Cache-Friendly Streaming Bitrate Adaptation by Congestion Feedback in ICN

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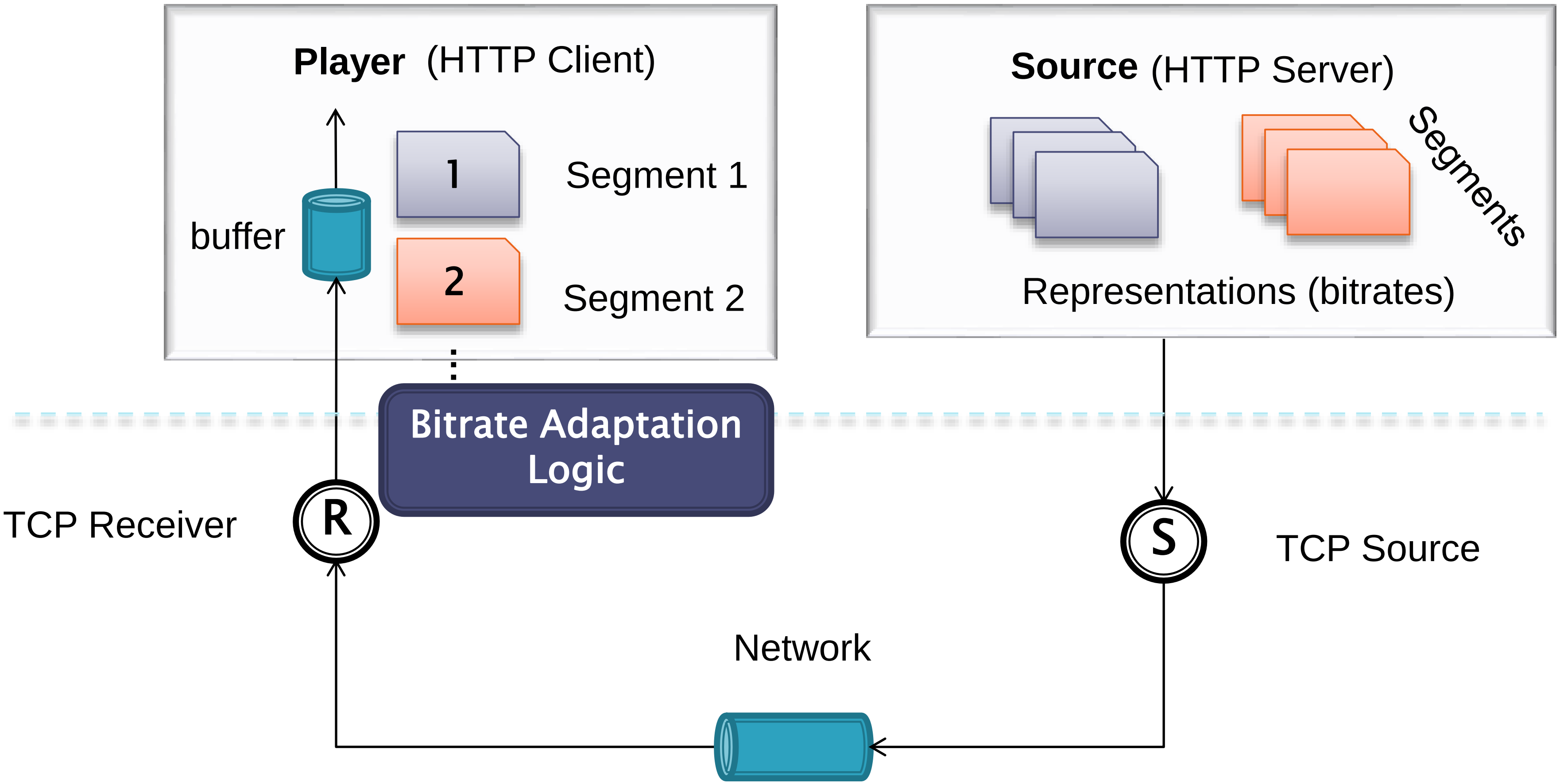
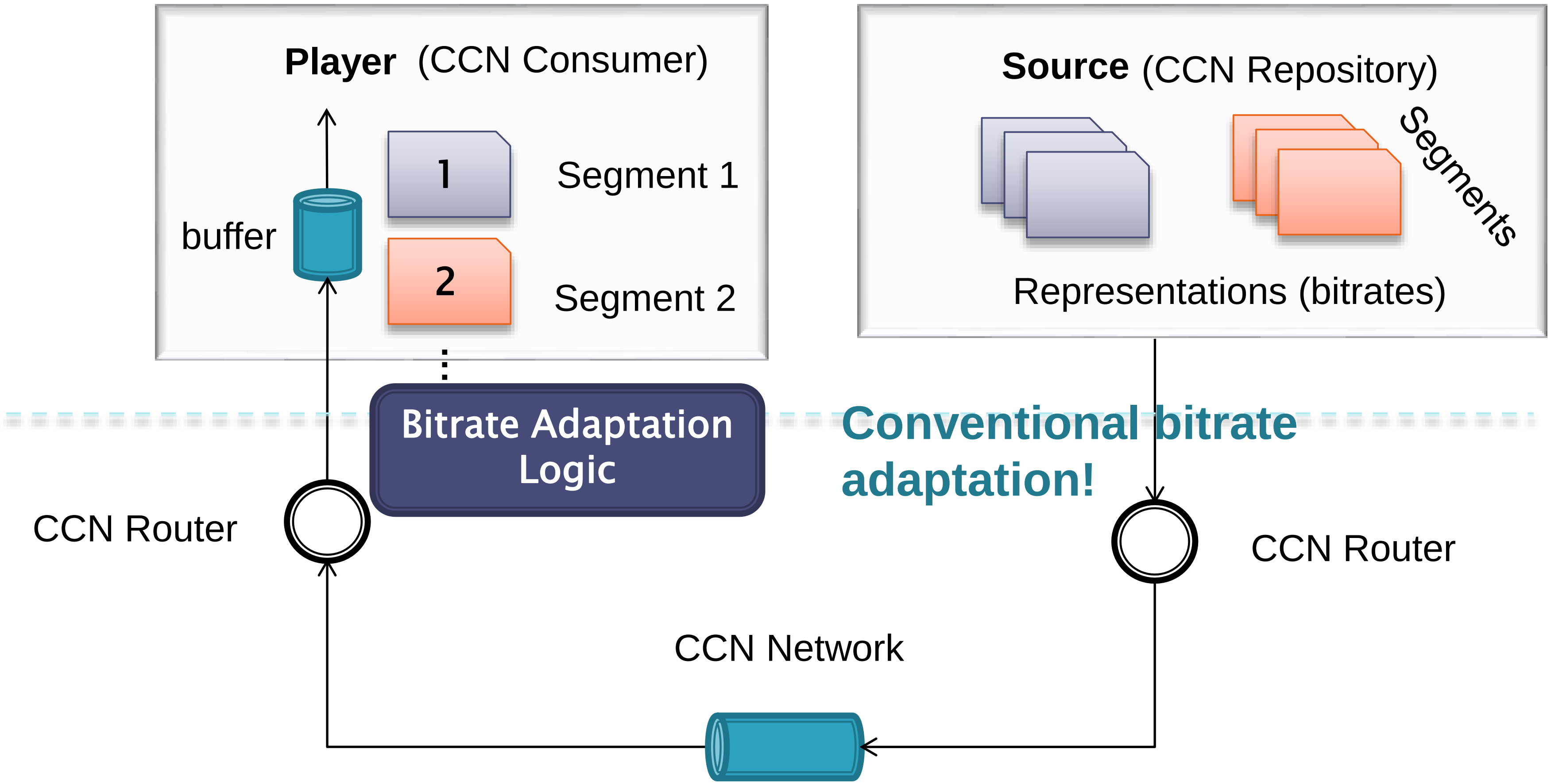
Dynamic Adaptive Streaming over HTTP



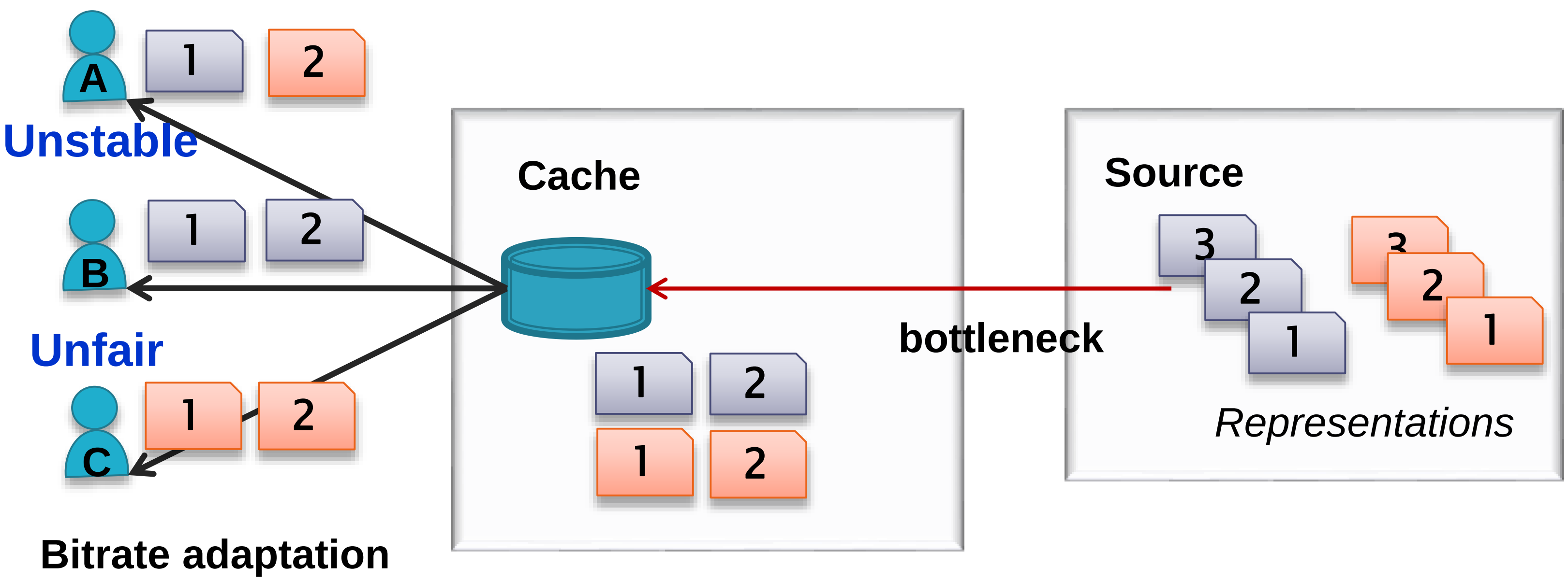
DASH over CCN



Liu, Y.; Geurts, J.; Point, J.-C.; Lederer, S.; Rainer, B.; Muller, C.; Timmerer, C. & Hellwagner, H.
Dynamic adaptive streaming over CCN: A caching and overhead analysis, *ICC* 2013, 3629-3633

The problem

- **Bitrate adaptation results in low cache hit**
  - Vanilla ICN caches admit every video segment
  - Non-repetitive requests from users due to unfair and unstable bitrate adaptation
  - **Multiple representations of the same segment**



Motivation

- Avoid the *side-effect* of bitrate adaptation to cache
  - High cache hit rate even with adaptive streaming
- Bitrate adaptation should be *friendly* to in-network caches
  - <u>Repetitive requests:</u> same bottleneck same bitrate
  - <u>Less fluctuation:</u> quickly settle at fair, stable bitrate
- To devise a streaming bitrate adaptation with
  - Fairness
  - Stability

Conventional bitrate adaptation

1. Estimate bandwidth in the last download

Estimate bandwidth

$$\tilde{x} = \frac{\text{segment\_size}}{\text{download\_time}}$$

inaccurate bandwidth share

2. Smooth the estimated bandwidth using e.g. EWMA

Smooth

$$\text{EWMA}(\tilde{x})$$

3. Choose nearest bitrate as the target video bitrate

Quantize

$$\hat{x} \leq \text{EWMA}(\tilde{x})$$

4. Request next segment of bitrate $\hat{x}$ after

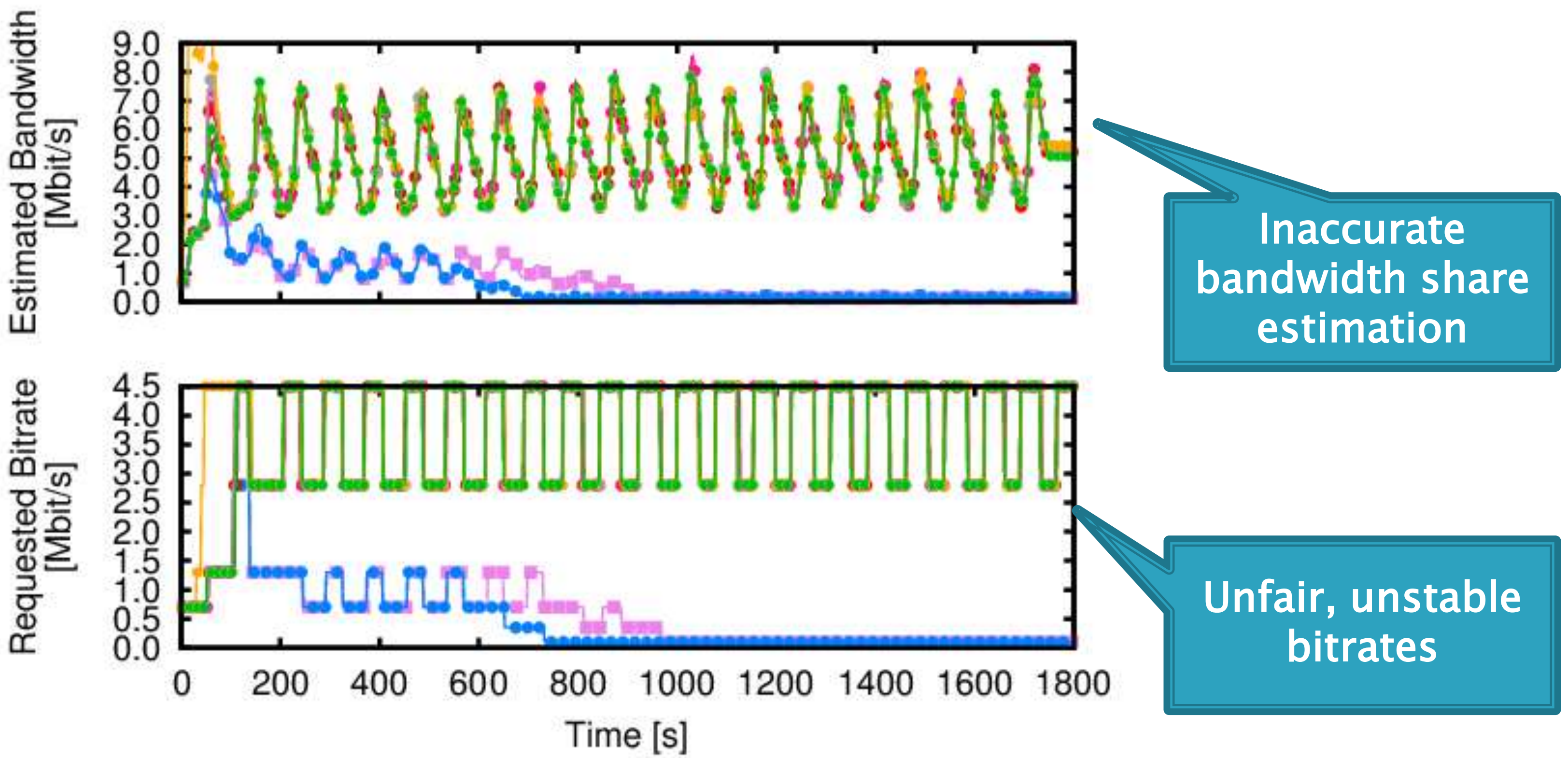
Schedule next request

$$\Delta t = \begin{cases} 0 \text{ if } B < B_{\max} \\ \tau \text{ if } B \geq B_{\max} \end{cases}$$

/* $B/B_{\max}$: current/max playback buffer */

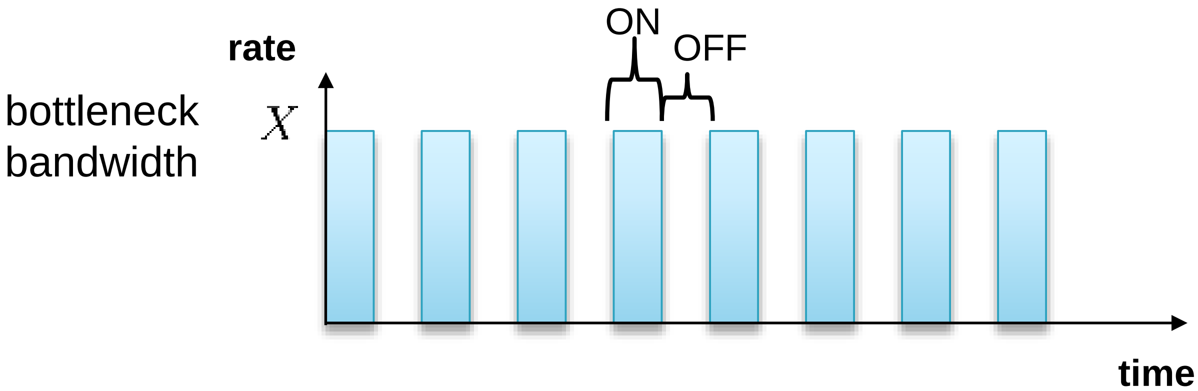
/* τ: segment length in second */

A simple test



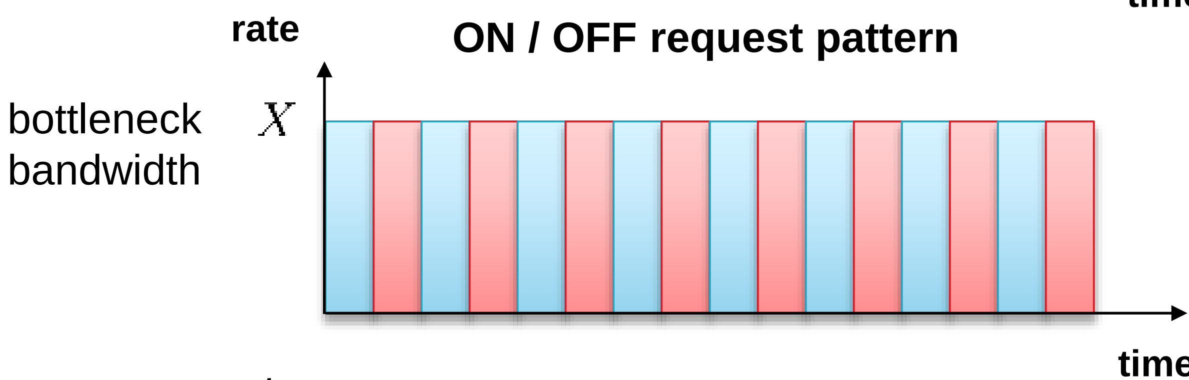
- 8 conventional adaptive streams compete over 24Mbit/s bottleneck

Inaccurate bandwidth estimation



ON / OFF request pattern

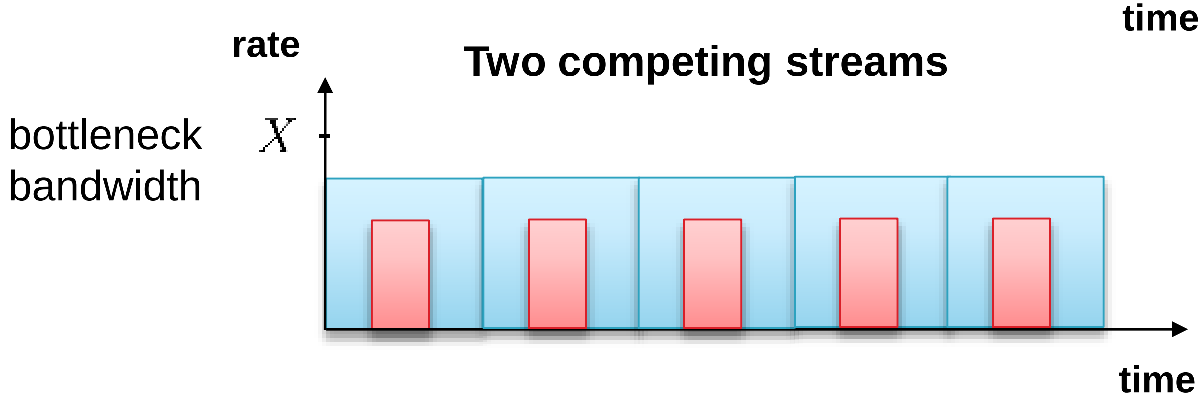
$\tilde{x} = X$



Two competing streams

$\tilde{x}_1 = \tilde{x}_2 = X$!!

Unstable



$\tilde{x}_1 > \tilde{x}_2$

Unfair

Utility fairness resource allocation

- Utility fairness optimization [Wang06]

$$\max_{x \geq 0} \quad \sum_{n \in N} \int_{m_n}^{x_n} \frac{1}{U_n(y)} dy$$

$$s.t. \quad \sum_{n:i,j \in L(n)} x_n \leq c_{i,j} \ \forall i,j$$

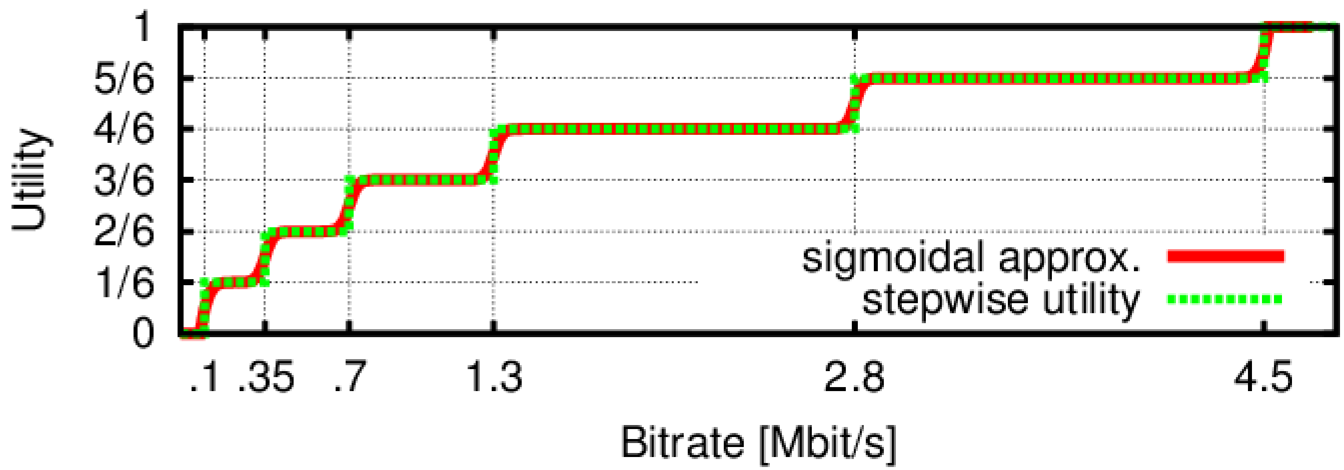
- Utility-fair bandwidth share

$$x_n(t+1) = U_n^{-1}\left(\underbrace{\frac{1}{q_n(t)}}_{\text{congestion feedback}}\right)$$

congestion feedback

Wang, W.-H.; Palaniswami, M. & Low, S., Application-Oriented Flow Control: Fundamentals, Algorithms and Fairness, *IEEE/ACM Trans. Netw.,* 2006*, 14*, 1282-1291

Utility functions



- Step-wise utility functions
- Logistic approximation at each step for continuity
- Could be different for users requesting the same content

Utility–fair bitrate adaptation

1a. Measure and smooth congestion price feedback

$$q_n = \mathrm{EWMA}[q(D)]$$

`/* ` $q_n/q(D)$`:  smooth/current congestion price */`

1b. Compute utility-fair bandwidth share

$$\tilde{x}_n = U_n^{-1}\left(\frac{1}{q_n}\right)$$

utility-fair bandwidth estimation

2. Smooth the estimated bandwidth

$$\mathrm{EWMA}(\tilde{x})$$

3. Choose nearest bitrate as the target video bitrate

$$\hat{x} \le \mathrm{EWMA}(\tilde{x})$$

4. Request next segment of bitrate $\hat{x}$ after

$$\Delta t = \begin{cases} 0 \text{ if } B < B_{\max} \\ \tau \text{ if } B \ge B_{\max} \end{cases}$$

`/* ` $B/B_{\max}$`:  current/max playback buffer */`
`/* ` τ`:  segment length in second */`

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Impact on caching (ext. to Che's)

- Fewer # representations in cache R
- Larger effective cache size

$$\bar{\boldsymbol{C}} = \frac{C}{S\left(\sum_{k=1}^{\boldsymbol{R}} b_k\right)}$$

- Longer characteristic time $T_{\bar{C}}$

$$\sum_{i=1}^{M}(1 - e^{-p_i \boldsymbol{T}_{\bar{\boldsymbol{C}}}}) = \bar{\boldsymbol{C}}$$

- Higher cache hit rate

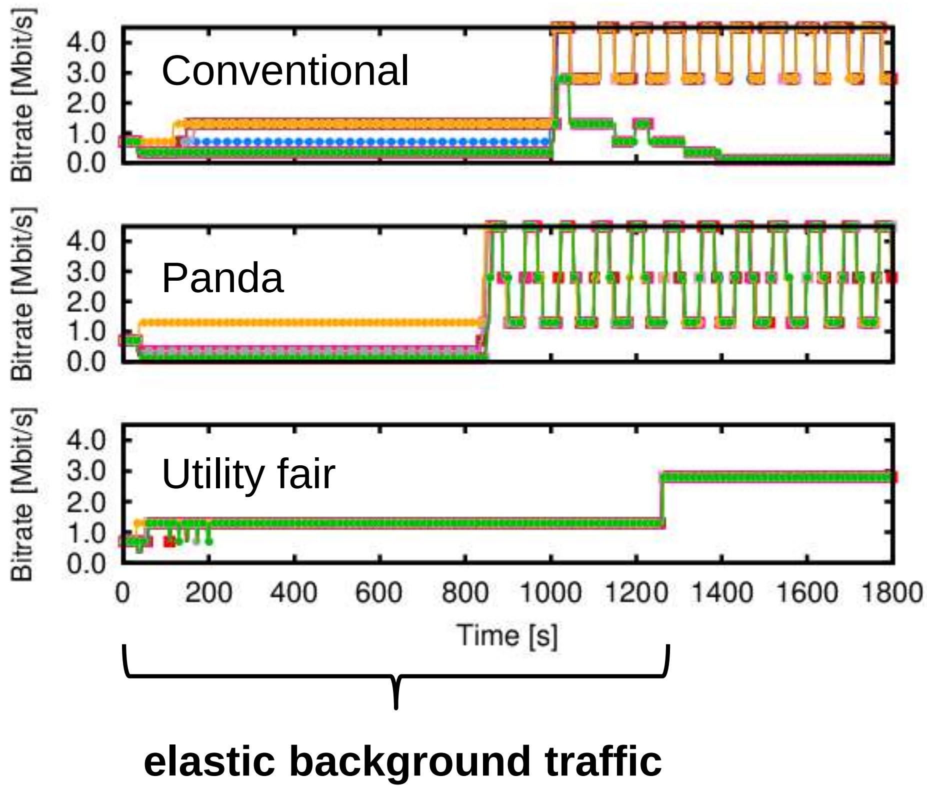
$$P_{\text{hit}} = \sum_{i=1}^{M} p_i(1 - e^{-p_i \boldsymbol{T}_{\bar{\boldsymbol{C}}}})$$

Simulation

- Chunk-level CCN simulation
- Congestion signal: queuing delay
- LRU caches
- Chain topology with bottleneck
- Playback buffer: 30 seg.
- Evaluate
  - Conventional adaptation
  - PANDA [Li2014]: AIMD bandwidth probe
  - Proposed utility-fair adaptation

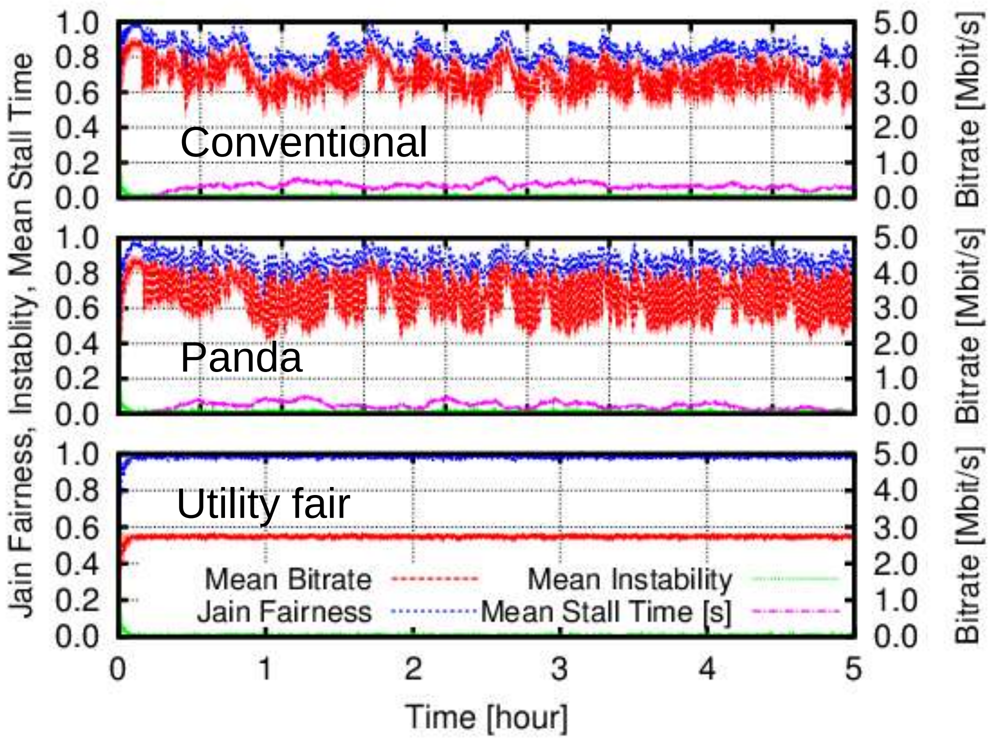
Li, Z.; Zhu, X.; Gahm, J.; Pan, R.; Hu, H.; Begen, A. & Oran, D.
Probe and Adapt: Rate Adaptation for HTTP Video Streaming At Scale
Selected Areas in Communications, IEEE Journal on, 2014, *32*, 719-733

Elastic background traffic



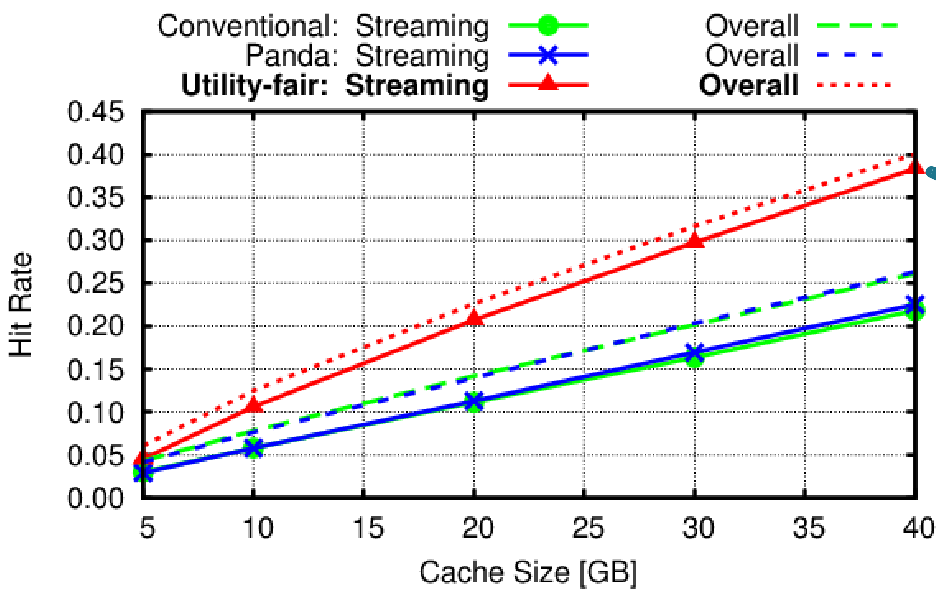
- 24 Mbit/s bottleneck
- 8 streaming sessions + 1 download

Stability and fairness

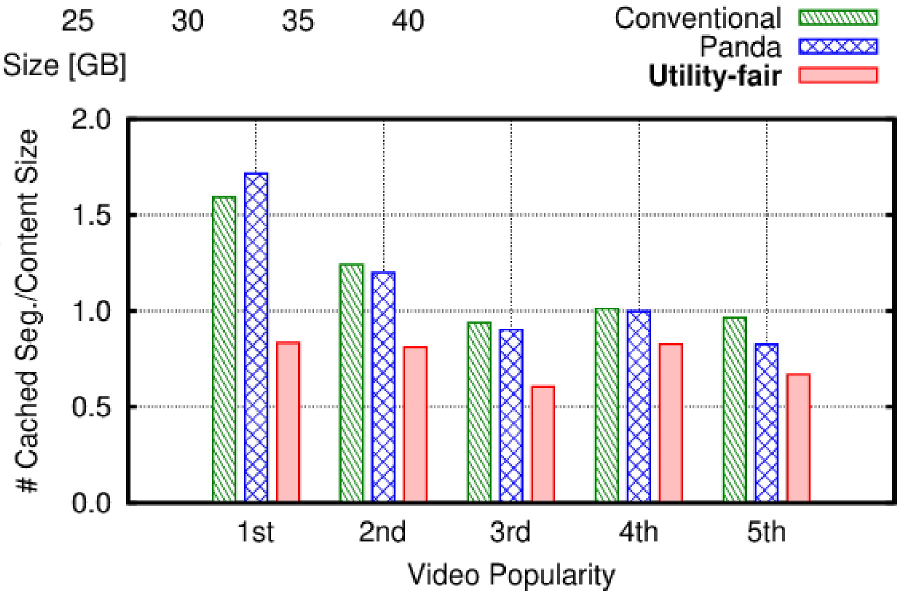


- 1Gbit/s bottleneck, chain topology
- 60% streaming + 40% downloading
- 2000 content objects (Zipf.8), Poisson arrival 0.8 req/s
- 20GB LRU cache @ all routers

Cache-friendliness



Much higher hit ratio



Fewer redundant representations

Conclusion

- Promising result on bitrate adaptation by congestion feedback in CCN
  - Accurate bandwidth estimation: using utility fairness framework
  - Cache-friendliness: fairness and stability in bitrate adaptation increase cache hit
- Future work
  - Testbed evaluation
  - Caching for video streaming
  - Exploiting better congestion feedback signal available in CCN/NDN

Thank you!