EECE5512
Networked XR Systems

The slides are borrowed from Dr. Timmerer [AAU/Bitmovin]'s tutorial at Sigcomm'17

Recap

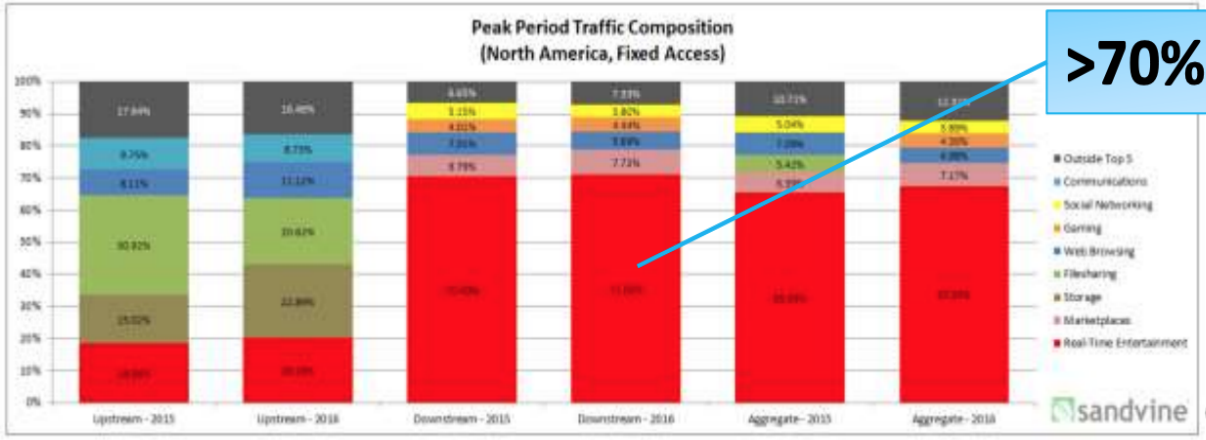
- Streaming Fundamentals
- Metaverse Class

Lecture Outline for Today

- Video Streaming
- Adaptive Bitrate Algorithms

Explosion in Video Applications

Importance of Internet Media



>70% Downstream Traffic

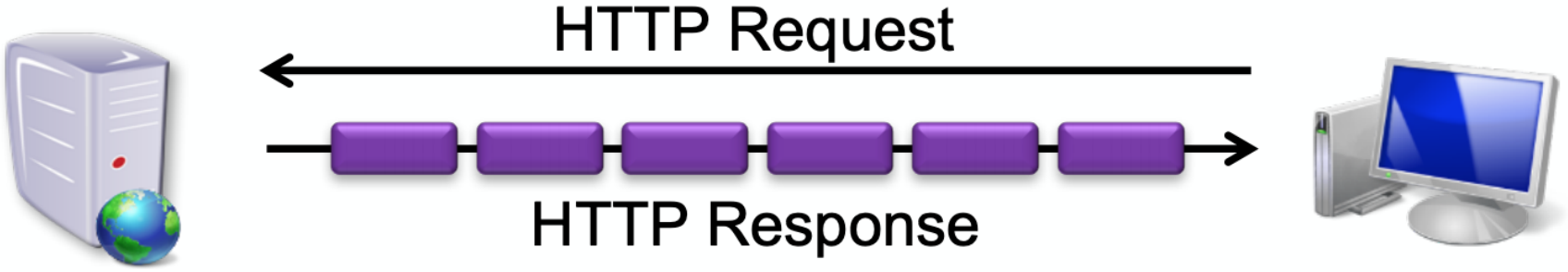
Global Internet Phenomena Report: 2016

- Real-time entertainment: Streaming video and audio; >70% of Internet traffic at peak periods
- Popular services
  - YouTube (17.53%), Netflix (35.15%), Amazon Video (4.26%), Hulu (2.68%); all delivered over-the-top (OTT)
- Forecast: **Visual Networking Index (VNI) 2016-2021 (Sep'17)**
  - IP video traffic will be 82% of all consumer Internet traffic by 2021 (up from 73% in 2016); will grow threefold from 2016 to 2021
  - Live Internet video will account for 13% of Internet video traffic by 2021; will grow 15-fold from 2016 to 2021
- More people now subscribe to Netflix (50.85M) than cable TV (48.61M) in the US (Q1 2017)

Beginning of Internet Video

Progressive Download

One request, One response



What is Streaming?

Streaming is transmission of a continuous content from a server to a client and its simultaneous consumption by the client

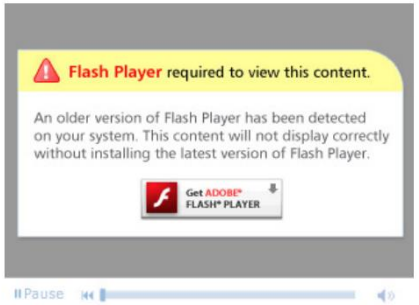
Two Main Characteristics

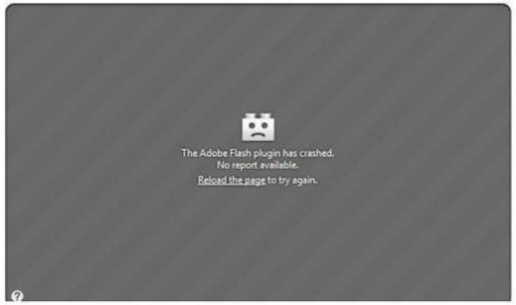
1. Client consumption rate may be limited by real-time constraints as opposed to just bandwidth availability
2. Server transmission rate (loosely or tightly) matches to client consumption rate

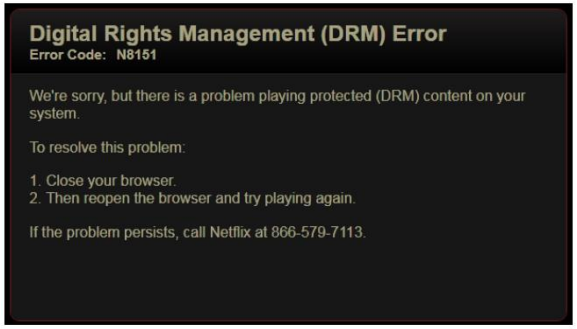
Some common Streaming Issues

Stalls, Slow Start-Up, Plug-In and DRM Issues

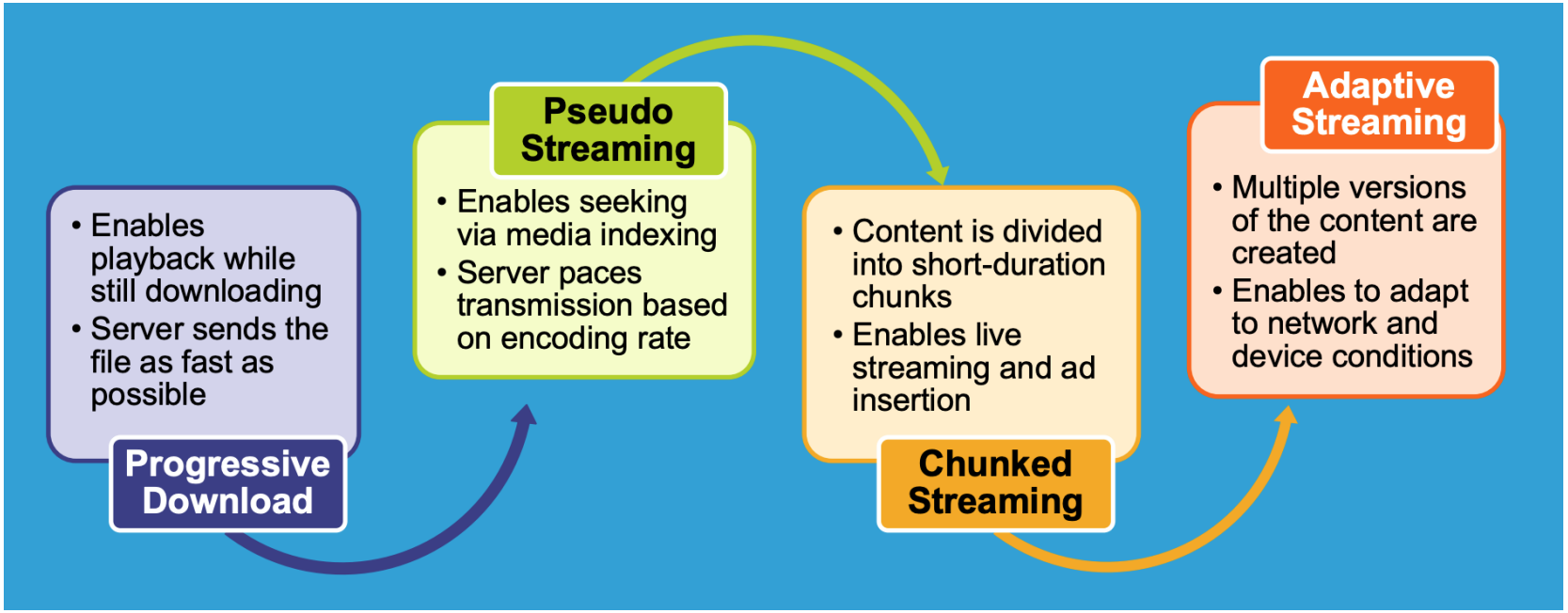
- Unsupported/wrong
  - protocol
  - plug-in
  - codec
  - format
  - DRM
- Slow start-up
- Poor quality, quality variation
- Frequent freezes/glitches
- Lack of seeking



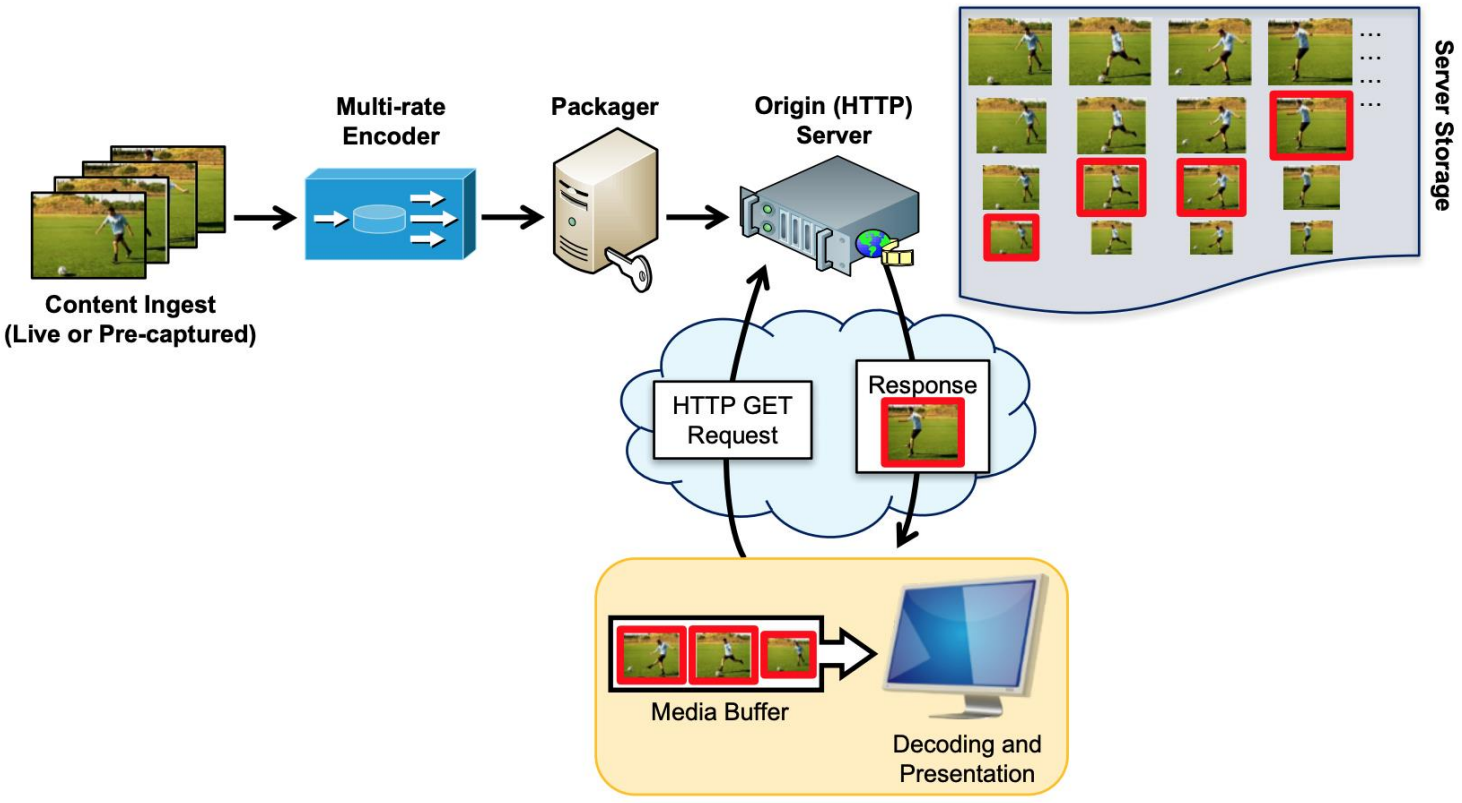




Evolution of Video Streaming

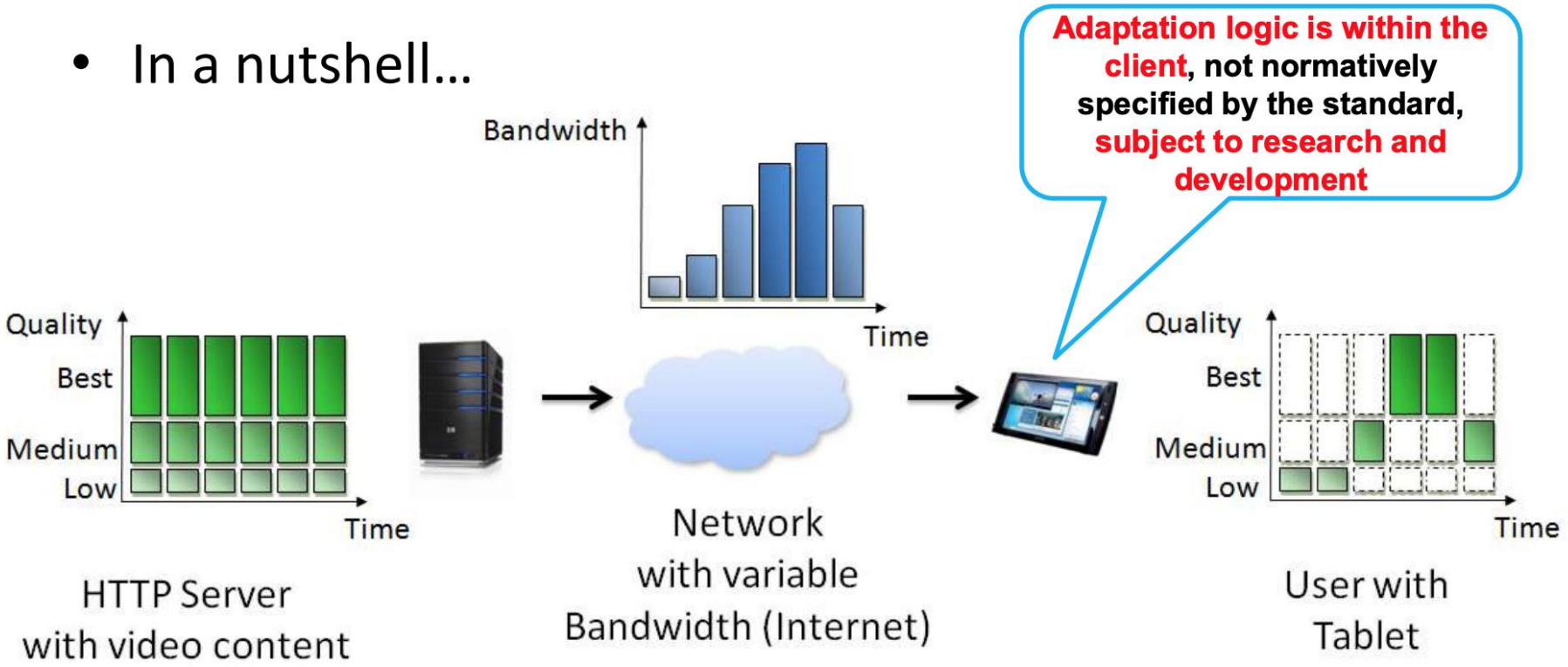


Adaptive Streaming



Adaptive Streaming

- In a nutshell…



Example Representations

Vancouver 2010

	Encoding Bitrate	Resolution
Rep. #1	3.45 Mbps	1280 x 720
Rep. #2	1.95 Mbps	848 x 480
Rep. #3	1.25 Mbps	640 x 360
Rep. #4	900 Kbps	512 x 288
Rep. #5	600 Kbps	400 x 224
Rep. #6	400 Kbps	312 x 176

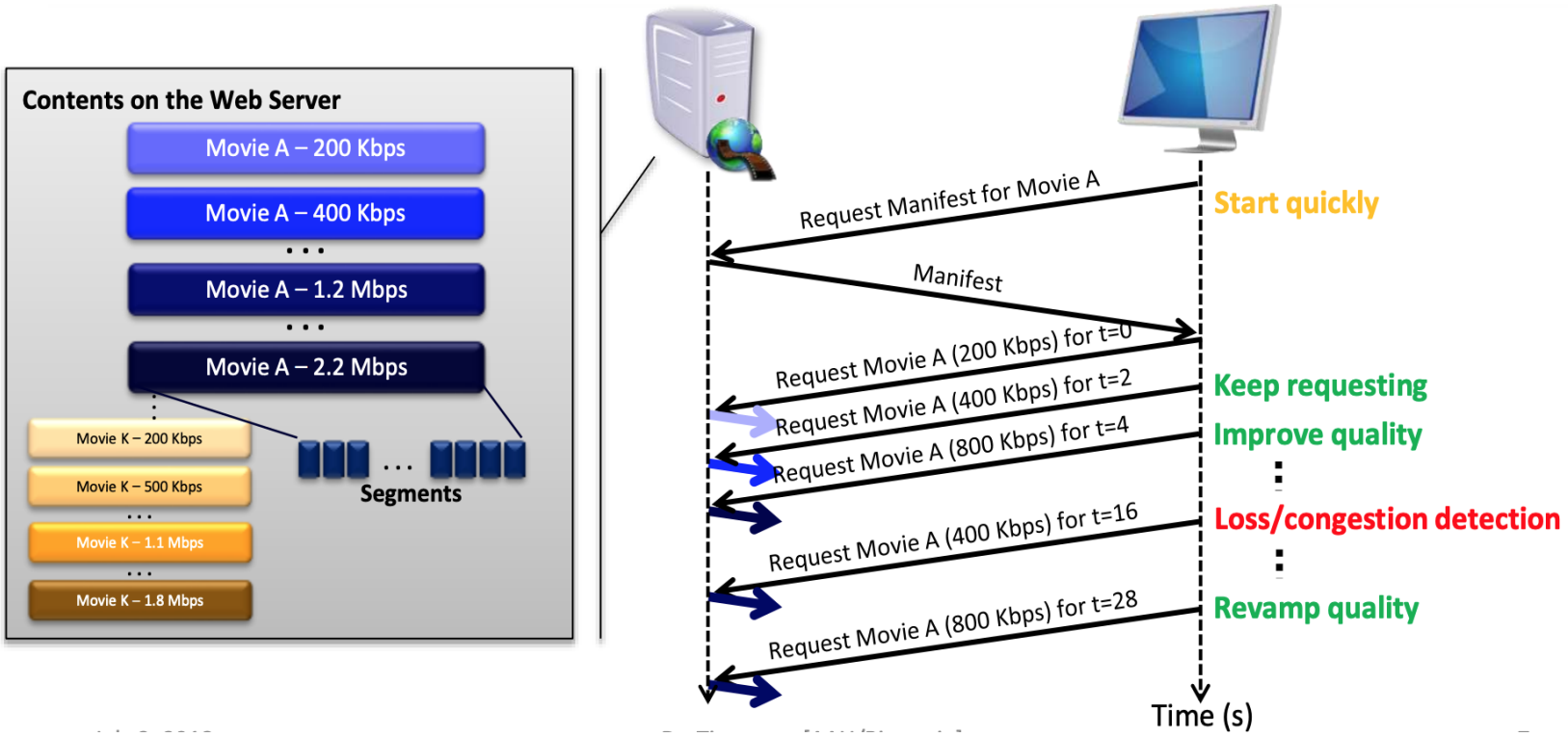
Sochi 2014

	Encoding Bitrate	Resolution
Rep. #1	3.45 Mbps	1280 x 720
Rep. #2	2.2 Mbps	960 x 540
Rep. #3	1.4 Mbps	960 x 540
Rep. #4	900 Kbps	512 x 288
Rep. #5	600 Kbps	512 x 288
Rep. #6	400 Kbps	340 x 192
Rep. #7	200 Kbps	340 x 192

FIFA 2014

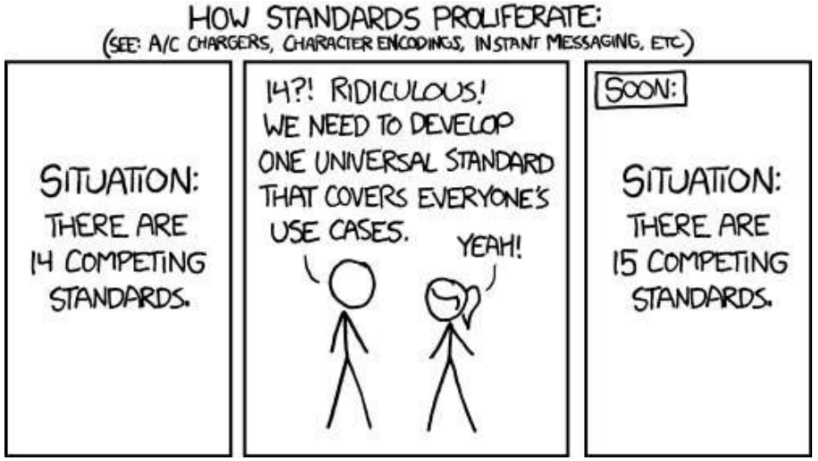
	Encoding Bitrate	Resolution
Rep. #1	3.45 Mbps	1280 x 720
Rep. #2	2.2 Mbps	1024 x 576
Rep. #3	1.4 Mbps	768 x 432
Rep. #4	950 Kbps	640 x 360
Rep. #5	600 Kbps	512 x 288
Rep. #6	400 Kbps	384 x 216
Rep. #7	250 Kbps	384 x 216
Rep. #8	150 Kbps	256 x 144

Representation switching



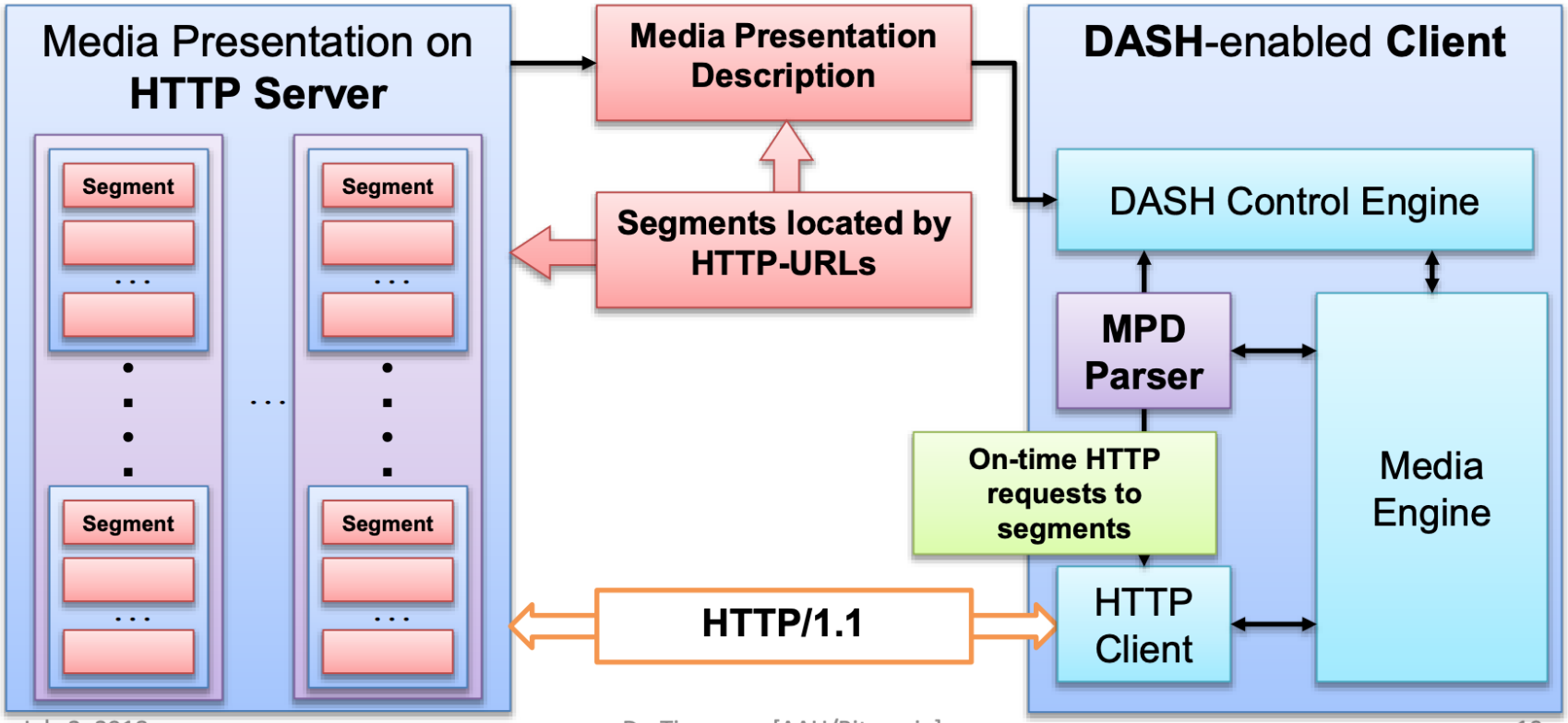
Adaptive Streaming Standards

- Adobe
  - HTTP Dynamic Streaming (HDS)
  - Switched to DASH
- Apple
  - HTTP Live Streaming (HLS)
  - Required for iOS
- Microsoft
  - Smooth Streaming
  - Switched to DASH, almost..
- MPEG Dynamic Adaptive Streaming over HTTP (DASH)
  - Supported by Netflix, YouTube, Bitmovin, etc.
- MPEG Common Media Application Format (MPEG-A Part 19)
  - The new kid on the block – support for "fragmented mp4 in HLS"
  - DASH/HLS convergence at segment level – some open issues with encryption format

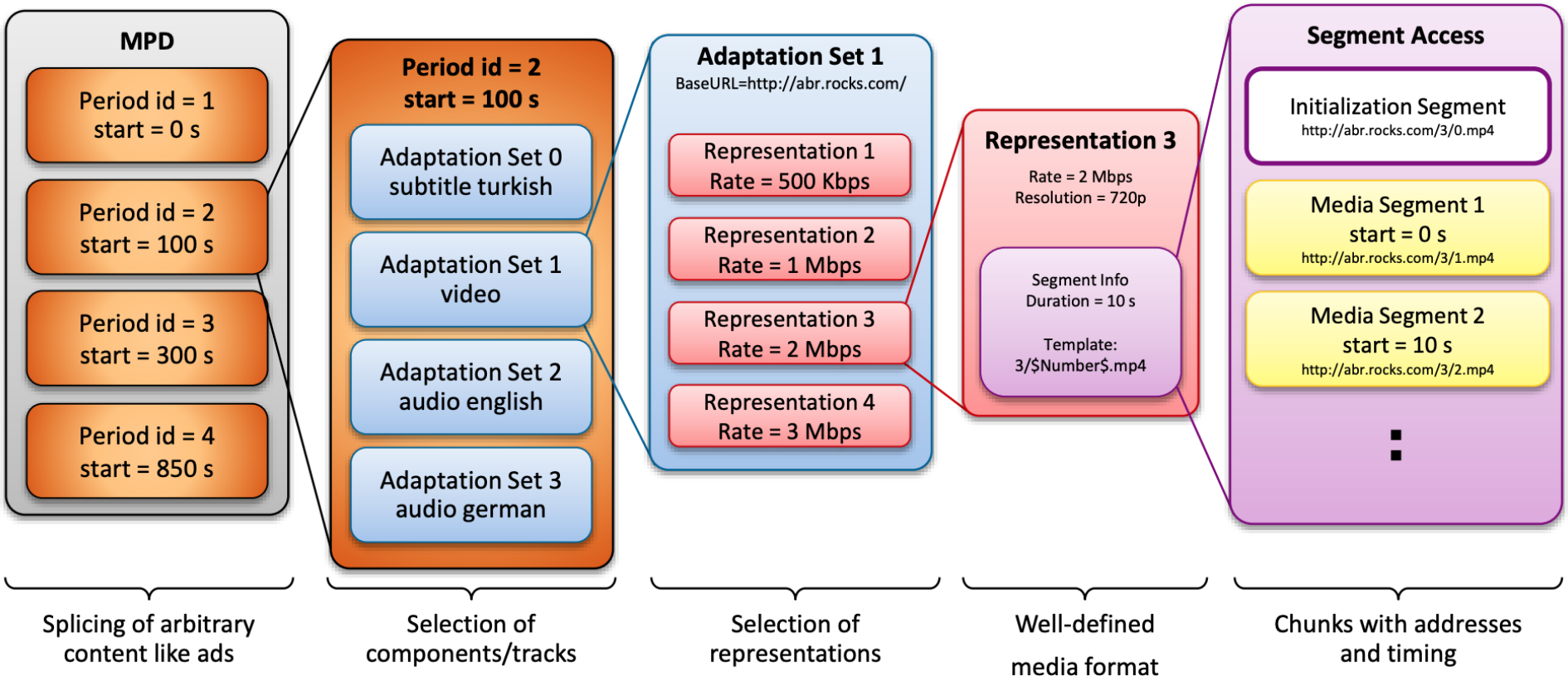


Source: http://xkcd.com/927/

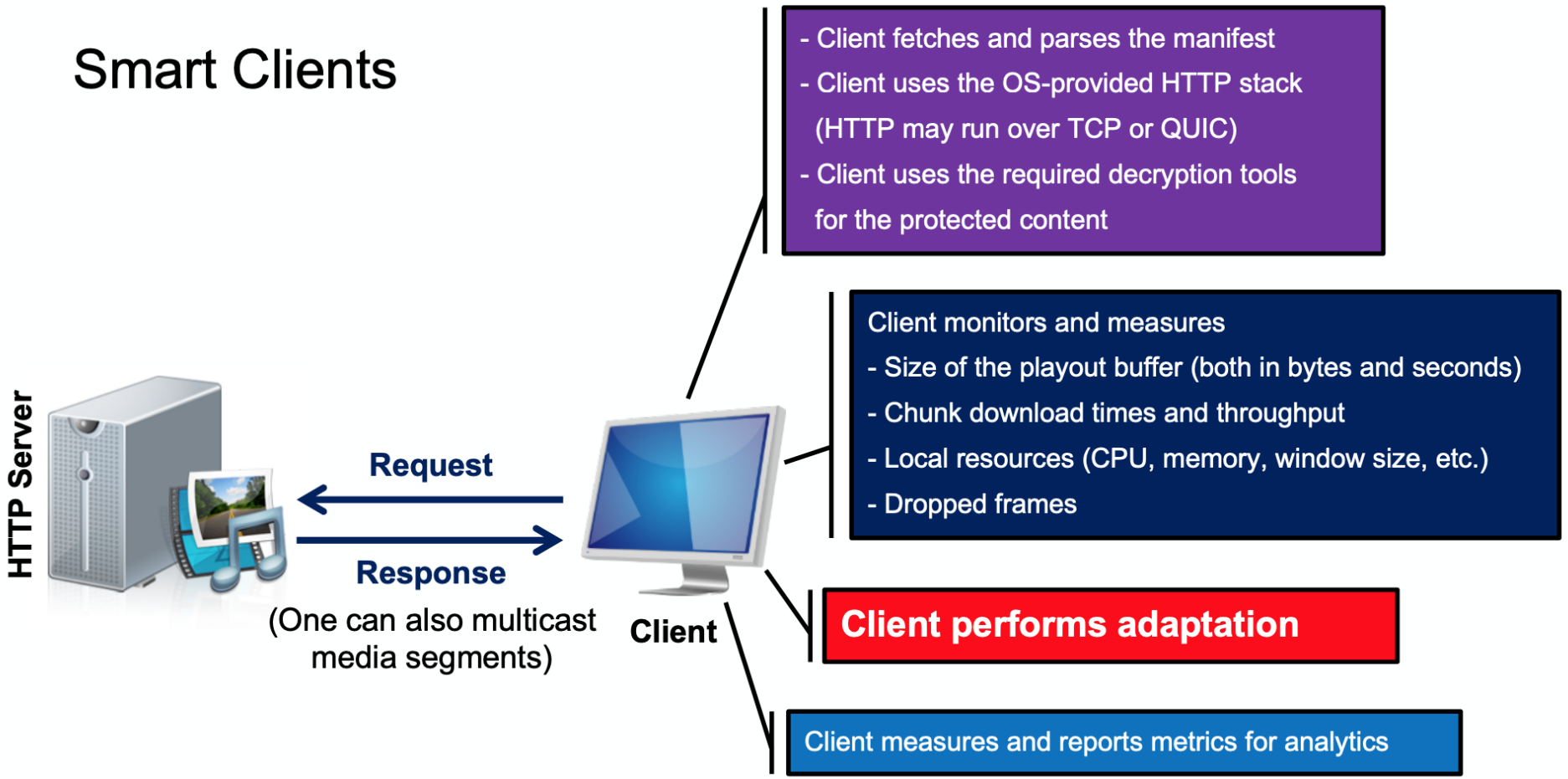
DASH Internals



DASH Internals – Manifest File



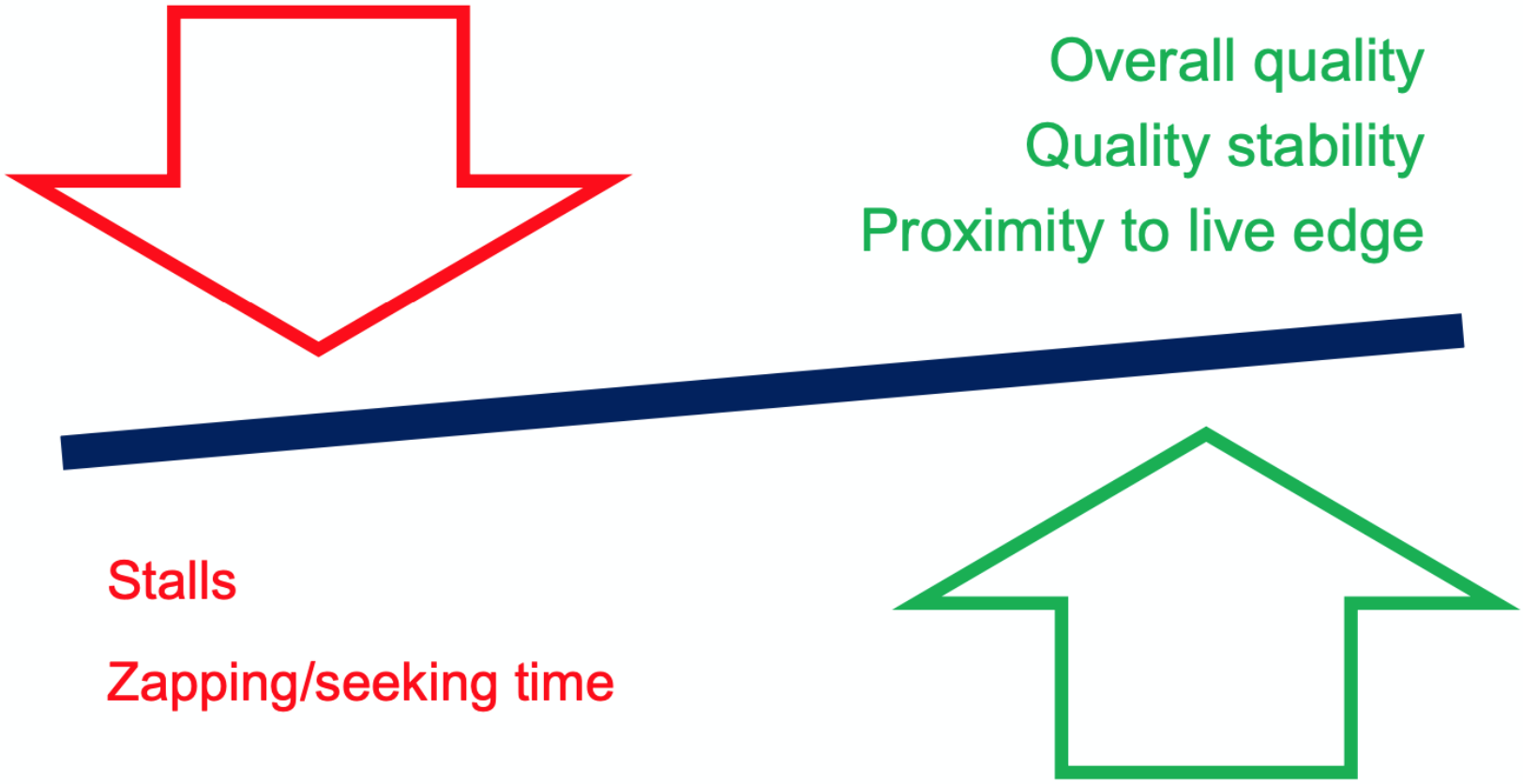
A Typical Client Does



Video Streaming - Quality of Experience

- Objective
  - Initial or startup delay (low)
  - Buffer underrun / stalls (zero)
  - Quality switches (low)
  - Media throughput (high)
  - [Other media-related configuration: encoding, representations, segment length, …]
- Subjective
  - Mean Opinion Score (MOS) – various scales
  - Various methodologies (e.g., DSCQS, DSIS, ACR, PC, …)

Adaptive Bitrate (ABR) Algorithm



Bitrate Selection is the key

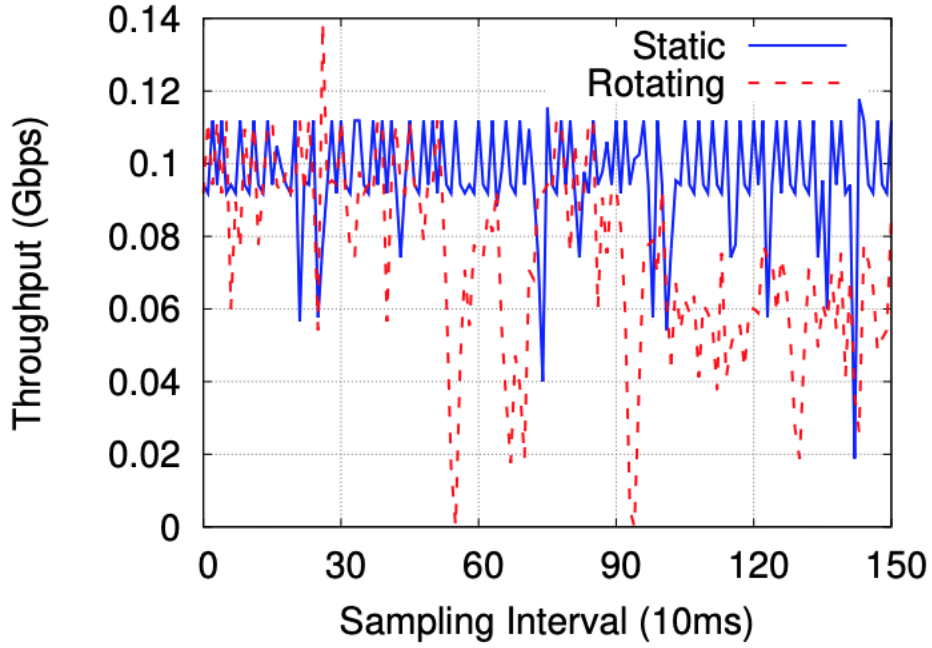
ABR algorithms

- The bitrate adaptation logic is typically controlled by the client
  - Bitrate adaptation heuristics based on:
    1. Available bandwidth
    2. Playback buffer size
    3. Chunk scheduling
    4. Hybrid-based
- Interesting algorithms
  - Li et al (2014), Liu et al (2011)
  - Huang et al (2014), Mueller et al (2015)
  - Jiang et al (2012), Chen et al (2013)
  - Yin et al (2015), Li et al. (2014), De Cicco et al. (2013), Miller et al. (2012), Zhou et al. (2012)

Classes of ABR algorithms

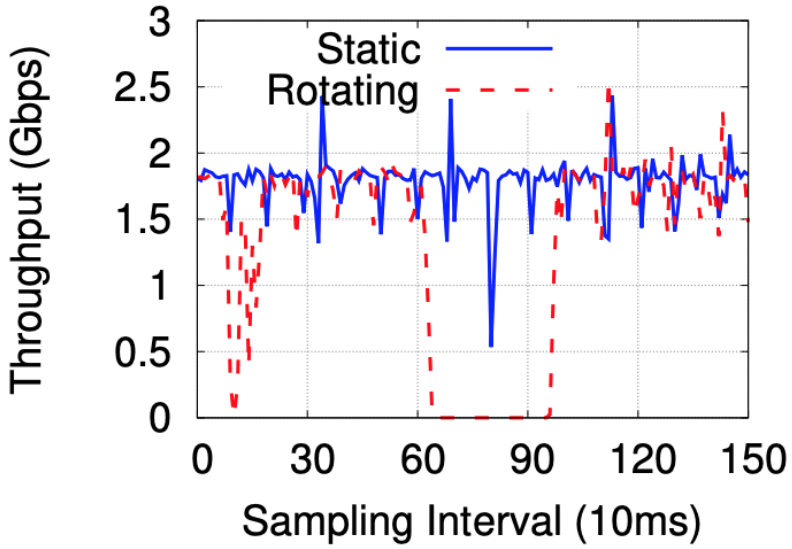
- Bandwidth prediction
  - Simple statistics
  - ML
- ABR Algorithms
  - Buffer based (e.g., BBA, BOLA)
  - Throughput based (e.g., Festive)
  - Hybrid (e.g., MPC, Pensieve)
- Identifying root causes
  - Client, Server, CDN, Routers

Some Wireless Network Conditions

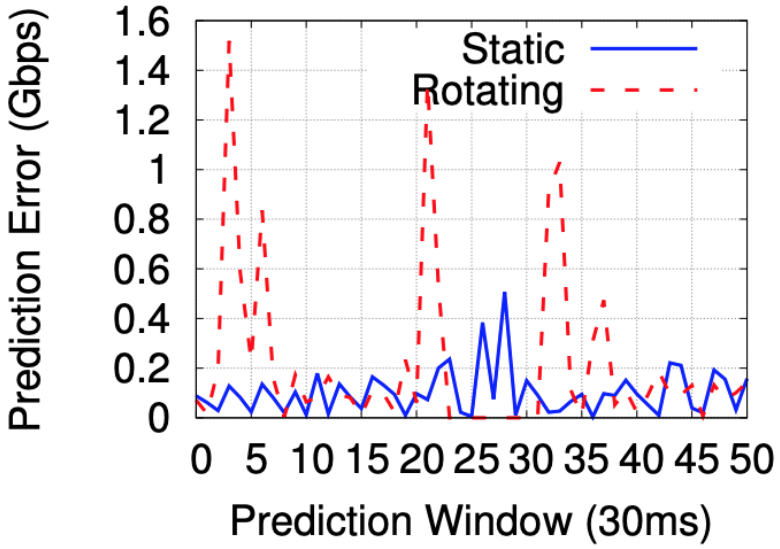


Reasons for fluctuation?

Some Wireless Network Conditions



(a) Throughput Variation



(b) Prediction Error

Increased bandwidth is not enough: reliability matters.

ABR Algorithms

- Key performance metrics
  - Quality (Q), Rebuffering (R), Quality switches (S)
- A general objective
  - Quality of Experience (QoE)

QoE = w1.Q – w2.R – w3.S

Maximize QoE

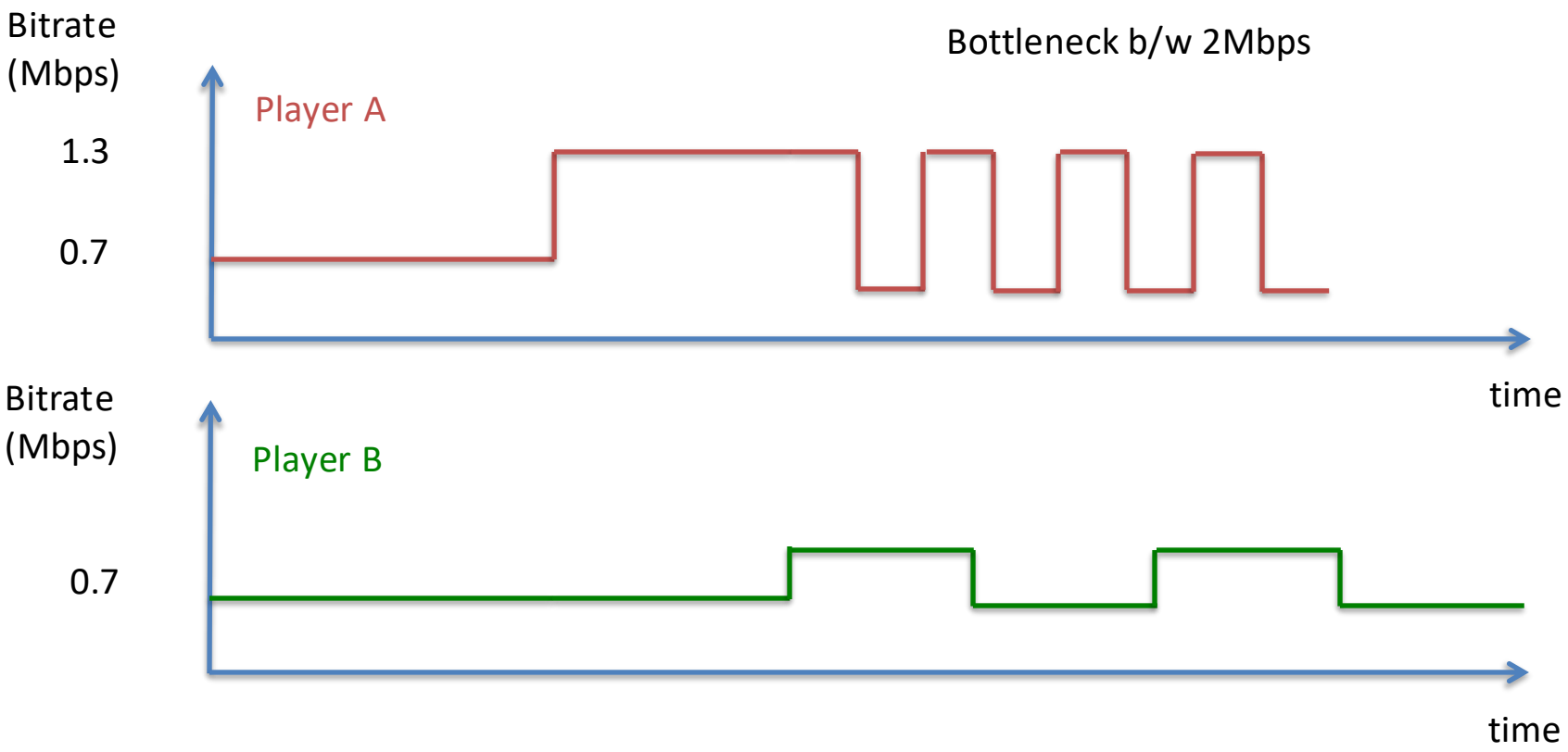
s.t network constraints

Throughput Based ABR (FESTIVE)

Inefficiency: Fraction of bandwidth not being used or overused

Unfairness: Discrepancy of bitrates used by multiple players

Instability: The frequency and magnitude of recent switches

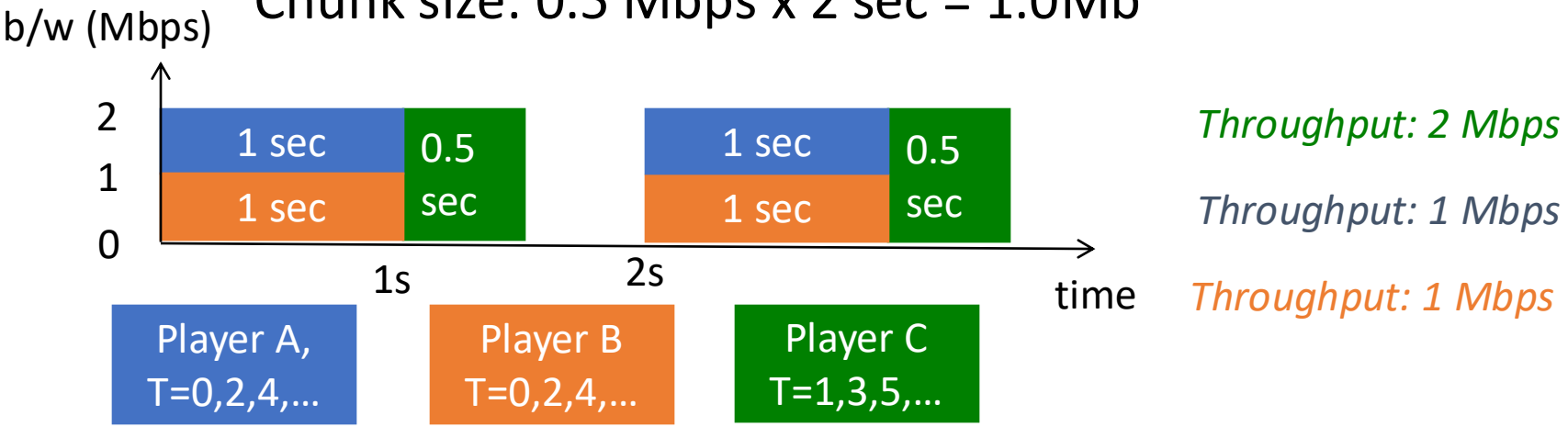


Throughput Based ABR (FESTIVE)

Many players use this to keep fixed video buffer

e.g., if chunk duration = 2 sec, chunk requests at T= 0,2,4,… sec

Example setup: Total bandwidth: 2Mbps
Bitrate 0.5 Mbps, 2 sec chunks
Chunk size: 0.5 Mbps x 2 sec = 1.0Mb



Unfair! Start time impacts observed throughput

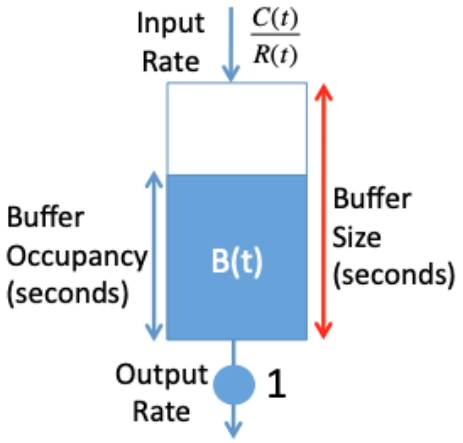
NOT a TCP problem!

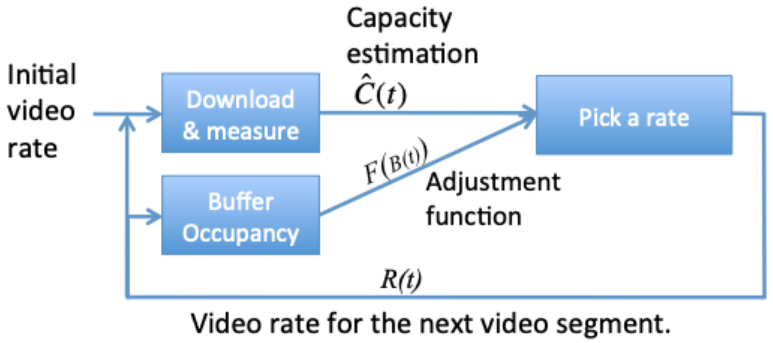
Buffer Based ABR (BBA)

- Adaptive Bit-Rate (ABR) selection algorithms
  - Adjust the bit-rate based on estimated capacity of the network
  - Estimating capacity is difficult b/c of variability
  - Playback buffer occupancy can be used as a heuristic

Buffer Based ABR (BBA)

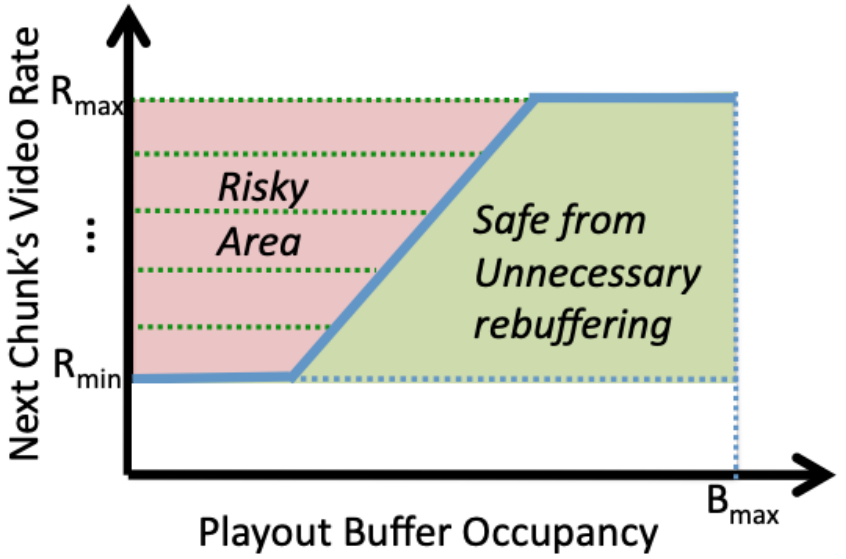
- Picks Video Rate R(t), with capacity C(t)
- Capacity overestimation leads to buffer depletion quickly
- Difficult to pick the right adjustment function when C(t) is highly variable in practice



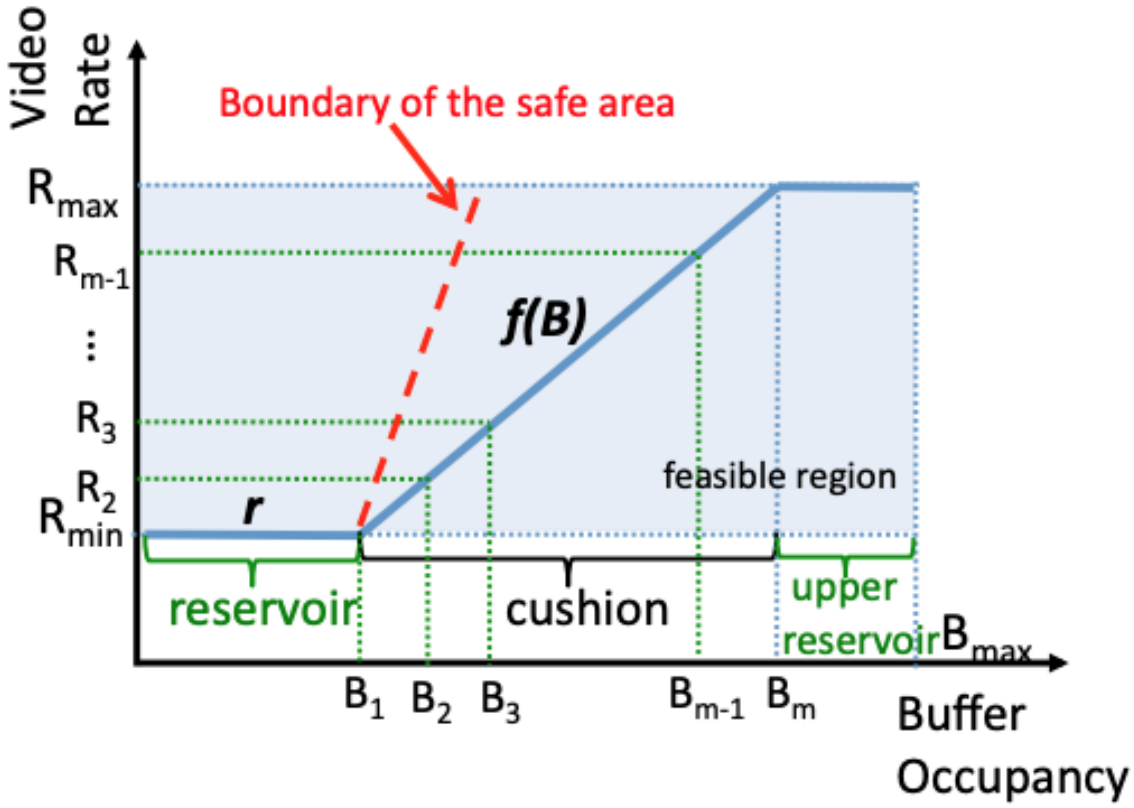


Buffer Based ABR (BBA)

- Pure Buffer based approach
- A function of the current buffer occupancy, B(t)
- A function that produces a video rate between R_min and R_max given the current buffer occupancy.



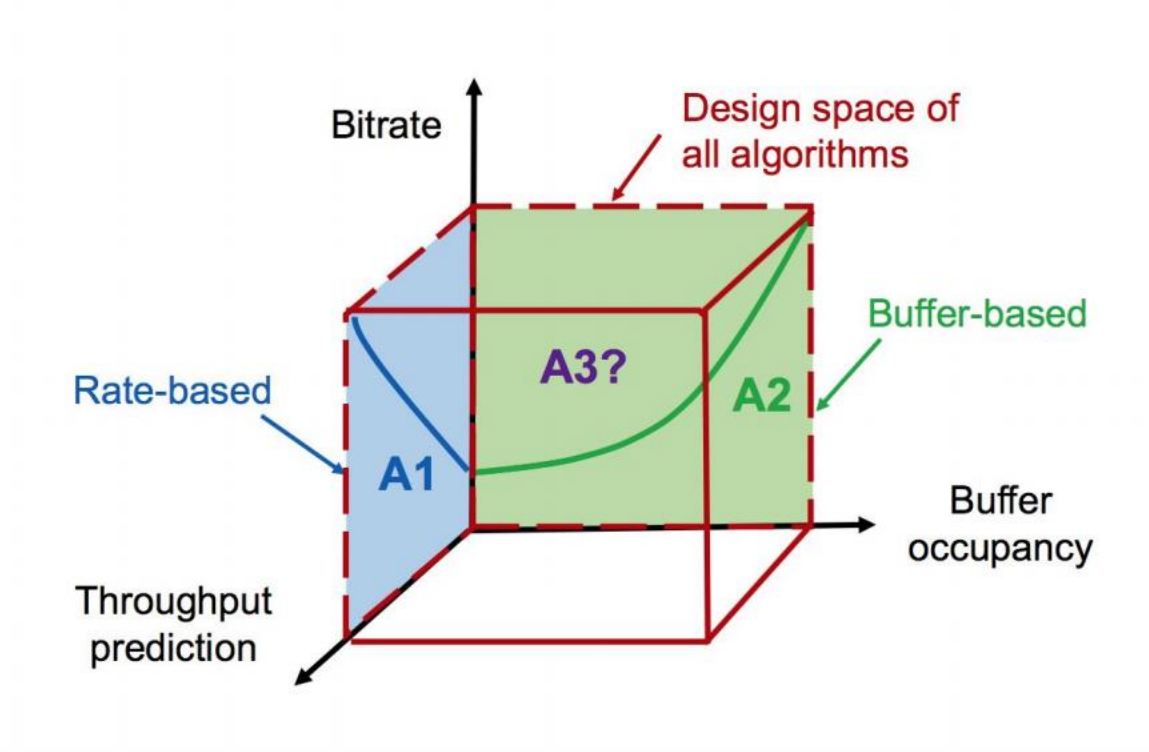
Buffer Based ABR (BBA)



Buffer Based ABR (BBA2)

- BBA-1 still suffers from poor video rate while the buffer is still filling up initially
  - The algorithm is too conservative in startup
  - Chunk map is useful for steady-state
  - Capacity estimate is still useful for startup
    - Estimate based on the throughput of the last chunk

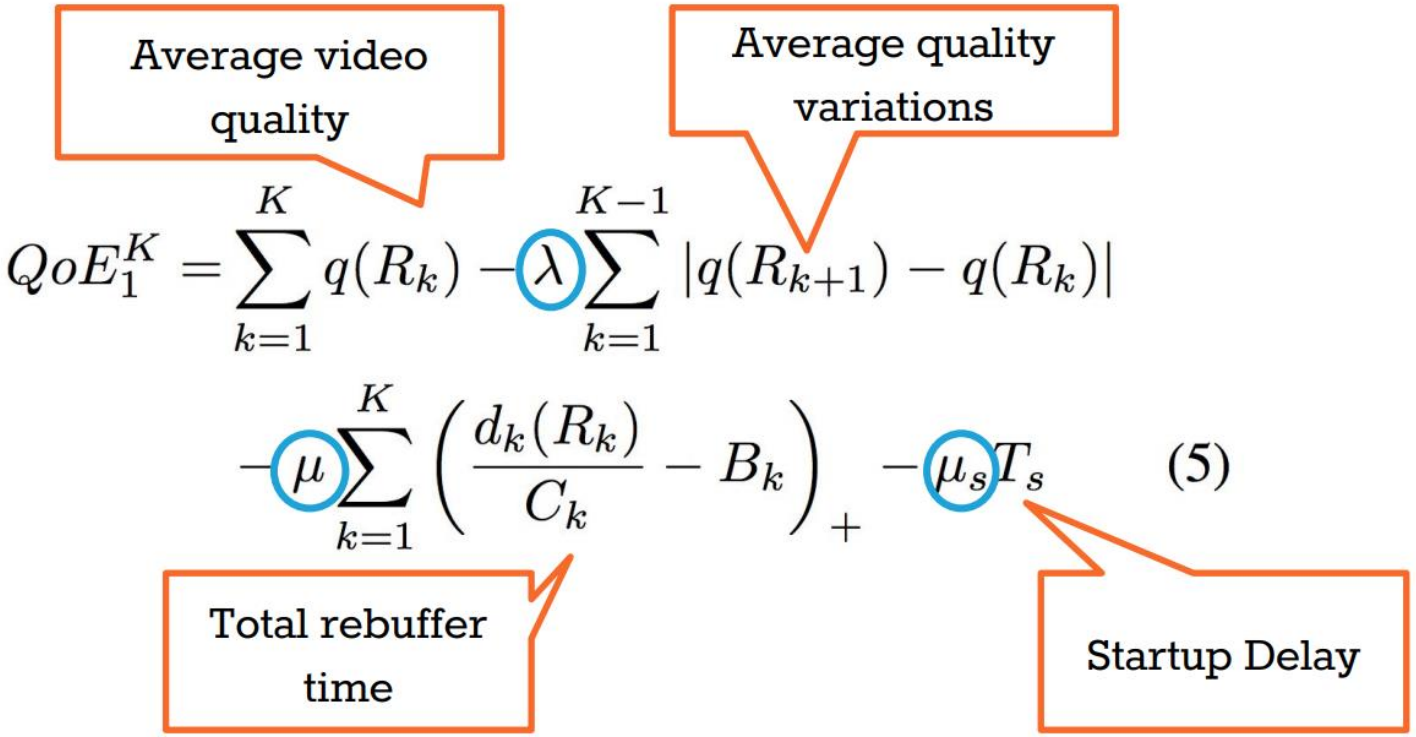
Throughput and Buffer Based ABR (MPC)



Model Predictive Control - MPC

Throughput and Buffer Based ABR (MPC)

- the QoE of video segment 1 through K by a weighted sum of the aforementioned components:



Throughput and Buffer Based ABR (basicMPC)

Algorithm 1 Video adaptation workflow using MPC

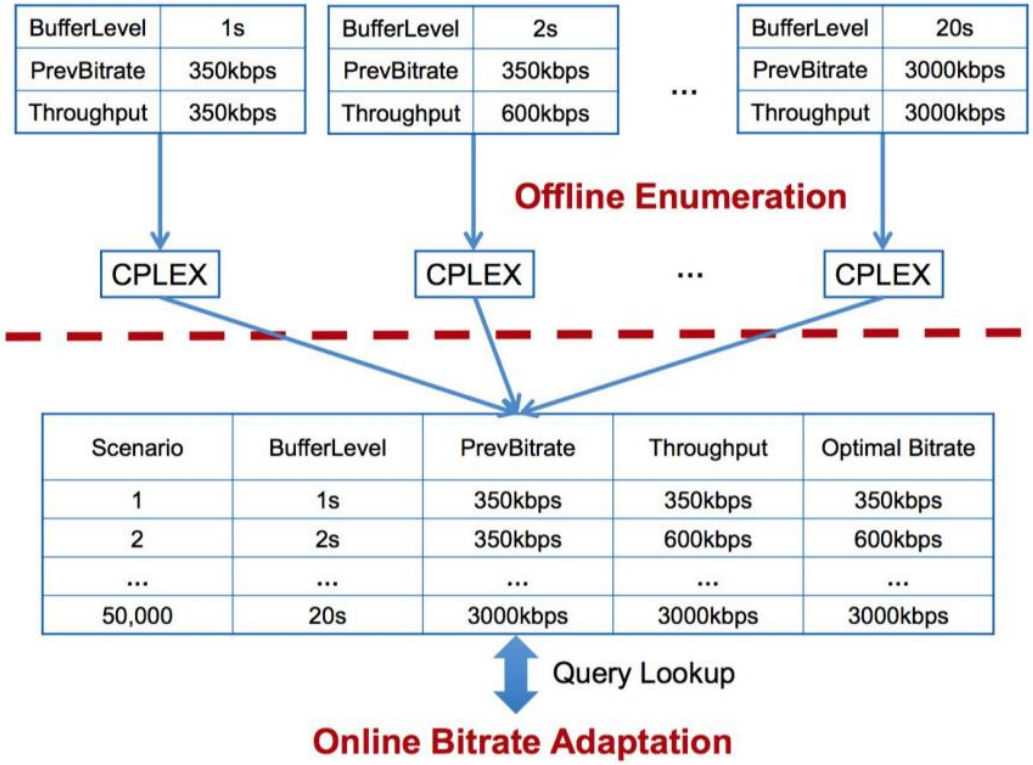
1: Initialize
2: **for** $k = 1$ to K **do**
3: **if** player is in startup phase **then**
4: $\hat{C}_{[t_k, t_{k+N}]}$= ThroughputPred($C_{[t_1, t_k]}$)
5: $[R_k, T_s] = f^{st}_{mpc}\left(R_{k-1}, B_k, \hat{C}_{[t_k, t_{k+N}]}\right)$
6: Start playback after T_s seconds
7: **else if** playback has started **then**
8: $\hat{C}_{[t_k, t_{k+N}]}$= ThroughputPred($C_{[t_1, t_k]}$)
9: $R_k = f_{mpc}\left(R_{k-1}, B_k, \hat{C}_{[t_k, t_{k+N}]}\right)$
10: **end if**
11: Download chunk k with bitrate R_k, wait till finished
12: **end for**

Throughput and Buffer Based ABR (robustMPC)

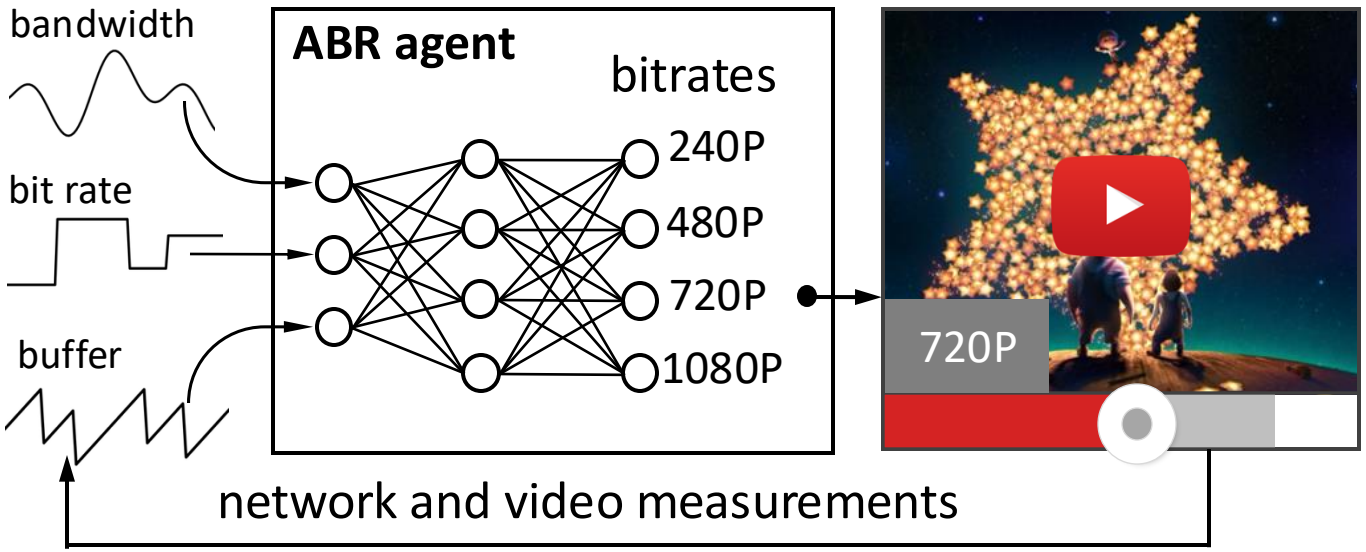
- The basic MPC algorithm assumes the existence of an accurate throughput predictor.
- Robust MPC essentially optimizes the worst-case QoE assuming that the actual throughput can take any value in a range in contrast to a point estimate
- Robust MPC makes conservative estimation

Throughput and Buffer Based ABR (fastMPC)

- Why FastMPC?
  - MPC has large computational overhead
  - Video player cannot be bundled with the solver
- Solution: Table lookup



Learning Based ABR (Pensieve)

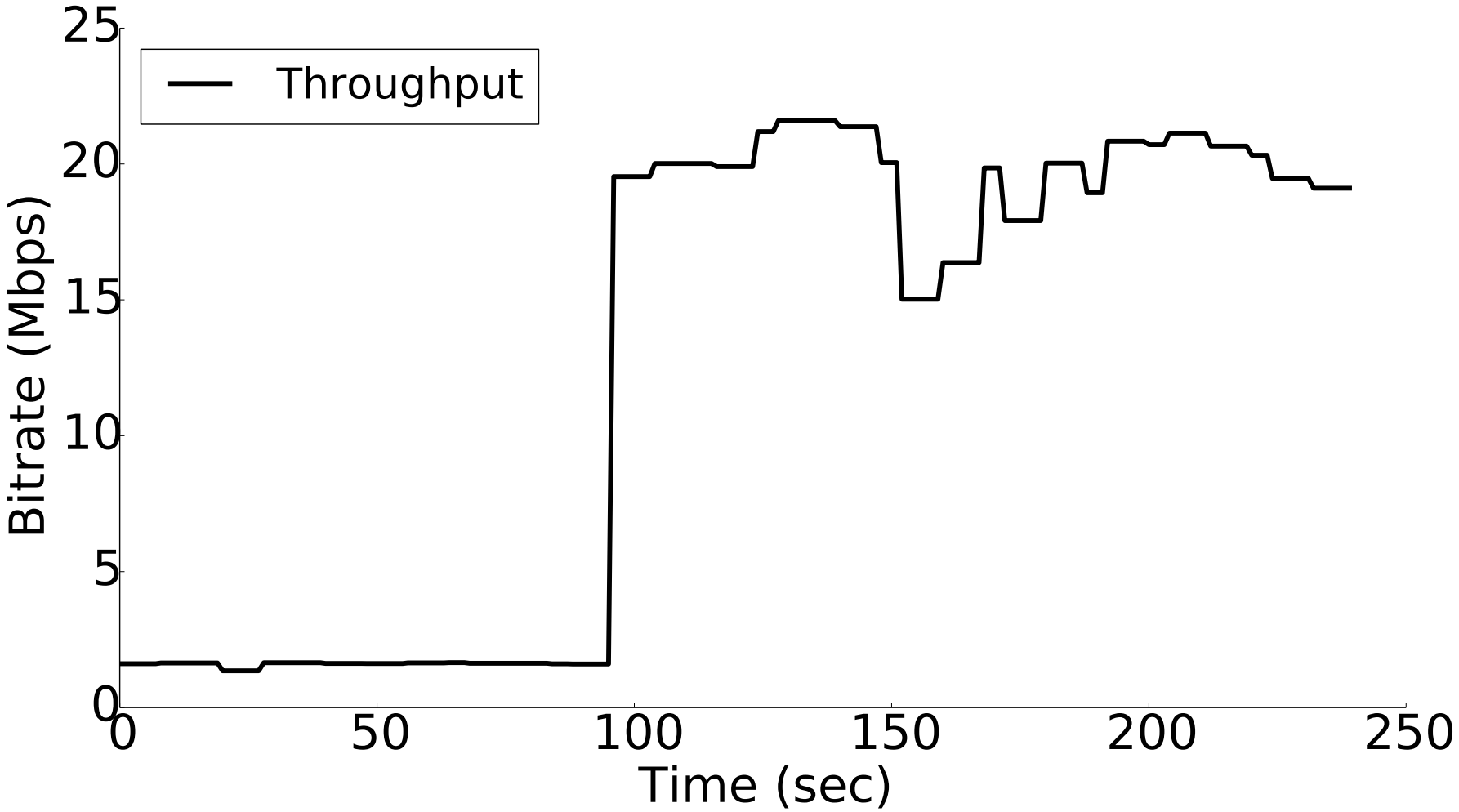


Pensieve learns ABR algorithm automatically through experience

Fast Switching

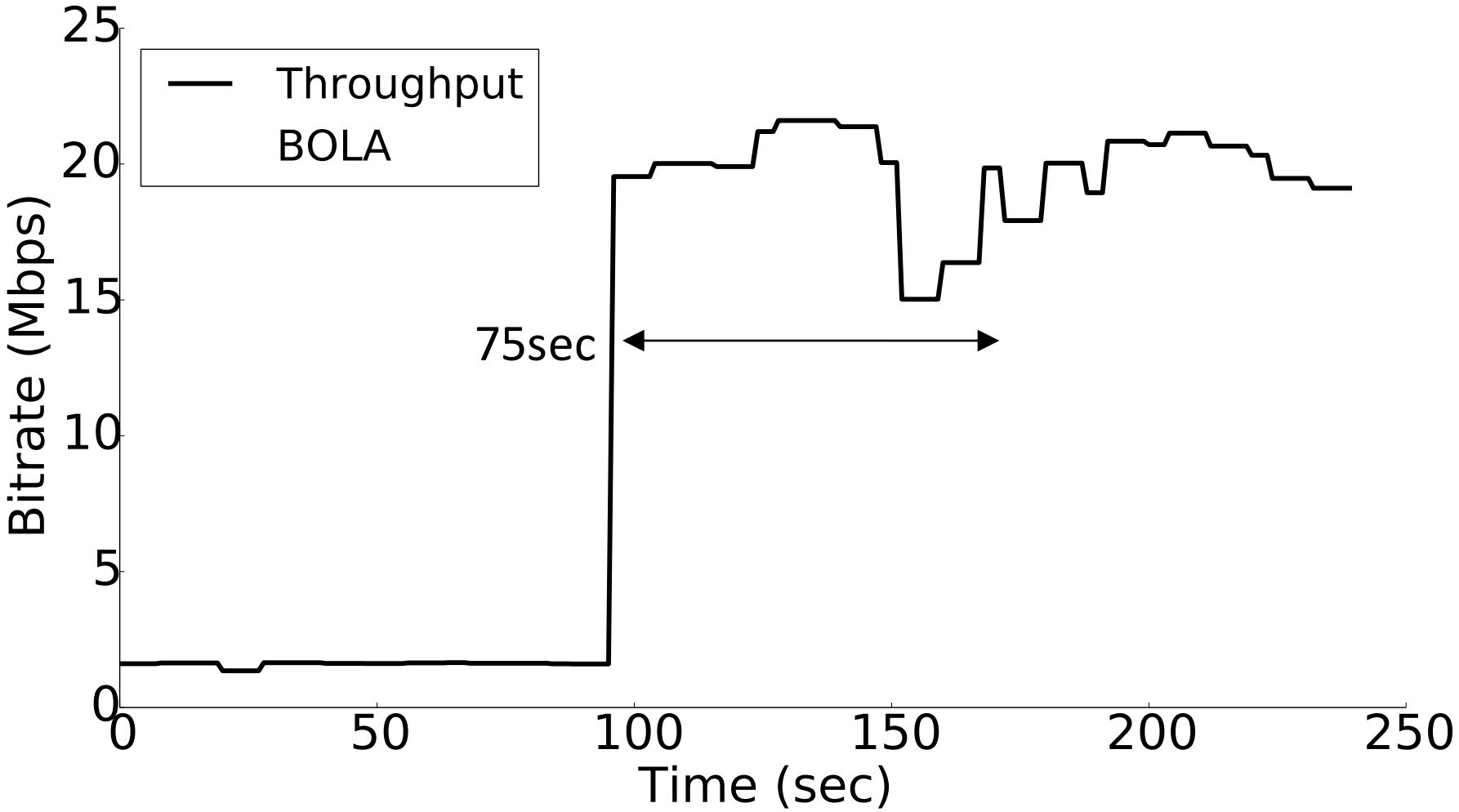
- Responsiveness to higher network throughput by replacing segments already in the buffer
- Decide whether to download a new segment or a replacement segment
- Determine which segment to replace
- Works with both throughput based and buffer-based ABR algorithms
  - Any problems with buffer based?

Fast Switching

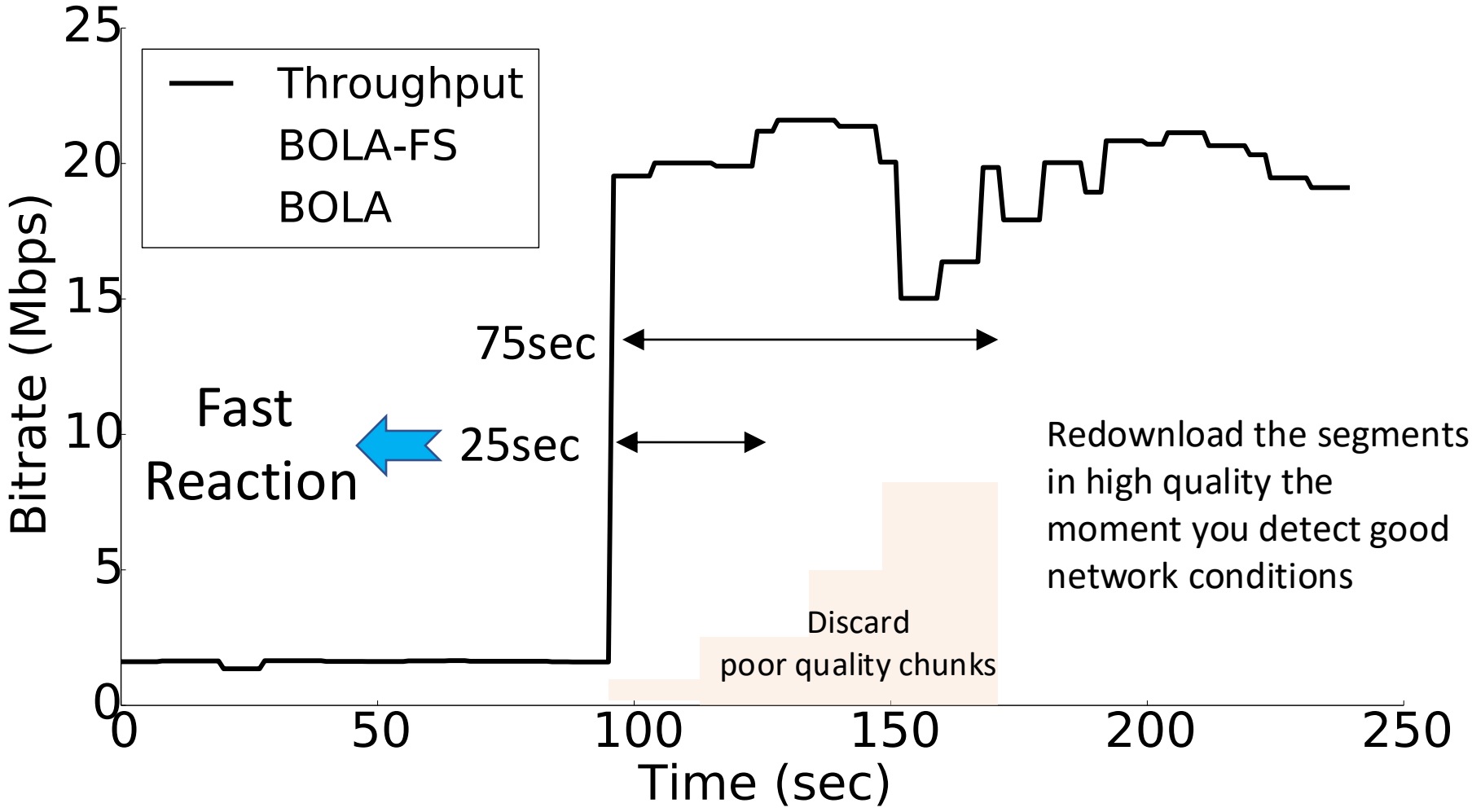


Throughput trace is from ACM/IEEE TON'2020

Fast Switching



Fast Switching



Summary of the Lecture

- ABR for advanced video applications
- ABR Algorithms
  - Buffer based
  - Throughput based
  - Hybrid
  - Learned
- Bandwidth prediction
- Fast switching for high throughput network

Next up: 360-degree video streaming