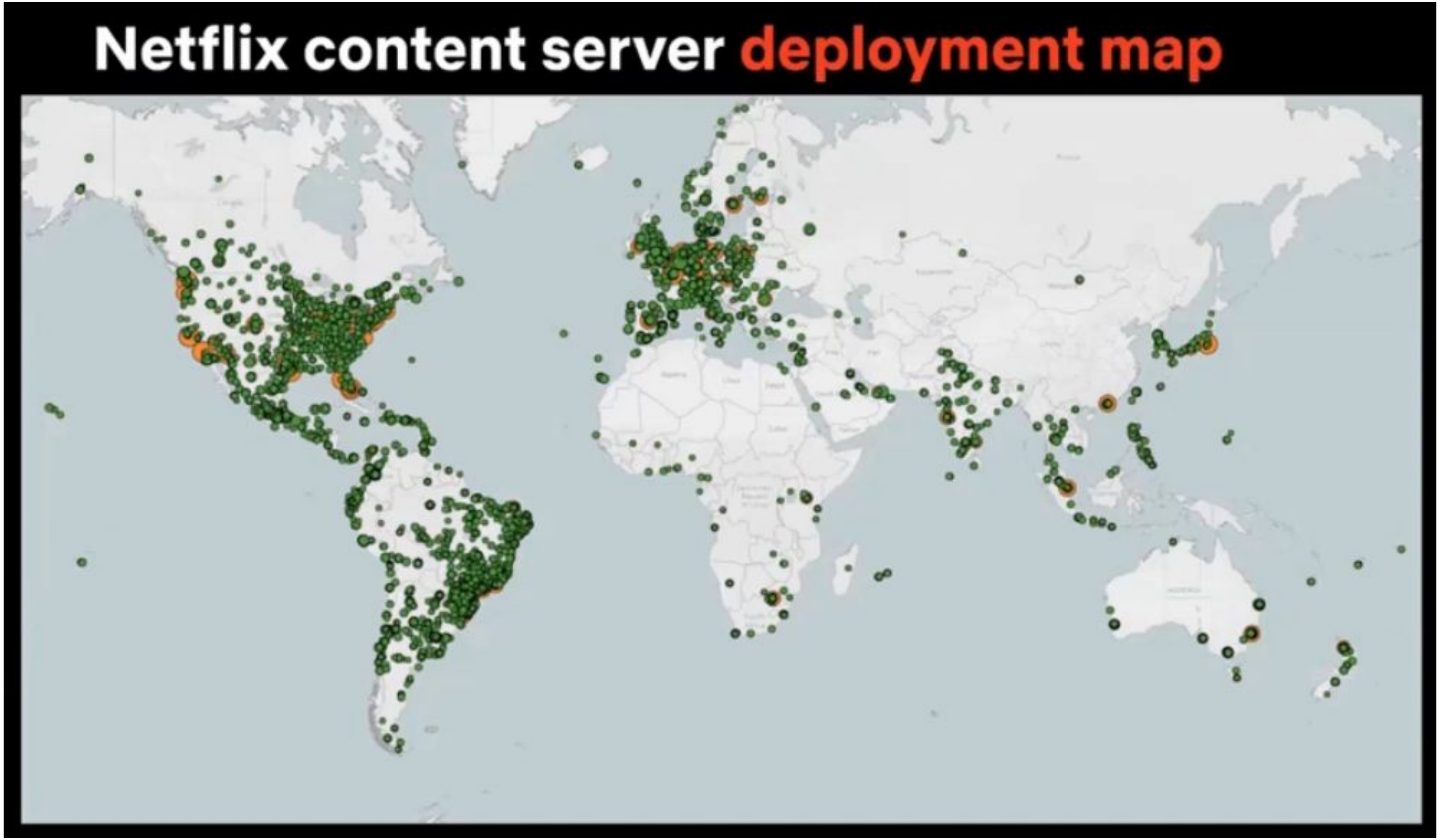
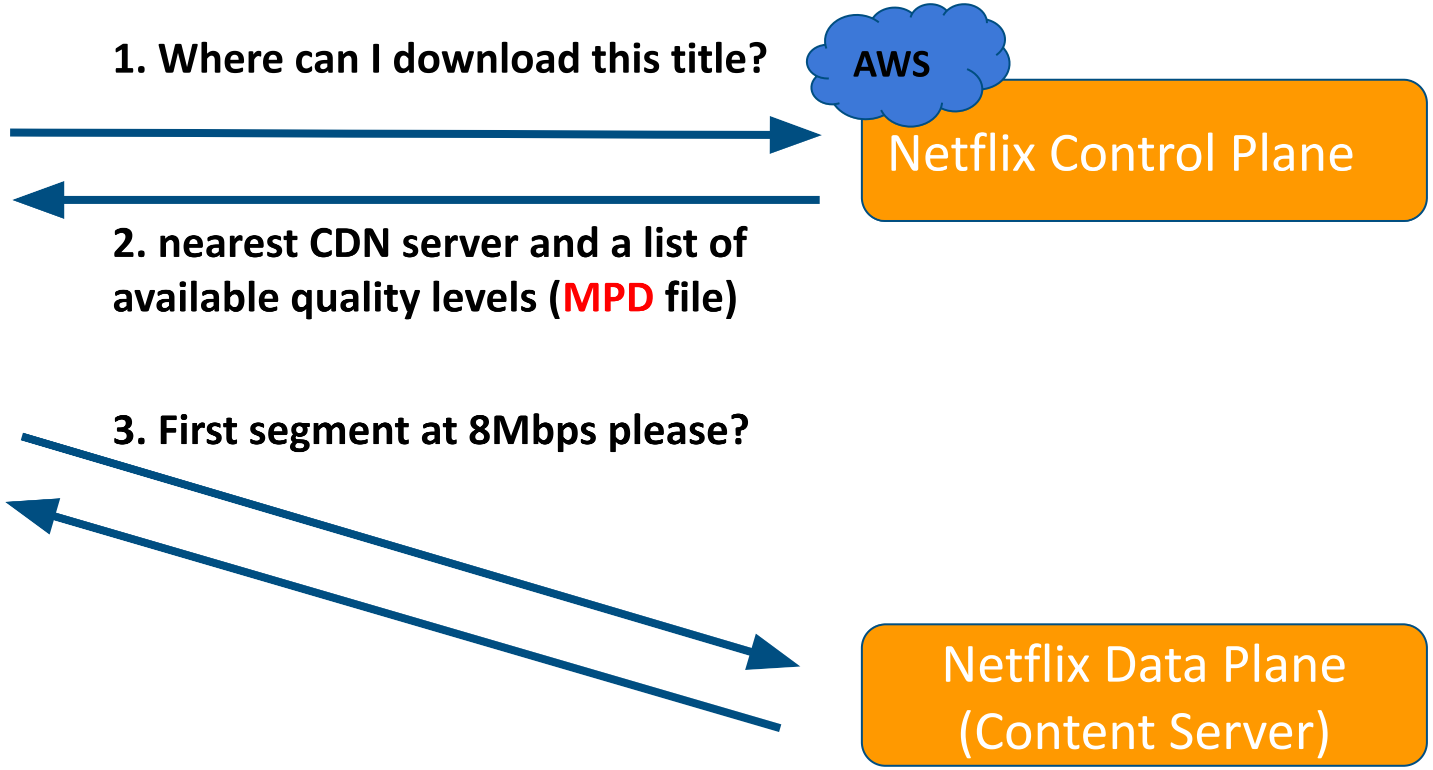


https://www.youtube.com/watch?v=kCshXyCmUho

What happens when we click play?

Netflix client



All around the world

4. Constantly makes ABR decisions based on previous statistic and future bandwidth prediction

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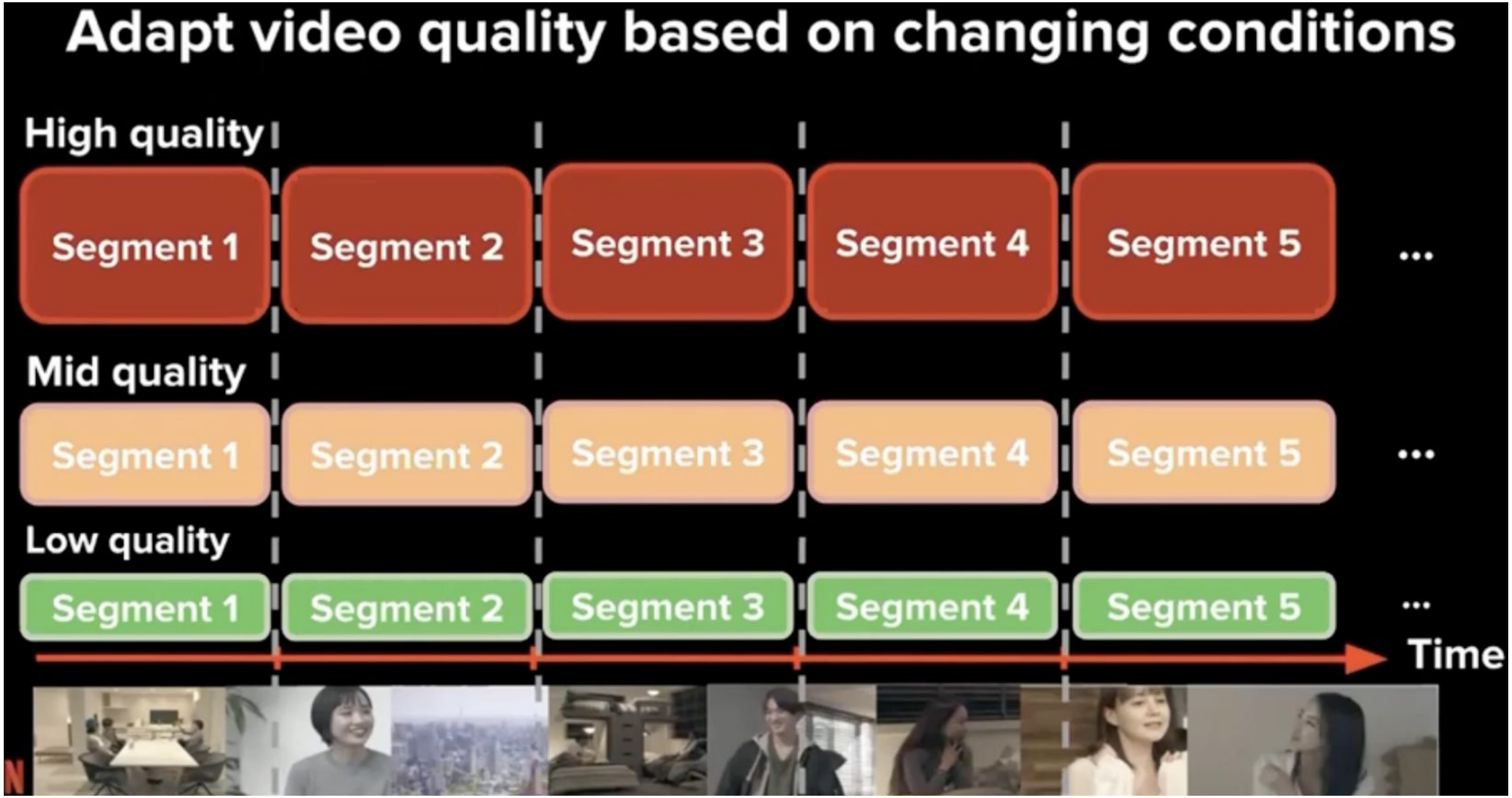
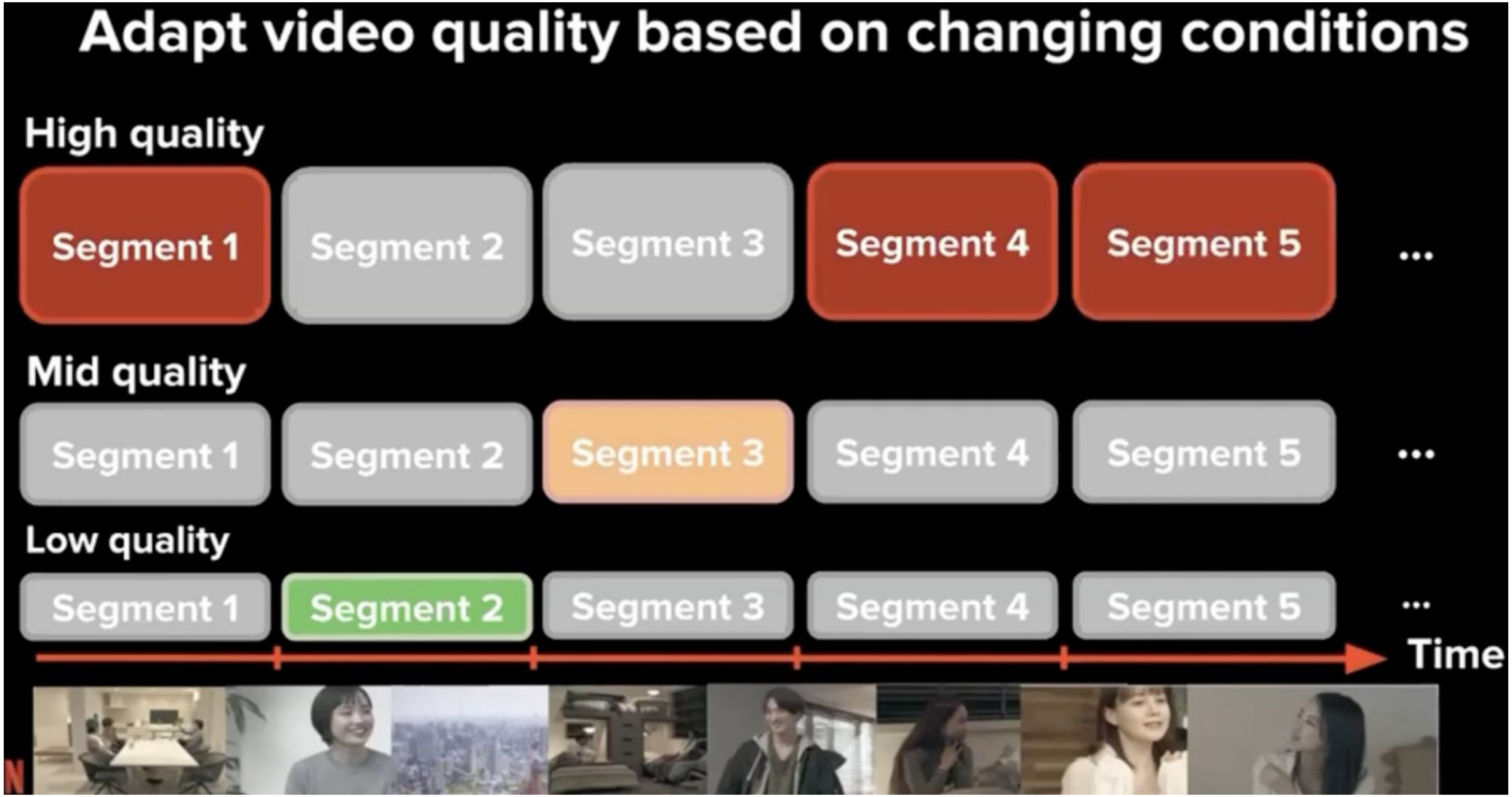
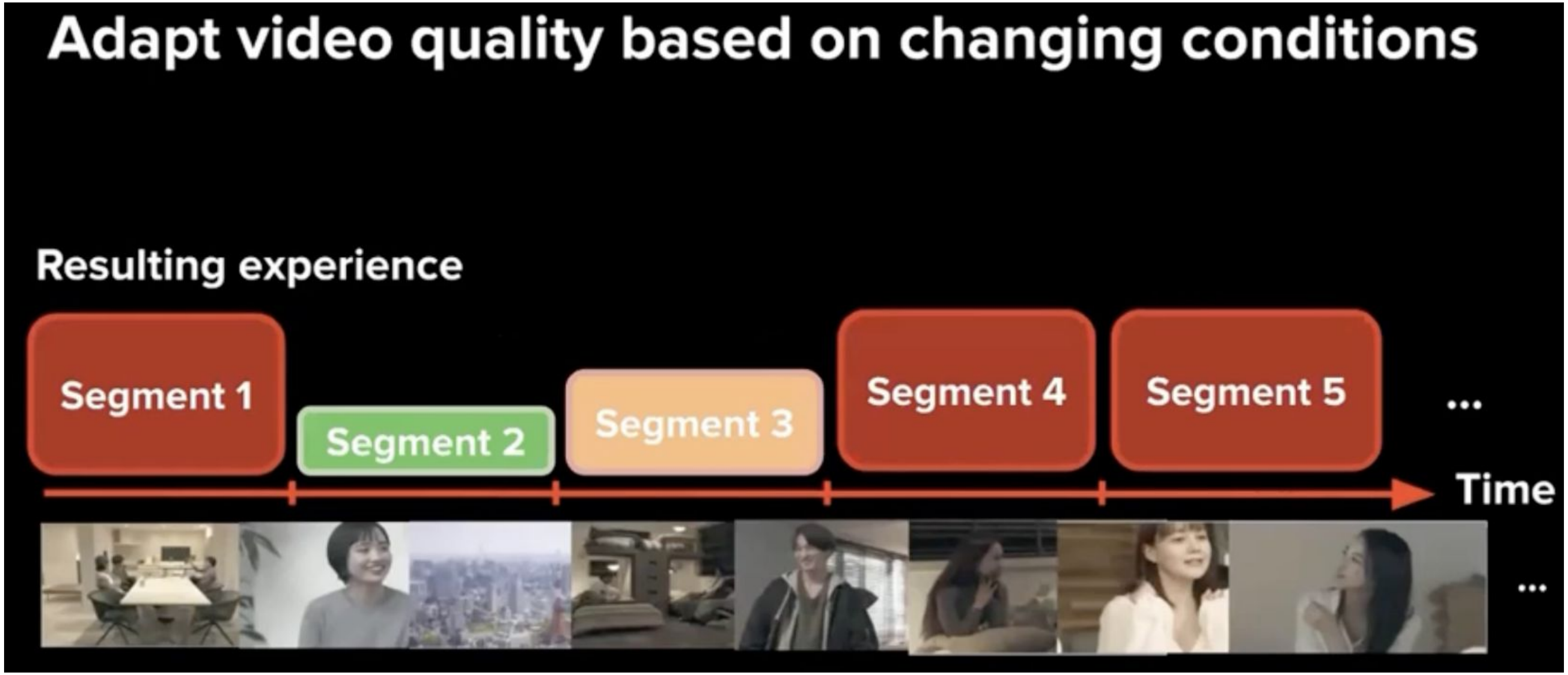


https://www.youtube.com/watch?v=kCshXyCmUho


Adapt video quality based on changing conditions
High quality
Segment 1
Segment 2
Segment 3
Segment 4
Segment 5
...
Mid quality
Segment 1
Segment 2
Segment 3
Segment 4
Segment 5
...
Low quality
Segment 1
Segment 2
Segment 3
Segment 4
Segment 5
...
Time



Potential problems under fast changing network environments?

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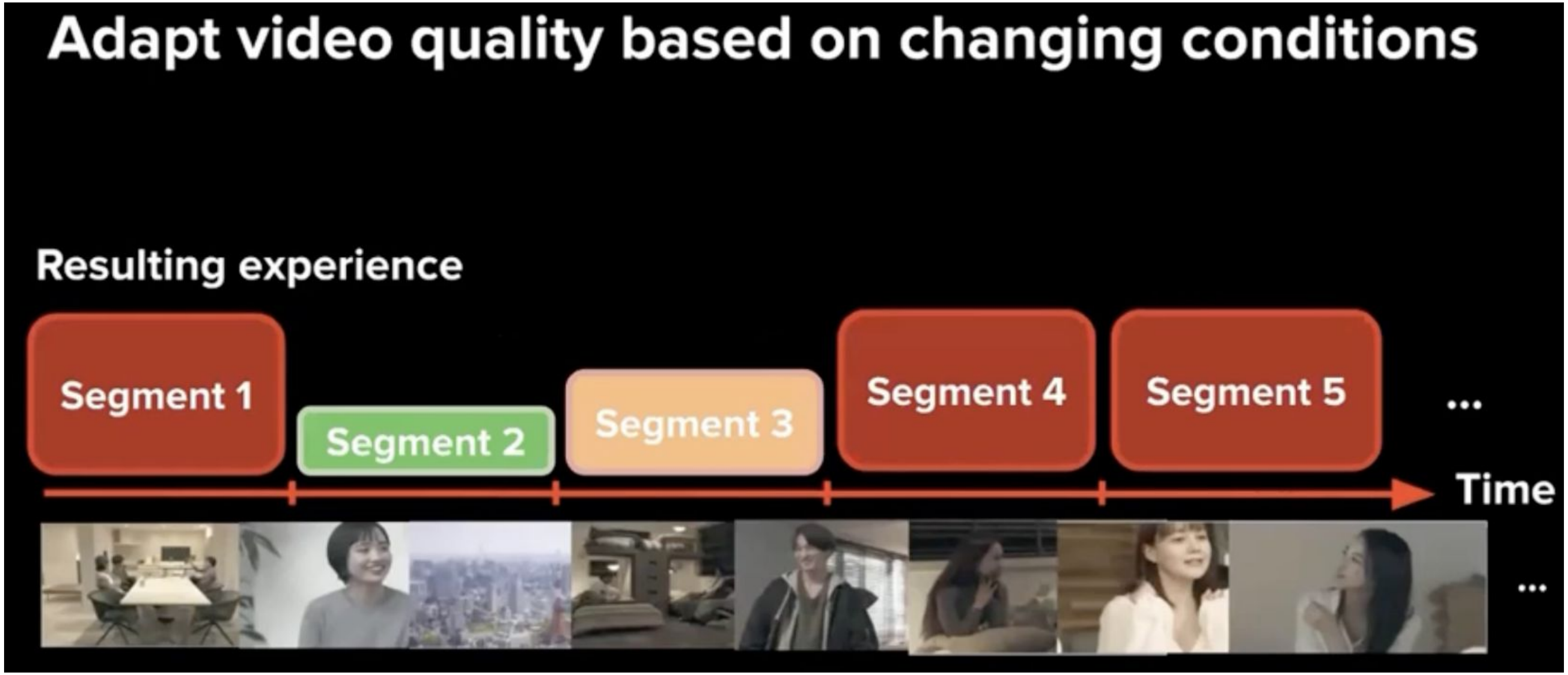

Potential problems under fast changing network environments?

Fluctuations

Research topics

- Video encoding
- Better adaptive bitrate algorithms
- Client assistance
  - super resolution
- New protocols design
  - QUIC
  - Multipath protocols
- Streaming to machines/ML applications
- SDN assisted approaches

(The list is not exhaustive nor complete)

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Research topics

- Video encoding (More on the computer vision side)
  - More efficient general video encoding algorithms
    - H.264,H.265,VP9…
  - Content aware encoding, take Netflix as an example

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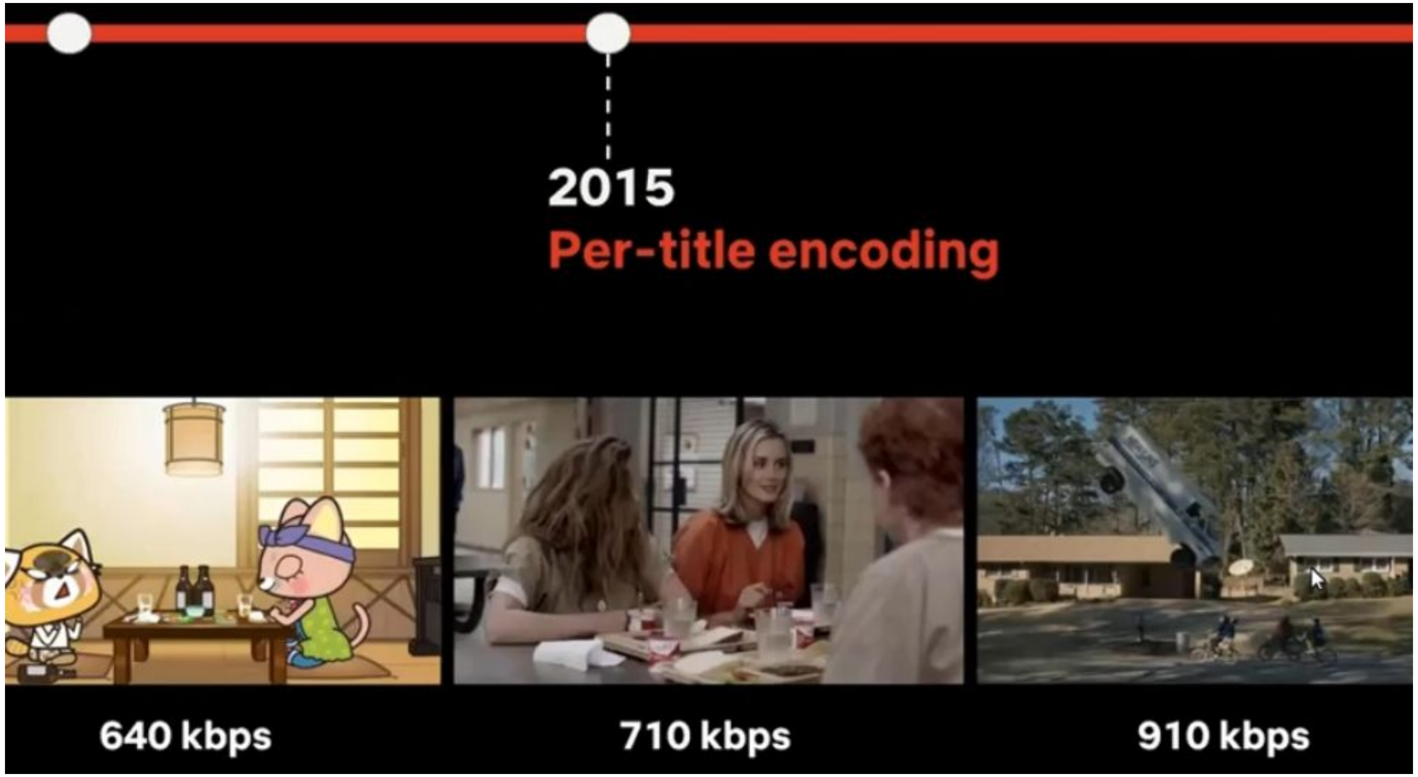
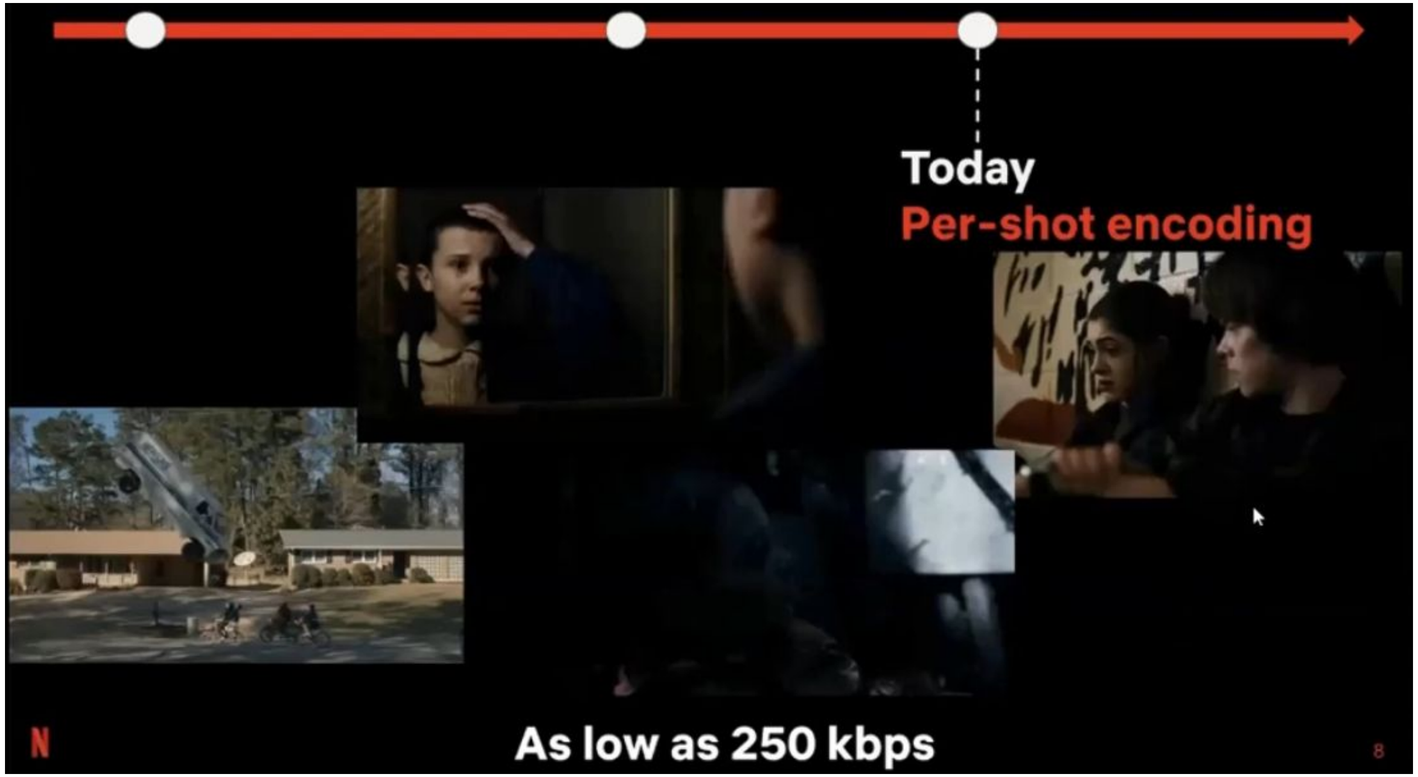


e.g., different genres of movies
anime
comedy
action
…

Research topics

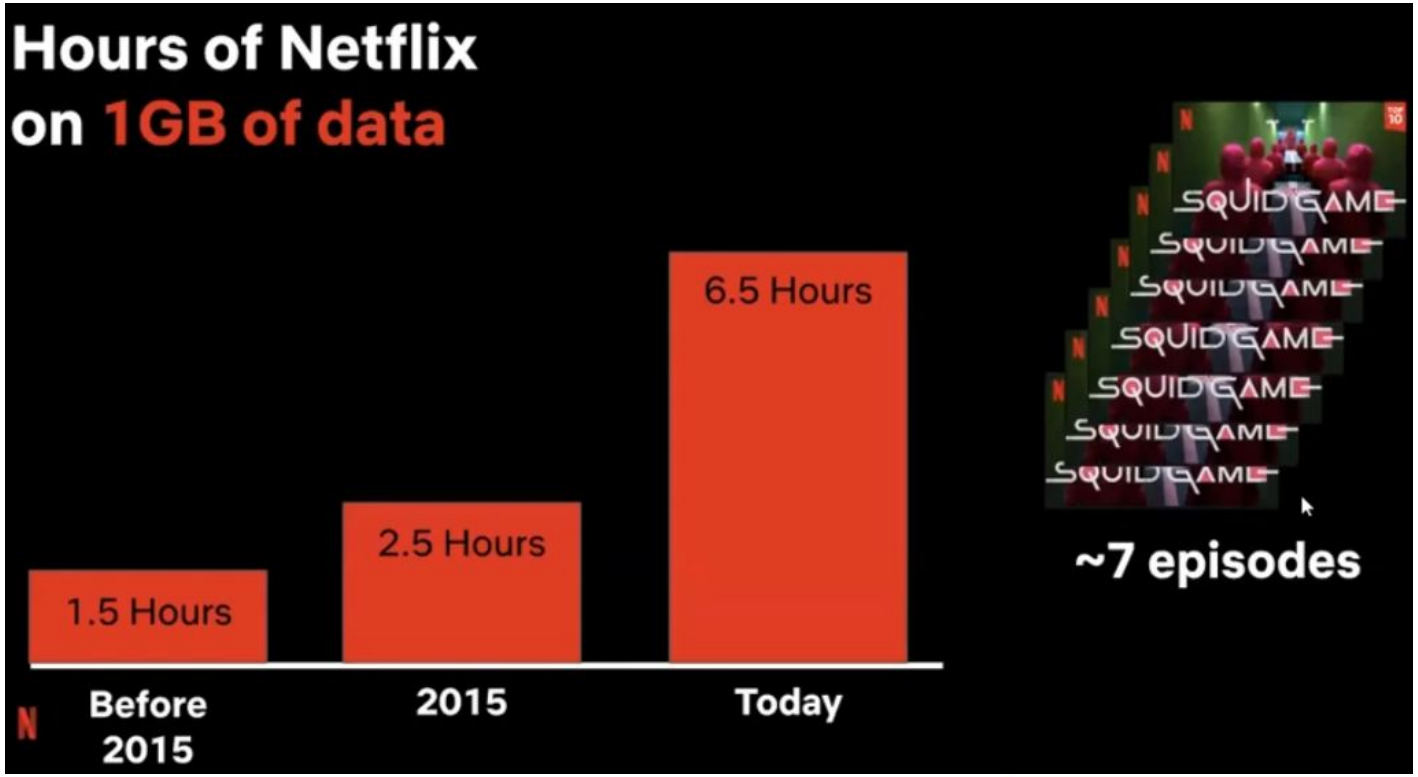
- Video encoding (More on the computer vision side)
  - More efficient general video encoding algorithms
    - H.264,H.265,VP9…
  - Content aware encoding, take Netflix as an example



e.g., static shot vs action shot contains different amount of information

Research topics

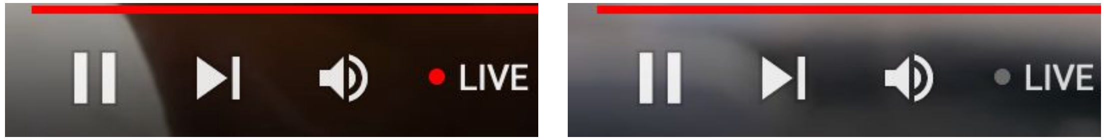
- Video encoding (More on the computer vision side)
  - More efficient general video encoding algorithms
    - H.264,H.265,VP9…
  - Content aware encoding, take Netflix as an example



More efficient video encoding algorithms
=>
Reduced data consumption

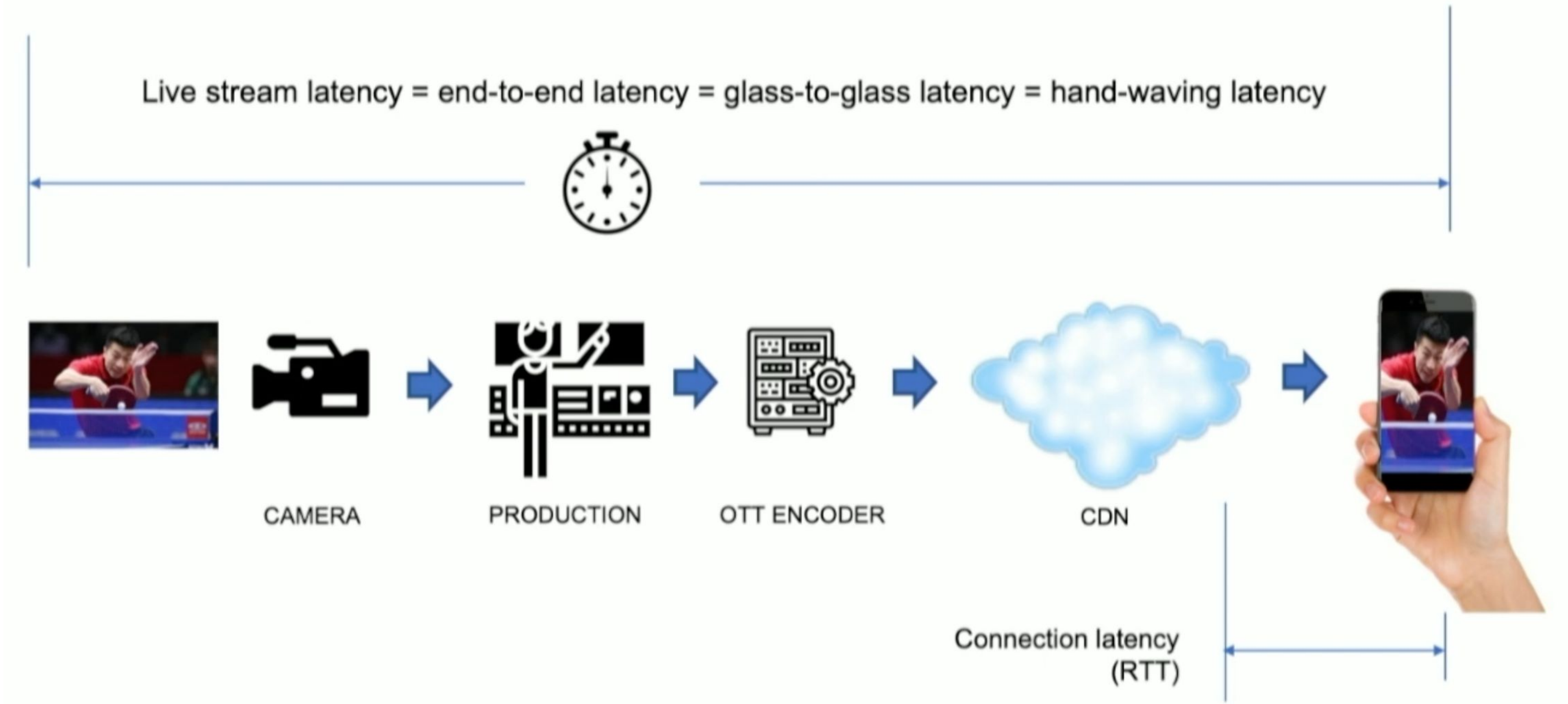
Live Streaming

- Live streaming is more sensitive to network fluctuation compared with video-on-demand services
  - The requirement of latency target: Keep up with “live” event within x seconds



  - The larger playback buffer, the longer live latency
  - Catchup mechanism: Increase/Decrease playback speed to reduce live latency
  - Seek to edge: Drop segments and jump to the live edge when the live delay is too significant to catch up

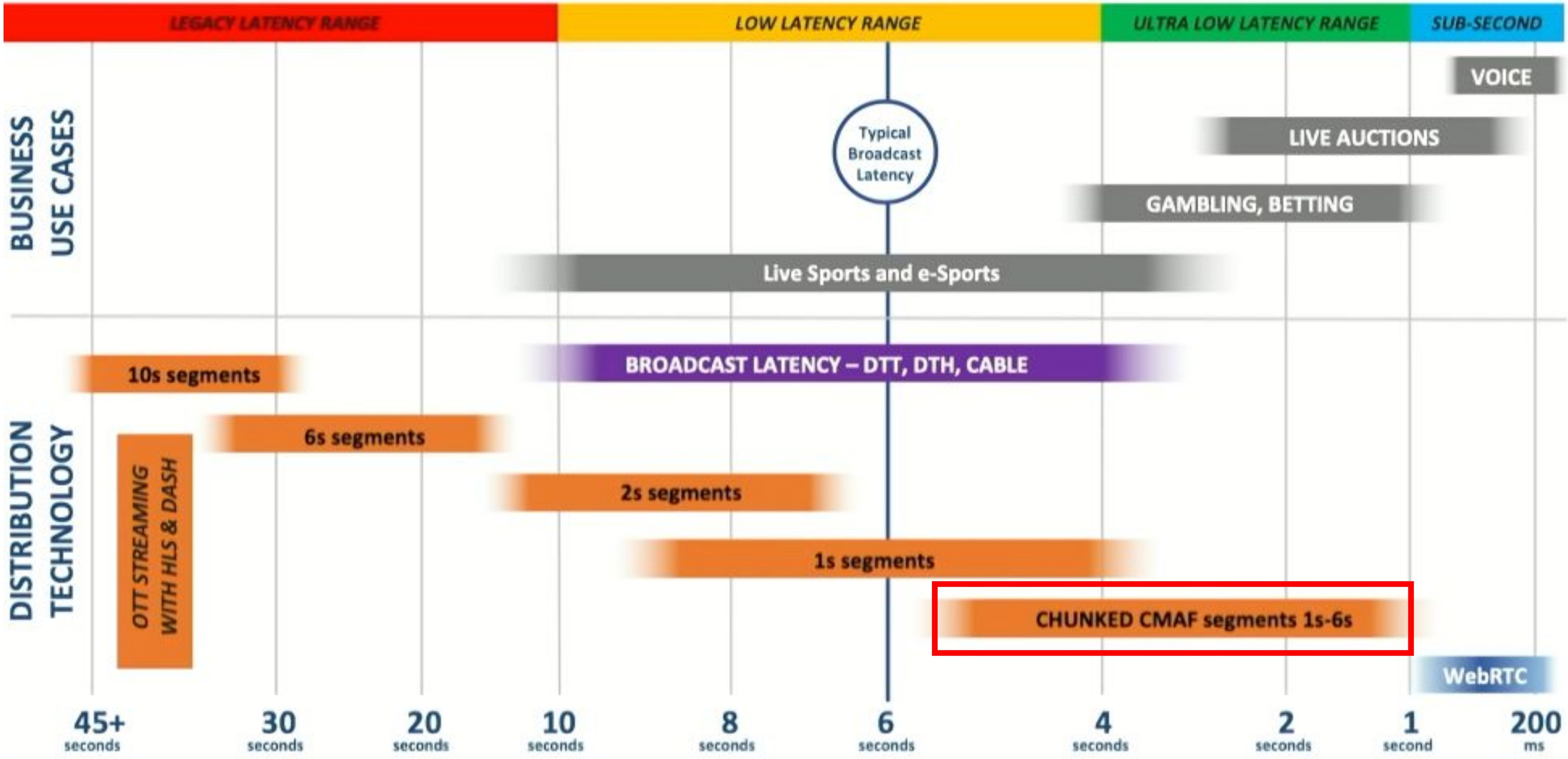
Latency vs RTT



In practice, end-to-end live streaming latency is the major concern

In the following, we assume there is zero delay between camera and video encoder

Latency Achievable at Scale Via Mainstream CDNs Streaming Technologies



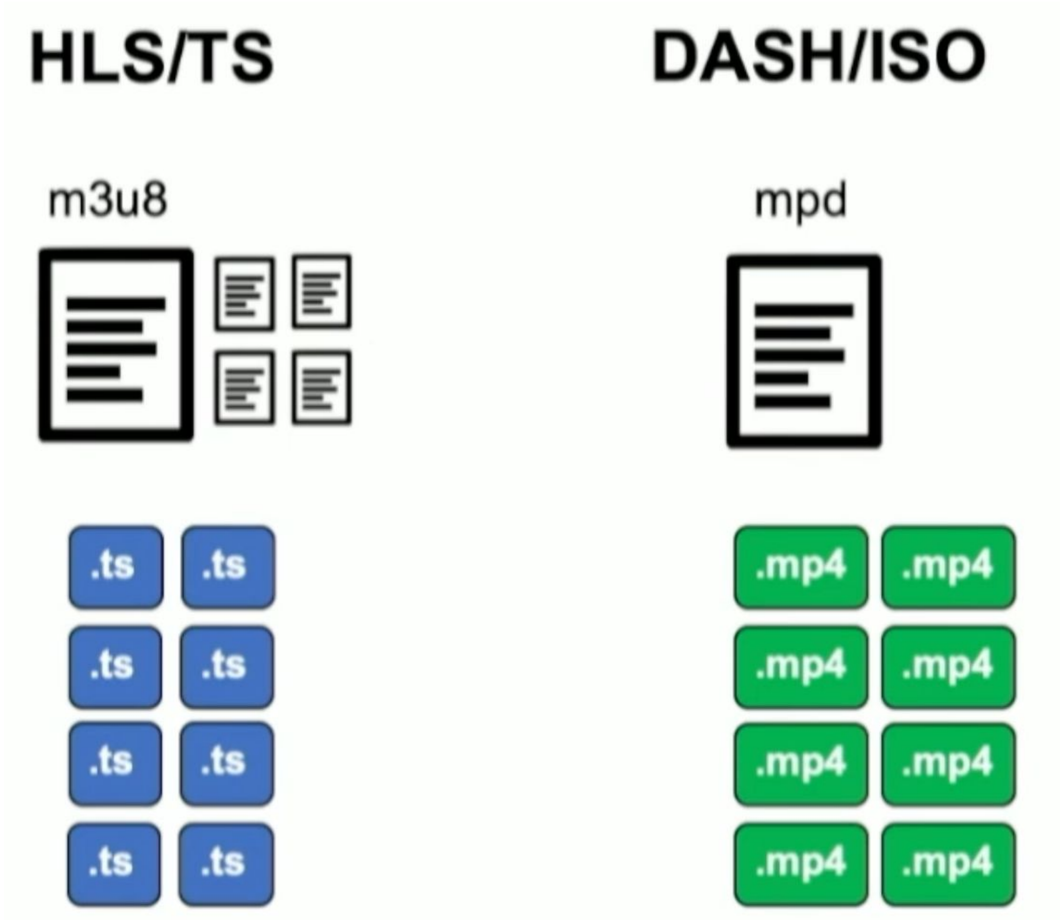
Video Container Formats vs Video Encoding Formats

Container format	File extension	Video encoding algorithms	Audio encoding algorithms
Matroska	.mkv	Many…	Many…
MPEG-4/ISO base media file format (ISOBMFF)	.mp4	H.264, H.265, AV1, VP8, VP9…	AAC, MP3, …
MPEG Transport Stream	.ts	H.262/MPEG-2 Video, H.264, H.265…	MP3, Opus, …
Apple QuickTime	.mov	H.264, H.265, Apple ProRes…	AAC, ALAC, Opus, …

But not all containers are capable of online video streaming

https://en.wikipedia.org/wiki/Comparison_of_video_container_formats

Video Streaming Protocols



Pre 2010: Adobe Flash

HLS

Developed by Apple since 2009, became RFC 8216 in 2017

DASH

Standardized in 2012 as ISO/IEC 23009-1:2012

There is twice the cost of encoding time and storage in CDN in order to support both Apple and other systems

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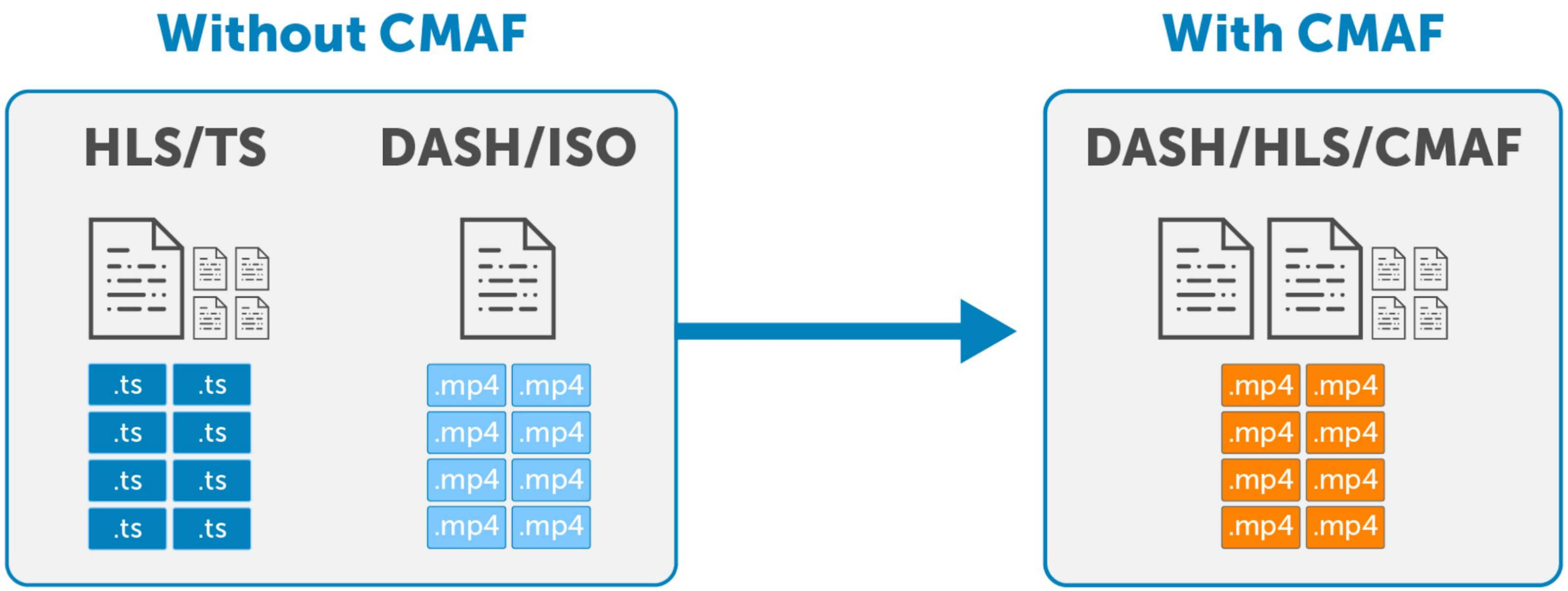
CMAF (Common Media Application Format)



CMAF can only achieve low latency with the help of chunked encoding and chunked transfer, not by itself

Goal of CMAF

- Eliminate investments associated with encoding and storing multiple copies of the same content
- Decrease video latency by with chunked-encoded and chunked-transfer CMAF.

February 2016: Apple and Microsoft proposed CMAF to the Moving Pictures Expert Group (MPEG).
January 2018: CMAF standard officially published. (ISO/IEC 23000-19:2018)

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Chunked Encoding and Chunked Transfer

Without chunked encoding and chunked transfer

- An encoder must wait to encode the last byte of content before it uploads the file to the CDN for distribution, which introduces a delay of one segment duration
- In addition, CDNs receiving the incoming segments typically wait to receive the last byte before it can be downloaded by clients
- Video players wait to receive the last byte from the CDN before beginning to decode the first byte.

This pattern of repeated accumulation results in an overall latency loss that is an integer multiple of the segment duration.

Delays of 5x segment duration are quite common in status quo deployments, ~10s with 2s segments and 20s with 4s segments, which still lags TV broadcast levels of latency.

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Chunked Encoding

Imagine a video segment with 20 frames

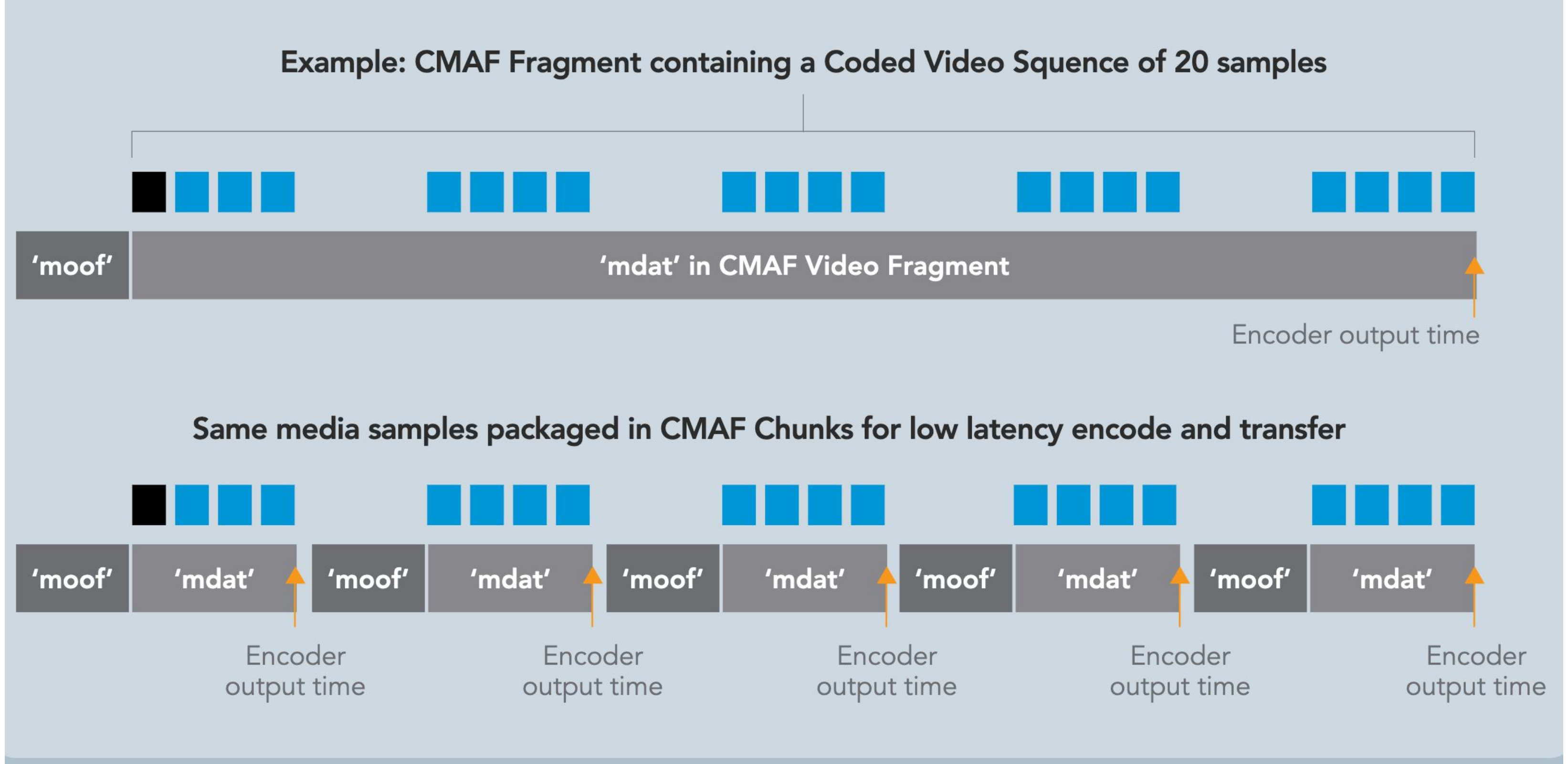

Figure 2: Chunked encoding of a CMAF segment

There is no fixed rule for how many frames are included in each chunk. Current encoder practice ranges from 1–15 frames. Taking the example of a 1 second segment at 20 fps with 4 frame per chunk, the media content is released 0.8 seconds earlier than if the encoder had waited to produce the entire segment before uploading the file.

$0.8 = 1 - 4/20$

The advantage of breaking up the segment into these shorter pieces is that the encoder can output each chunk for delivery immediately after encoding it.

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https://web.archive.org/web/20210728231318/https://www.akamai.com/us/en/multimedia/documents/white-paper/low-latency-streaming-cmaf-whitepaper.pdf

Chunked Transfer

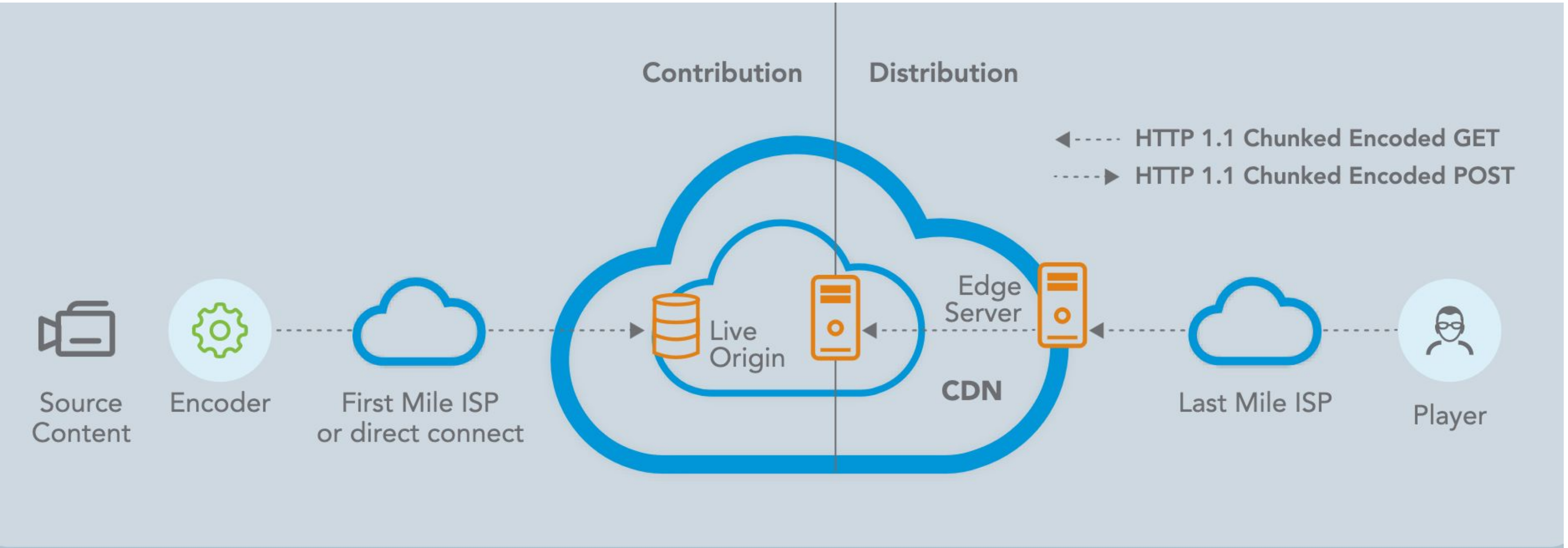

Figure 2: HAS media distribution system

Chunked transfer is available since HTTP/1.1

The server does not know the final size of the object it is sending, which enables the encoder to send video chunks as it produces to CDN, and enables the player to continuously download the chunks from CDN

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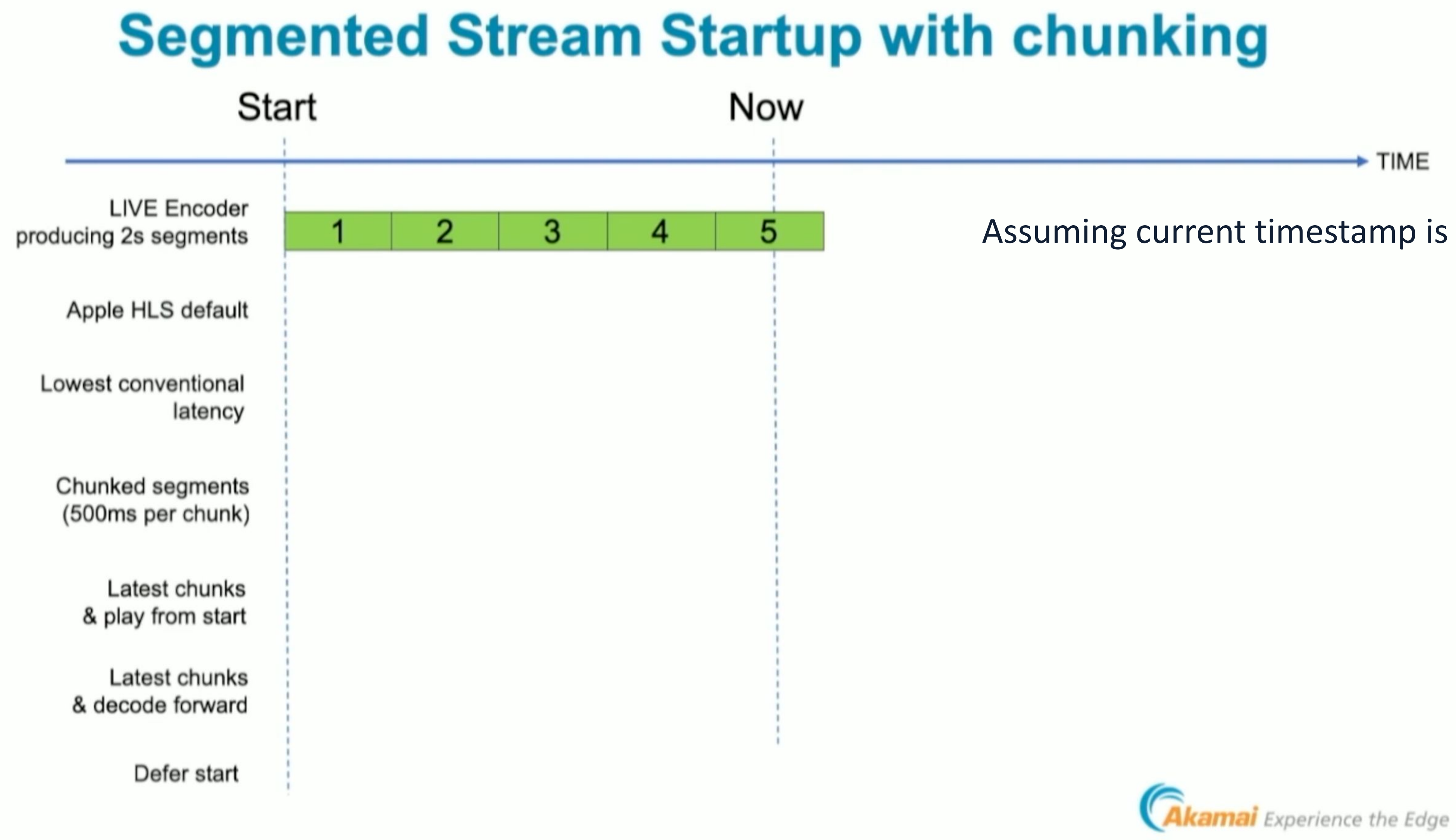
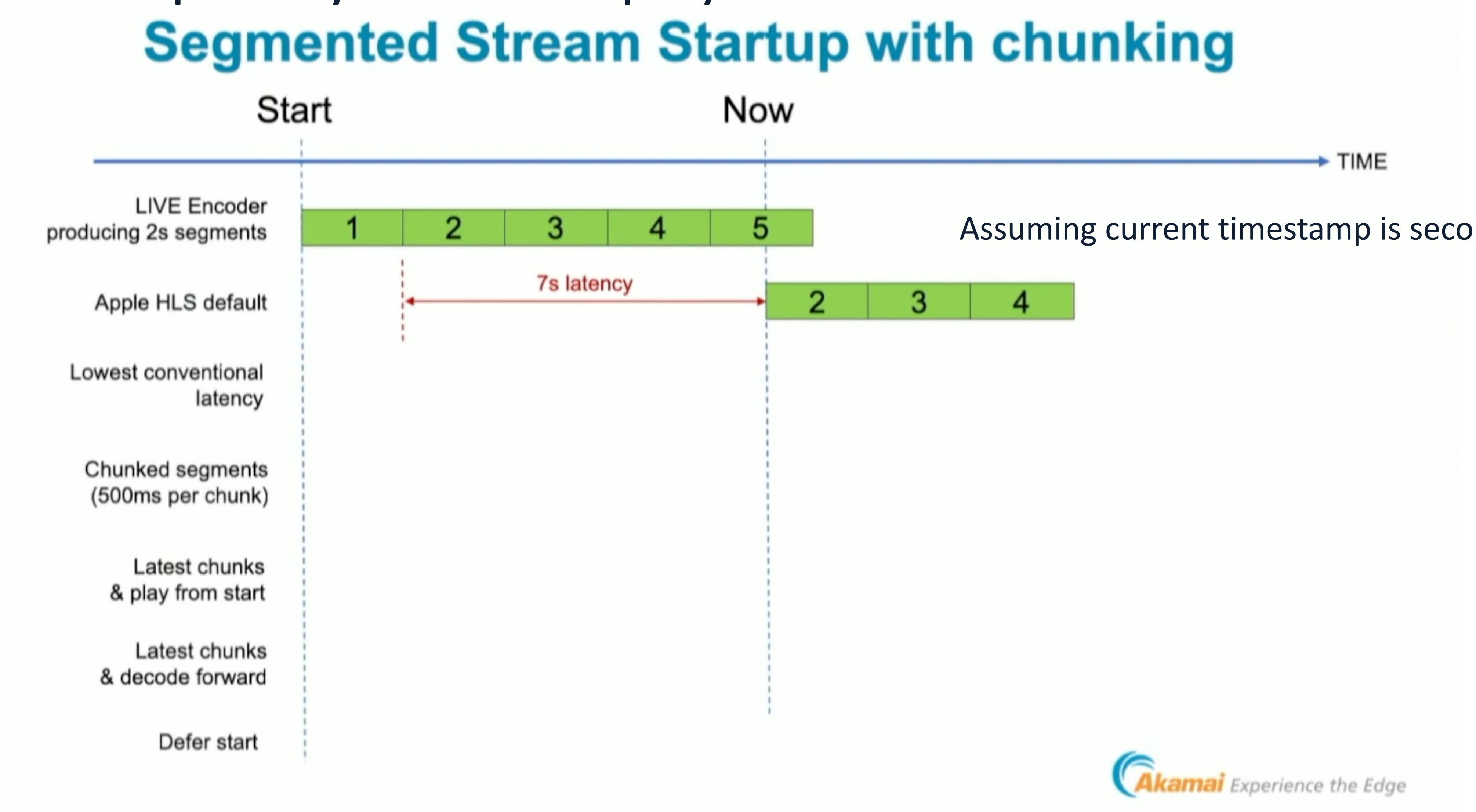
Startup delay on media player



Assuming current timestamp is second 9

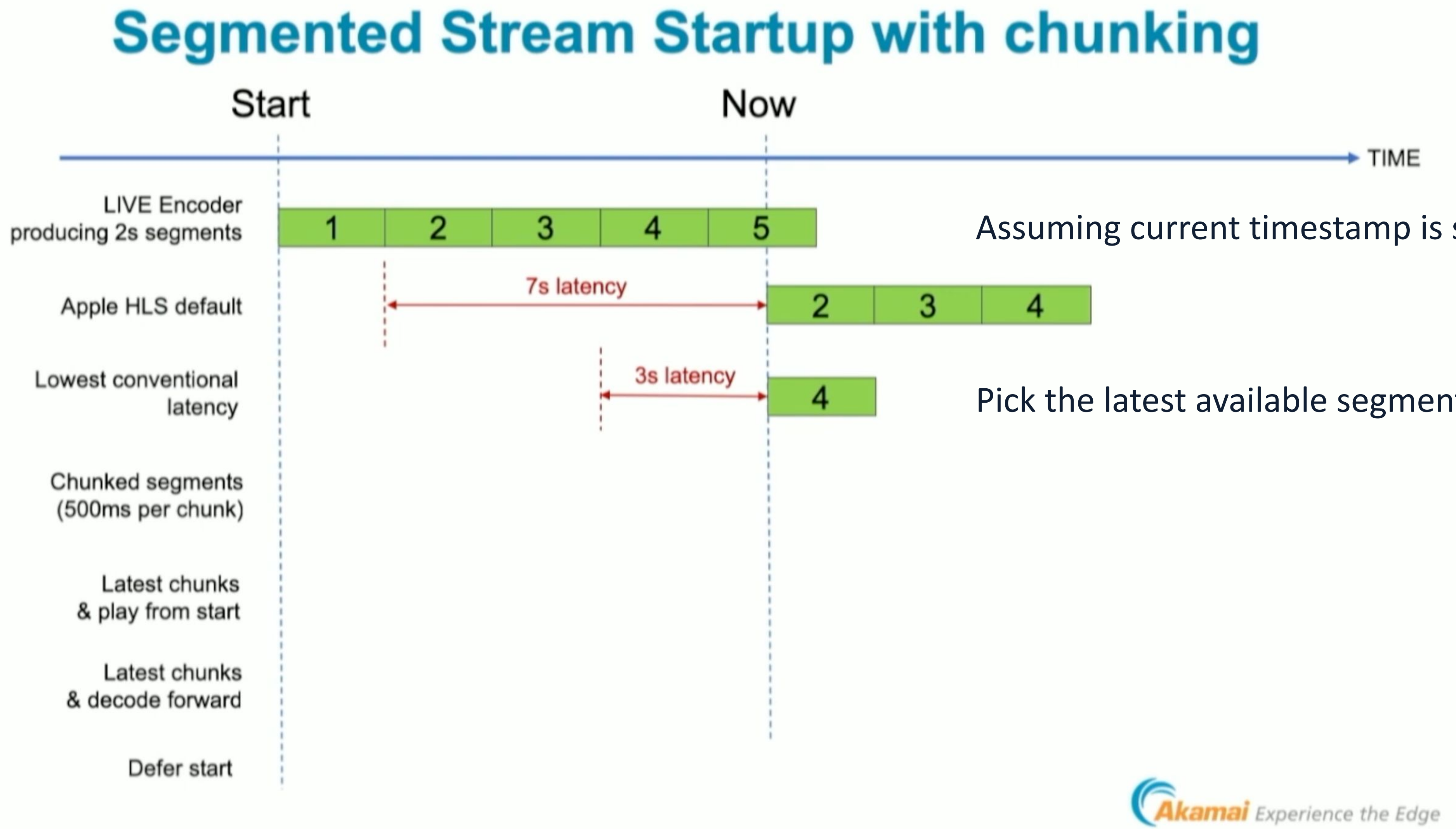
Startup delay on media player



Assuming current timestamp is second 9

* In this example, we also assume the download finishes instantly

Startup delay on media player



Assuming current timestamp is second 9

Pick the latest available segment

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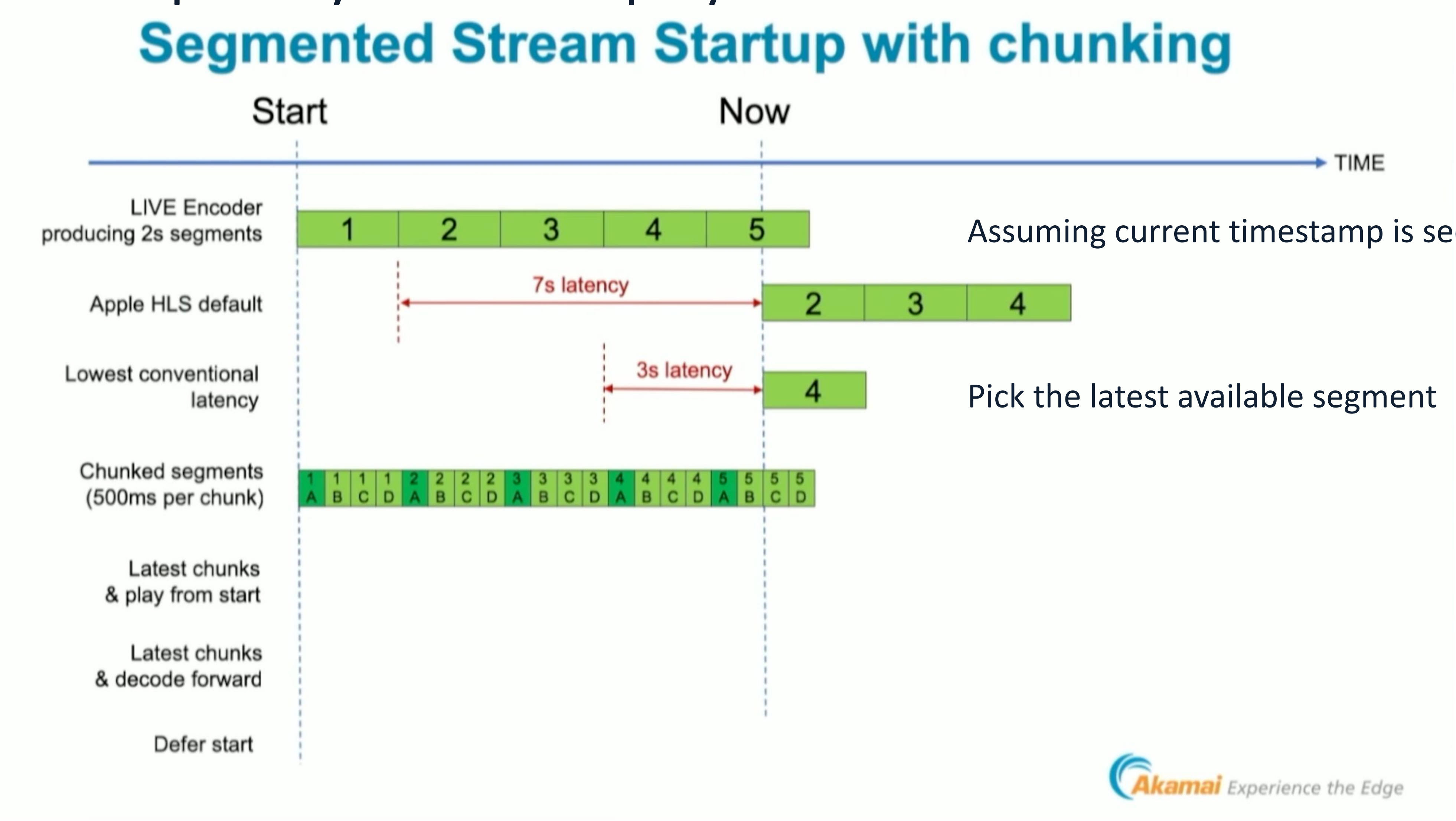
Startup delay on media player



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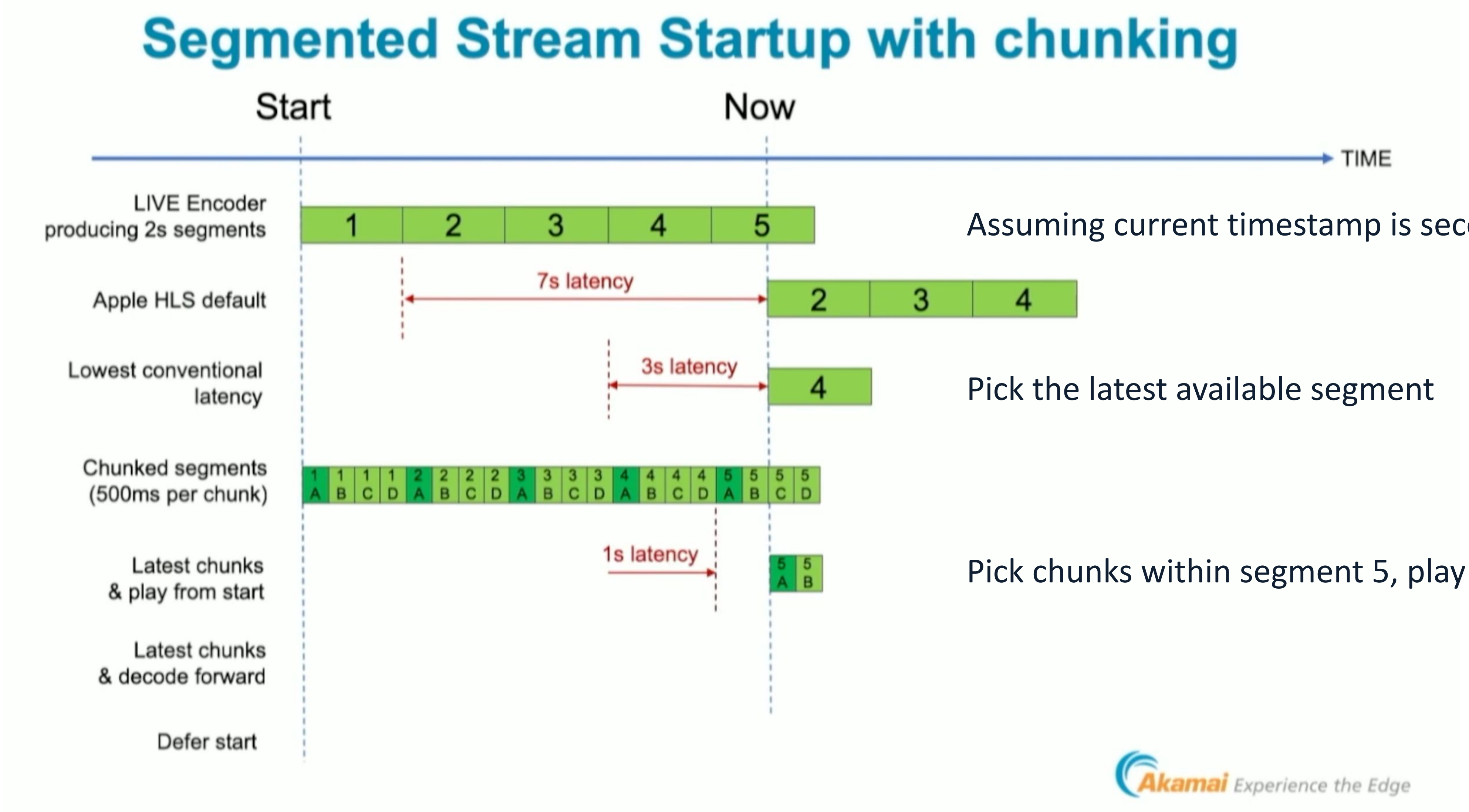

Assuming current timestamp is second 9

Pick the latest available segment

Pick chunks within segment 5, play from start

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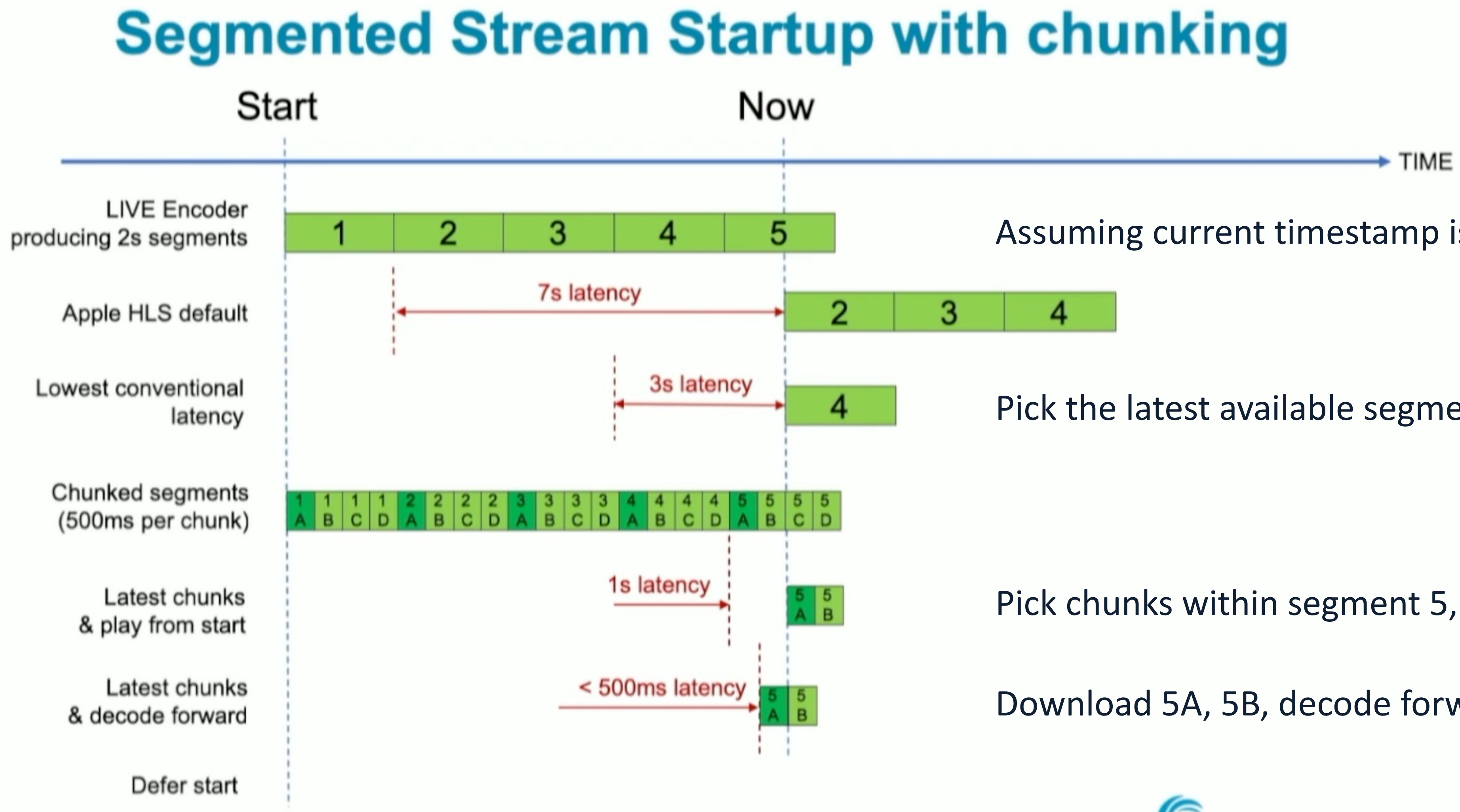
Startup delay on media player



Assuming current timestamp is second 9

Pick the latest available segment

Pick chunks within segment 5, play from start

Download 5A, 5B, decode forward to 5B

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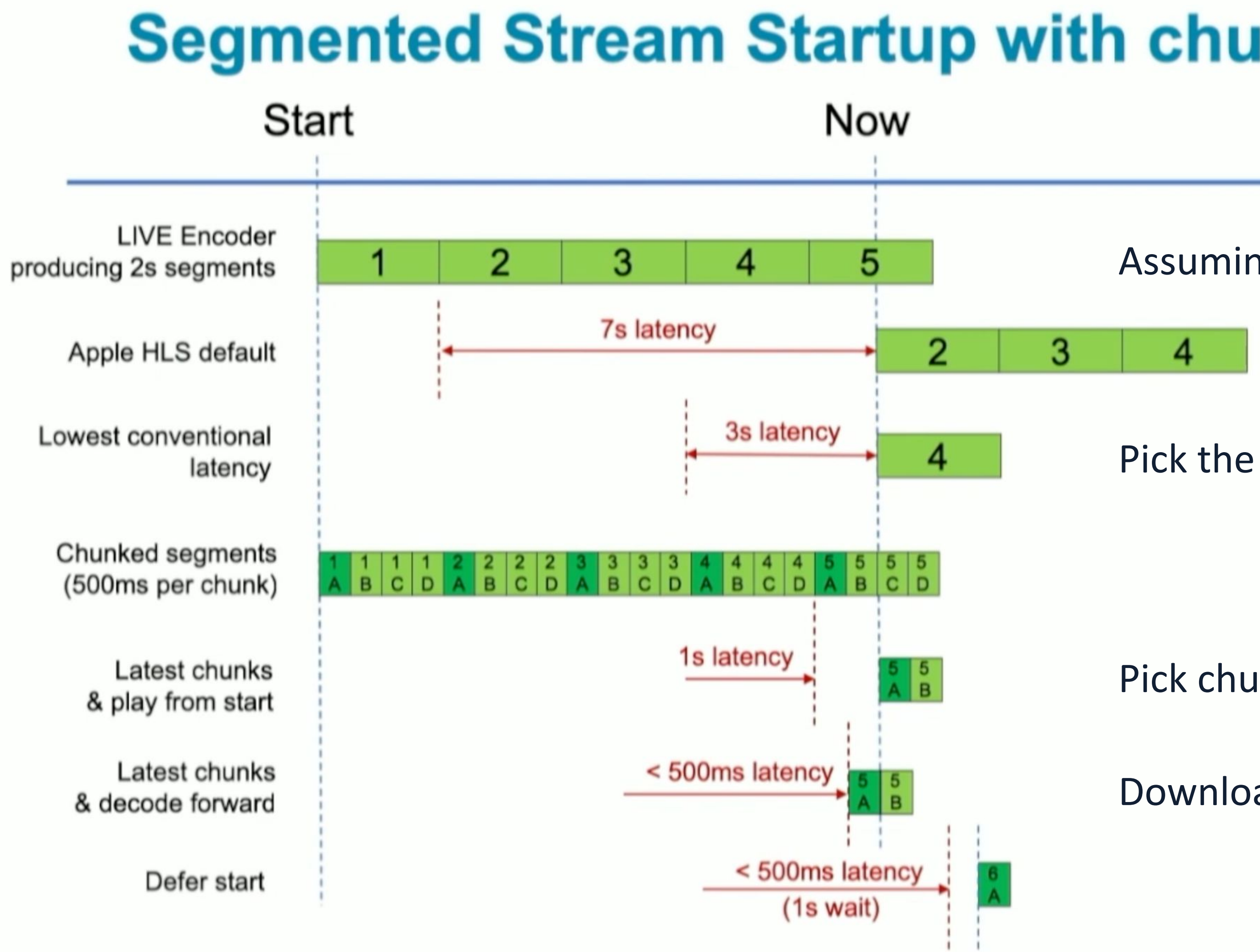
* In this example, we also assume the download finishes instantly

Startup delay on media player



Assuming current timestamp is second 9

Pick the latest available segment

Pick chunks within segment 5, play from start

Download 5A, 5B, decode forward to 5B

Akamai Experience the Edge

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Wait 1s, immediately request 6A after it's produced

* In this example, we also assume the download finishes instantly

My research work

- QoE-driven Joint Decision-Making for Multipath Adaptive Video Streaming
  - *Jinwei Zhao, Jianping Pan*
  - Accepted by IEEE Globecom 2023
  - Video on demand (VoD) scenario; Cross layer information sharing and joint decision making for multipath selection and video bitrate adaptation
  - Preprint pdf on https://pan.uvic.ca/~clarkzjw/

Ongoing

- Low Latency Live Streaming over Low-Earth-Orbit Satellite Network with DASH
  - Measuring the performance of low latency DASH ABR algorithms over Starlink; Potential improvements with satellite handover consideration to adjust playback speed and bitrate selection

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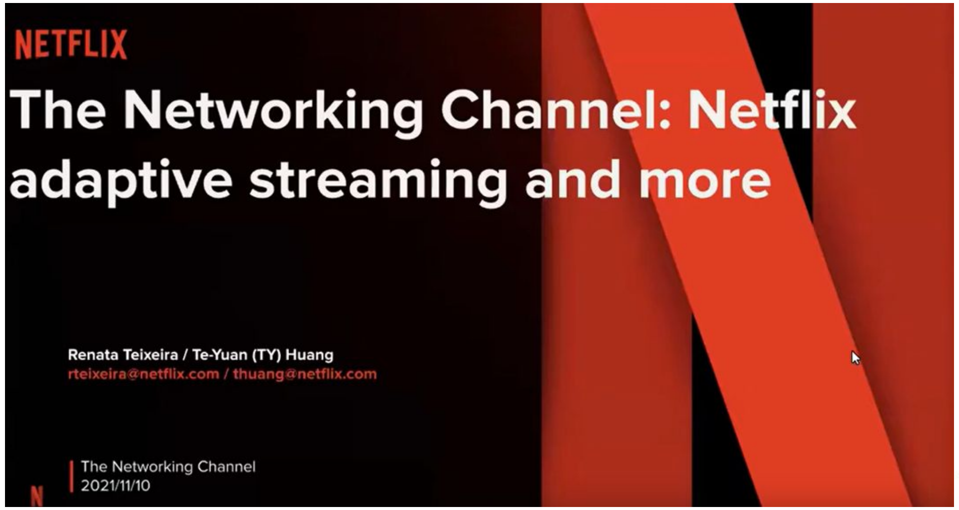
Credits

Some slides are borrowed from
Will Law (Akamai)'s talk in 2018
https://www.youtube.com/watch?v=BYRjZNUgzFc and
TY Huang (Netflix)'s talk in 2021
https://www.youtube.com/watch?v=kCshXyCmUho



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