Fraunhofer FOKUS
Institut für Offene Kommunikationssysteme

Foundations of Media Streaming

Advanced Web Technologies | Open Distributed Systems

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Oct 30th, 2023

Schedule

No	Week	Date	Topic
1	42	16.10.2023	Introduction and Framework
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3	44	30.10.2023	Foundations of Media Streaming
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9	50	11.12.2023	Context-Aware Media Streaming & Encoding
	51	18.12.2023	Holiday break
	52	25.12.2023	Holiday break
	1	01.01.2024	Holiday break
10	2	08.01.2024	Media Delivery in 5G Networks (1)
11	3	15.01.2024	Media Delivery in 5G Networks (2)
12	4	22.01.2024	Metaverse Platforms and Technologies
13	5	29.01.2024	Securing Content-Provenance and Authenticity
14	6	05.02.2024	Interoperable Web-supported Learning Technologies
15	7	12.02.2024	Exercise and Test Preparation
16	8	19.02.2024	Written Test (60min) first slot

Agenda

1 Intro

2 ABR Streaming

3 Streaming Formats

4 Low-Latency Streaming

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Intro

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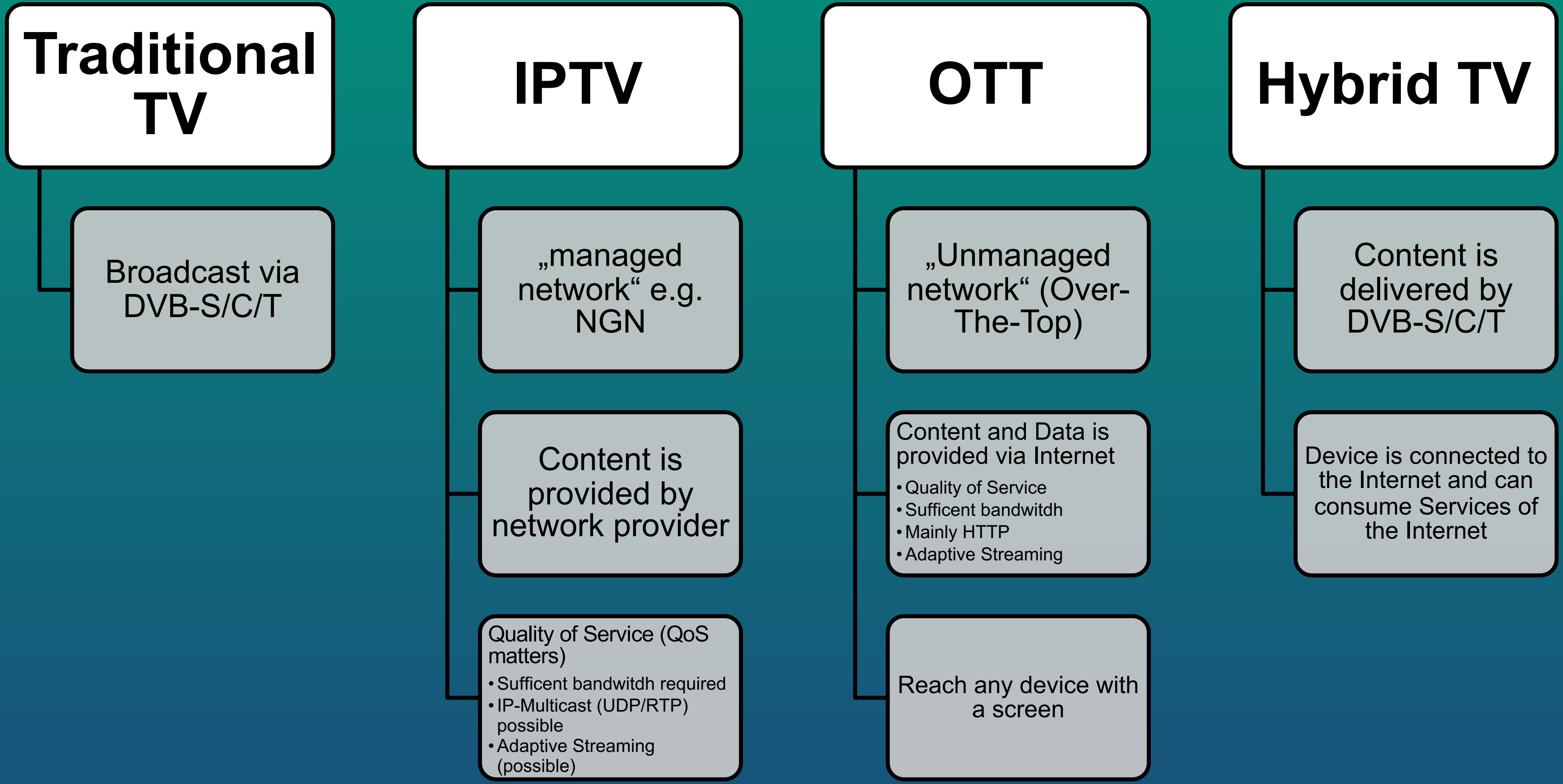
Linear TV Distribution



Traditional TV

- Broadcast via DVB-S/C/T

IPTV

- „managed network“ e.g. NGN
- Content is provided by network provider
- Quality of Service (QoS matters)
  - Sufficent bandwitdh required
  - IP-Multicast (UDP/RTP) possible
  - Adaptive Streaming (possible)

OTT

- „Unmanaged network“ (Over-The-Top)
- Content and Data is provided via Internet
  - Quality of Service
  - Sufficent bandwitdh
  - Mainly HTTP
  - Adaptive Streaming
- Reach any device with a screen

Hybrid TV

- Content is delivered by DVB-S/C/T
- Device is connected to the Internet and can consume Services of the Internet

OTT Delivery: Tech to understand

ABR – Adaptive Bitrate

DASH – Dynamic Adaptive Streaming over HTTP for live and on demand video; MPEG standard

HLS – HTTP Live Streaming for live and on demand video by Apple

MSS – Microsoft Smooth Streaming

CMAF – Common Media Application Format for HLS and DASH

IMSC – Internet Media Subtitles and Captions

CENC – Common Encryption for many DRM & delivery channels

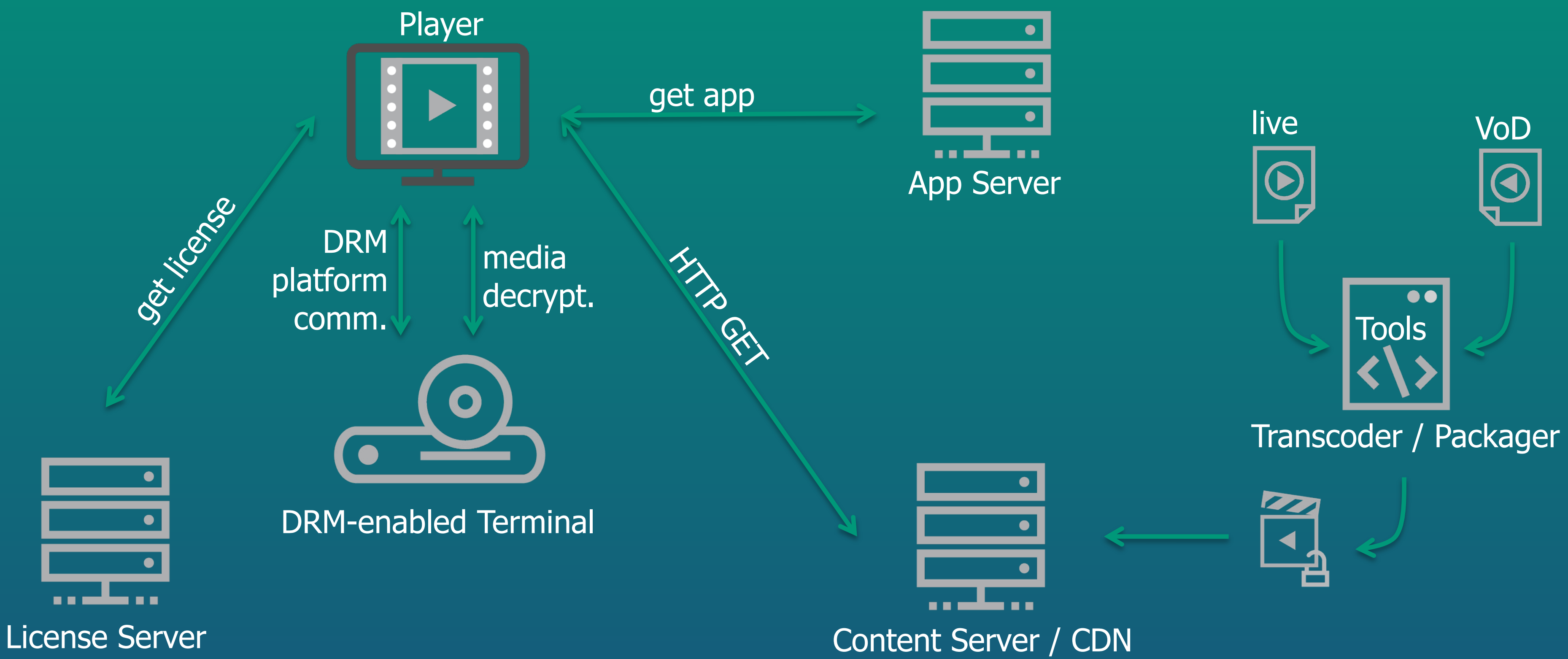
MSE – Media Source Extension to trick-function HTML5 video-objects via JavaScript (control AV media streams)

EME – Encrypted Media Extension to play back DRM-protected media in standard browsers w/o the use of proprietary plug-ins

CDM – Content Decryption Module - addition to the browser that provides functionality for one or more Key Systems

CPIX – Content Protection Information Exchange Format - standardizes the way entities involved in the content creation workflow exchange protection information

Media Streaming Workflow



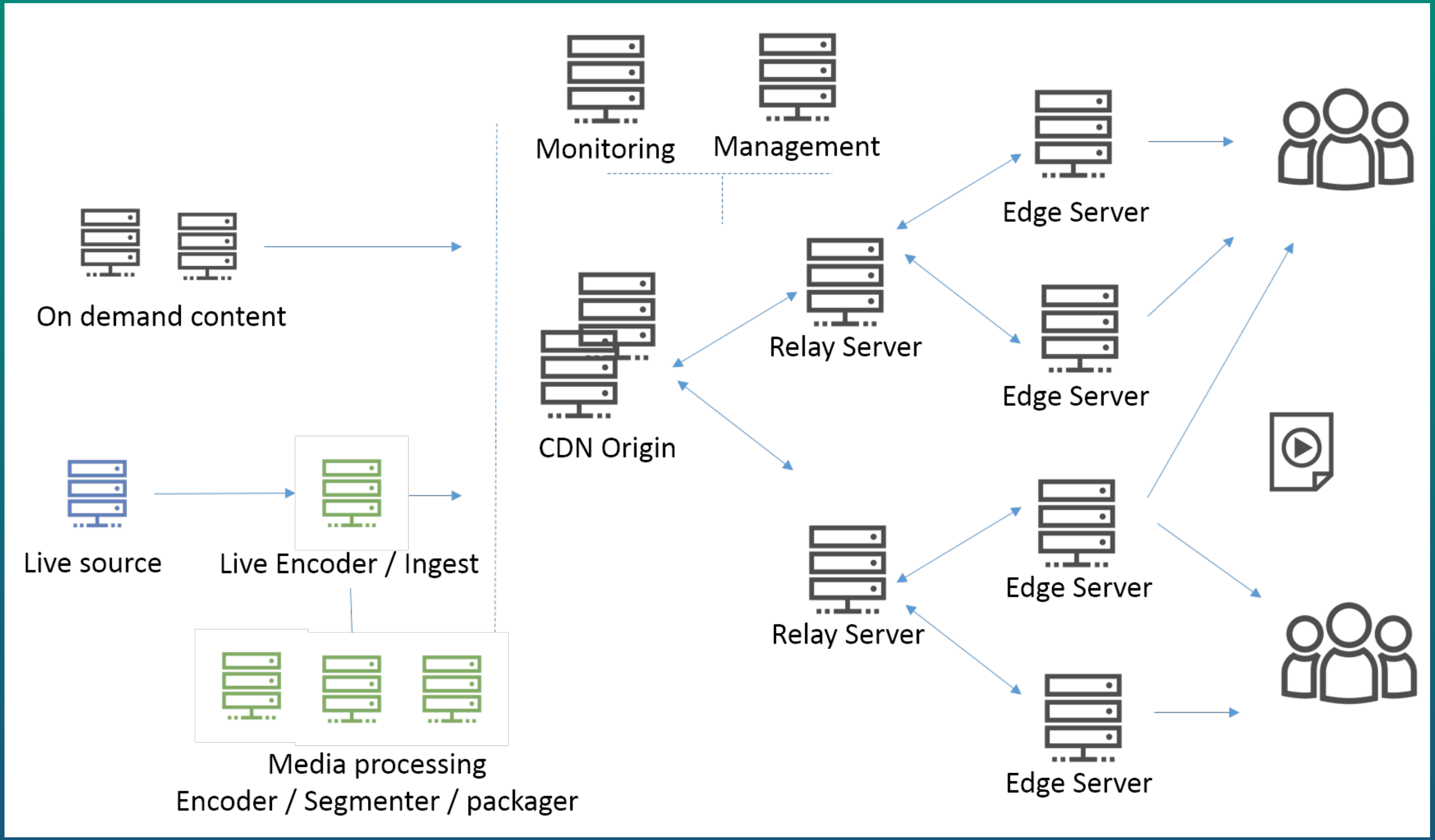
Media Streaming Workflow

1. Content Generation: Original content (Live or VoD) is encoded into different bitrates and resolutions. Afterward it is split into segments, packaged into a transport format and a manifest file is created. Encryption/DRM is optionally applied by the packager.

2. Content Delivery: Segments and manifest are pushed to a CDN origin server. The web app is usually hosted on a different server.

3. Content Playback: Player gets the manifest from CDN edge and parses it. In case of DRM, license acquisition is triggered to retrieve a secure key, which is used to decrypt the segments. The adaptive bitrate (ABR) algorithm detects a user's available codec, resolution, bandwidth and selects appropriate segments from the MPD, which is then requested from the CDN. Downloaded segments are fed into the video buffer and then rendered.

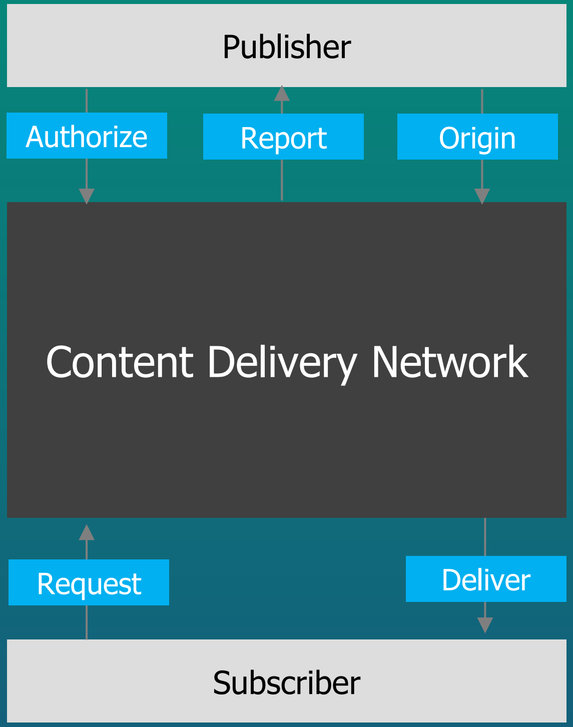
CDN Topology



CDN

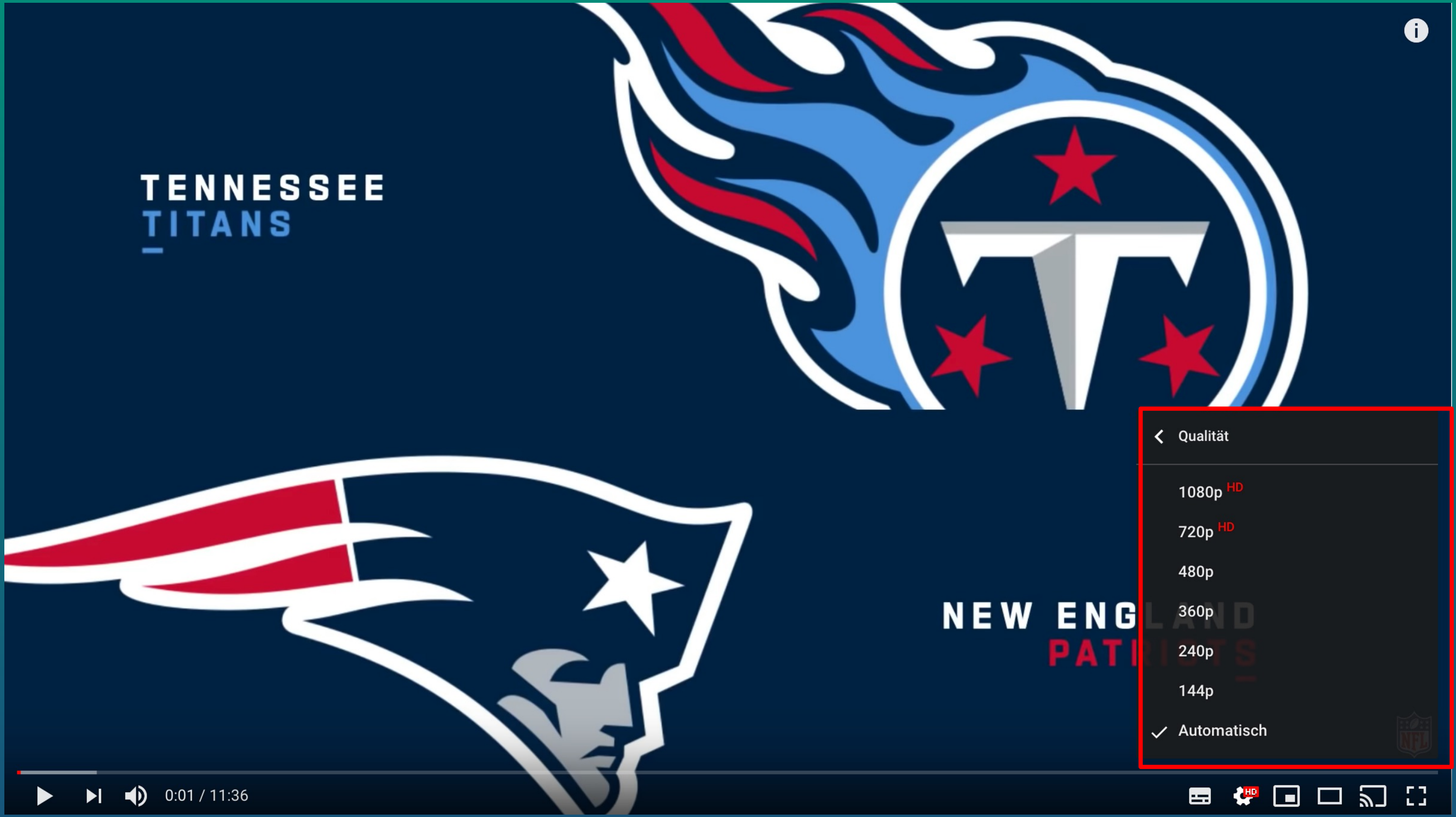
- A system of server caches
  - containing copies of data,
  - placed at various points in a network
  - to maximize bandwidth and provide low latency for access from clients
- Clients accesses a copy of the data near to the client (CDN edge)
  - Opposed to all clients accessing the same origin server
  - Edge location is determined by DNS
  - If CDN edge has the data, it is delivered to the client. Otherwise, it is requested from the origin and cached for other client sessions.

- Load balancers manage the distribution of content and dynamically adjust routing according to business rules (e.g. live vs vod streaming)



ABR Streaming

ABR Streaming - Youtube



Qualität

1080p HD

720p HD

480p

360p

240p

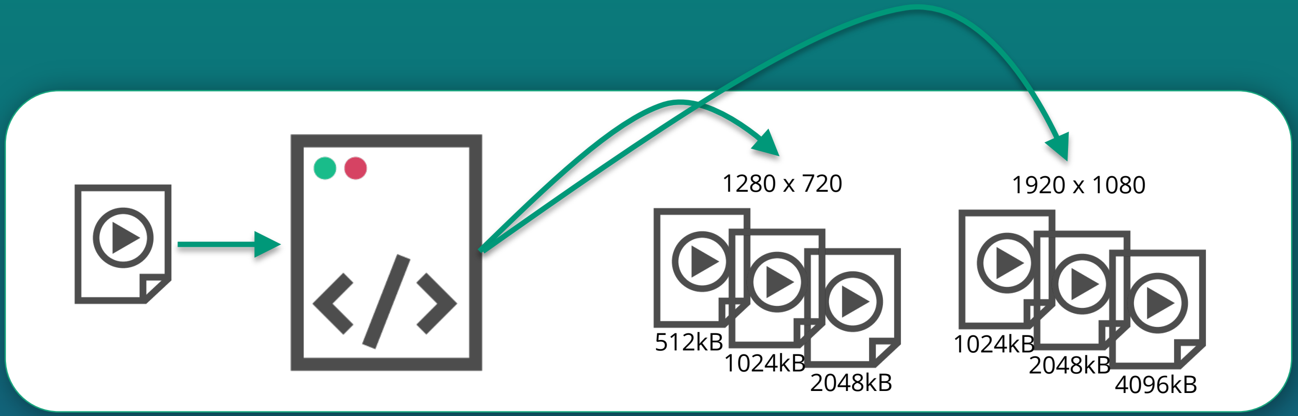
144p

✓ Automatisch

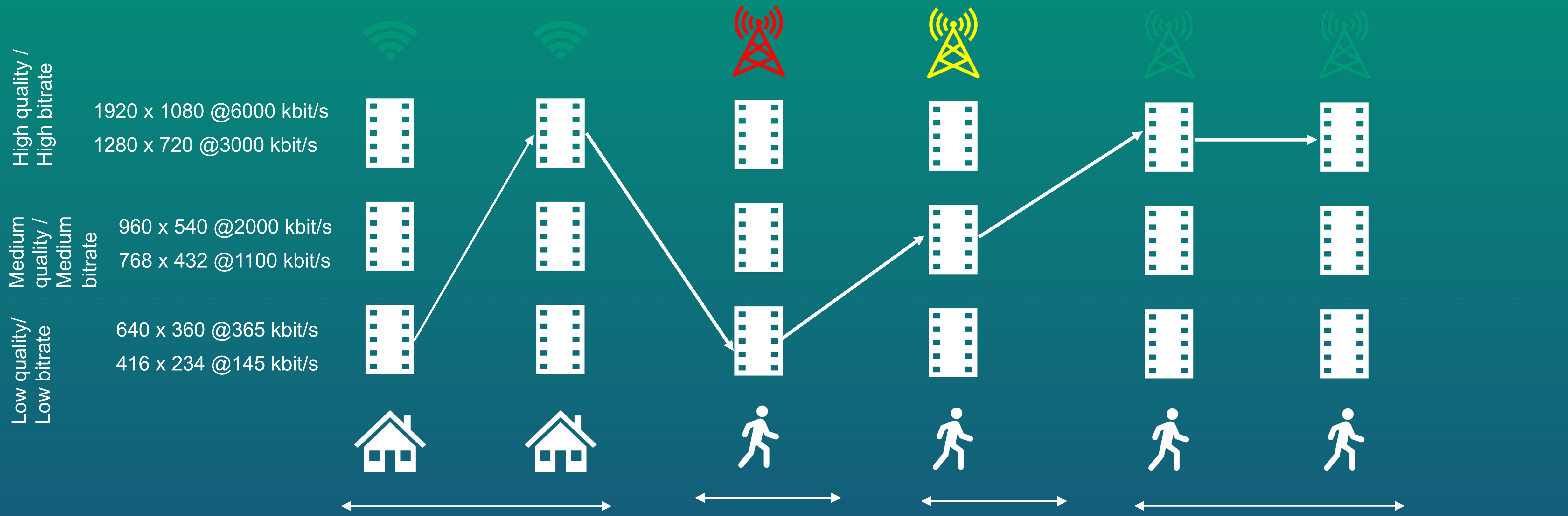
0:01 / 11:36

ABR Streaming - Exercise

- Observe adaptive bitrate (ABR) behaviour: dash.js+BBB
- Chrome DevTools to
  - View network traffic
  - Throttle bandwidth



ABR Streaming – Network Adaptation



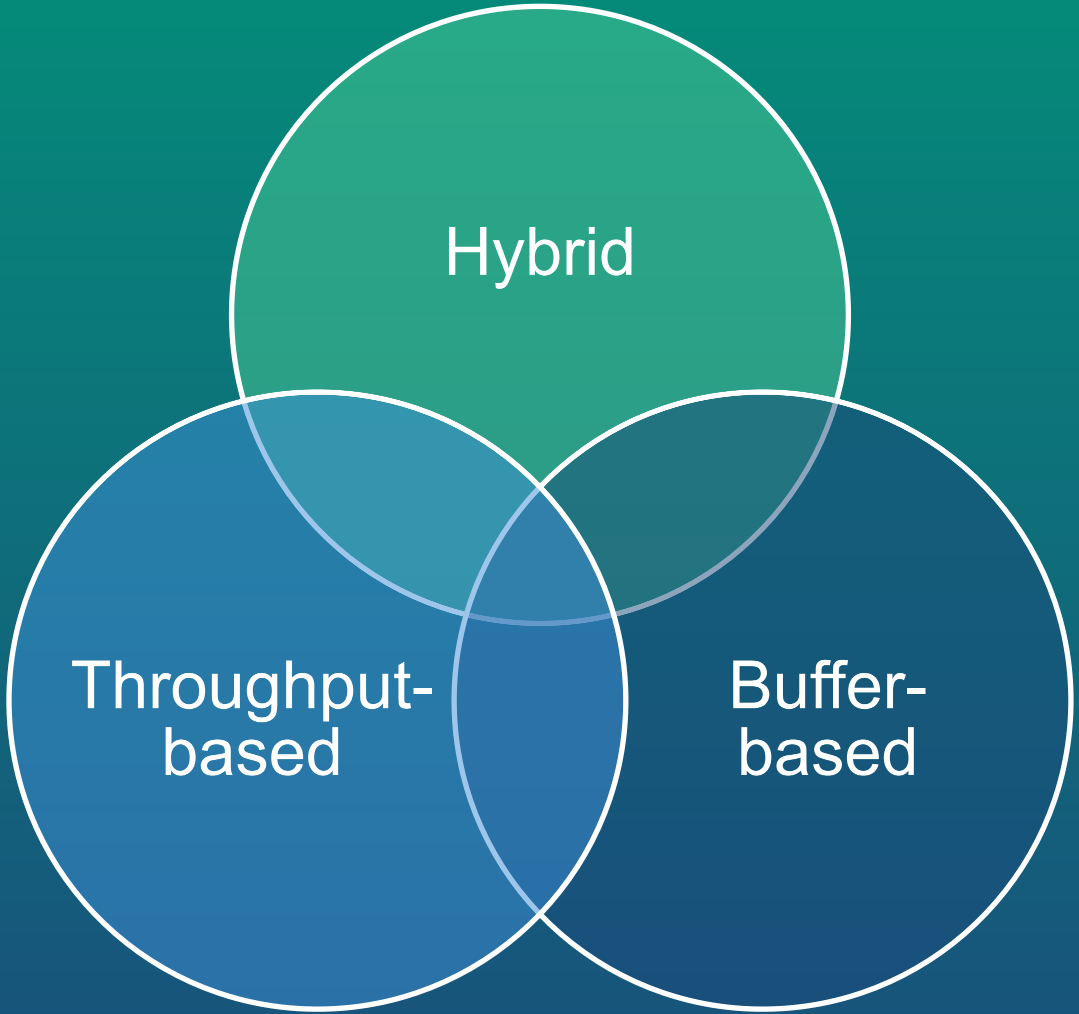
Local WIFI: High bandwidth, fast startup phase

Mobile connection: Low bandwidth, quality is decreased

Mobile connection: Medium bandwidth, quality is increased

Mobile connection: High bandwidth, quality is increased

ABR Streaming – ABR Algorithms



ABR Streaming – Next-gen Codecs

- High Efficiency Video Coding (H.265/HEVC/MPEG-H Part 2)
  - Successor of H.264
  - Offers 25-50% better data compression compared to H.264
  - Supports resolutions up to 8k, mainly used for delivery of 4k

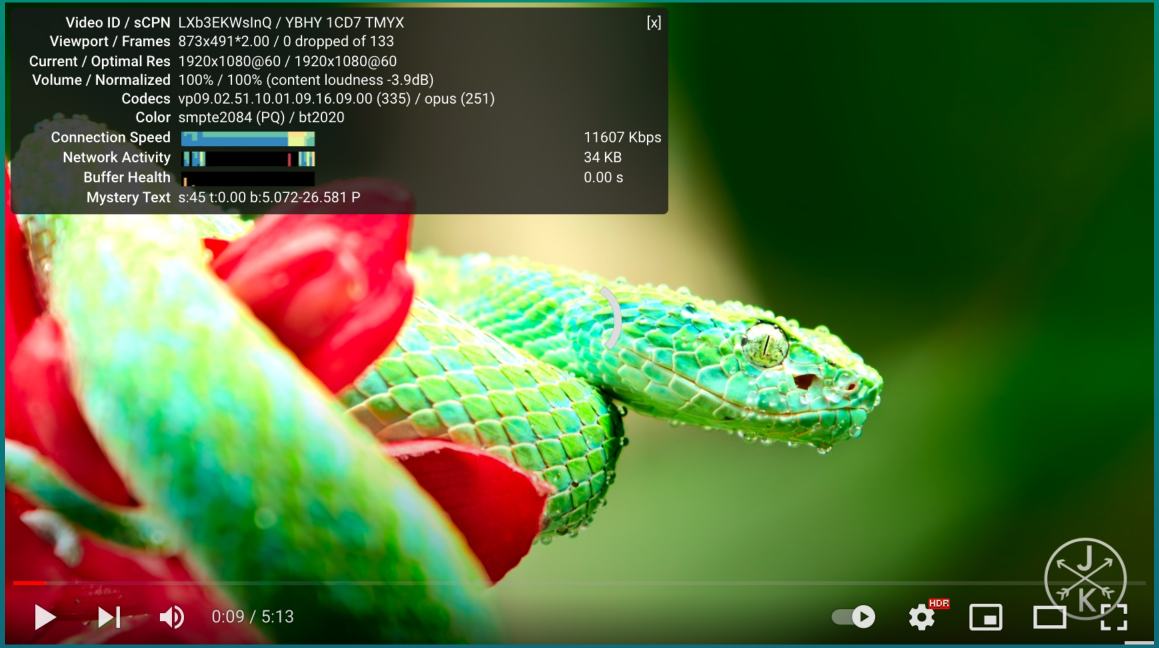
- Versatile Video Coding (VVC, H.266, ISO/IEC 23090-3, MPEG-I Part 3)
  - Successor of H.265
  - Up to 50% better data compression compared to H.265

- Low Complexity Enhancement Video Coding (LCEVC)
  - Specified an enhancement layer that can be combined with a separate codec (AVC, HEVC, VP9, AV1…)
  - Provides additional efficiency to existing or future video codecs
  - Enhancement layer is supposed to processed in the software

ABR Streaming – (Potentially) Royalty-free Video Codecs

- VP9
  - Developed by Google
  - Aims to achieve similar compression efficiency as HEVC
  - Used for instance by YouTube and Netflix

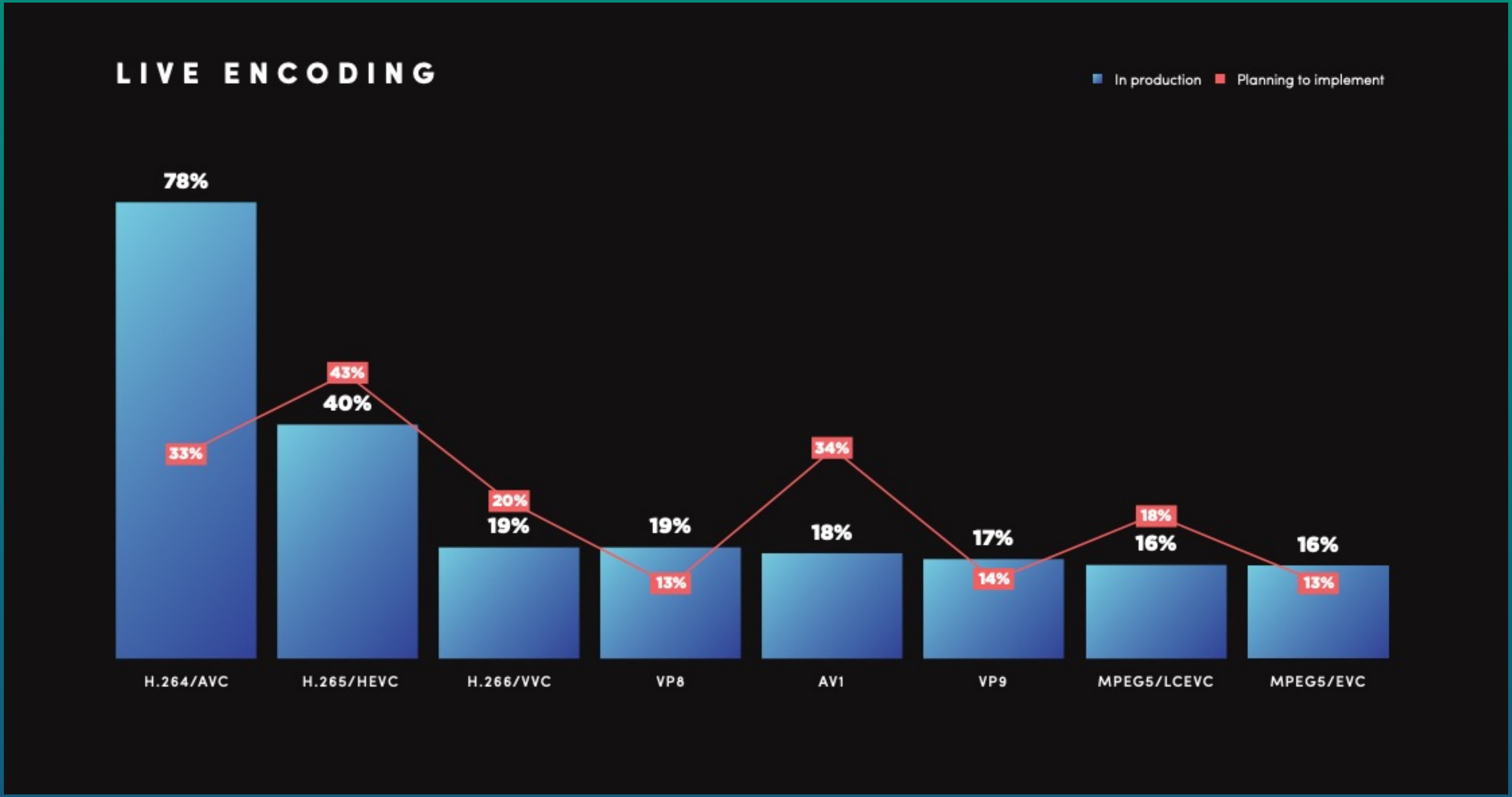
- AV1
  - Successor of VP9
  - Developed by Alliance for Open Media (AOMedia)
  - In 2018, Facebook conducted testing that approximated real world conditions, and the AV1 reference encoder achieved 34%, 46.2% and 50.3% higher data compression than libvpx-vp9, x264 high profile, and x264 main profile respectively



```
     Video ID / sCPN  LXb3EKWsInQ / YBHY 1CD7 TMYX                          [x]
    Viewport / Frames  873x491*2.00 / 0 dropped of 133
 Current / Optimal Res  1920x1080@60 / 1920x1080@60
  Volume / Normalized  100% / 100% (content loudness -3.9dB)
               Codecs  vp09.02.51.10.01.09.16.09.00 (335) / opus (251)
                Color  smpte2084 (PQ) / bt2020
     Connection Speed                                               11607 Kbps
     Network Activity                                               34 KB
        Buffer Health                                               0.00 s
         Mystery Text  s:45 t:0.00 b:5.072-26.581 P
```

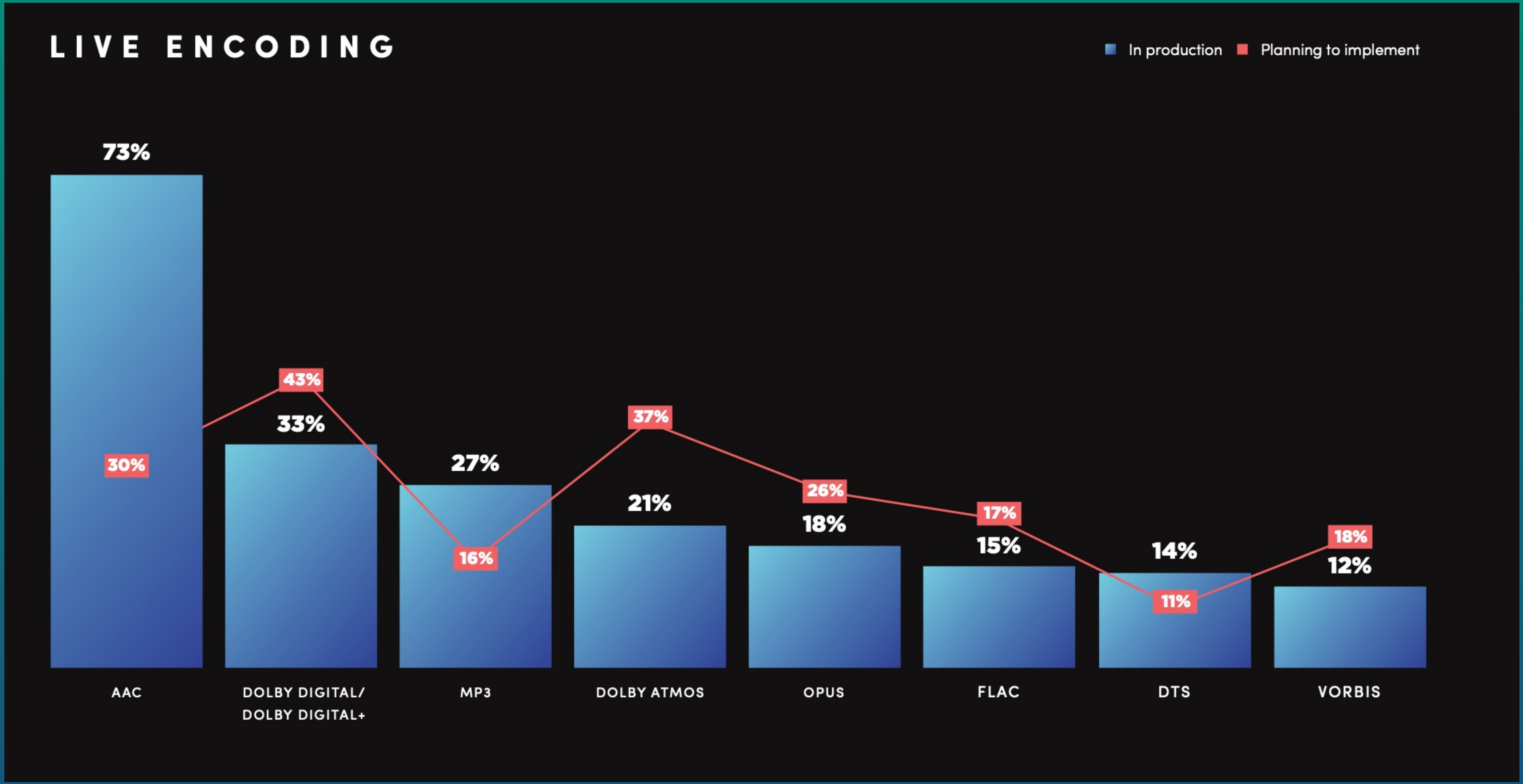
Pay close attention when reading encoding efficiency studies.
Best approach: Perform your own tests

ABR Streaming – Video Codecs



Source: https://bitmovin.com/wp-content/uploads/2022/12/bitmovin-6th-video-developer-report-2022-2023.pdf

ABR Streaming – Audio Codecs



Source: https://bitmovin.com/wp-content/uploads/2022/12/bitmovin-6th-video-developer-report-2022-2023.pdf

HLS Encoding Ladder – H.264

16:9 aspect ratio	H.264/AVC	Frame rate
416 x 234	145	≤ 30 fps
640 x 360	365	≤ 30 fps
768 x 432	730	≤ 30 fps
768 x 432	1100	≤ 30 fps
960 x 540	2000	Same as source
1280 x 720	3000	Same as source
1280 x 720	4500	same as source
1920 x 1080	6000	same as source
1920 x 1080	7800	same as source

Source: https://developer.apple.com/documentation/http_live_streaming/hls_authoring_specification_for_apple_devices

HLS Encoding Ladder – HEVC

16:9 aspect ratio	HEVC/H.265 30 fps	HDR (HEVC) 30fps	Frame rate
640 x 360	145	160	≤ 30 fps
768 x 432	300	360	≤ 30 fps
960 x 540	600	730	≤ 30 fps
960 x 540	900	1090	≤ 30 fps
960 x 540	1600	1930	Same as source
1280 x 720	2400	2900	Same as source
1280 x 720	3400	4080	Same as source
1920 x 1080	4500	5400	Same as source
1920 x 1080	5800	7000	Same as source
2560 x 1440	8100	9700	Same as source
3840 x 2160	11600	13900	Same as source
3840 x 2160	16800	20000	Same as source

The bit rates are initial encoding targets for typical content delivered via HLS. Apple recommends that you evaluate them against your specific content and encoding workflow, then adjust accordingly.

Source: https://developer.apple.com/documentation/http_live_streaming/hls_authoring_specification_for_apple_devices

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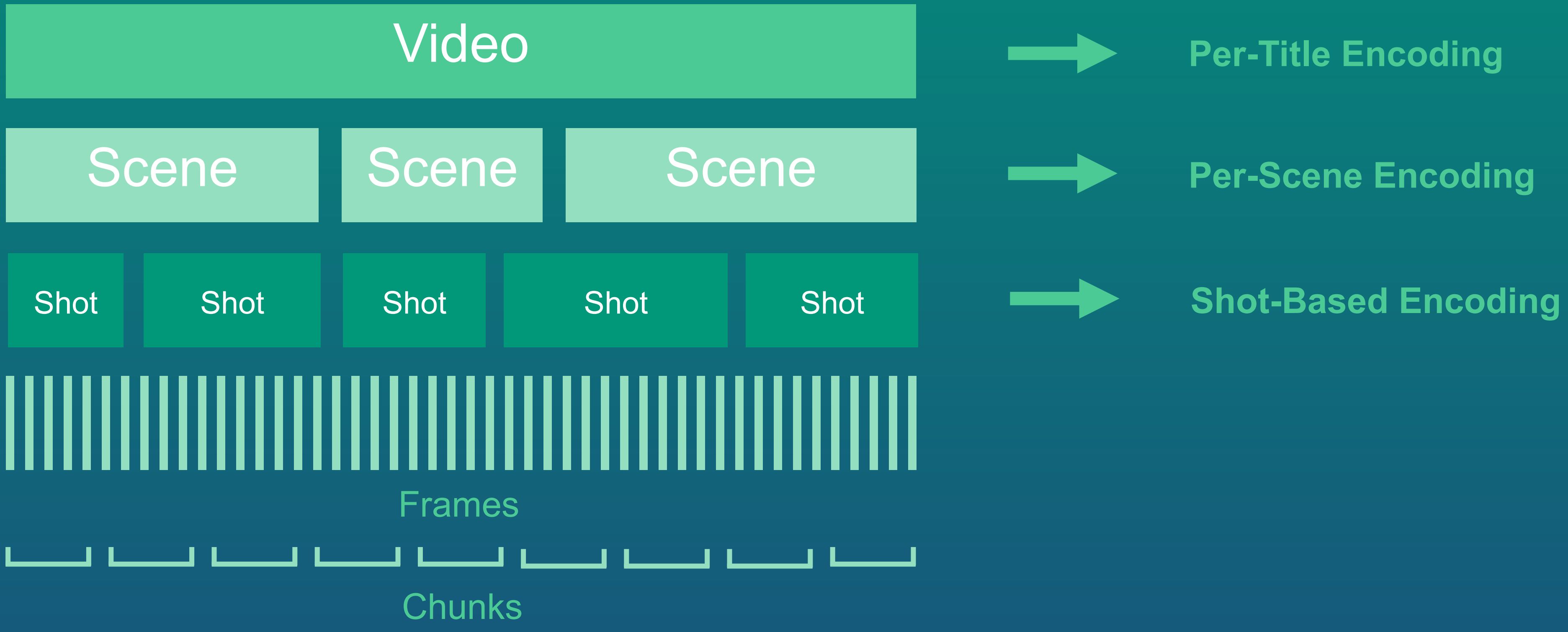
ABR Streaming – Content-Aware Encoding



ABR Streaming - Summary

- OTT ABR streaming enables adaptation to different network conditions of a device
- Encoding Ladders
  - Bitrate depends on codec, e.g. h.264/h.265
  - Resolution depends on product, e.g. SD/HD/UHD, Live/VoD
  - Lowest and highest bitrate are most interesting
  - Equal spacing between bitrates
- Outlook: Deep/Smart/Context-Aware Encoding
  - Non-static encoding ladders, which consider
    - Content (per-title, per-scene)
    - Network (are all bitrates needed)
    - Devices

Streaming Formats

Streaming Formats – DASH/HLS

Two main formats used today

MPEG – DASH (Dynamic Adaptive Streaming over HTTP)

- Based on an MPD (Media Presentation Description) file
  - Provides a structured description of the content in XML format
- Typically used on non Apple devices and platforms
- Serves as input for dash.js, exoPlayer
- Typically uses the ISOBMFF/CMAF media container

HLS (HTTP Live Streaming)

- Based on master and media playlists (m3u8 files)
- Master playlist links to media playlists
- Media playlists describe the content
- Mainly used on Apple platforms due to native support
- Typically uses the Transport Stream (TS) media container
- Added support for f-mp4/CMAF

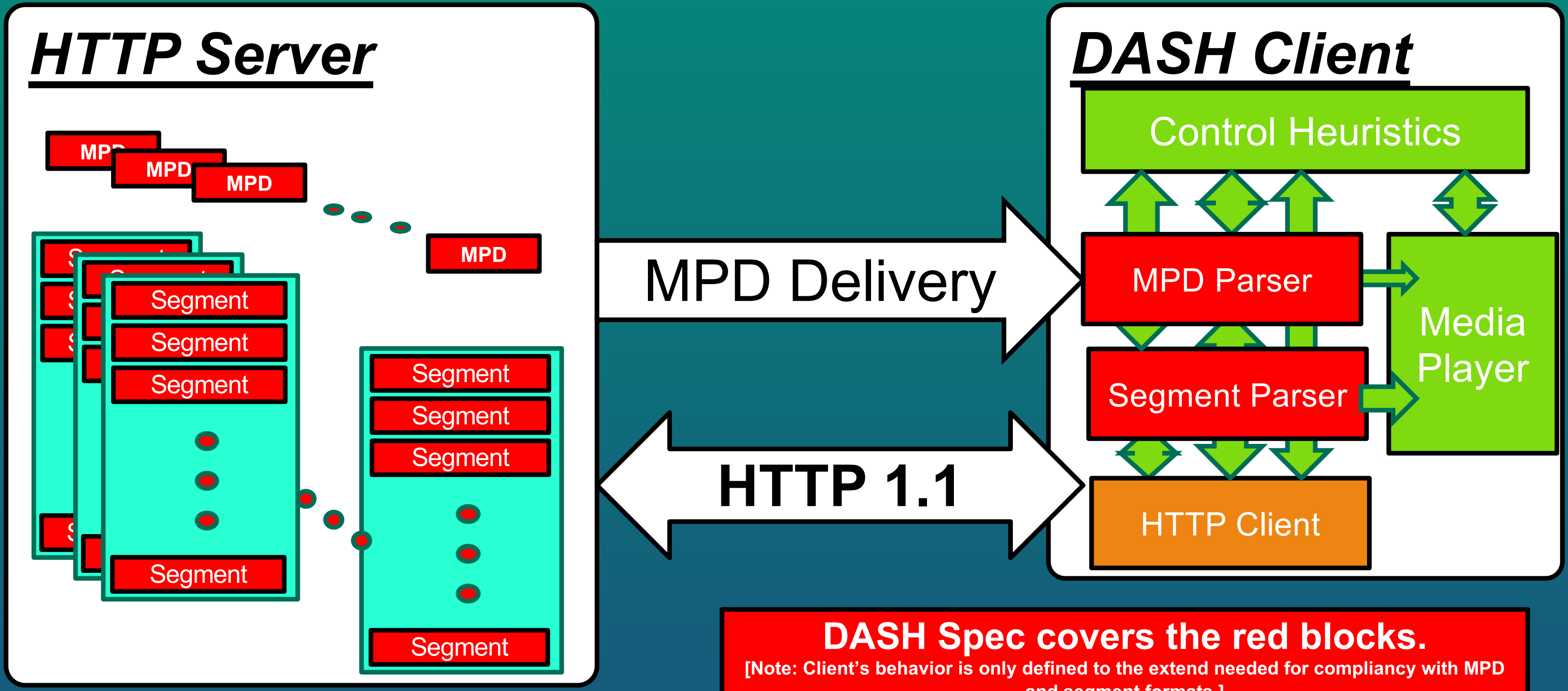
Streaming Formats - MPEG-DASH

Dynamic Adaptive Streaming over HTTP (DASH) - ISO/IEC 23009

- Part 1: Media presentation description and segment formats (available here)
- Part 2: Conformance and reference software
- Part 3: Implementation guidelines
- Part 4: Segment encryption and authentication
- Part 5: Server and network assisted DASH (SAND)
- Part 6: DASH with Server Push and Web Sockets

- Extensions for common DRM-interoperable encryption and encoding (CENC)
- DASH-IF Interoperability Guidelines: Ad-Insertion, Low-Latency, Content Protection etc.
- Different profiles: DVB-DASH, HbbTV, CTA-WAVE etc.
  - E.g. "urn:mpeg:dash:profile:isoff-live:2011,urn:com:dashif:dash264"

Streaming Formats - MPEG-DASH Scope



DASH Spec covers the red blocks.
[Note: Client's behavior is only defined to the extend needed for compliancy with MPD and segment formats.]

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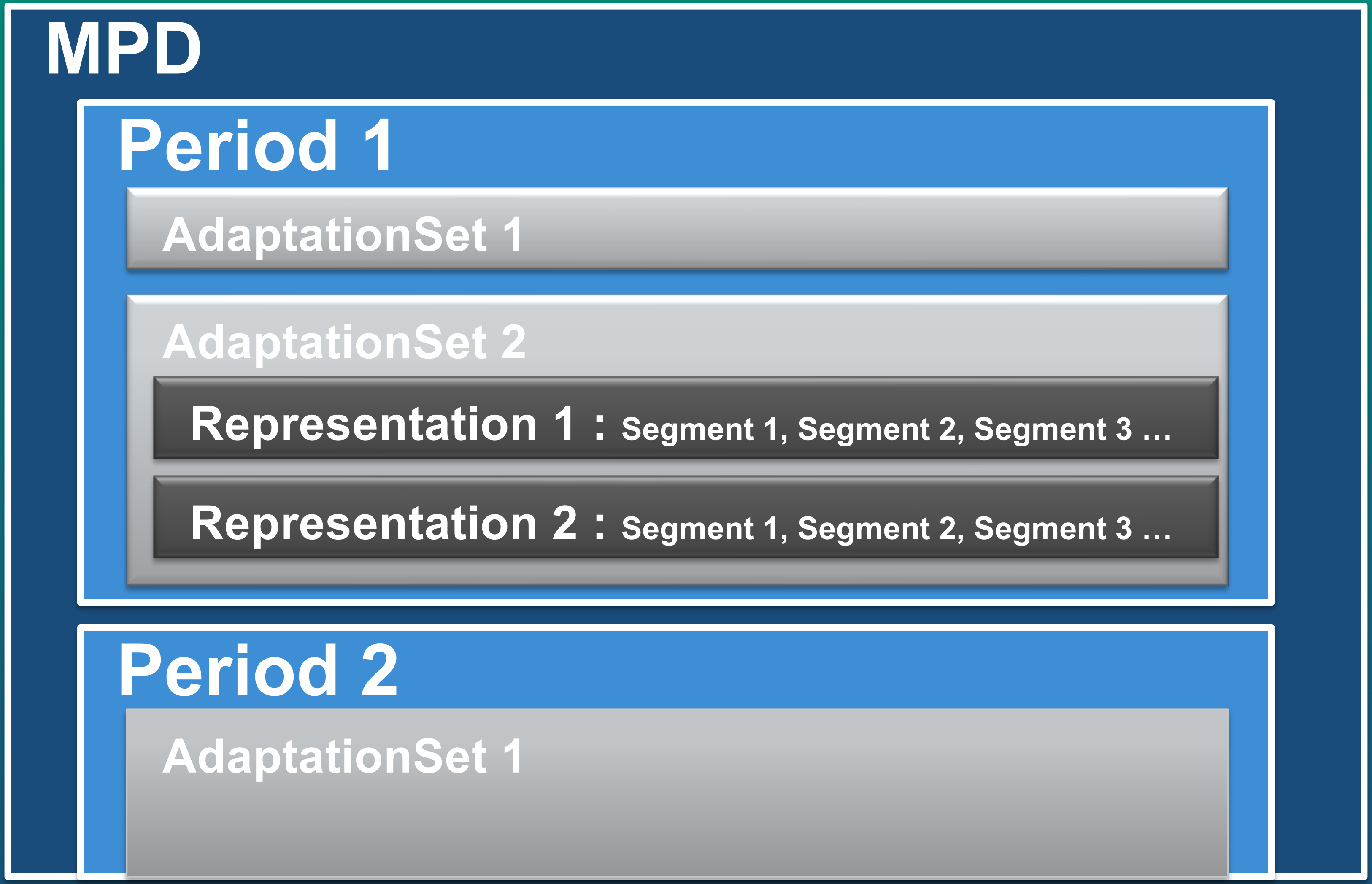
Streaming Formats - MPD



MPD

Period 1

AdaptationSet 1

AdaptationSet 2

Representation 1 : Segment 1, Segment 2, Segment 3 …

Representation 2 : Segment 1, Segment 2, Segment 3 …

Period 2

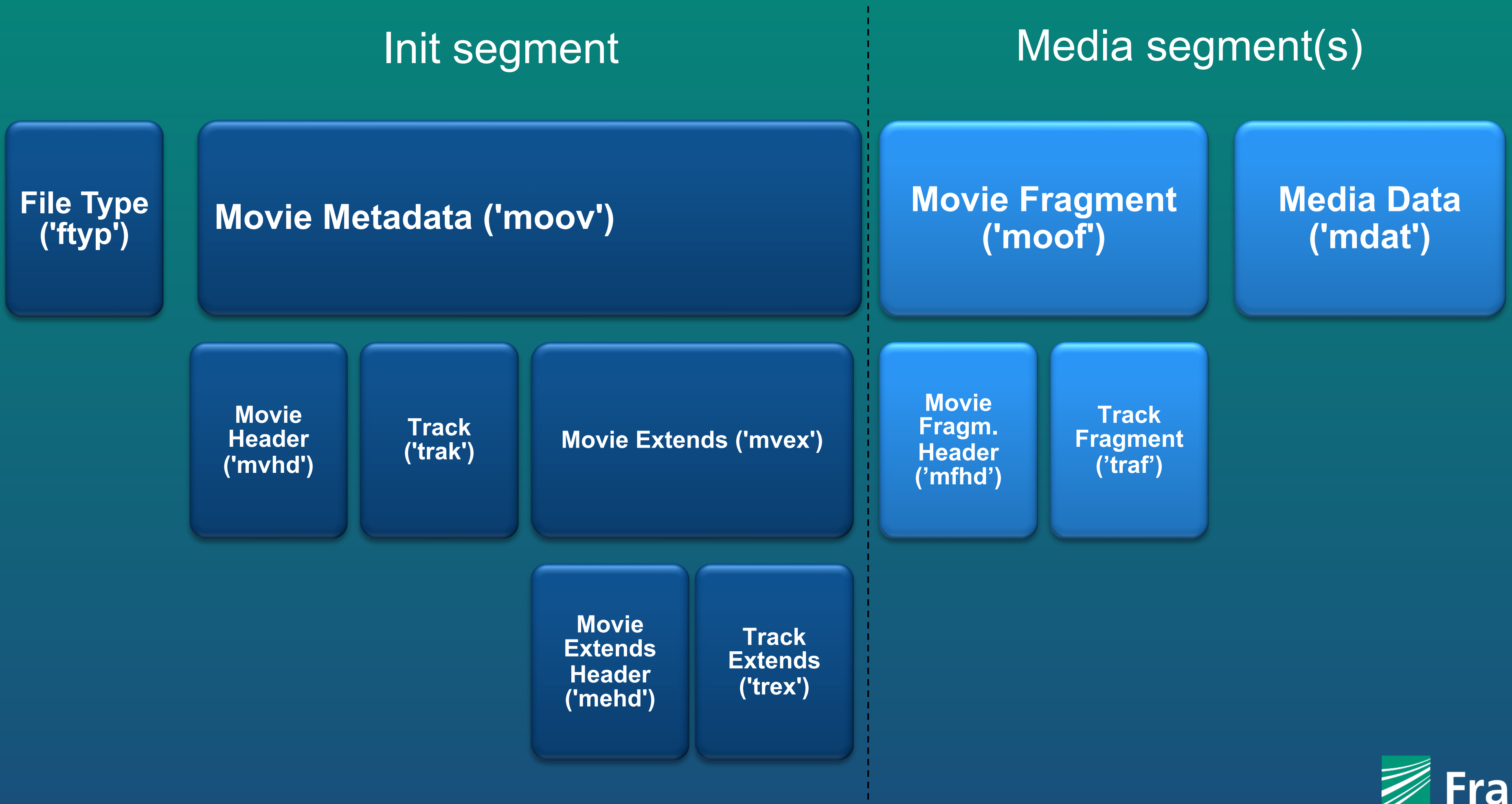
AdaptationSet 1

Streaming Formats –MPD Examples

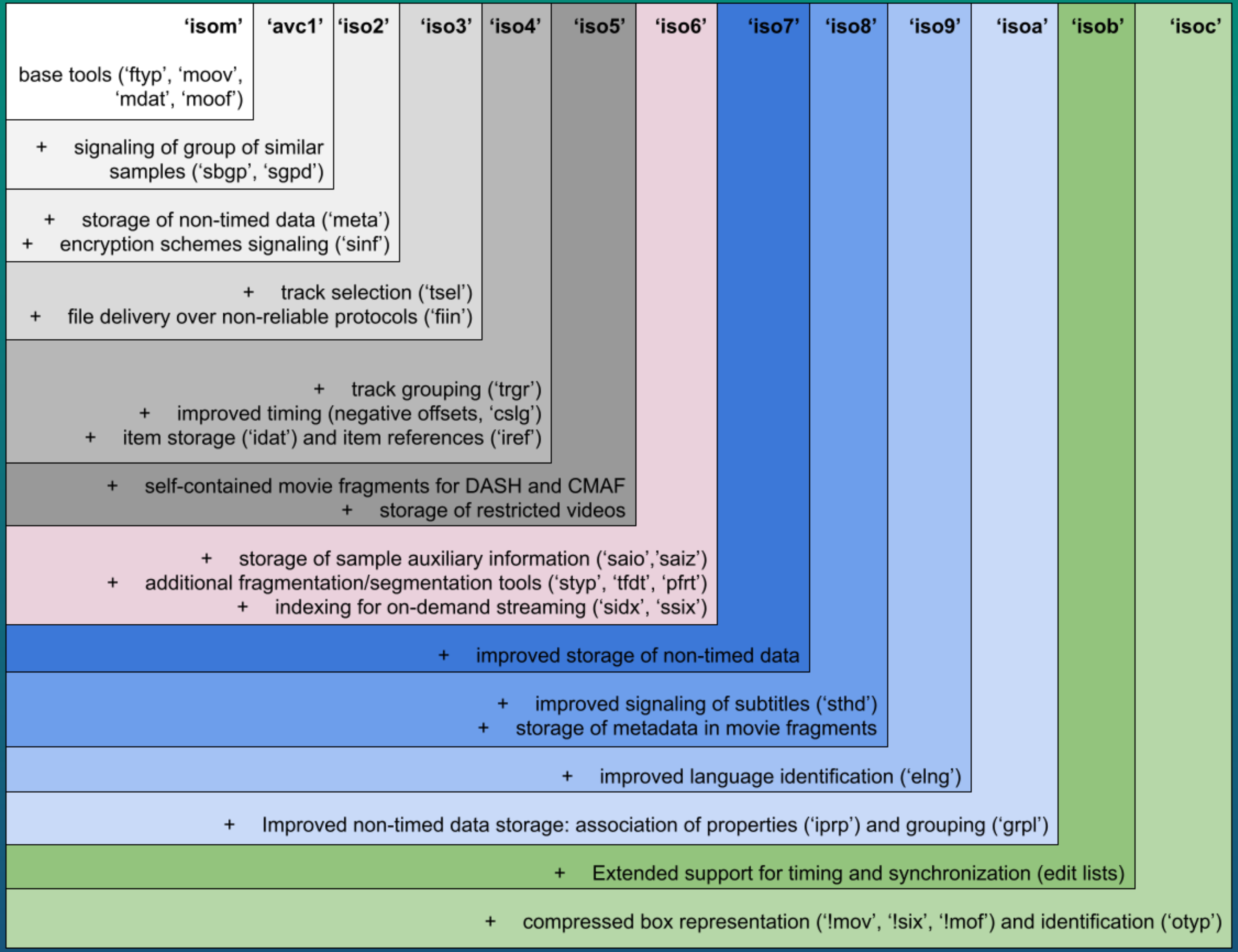
- Google BBB
  - urn:mpeg:dash:profile:isoff-on-demand:2011, SegmentBase, avc1/vp9
- DASH-IF BBB
  - SegmentTemplate, $Number$
- DASH-IF multi period
- DASH-IF multi subtitles
- DASH-IF SCTE35
- DASH-IF thumbnail tiles

Streaming Formats - MPEG-DASH File Format

- ISO base media file format (ISOBMFF)
- Codec-agnostic



Streaming Formats - ISOBMFF



'isom' 'avc1' 'iso2' 'iso3' 'iso4' 'iso5' 'iso6' 'iso7' 'iso8' 'iso9' 'isoa' 'isob' 'isoc'

base tools ('ftyp', 'moov', 'mdat', 'moof')

- + signaling of group of similar samples ('sbgp', 'sgpd')

- + storage of non-timed data ('meta')
- + encryption schemes signaling ('sinf')

- + track selection ('tsel')
- + file delivery over non-reliable protocols ('fiin')

- + track grouping ('trgr')
- + improved timing (negative offsets, 'cslg')
- + item storage ('idat') and item references ('iref')

- + self-contained movie fragments for DASH and CMAF
- + storage of restricted videos

- + storage of sample auxiliary information ('saio','saiz')
- + additional fragmentation/segmentation tools ('styp', 'tfdt', 'pfrt')
- + indexing for on-demand streaming ('sidx', 'ssix')

- + improved storage of non-timed data

- + improved signaling of subtitles ('sthd')
- + storage of metadata in movie fragments

- + improved language identification ('elng')

- + Improved non-timed data storage: association of properties ('iprp') and grouping ('grpl')

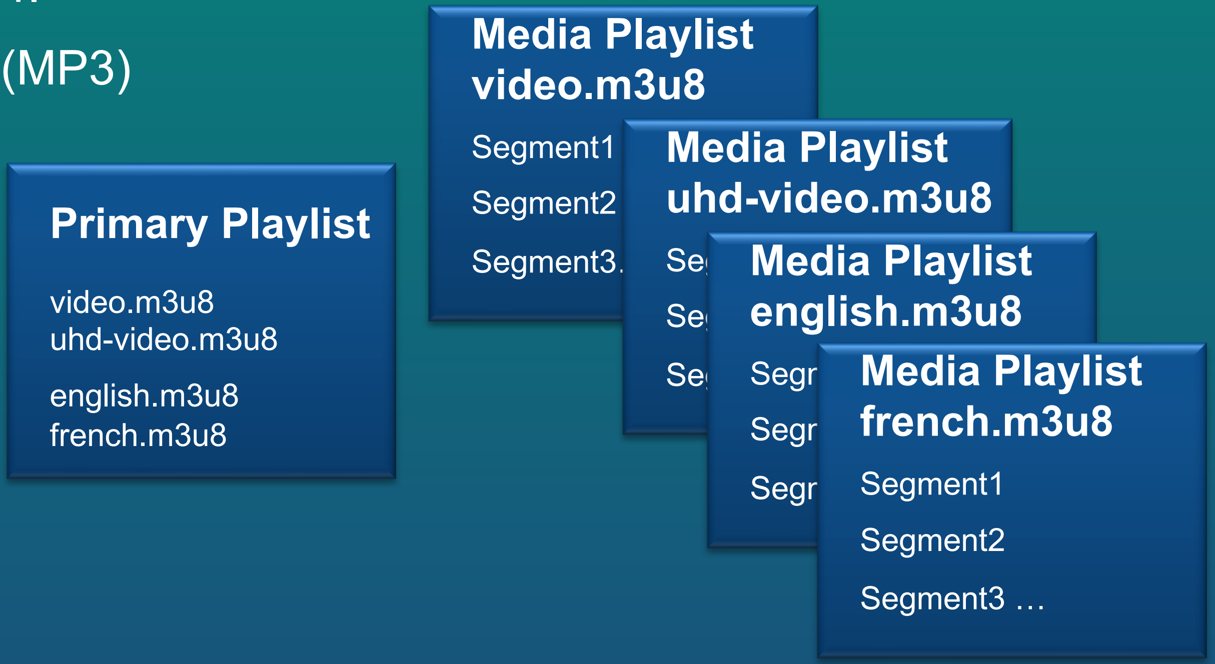
- + Extended support for timing and synchronization (edit lists)

- + compressed box representation ('!mov', '!six', '!mof') and identification ('otyp')

Source: https://netflixtechblog.com/packaging-award-winning-shows-with-award-winning-technology-c1010594ba39

Streaming Formats - Apple HTTP Live Streaming (HLS)

- HTTP ABR streaming format mainly used for iPhone, iPad, Mac/Safari, AppleTV
- Apple authoring guidelines
  - All video MUST be encoded using H.264/AVC or HEVC/H.265
  - The container format for H.264 video MUST be fragmented MP4 (fMP4) files or MPEG transport streams.
  - The container format for HEVC video MUST be fMP4.
- The M3U8 playlist format is based on the M3U format (MP3)
  - A Primary Playlist contains multiple Media Playlists
  - Media Playlists can be for
    - Different encodings
    - Audio languages
    - Subtitles
    - Trick-Play



Primary Playlist

video.m3u8
uhd-video.m3u8

english.m3u8
french.m3u8

Media Playlist video.m3u8

Segment1
Segment2
Segment3.

Media Playlist uhd-video.m3u8

Se
Se
Se

Media Playlist english.m3u8

Segr
Segr
Segr

Media Playlist french.m3u8

Segment1
Segment2
Segment3 …

Streaming Formats – Apple HLS Examples - VoD

```
#EXTM3U
#EXT-X-PLAYLIST-TYPE:VOD
#EXT-X-TARGETDURATION:10
#EXT-X-VERSION:4
#EXT-X-MEDIA-SEQUENCE:0
#EXTINF:10.0,
http://example.com/movie1/fileSequenceA.ts
#EXTINF:10.0,
http://example.com/movie1/fileSequenceB.ts
#EXTINF:10.0,
http://example.com/movie1/fileSequenceC.ts
#EXTINF:9.0,
http://example.com/movie1/fileSequenceD.ts
#EXT-X-ENDLIST
```

Source: https://developer.apple.com/documentation/http_live_streaming/example_playlists_for_http_live_streaming

Streaming Formats – Apple HLS Examples - Live

```
#EXTM3U
#EXT-X-TARGETDURATION:10
#EXT-X-VERSION:4
#EXT-X-MEDIA-SEQUENCE:1
#EXTINF:10.0,
fileSequence1.ts
#EXTINF:10.0,
fileSequence2.ts
#EXTINF:10.0,
fileSequence3.ts
#EXTINF:10.0,
fileSequence4.ts
#EXTINF:10.0,
fileSequence5.ts
```

reload

```
#EXTM3U
#EXT-X-TARGETDURATION:10
#EXT-X-VERSION:4
#EXT-X-MEDIA-SEQUENCE:2
#EXTINF:10.0,
fileSequence2.ts
#EXTINF:10.0,
fileSequence3.ts
#EXTINF:10.0,
fileSequence4.ts
#EXTINF:10.0,
fileSequence5.ts
#EXTINF:10.0,
fileSequence6.ts
```

Source: https://developer.apple.com/documentation/http_live_streaming/example_playlists_for_http_live_streaming

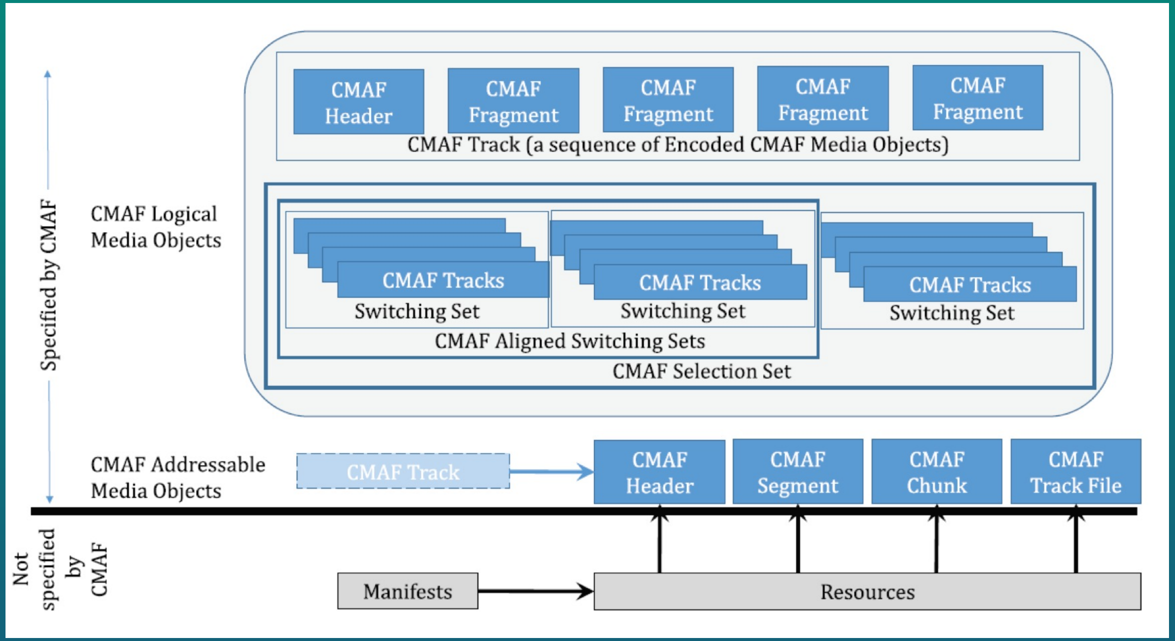
Streaming Formats – Apple HLS Examples – Primary Playlist

```
#EXTM3U
#EXT-X-STREAM-INF:BANDWIDTH=150000,RESOLUTION=416x234,CODECS="avc1.42e00a,mp4a.40.2"
http://example.com/low/index.m3u8
#EXT-X-STREAM-INF:BANDWIDTH=240000,RESOLUTION=416x234,CODECS="avc1.42e00a,mp4a.40.2"
http://example.com/lo_mid/index.m3u8
#EXT-X-STREAM-INF:BANDWIDTH=440000,RESOLUTION=416x234,CODECS="avc1.42e00a,mp4a.40.2"
http://example.com/hi_mid/index.m3u8
#EXT-X-STREAM-INF:BANDWIDTH=640000,RESOLUTION=640x360,CODECS="avc1.42e00a,mp4a.40.2"
http://example.com/high/index.m3u8
#EXT-X-STREAM-INF:BANDWIDTH=64000,CODECS="mp4a.40.5"
http://example.com/audio/index.m3u8
```

Source: https://developer.apple.com/documentation/http_live_streaming/example_playlists_for_http_live_streaming/creating_a_primary_playlist

Streaming Formats – Common Media Application Format (CMAF)

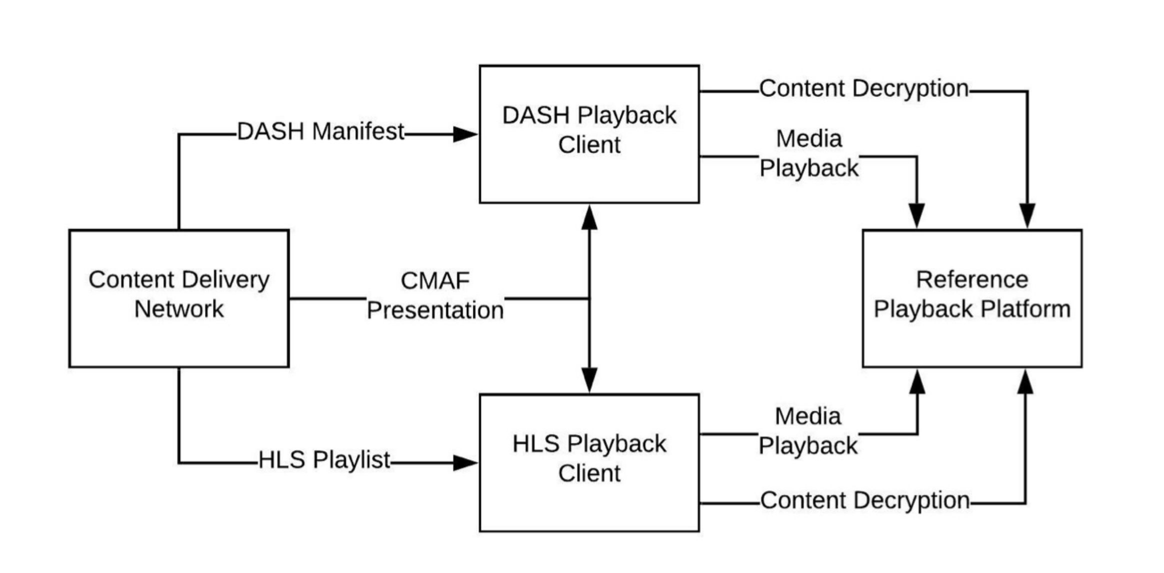
- Interoperable container format (derived from ISOBMFF) for DASH and HLS
- Standardized as ISO/IEC 23000-19:2020 3rd Edition
- CMAF does not specify manifests or delivery protocols
- CMAF defines media objects:
  - **CMAF Header:** Headers contain information that includes information for initializing a track.
  - **CMAF Segment:** A sequence of one or more consecutive fragments from the same track.
  - **CMAF Chunk:** A chunk contains a sequential subset of samples from a fragment.
  - **CMAF Track File:** A complete track in one ISO_BMFF file.



Sources:
https://developer.apple.com/documentation/http_live_streaming/about_the_common_media_application_format_with_http_live_streaming
https://cdn.cta.tech/cta/media/media/resources/standards/pdfs/cta-5005-final.pdf

Streaming Formats – CMAF Interoperability

- Playback:
  - Compatible with most DASH players
  - Apple hardware running iOS 10.0, macOS 10.12, and tvOS 10.0 or later OS versions
- Subtitles: IMSC1 text and image profiles
- CMAF-IF/WAVE:
  CTA-5005 Web Application Video Ecosystem – DASH-HLS Interoperability Specification
- MPEG:
  The DASH 5th Edition introduces a DASH Profile for CMAF Content, “urn:mpeg:dash:profile:cmaf:2019”
- Apple
  About the Common Media Application Format with HTTP Live Streaming



https://cdn.cta.tech/cta/media/media/resources/standards/pdfs/cta-5005-final.pdf

Streaming Formats - Summary

- CMAF has become the standard container format
  - Improved CDN caching efficiency
  - Adopted by DVB, ATSC, DASH-IF, 3GPP etc.
- HLS for the Apple ecosystem; DASH for everything else
  - Different HLS version with different feature sets and iOS support
  - DASH manifests are more flexible → higher complexity, different profiles
  - Check CTA WAVE/CMAF-IF/DASH-IF/Apple guidelines and specifications

Low-Latency Streaming

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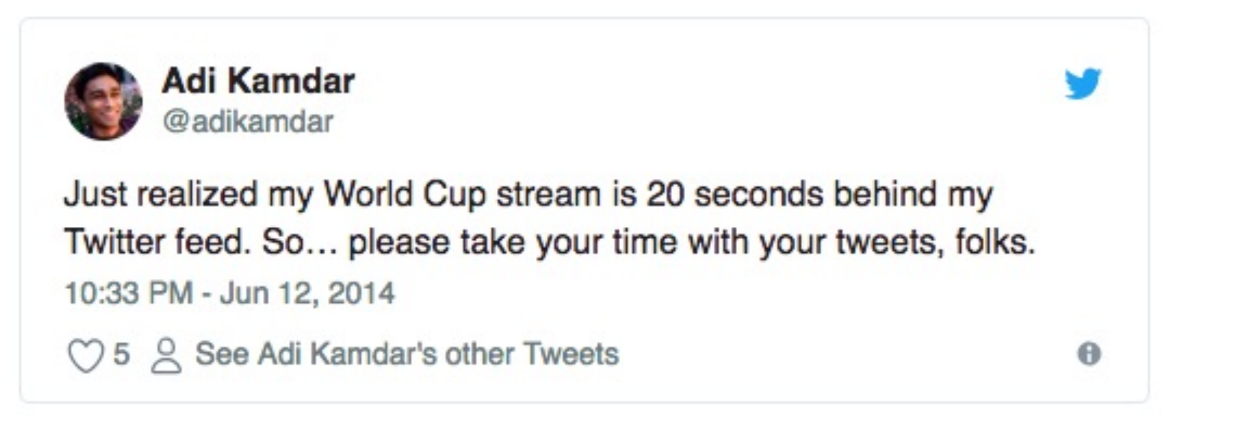
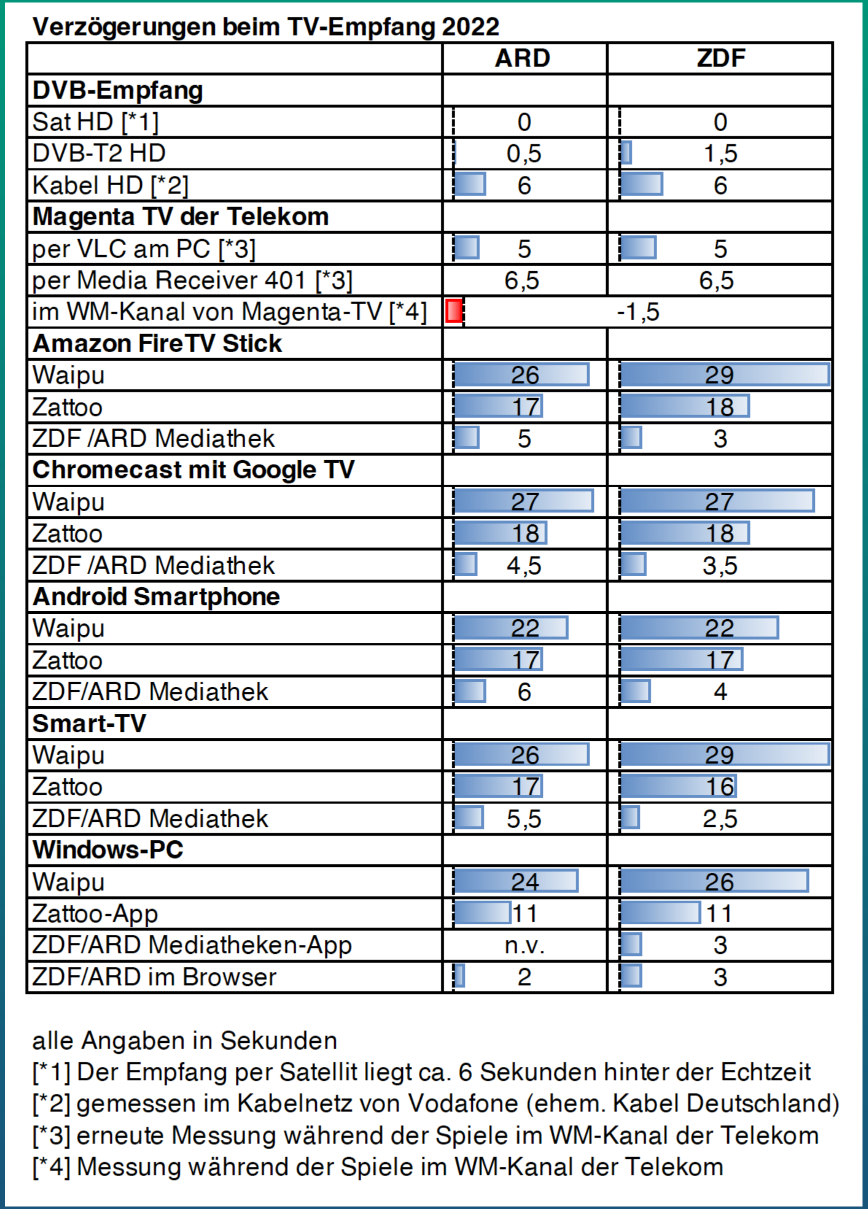
Low-Latency Streaming - Motivation



Adi Kamdar
@adikamdar

Just realized my World Cup stream is 20 seconds behind my Twitter feed. So… please take your time with your tweets, folks.

10:33 PM - Jun 12, 2014



Verzögerungen beim TV-Empfang 2022

	ARD	ZDF
DVB-Empfang		
Sat HD [*1]	0	0
DVB-T2 HD	0,5	1,5
Kabel HD [*2]	6	6
Magenta TV der Telekom		
per VLC am PC [*3]	5	5
per Media Receiver 401 [*3]	6,5	6,5
im WM-Kanal von Magenta-TV [*4]	🟥	-1,5
Amazon FireTV Stick		
Waipu	26	29
Zattoo	17	18
ZDF /ARD Mediathek	5	3
Chromecast mit Google TV		
Waipu	27	27
Zattoo	18	18
ZDF /ARD Mediathek	4,5	3,5
Android Smartphone		
Waipu	22	22
Zattoo	17	17
ZDF/ARD Mediathek	6	4
Smart-TV		
Waipu	26	29
Zattoo	17	16
ZDF/ARD Mediathek	5,5	2,5
Windows-PC		
Waipu	24	26
Zattoo-App	11	11
ZDF/ARD Mediatheken-App	n.v.	3
ZDF/ARD im Browser	2	3

alle Angaben in Sekunden

[*1] Der Empfang per Satellit liegt ca. 6 Sekunden hinter der Echtzeit

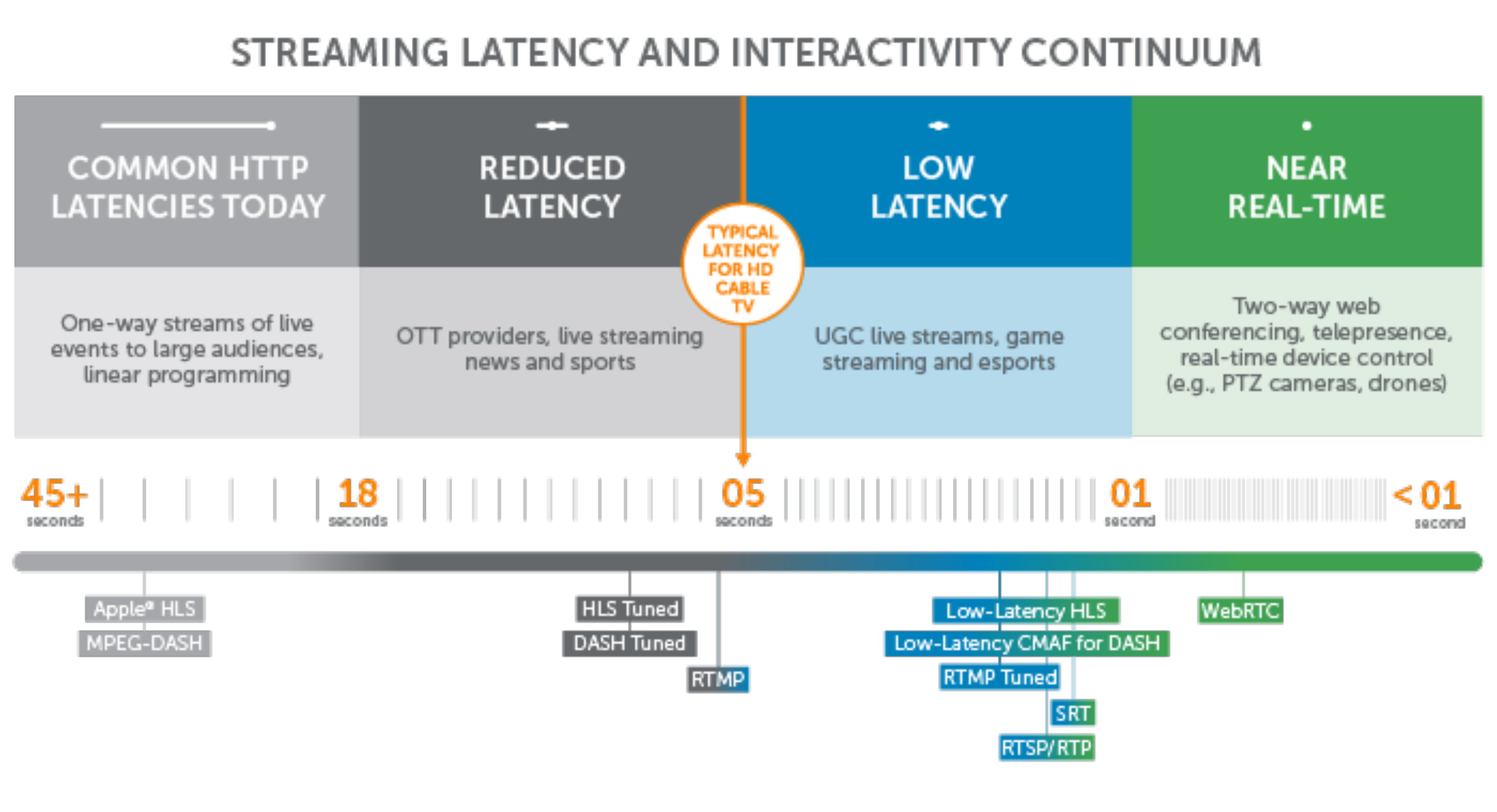
[*2] gemessen im Kabelnetz von Vodafone (ehem. Kabel Deutschland)

[*3] erneute Messung während der Spiele im WM-Kanal der Telekom

[*4] Messung während der Spiele im WM-Kanal der Telekom

Source: https://www.heise.de/news/Verzoegerungarmer-TV-Empfang-Wer-sieht-den-WM-Ball-zuerst-im-Tor-7346271.html

Low-Latency Streaming – Who needs it



STREAMING LATENCY AND INTERACTIVITY CONTINUUM

COMMON HTTP LATENCIES TODAY

One-way streams of live events to large audiences, linear programming

REDUCED LATENCY

OTT providers, live streaming news and sports

TYPICAL LATENCY FOR HD CABLE TV

LOW LATENCY

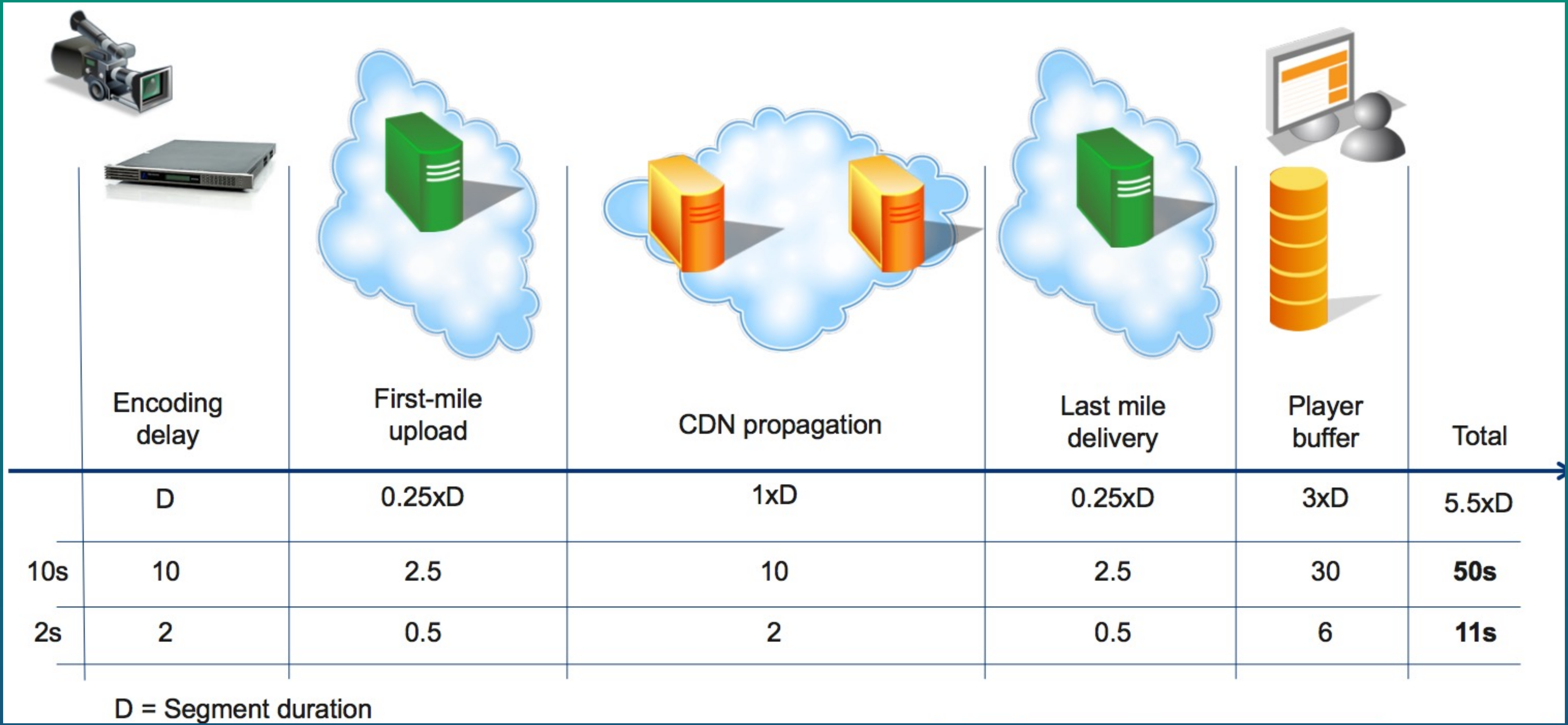
UGC live streams, game streaming and esports

NEAR REAL-TIME

Two-way web conferencing, telepresence, real-time device control (e.g., PTZ cameras, drones)

Source: https://www.wowza.com/blog/what-is-low-latency-and-who-needs-it

Low-Latency Streaming - What Causes Latency?

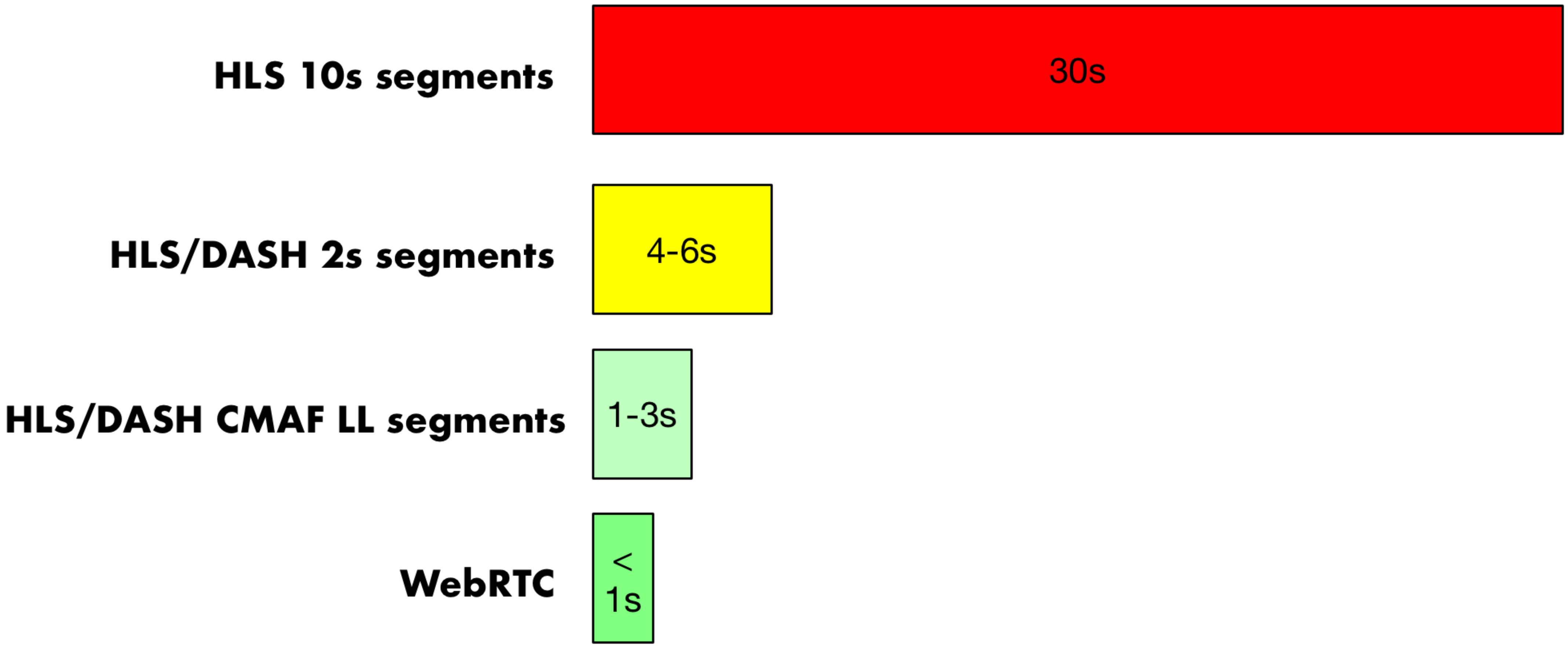


	Encoding delay	First-mile upload	CDN propagation	Last mile delivery	Player buffer	Total
	D	0.25xD	1xD	0.25xD	3xD	5.5xD
10s	10	2.5	10	2.5	30	**50s**
2s	2	0.5	2	0.5	6	**11s**

D = Segment duration

Source: CMAF Low Latency Streaming – Will Law 11.17

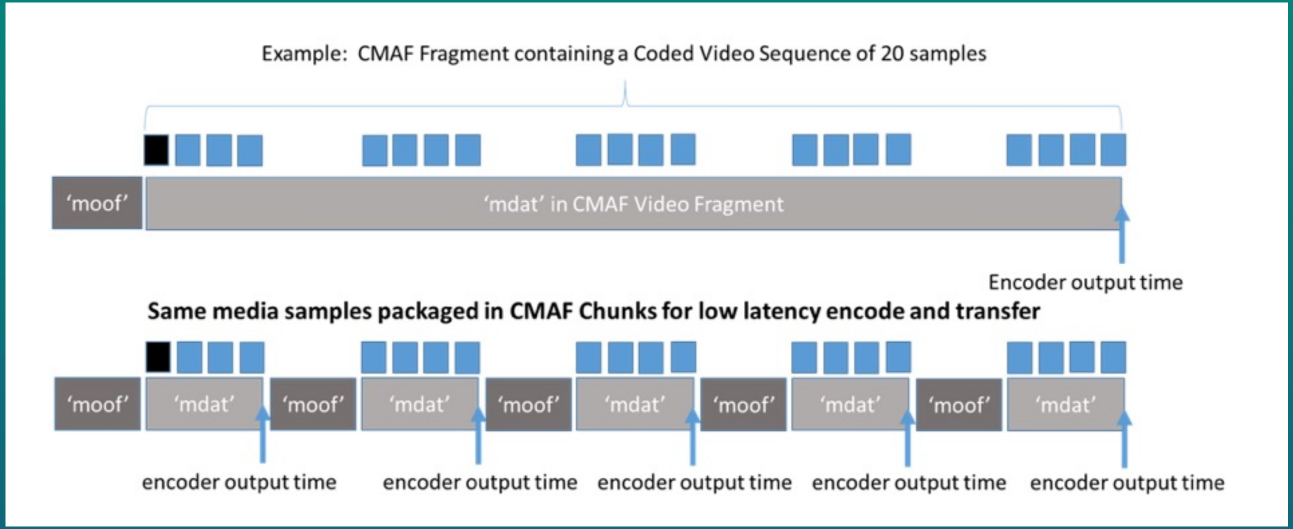
Low-Latency Streaming – Player Buffer Latency



Source: CMAF Low Latency Streaming – Will Law 11.17

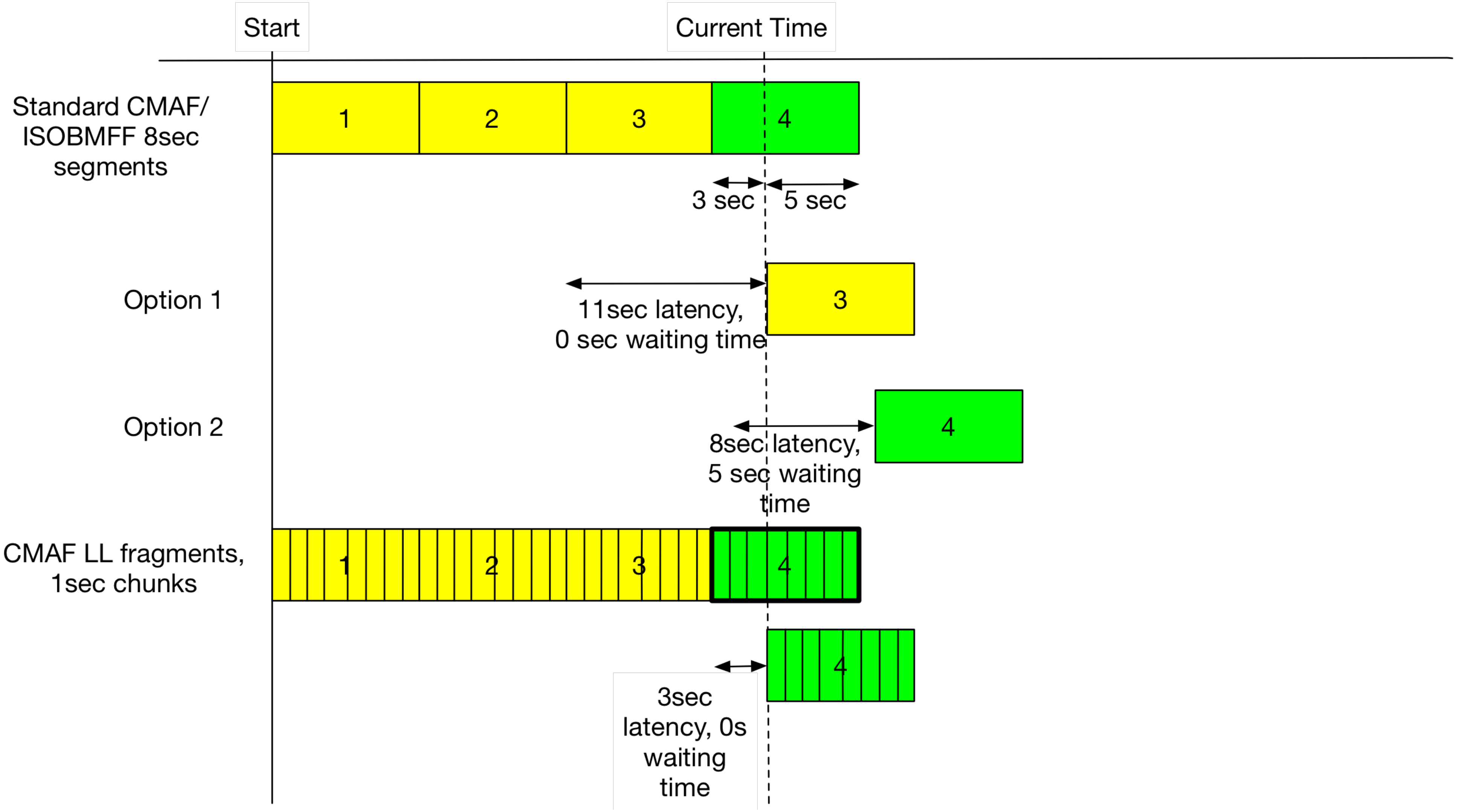
Low-Latency Streaming – LL-DASH

- Key concepts:
  - HTTP/1.1 chunked transfer encoding (CTE)
  - CMAF chunks
  - Playback rate
- Specified in:
  - section 10.20 of the DVB-DASHv.1.3.1 spec from February 2020
  - DASH-IF Low LatencyModes for DASH IOP extension in March 2020
- Example:
  - DASH-IF LL
    - availabilityTimeOffset
    - ServiceDescription
    - UTCTiming, ProducerReferenceTime



Source: ISO/IEC 23000-19 Common Media Application Format for Segmented Media

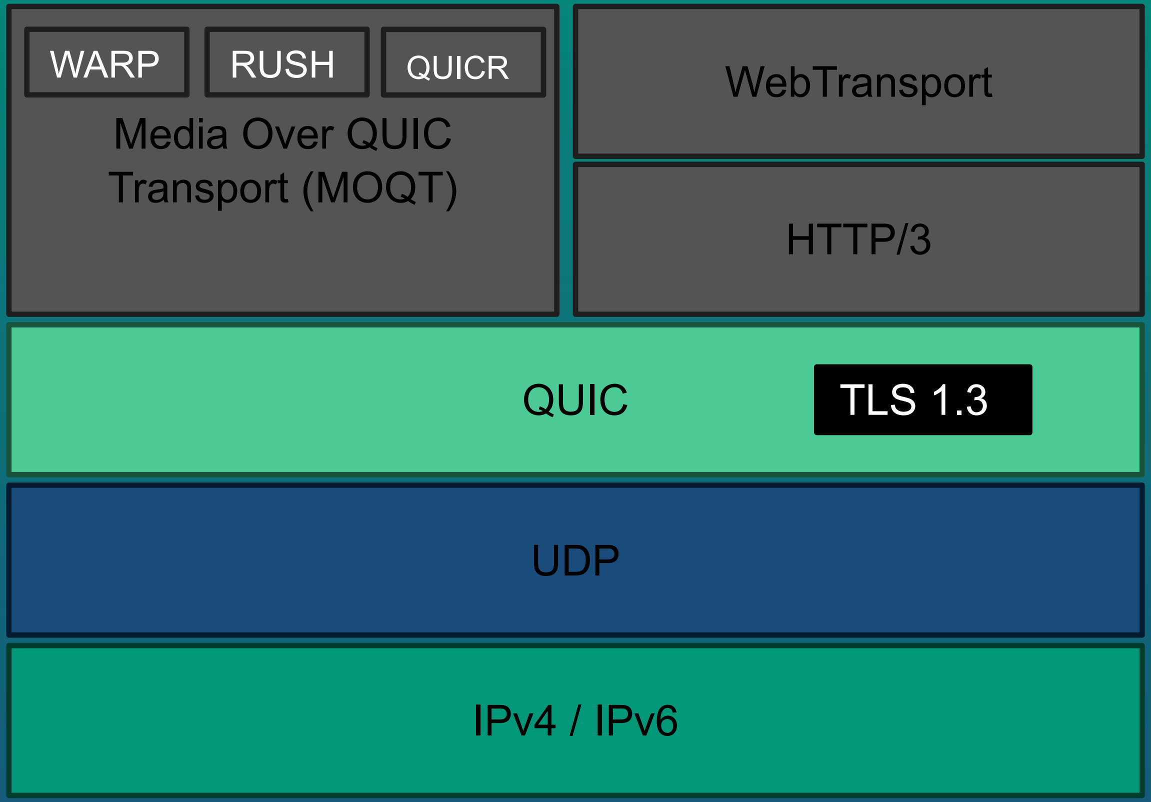
Low-Latency Streaming - CMAF Chunks


Start
Current Time
Standard CMAF/ ISOBMFF 8sec segments
1
2
3
4
3 sec
5 sec
Option 1
11sec latency, 0 sec waiting time
3
Option 2
8sec latency, 5 sec waiting time
4
CMAF LL fragments, 1sec chunks
1
2
3
4
4
3sec latency, 0s waiting time

Low-Latency Streaming – LL-HLS

- Introduced at WWDC19
  - Low-Latency extensions in draft-pantos-hls-rfc8216bis revision 7 and later (=protocol version 10/iOS14)
  - Enabling Low-Latency HLS article
- Key concepts
  - Generation of Partial Segments (=CMAF Chunks)
  - Playlist Delta Updates (EXT-X-SKIP)
  - Blocking of Playlist reload (via query parameters)
  - Preload hints and blocking of Media downloads (EXT-X-PRELOAD-HINT)
  - Rendition Reports (EXT-X-RENDITION-REPORT)
- Example:
  - Broadpeak LL-HLS
    - EXT-X-SERVER-CONTROL
    - EXT-X-PART, EXT-X-PRELOAD-HINT, EXT-X-RENDITION-REPORT

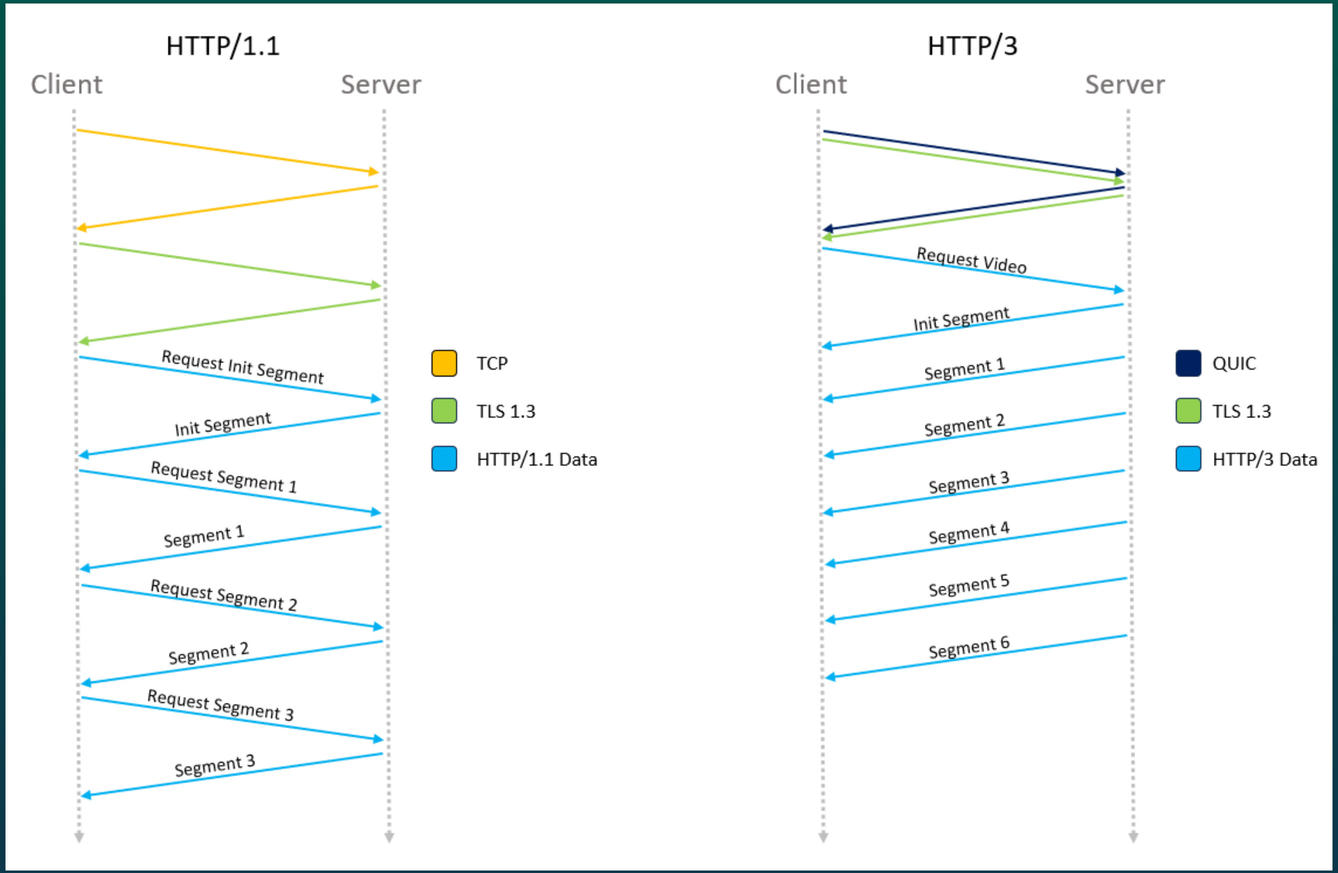
Low-Latency Streaming – QUIC, HTTP/3, WebTransport



Low-Latency Streaming – WebTransport Evaluation

- WebTransport acts as the **browser API** to connect and communicate with the HTTP/3 server
- Comparison between **ABR streaming with CMAF** over
  HTTP/1.1 (TCP) vs. HTTP/3 (UDP)
  - Faster handshake
  - Less client polling

- Measurement of startup time with different bandwidth trajectories and **playback via MSE**
  - ~50% faster startup time



OTT ABR Streaming – Mission accomplished?

- Encoding ladders are mainly static, but there is a trend towards dynamic/context-aware ladders
- OTT ABR Streaming with DASH and HLS is used everywhere
- CMAF has become the standard container format
- LL-HLS and LL-DASH are maturing and will be used for big sports events

Status quo:

Different device platforms & interoperability – *how to reach them all? Best practices?*

Other factors:

– ***Monetization*** **(DAI),**

– ***Regulatory*** **(DRM, watermarking),**

– ***Quality*** **(UHD, 8K, HDR, Codec evolution),**

– ***Analytics*** **(streaming metrics, troubleshooting),**

– ***UX*** **(AR/VR, 360°, interactivity, 6DoF)**

– ***Transport (HTTP/3, 5G Broadcast)***

Vielen Dank für Ihre Aufmerksamkeit

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