A Case for a Coordinated Video Control Plane

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Hui Zhang
(Conviva, CMU, Intel, and UC Berkeley)

# Video Is Dominating the Internet Traffic

- Netflix traffic alone exceeds **20%** of US traffic[1]

- 2011's Cisco Visual Networking Index[2]
  - 2011: video represents **51%** of the Internet traffic
  - 2016: all types of video will represent **86%** of the Internet traffic

[1]http://blogs.cisco.com/sp/comments/cisco_visual_networking_index_forecast_annual_update

[2]http://web.cs.wpi.edu/~claypool/mmsys-2011/Keynote02.pdf

The Internet is becoming a Video Network

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Video Ecosystem: Data-Plane
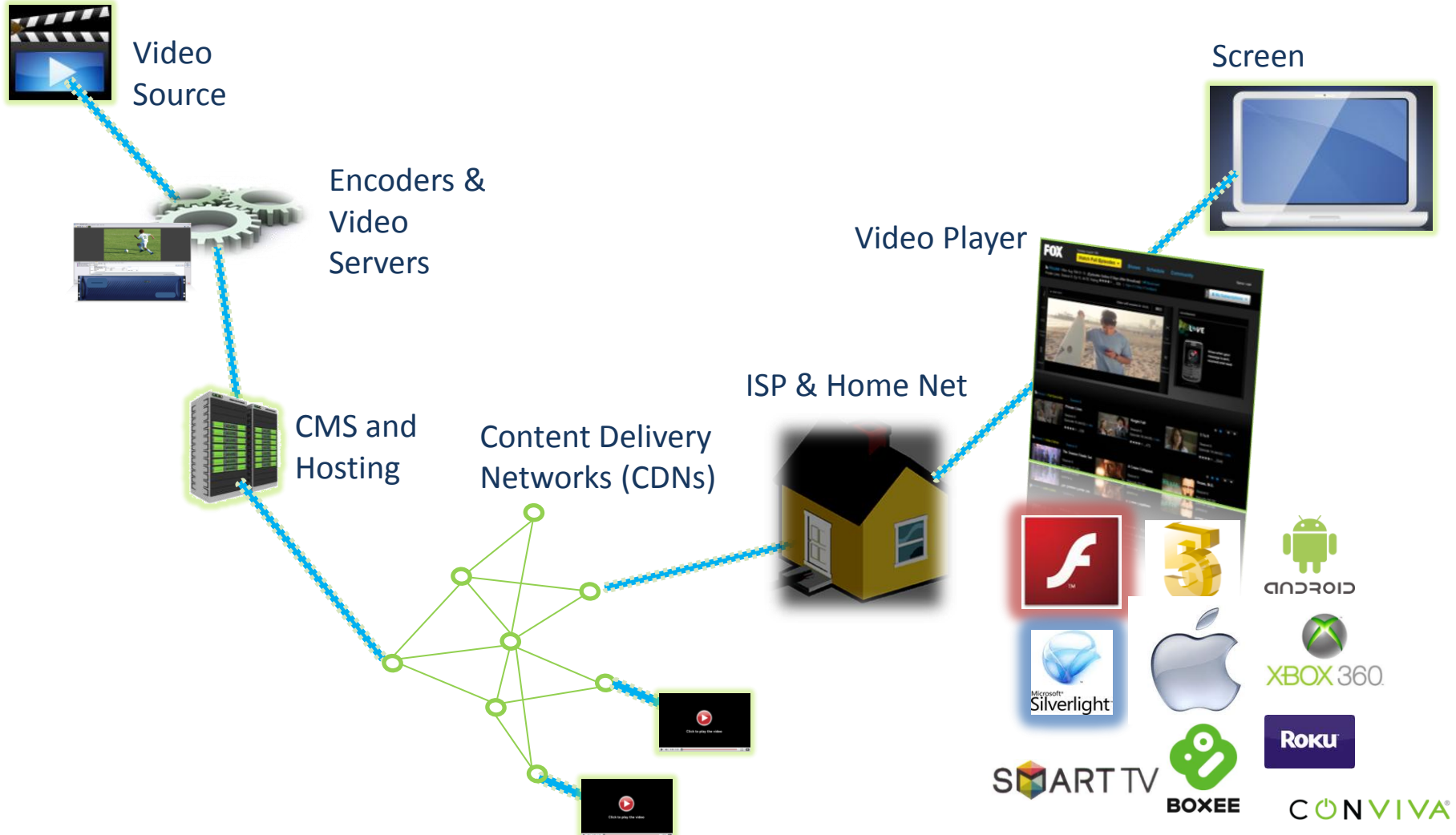
Video Quality Matters [Sigcomm'11]

- Quality has substantial impact on viewer engagement
  - Need to ensure uninterrupted streaming at high bitrates

- Buffering ratio is most critical across video traffic types
  - Highest impact for live: 1% of buffering reduced play time by 3min
 - **1% increase in buffering can lead to more than 60% loss in audience over one month**

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Our Argument

- CDN performance varies widely in time, geography, and ISPs

- Opportunity for significantly improving video Quality by selecting best CDN (and bitrate) for each viewer

- Hence, we argue for a logically **centralized** control plane to **dynamically** select CDN and bitrate

Assumptions:
- Content is encoded at multiple bitrates
- Content is delivered by multiple CDNs

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How do We Collect Data?
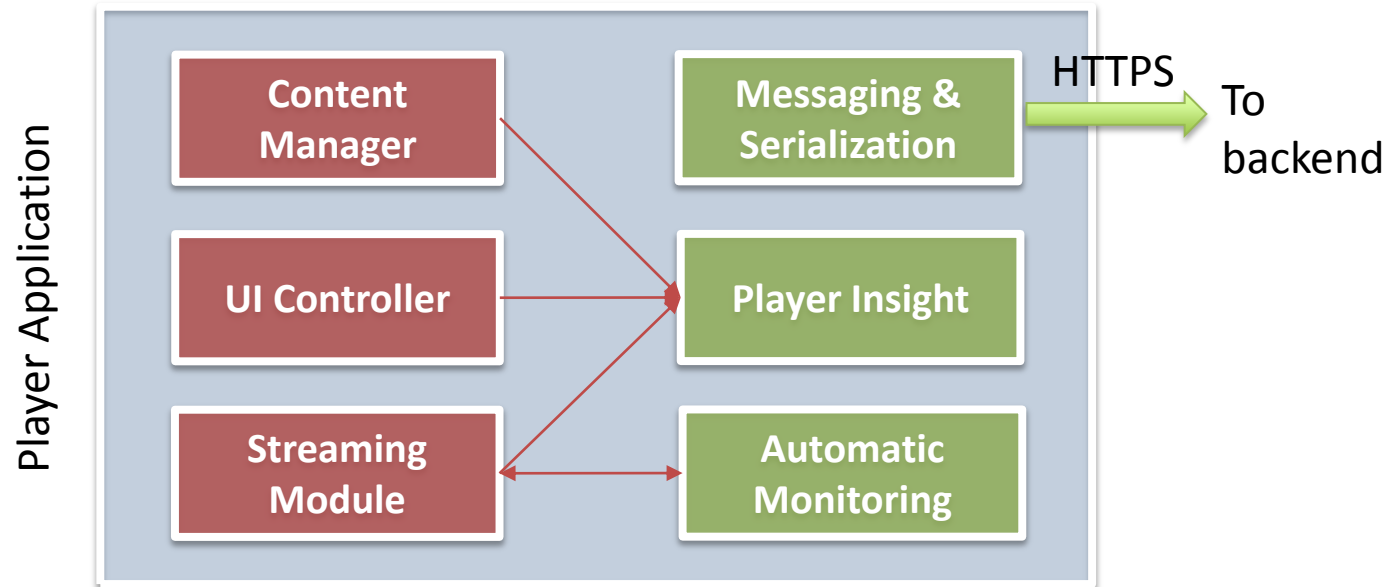
- Automatic and continuous monitoring of video player
  - Flash: NetStream, VideoElement
  - Silverlight: MediaElement, SmoothStreamMediaElement
  - iOS: MPMoviePlayerElement

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What Traffic do We See?

- Close to two billions streams per month

- Mostly **premium** content providers (e.g., HBO, ESPN, Disney) but also **User Generated Video sites** (e.g., Ustream)

- **Live events** (e.g., NCAA March Madness, FIFA World Cup, MLB), **short VoDs** (e.g., MSNBC), and **long VoDs** (e.g., HBO, Hulu)

- Various streaming protocols (e.g., Flash, SmoothStreaming, HLS), and devices (e.g., PC, iOS devices, Roku, XBOX, …)

- Traffic from all major CDNs, including ISP CDNs (e.g., Verizon, AT&T)

Time

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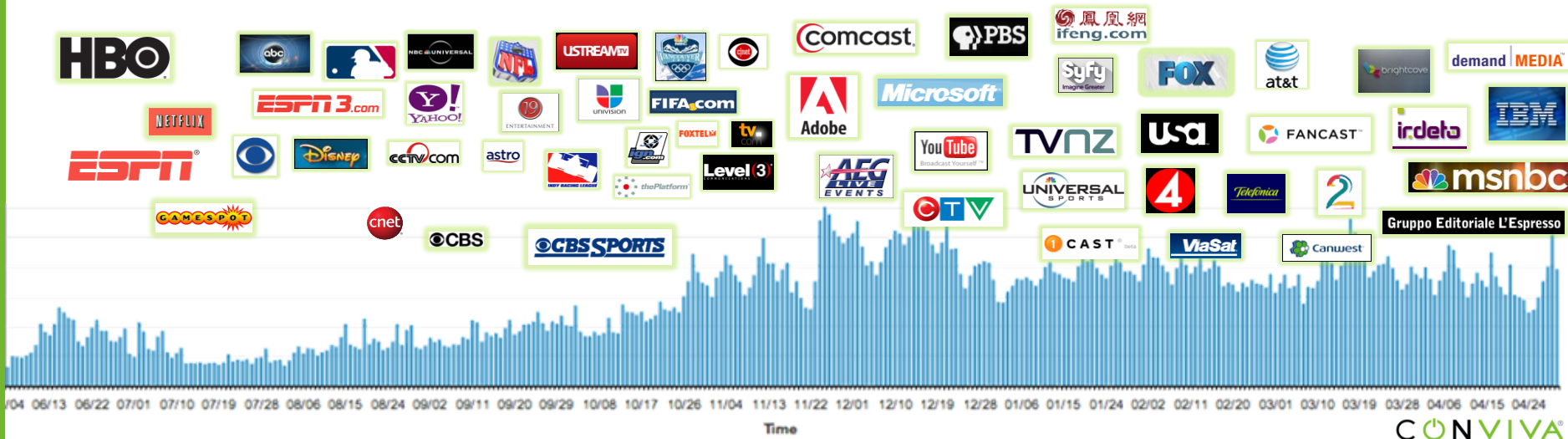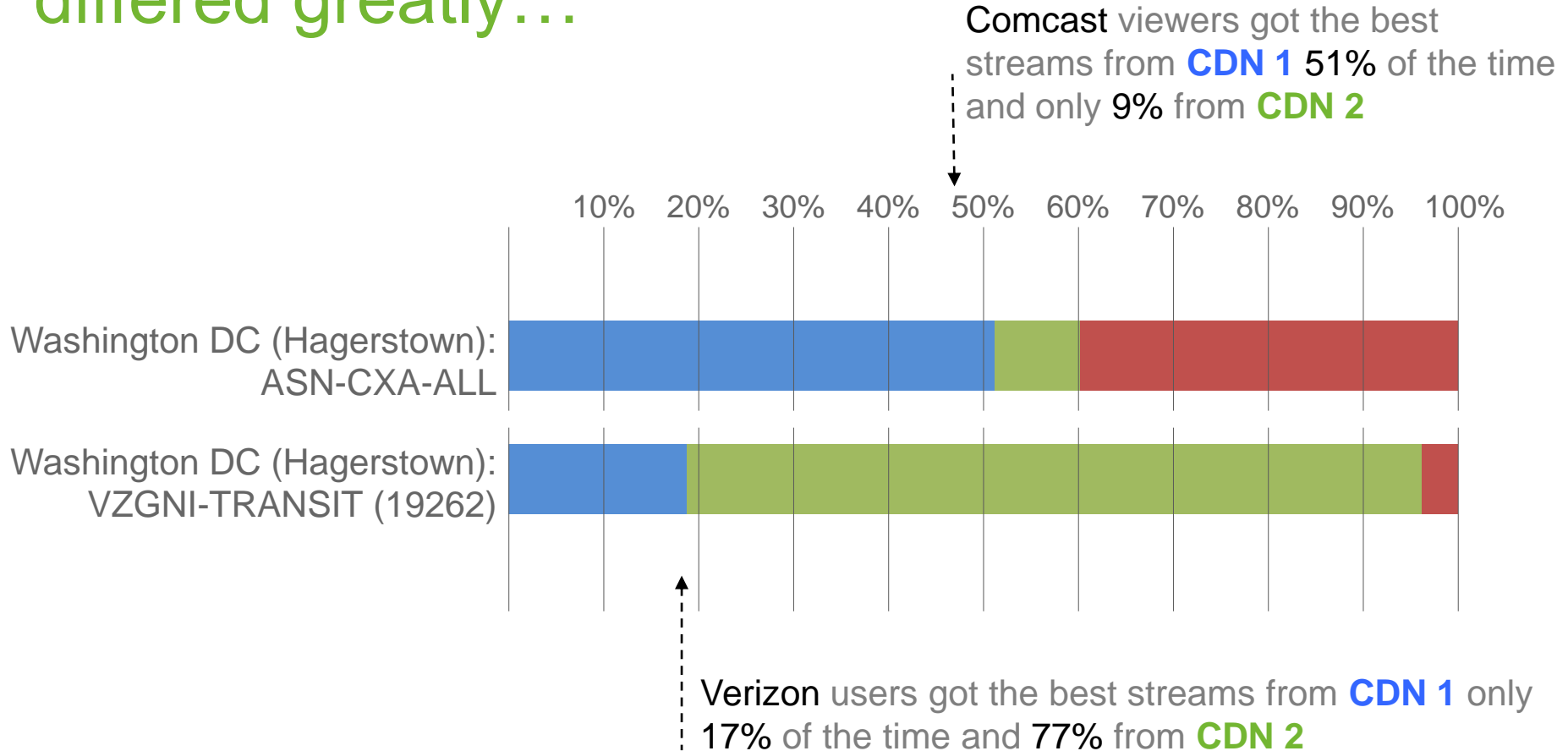
CDN Performance Varies Widely

CDNs Vary in Performance over Geographies and Time

- Metric: buffering ratio
- One month aggregated data-set
  - Multiple Flash (RTMP) customers
  - Three major CDNs
- 31,744 DMA-ASN-hour with > 100 streams from each CDN
  - DMA: Designated Market Area
- Percentage of DMA-ASN-hour partitions a CDN has lowest buffering ratio

CDN 2

25%

25%

50%

CDN 3

CDN 1
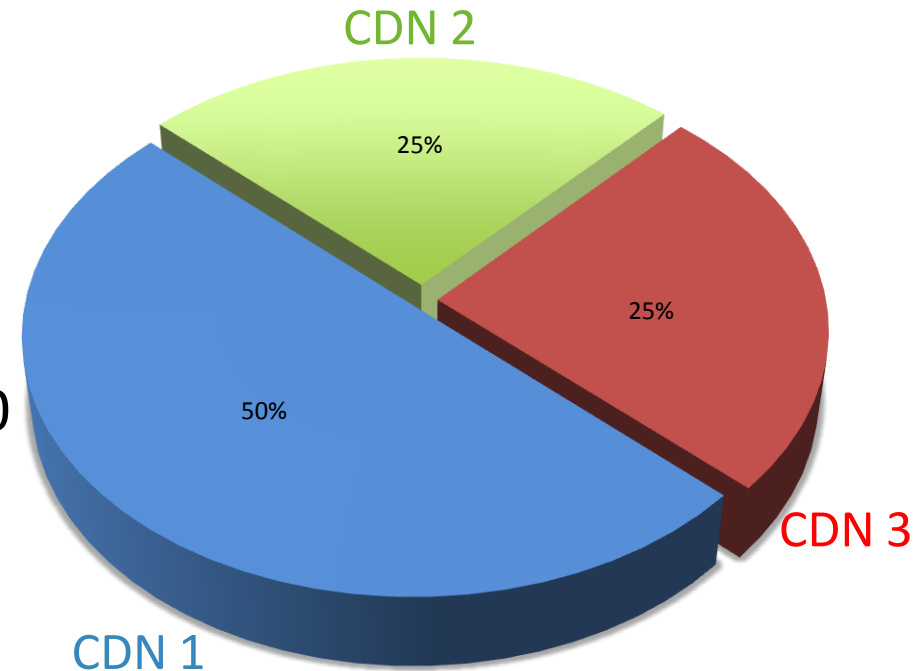
There is no single best CDN across geographies, network, and time

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Washington, DC viewer experience differed greatly…

Comcast viewers got the best streams from **CDN 1** 51% of the time and only 9% from **CDN 2**

10% 20% 30% 40% 50% 60% 70% 80% 90% 100%

Washington DC (Hagerstown): ASN-CXA-ALL

Washington DC (Hagerstown): VZGNI-TRANSIT (19262)

Verizon users got the best streams from **CDN 1** only 17% of the time and 77% from **CDN 2**

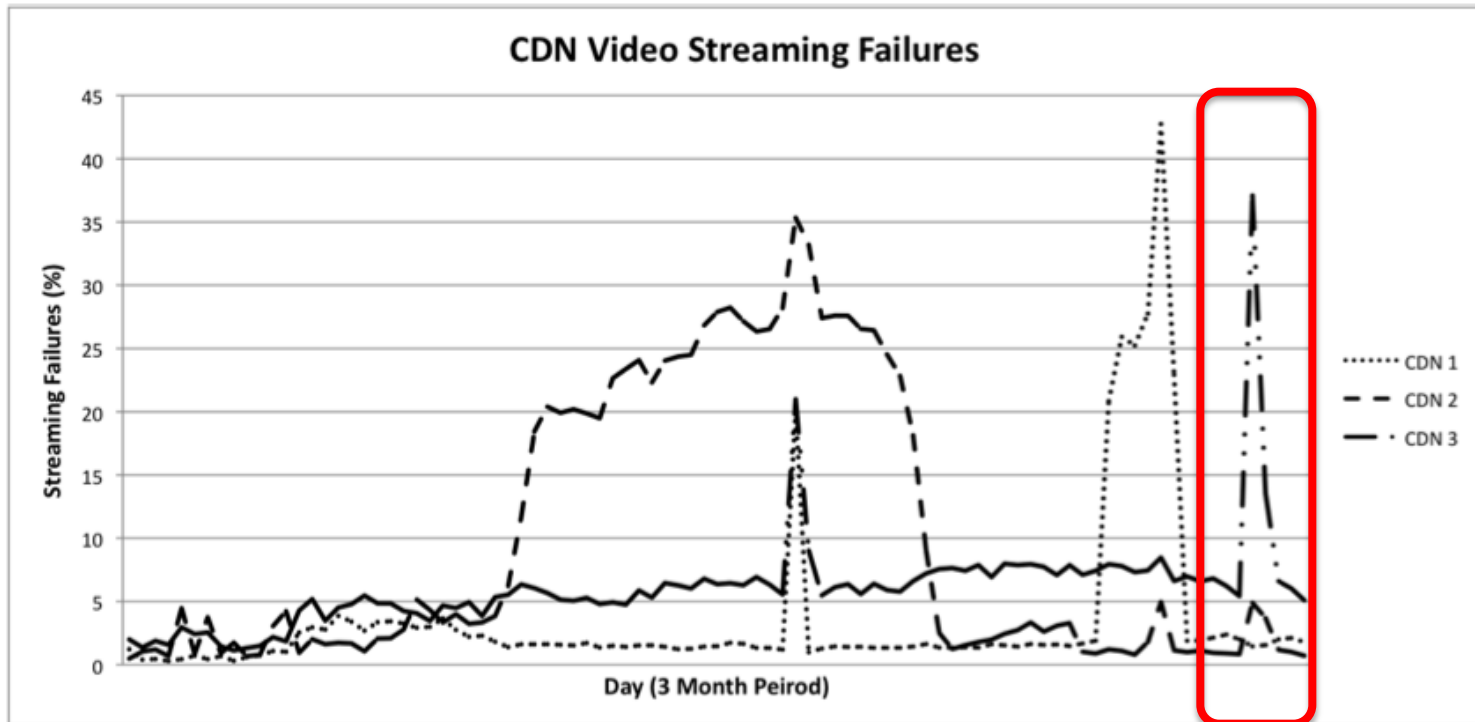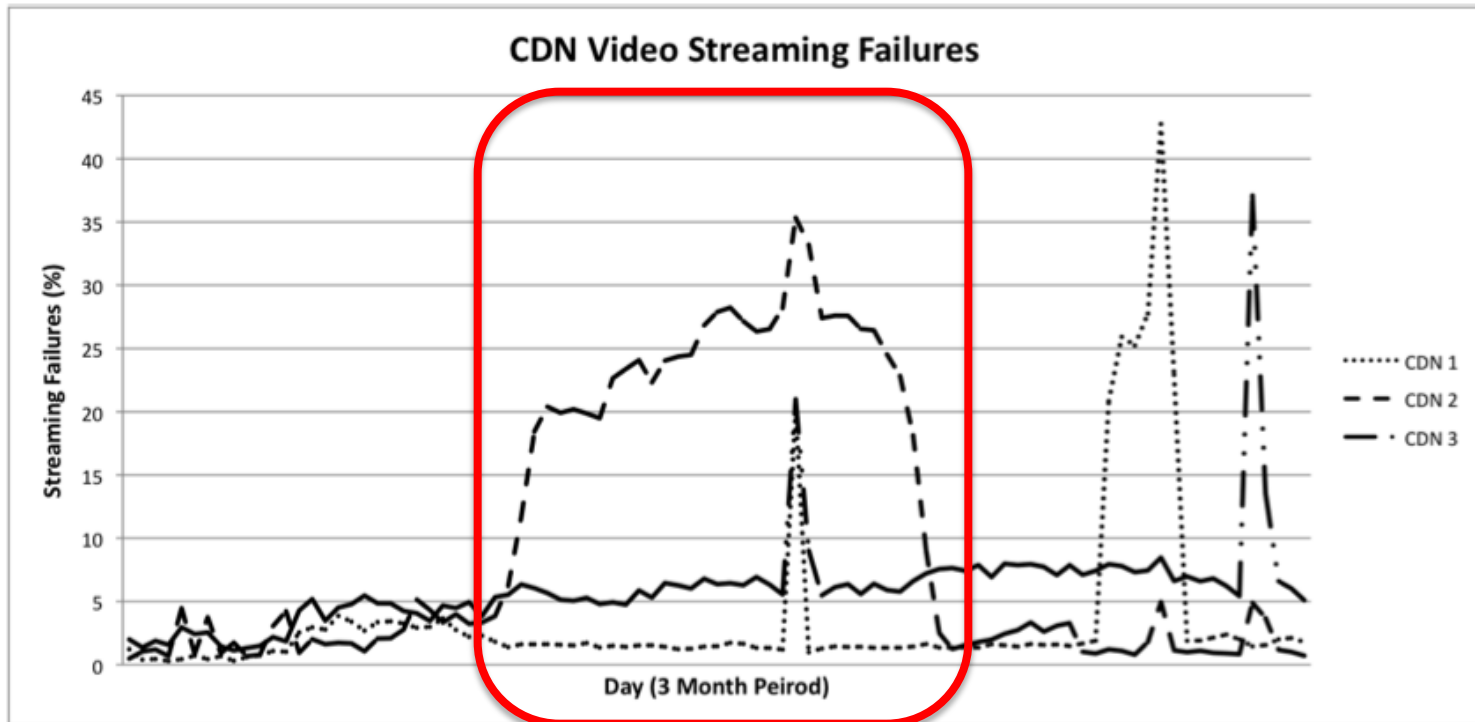**There is no single best CDN in the same geographic region or over time**

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CDN Streaming Failures Are Common Events

- % of stream failures: % of streams that failed to start
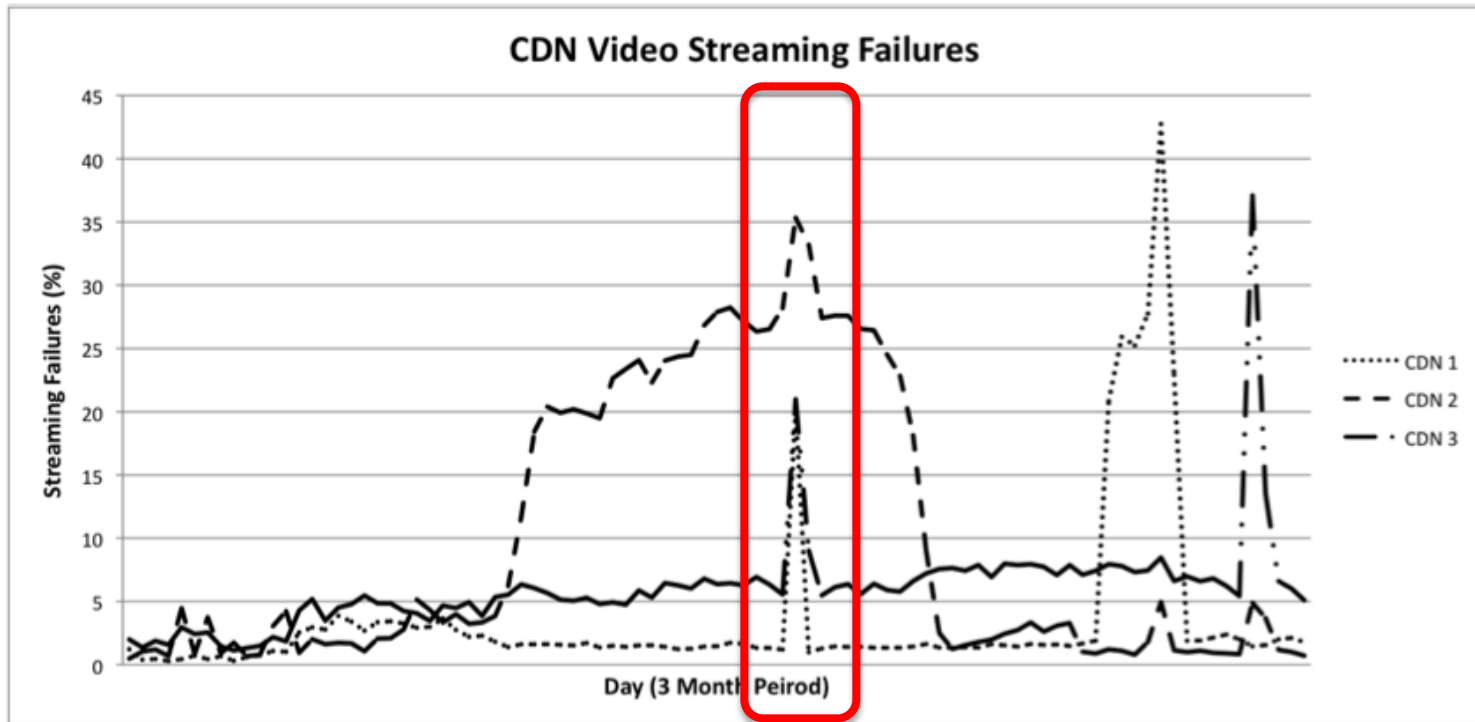- Three months dataset (May-July, 2011) for a premium customer using Flash

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CDN Streaming Failures Are Common Events

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CDN Video Streaming Failures

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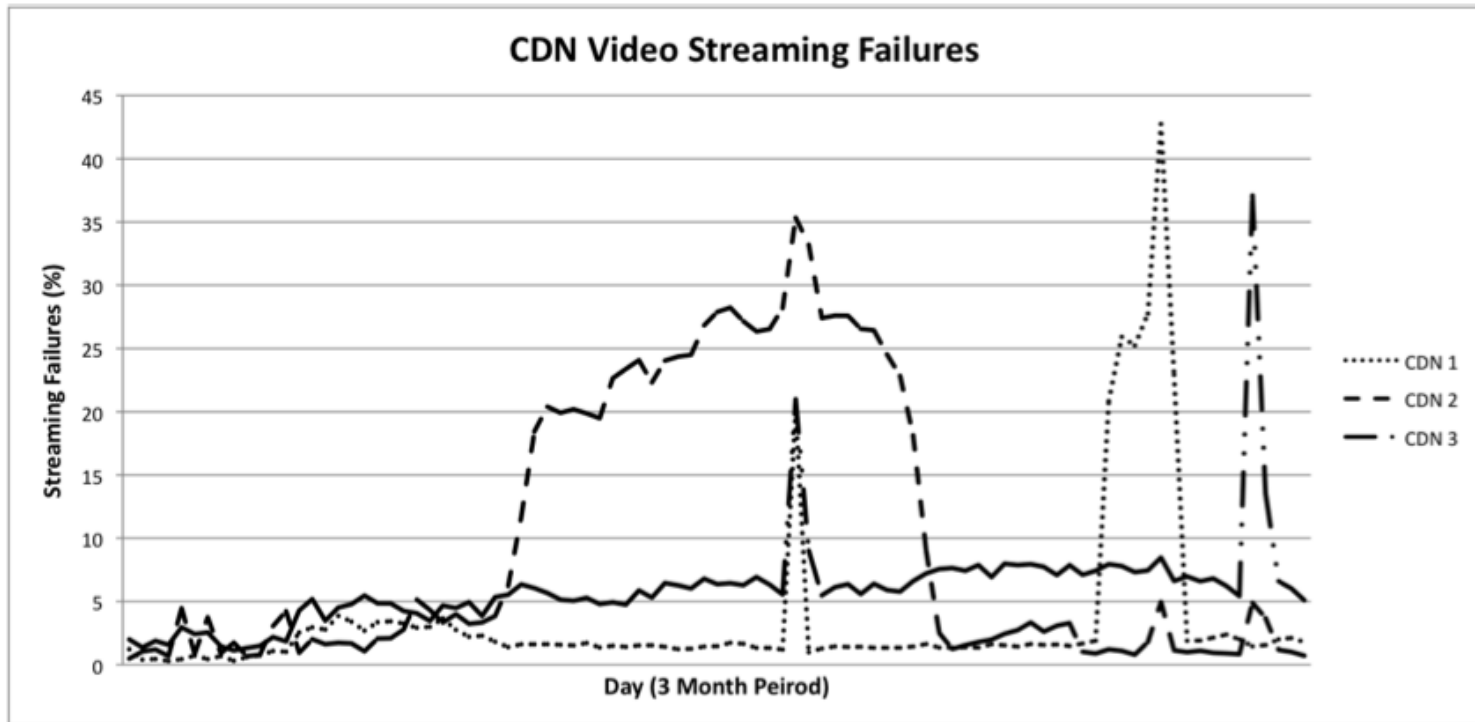# CDN Streaming Failures Are Common Events

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CDN Streaming Failures Are Common Events

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CDN Video Streaming Failures

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CDN Streaming Failures Are Common Events

- % of stream failures: % of streams that failed to start
- Three months dataset (May-July, 2011) for a premium customer using Flash

CDN Video Streaming Failures

CDN (relative) performance varies greatly over time

Opportunities for Improving Quality

Possible Actions to Improve Quality

- Switch the bitrate
  - ↓ Buffering, high frame drops, high start time, …
  - ↑ High available bandwidth, …
- Switch the CDN
  - ↔ Connection error, missing content, buffering on low bitrate, ...

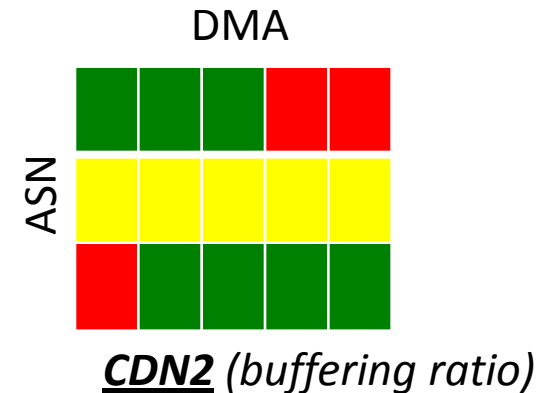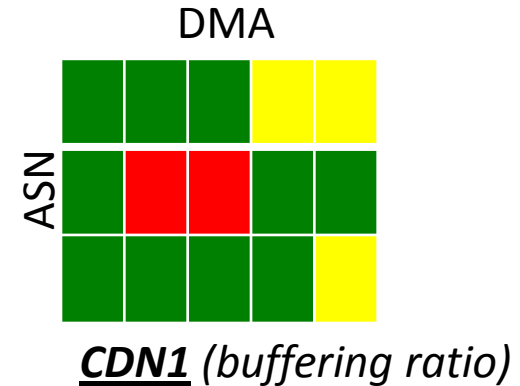- When to perform switching/selection?
  - Start time selection only
  - Start time selection & midstream switching

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Potential Improvement Example: CDN Switching Only

- For each CDN partition clients by (ASN, DMA)
  - DMA: Designated Market Area

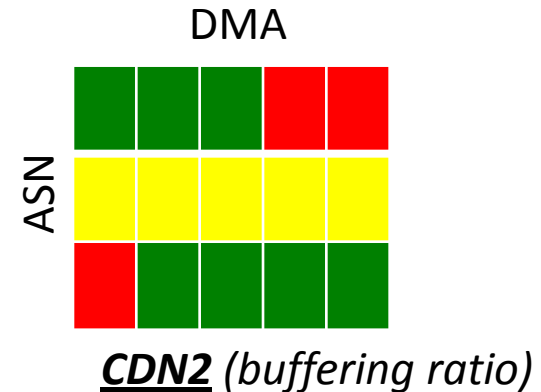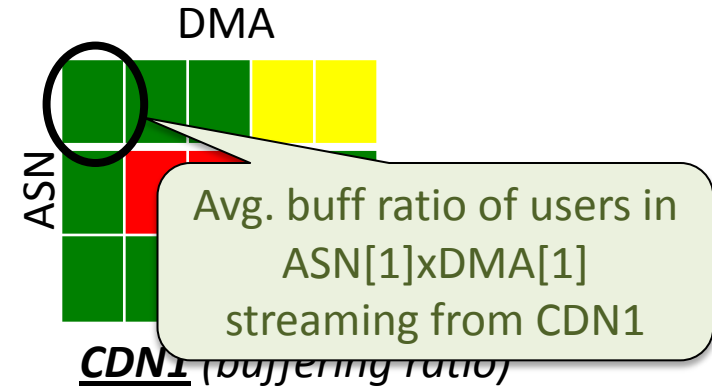# Potential Improvement Example: CDN Switching Only

- For each CDN partition clients by (ASN, DMA)
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- For each partition compute:
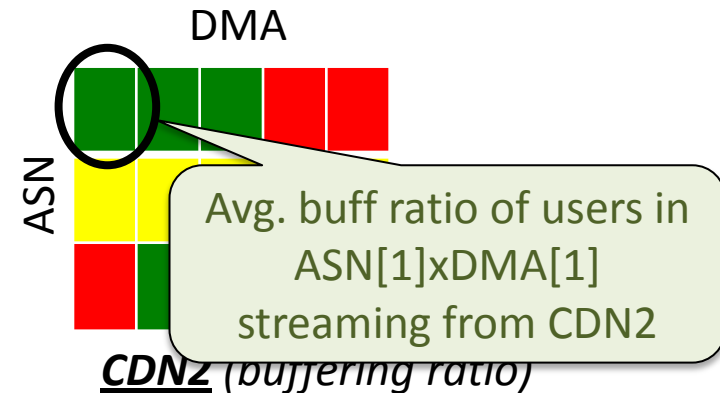 - Buffering ratio
  - Failure ratio
  - Start time
  - ….

DMA

ASN

CDN1 *(buffering ratio)*
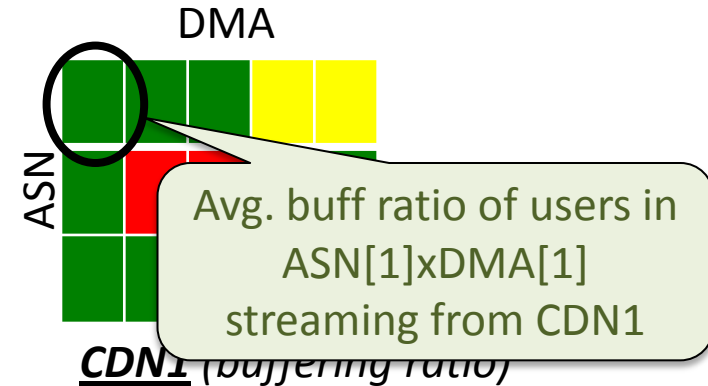
DMA

ASN

CDN2 *(buffering ratio)*

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Potential Improvement Example: CDN Switching Only

- ⟳ **For each CDN partition clients by (ASN, DMA)**
  - ⟳ DMA: Designated Market Area
- ⟳ **For each partition compute:**
  - ⟳ Buffering ratio
  - ⟳ Failure ratio
  - ⟳ Start time
  - ⟳ ….

DMA

ASN

Avg. buff ratio of users in ASN[1]xDMA[1] streaming from CDN1

***CDN1** (buffering ratio)*
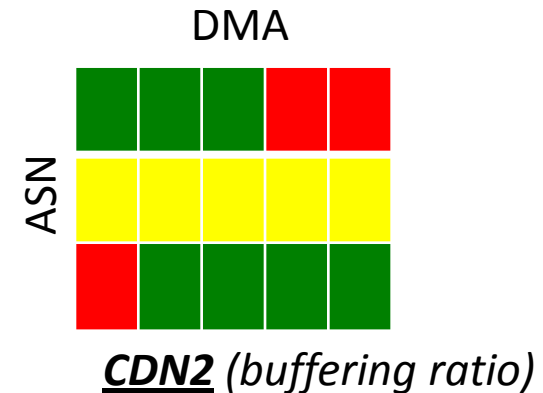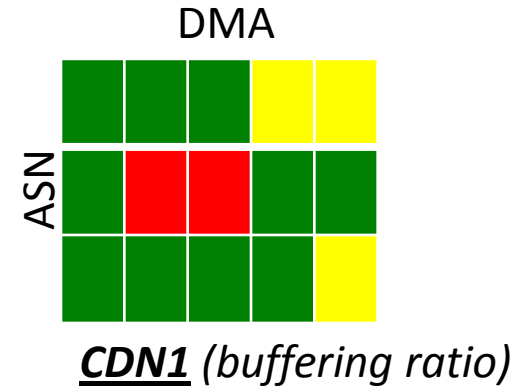
DMA

ASN

***CDN2** (buffering ratio)*

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Potential Improvement Example: CDN Switching Only

- For each CDN partition clients by (ASN, DMA)
  - DMA: Designated Market Area
- For each partition compute:
  - Buffering ratio
  - Failure ratio
  - Start time
  - ….

CDN1 (buffering ratio)

Avg. buff ratio of users in ASN[1]xDMA[1] streaming from CDN1

CDN2 (buffering ratio)

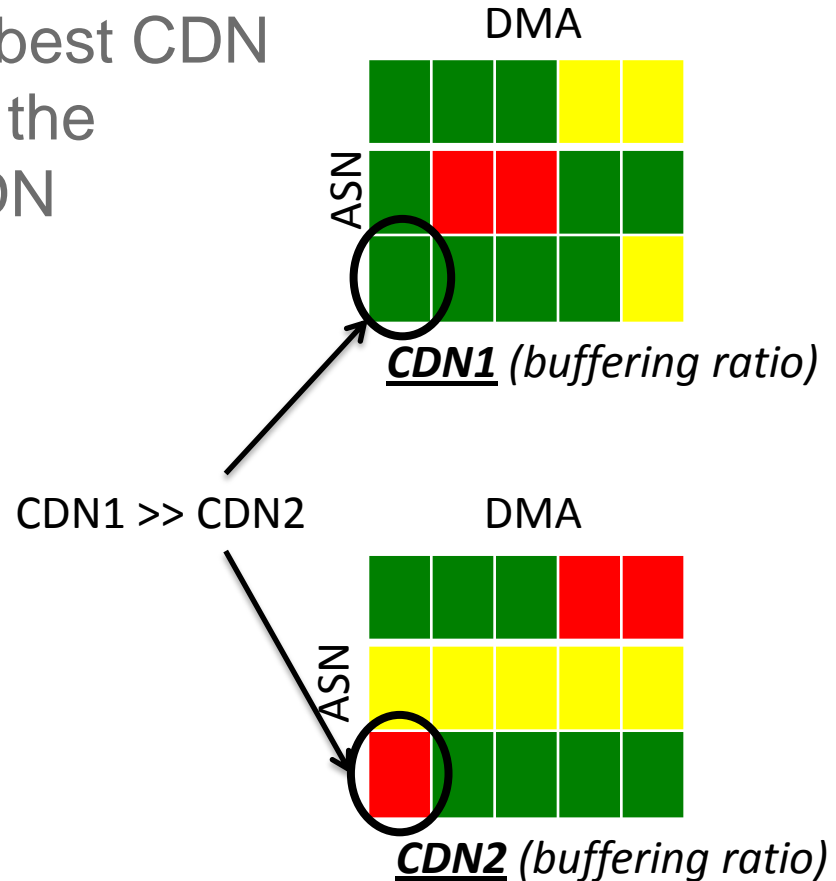Avg. buff ratio of users in ASN[1]xDMA[1] streaming from CDN2

Potential Improvement Example: CDN Switching Only

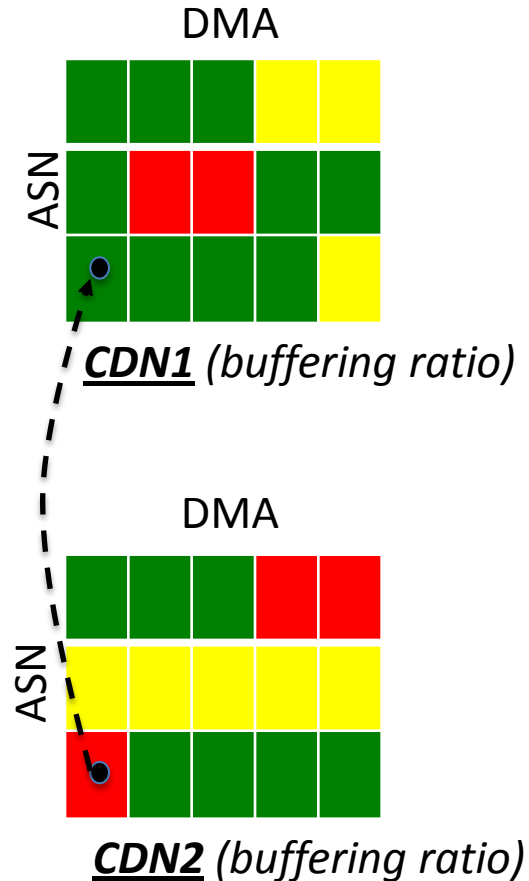⟳ For each partition select best CDN and assume all clients in the partition selected that CDN

DMA

CDN1 *(buffering ratio)*

DMA

CDN2 *(buffering ratio)*

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Potential Improvement Example: CDN Switching Only

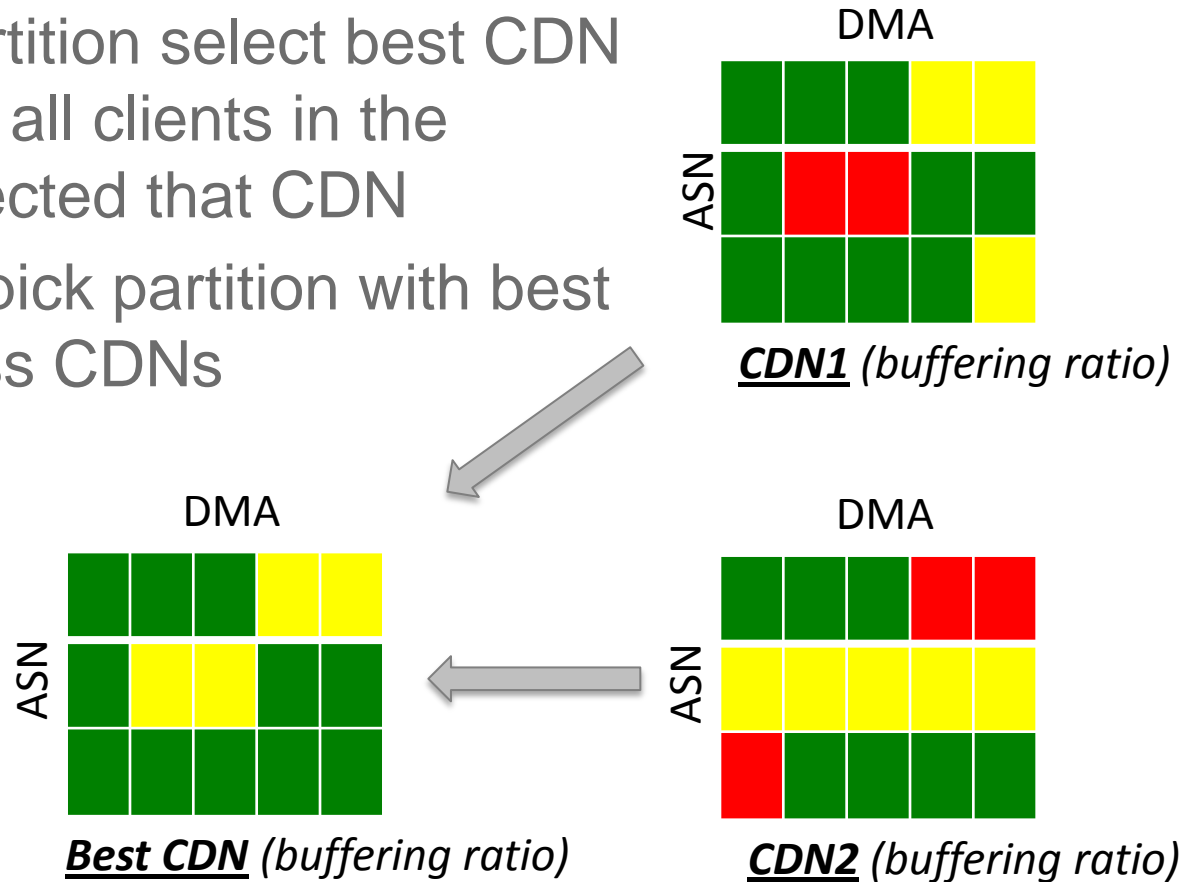⟳ For each partition select best CDN and assume all clients in the partition selected that CDN

DMA

ASN

CDN1 *(buffering ratio)*

CDN1 >> CDN2

DMA

ASN

CDN2 *(buffering ratio)*

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Potential Improvement Example: CDN Switching Only

⟳ For each partition select best CDN and assume all clients in the partition selected that CDN

CDN1 *(buffering ratio)*

CDN2 *(buffering ratio)*

Potential Improvement Example: CDN Switching Only

- For each partition select best CDN and assume all clients in the partition selected that CDN

- Essentially, pick partition with best quality across CDNs

DMA

CDN1 *(buffering ratio)*

DMA

Best CDN *(buffering ratio)*

DMA

CDN2 *(buffering ratio)*

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Potential Improvements

- Provider1: large UGV (User Generated Video) site
- Provider2: large premium VoD content provider
- Base-line: existing assignment of viewers (clients) to CDNs

Metric	Provider1 (UGV)			Provider2 (Premium)		
	Base line	Start-time Selection	Mid-stream Switching	Base line	Start-time Selection	Mid-stream Switching
Buffering ratio (%)	6.8	**2.5**	**1**	1	**0.3**	**0.1**

Between x2.7 and x10 improvement in buffering ratio
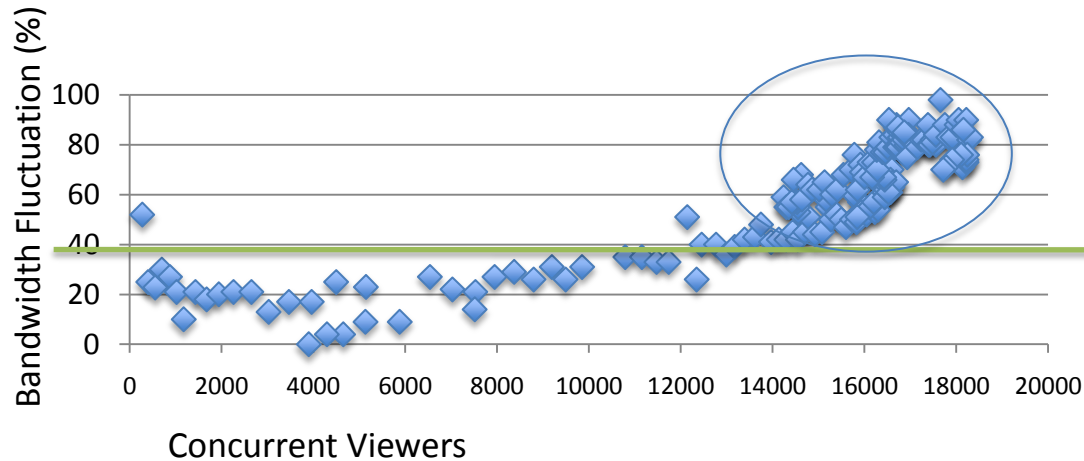
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Coordinated Control Plane for High Quality Video Delivery

Video Control Plane Architecture

⏻ Coordinator implementing a global optimization algorithm that dynamically select CDN & bitrate for each client based on

  ⏻ Individual client
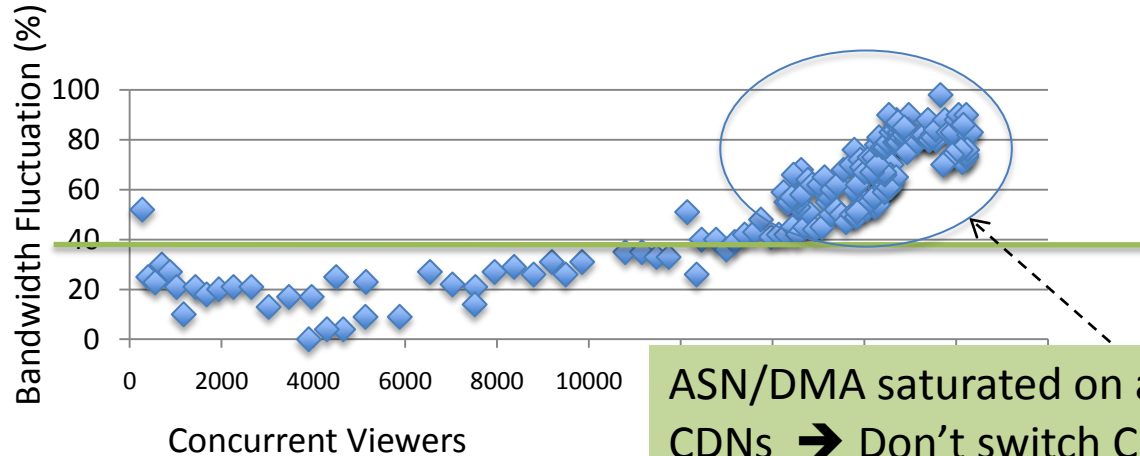
  ⏻ Aggregate statistics

  ⏻ Content owner policies

  ⏻ (CDN/ISP info)
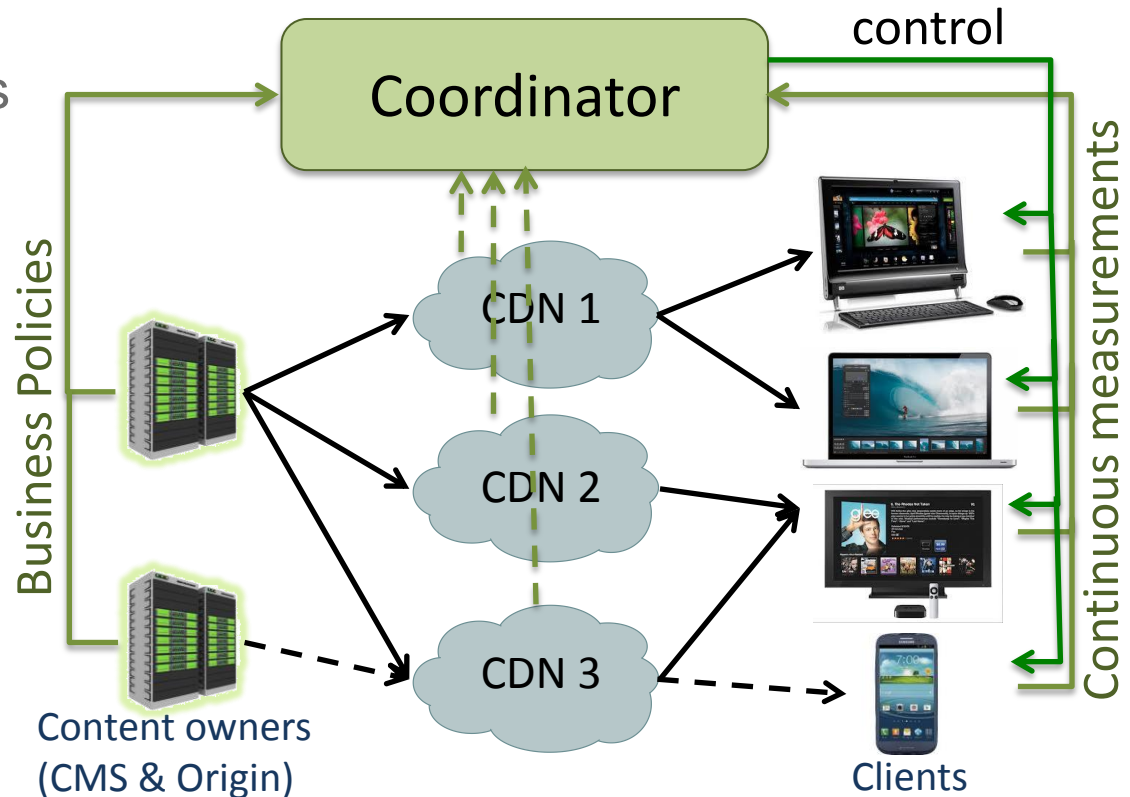
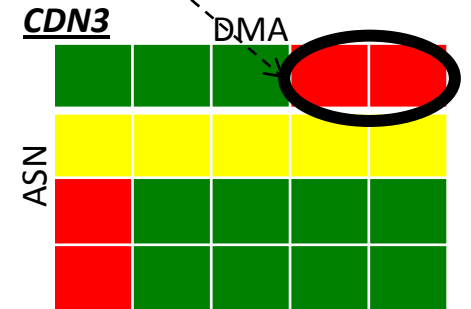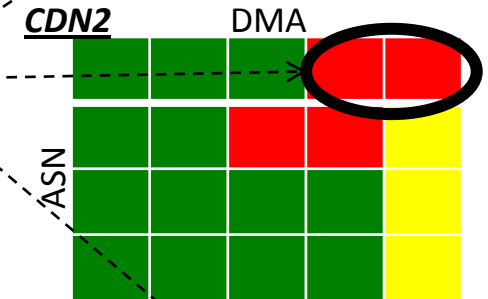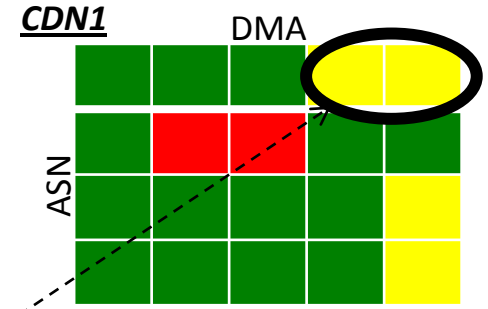# Example: Local vs. Global Optimization

Bandwidth fluctuation = (Max Bandwidth – Min Bandwidth)/(Average Bitrate)

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Example: Local vs. Global Optimization

ASN/DMA saturated on all CDNs ➜ Don't switch CDN; cap bitrates, instead
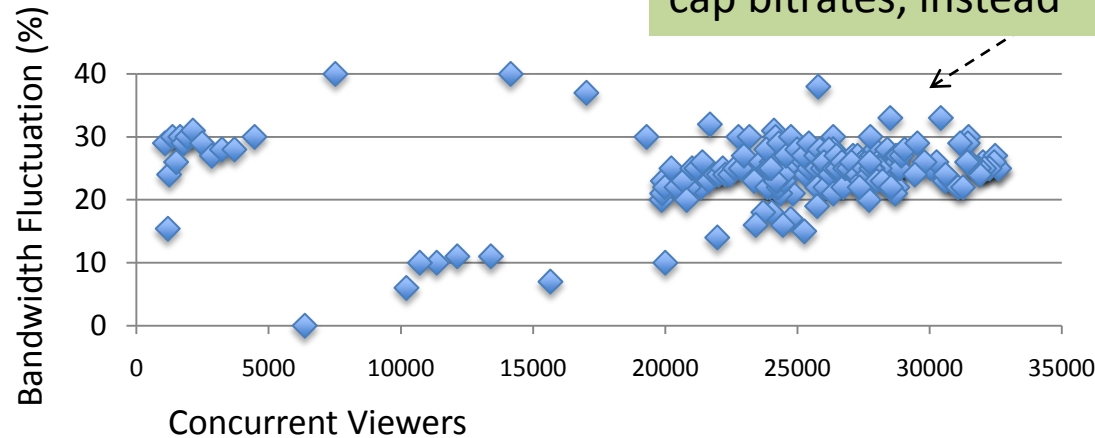
Concluding Remarks (I)

- Key transition of main-stream video to the Internet

- Video quality presents opportunity and challenge
    - Premium video on big screens → zero tolerance for poor quality

- Video player continuous monitoring and global optimization has best chance of delivering high quality video

- Many challenges remain, e.g.,
    - Scalability
    - How do multiple coordinators interact?
    - …

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Concluding Remarks (II)

- The video traffic dominance in the Internet is growing
  - Over 51% Internet traffic today, will be more than 86% in the next 4 years

- The Internet is becoming a Video Network

- Managing video delivery and maximizing video quality must be at the core of any future Internet architecture!

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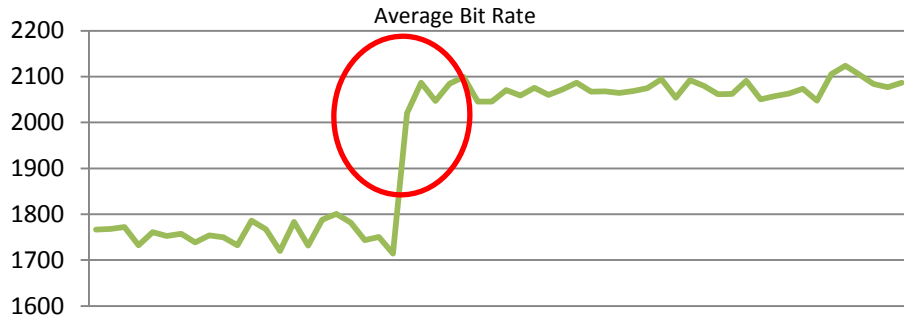Backup Slides

Conviva Optimization in the Wild

Reduced views impacted by buffering from 16.13% to 5.56% …

Views Impacted by Buffering
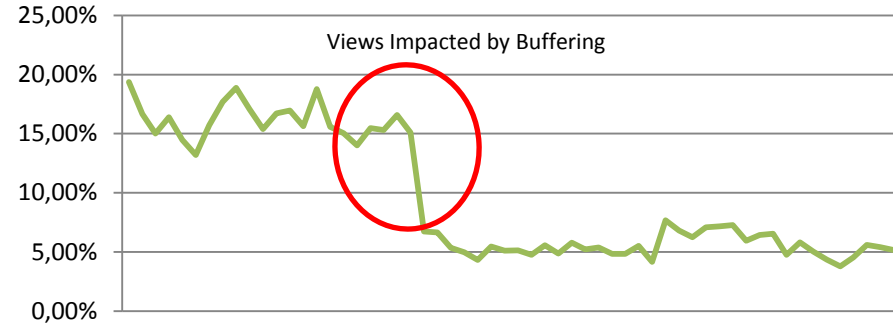
Average Bit Rate

… increased average bit-rate from 1.7 Mbps to 2.1 Mbps…

… and raised engagement by 36%

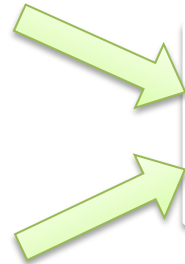|	Dates	02/14 - 02/21	02/28 - 03/07	Improvement
	Views	41,652	49,607	19%
	Uniques	9,930	11,449	15%
Audience	Viewed Minutes	855,002	1,160,667	36%
	Minutes per View	20.5	23.4	14%
	Minutes per Unique	86.1	101.4	18%

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Possible Coordinator Architecture

Continuous real-time measurements from every client
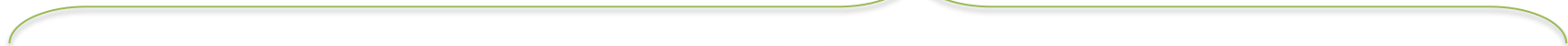
| Real-time Global Data Aggregation and Correlation |

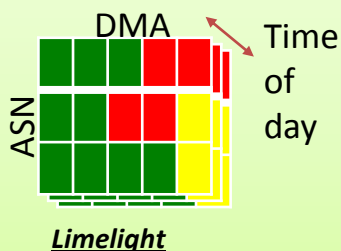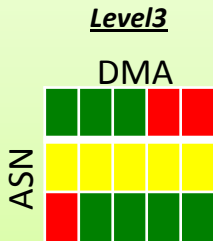| Historical Data Aggregation and Analysis |

| Global Inference, Decision & Policy Engine |

| Real-time global optimizations |

Localize issues by region, network, CDN, and time

| Inference Engine | → | Decision Engine |

DMA

ASN

Akamai

Level3

DMA

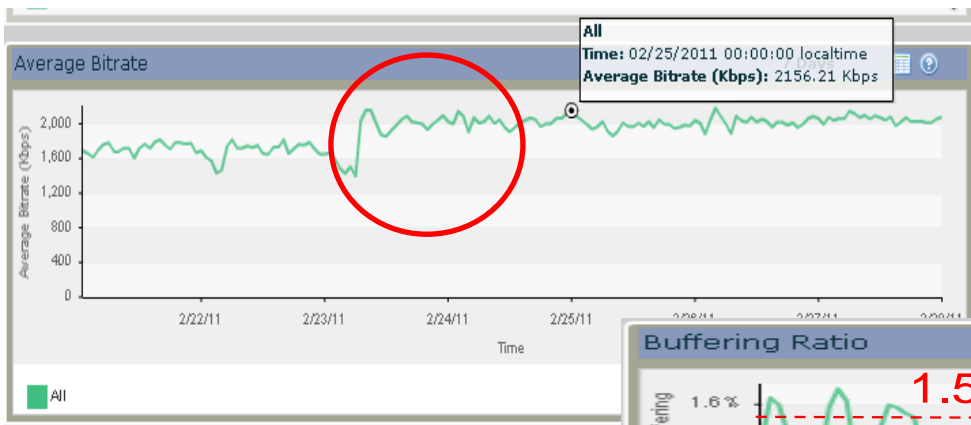ASN

DMA

ASN

Time of day

*Limelight*
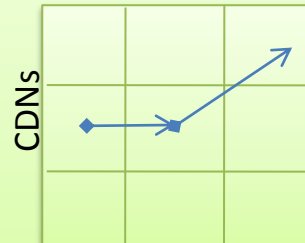
Bit Rates

CDNs

Optimize viewer performance by selecting the best option within the set of bit rates and CDNs

Conviva Services Enhance the Viewer Experience and Lift Engagement by Lifting Bit Rate and Reducing Buffering

All
Time: 02/25/2011 00:00:00 localtime
Average Bitrate (Kbps): 2156.21 Kbps

Increased average bit-rate from 1.6 Mbps to 2.1 Mbps ...

... reduced buffering ratio from 1.5% to 0.5%

1.5%

1.0%

0.5%

DMS LAUNCH

EMS LAUNCH
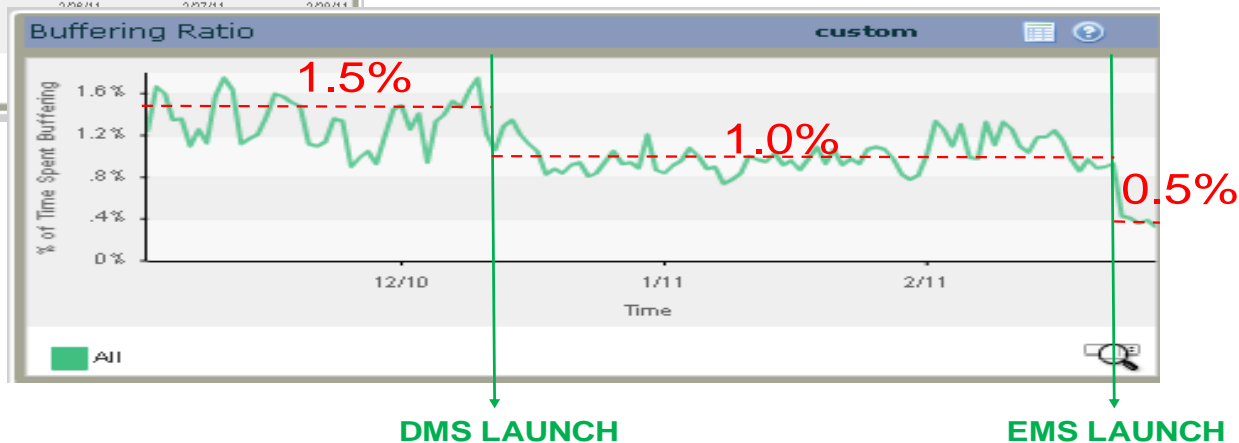
... and raised engagement by 36%

|	Dates	02/14 - 02/21	02/28 - 03/07	Improvement
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	Minutes per View	20.5	23.4	14%
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Potential Improvements

- Customer1: large UGV site
- Customer2: large premium content provider
- Note: * denotes improvements when using mid-stream switching

| Metric	Customer1		Customer2	
	Current	**Projected**	**Current**	**Projected**
Buffering ratio (%)	6.8	**2.5 / 1***	1	**0.3 / 0.1***
Start time (s)	6.41	**2.91**	1.36	**0.9**
Failure ratio (%)	16.57	**2.4**	1.1	**0.7**

Between x2.7 and x10 improvement in buffering ratio

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Video Quality Matters [Sigcomm'11]

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  - Need to ensure uninterrupted streaming at high bitrates
- Buffering ratio is most critical across genres
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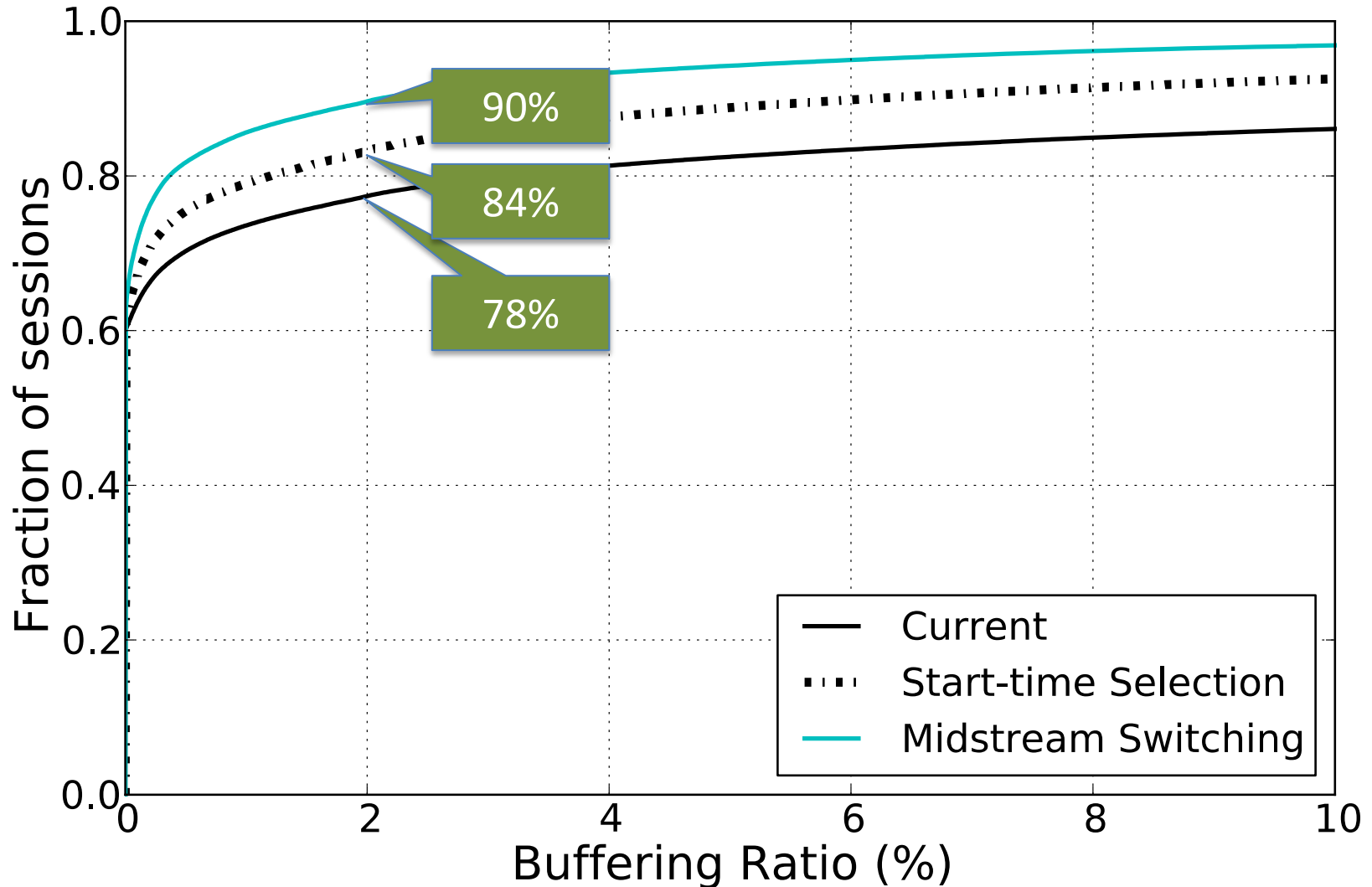 - **1% increase in buffering leads to more than 60% loss in audience**
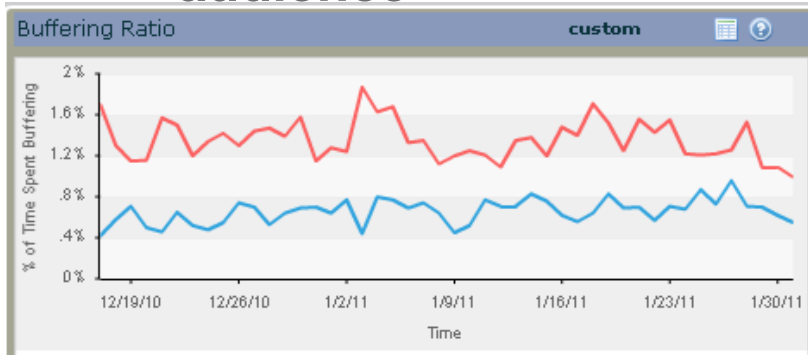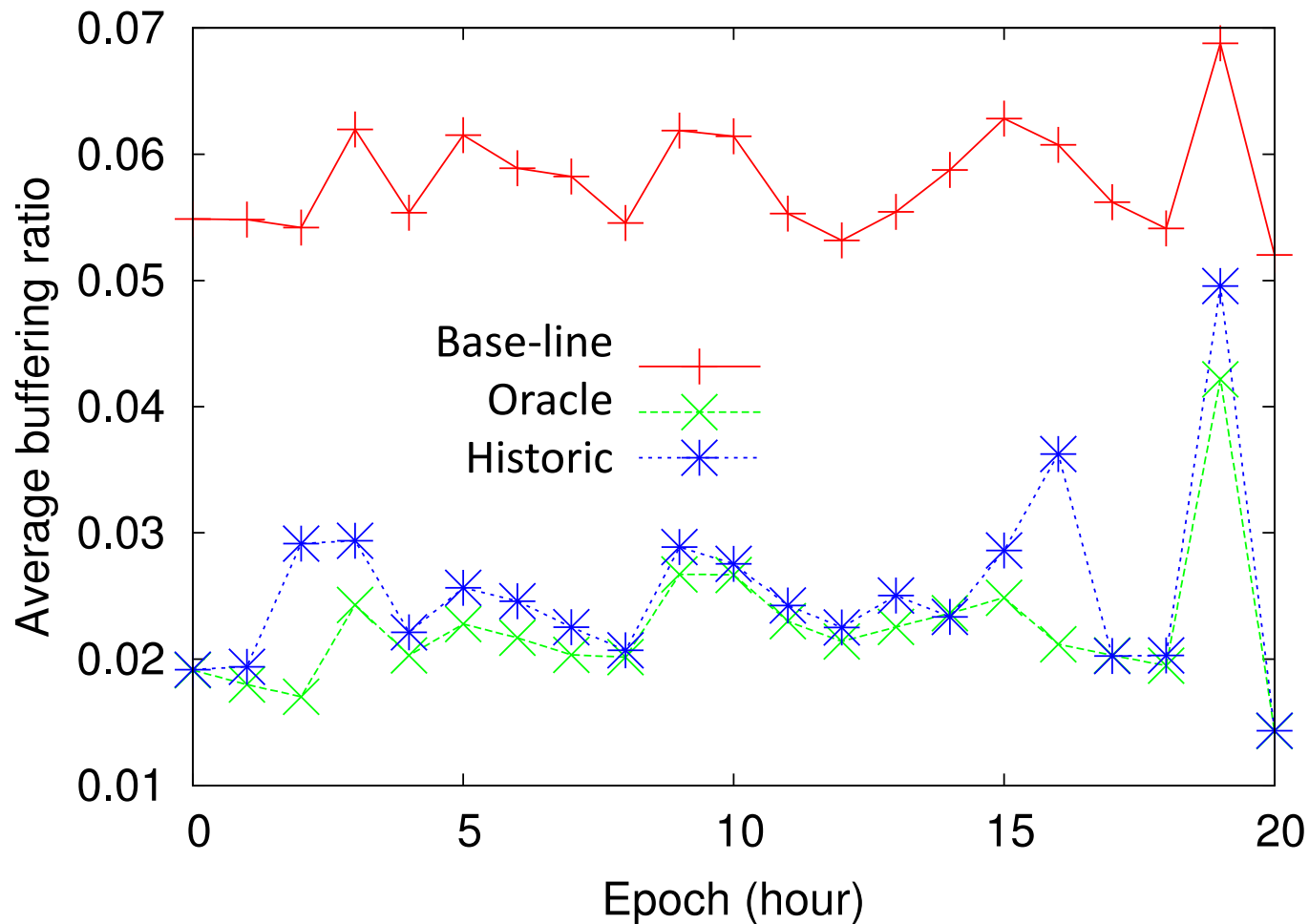

**1% difference in buffering
between two ISPs**
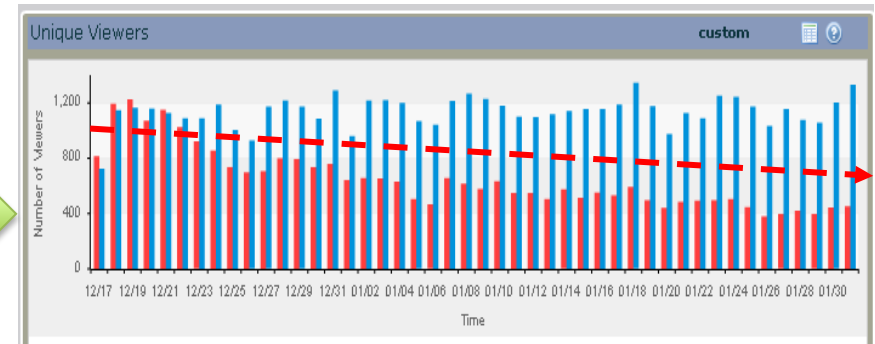
**68% monthly loss in uniques for ISP
with poor performance**

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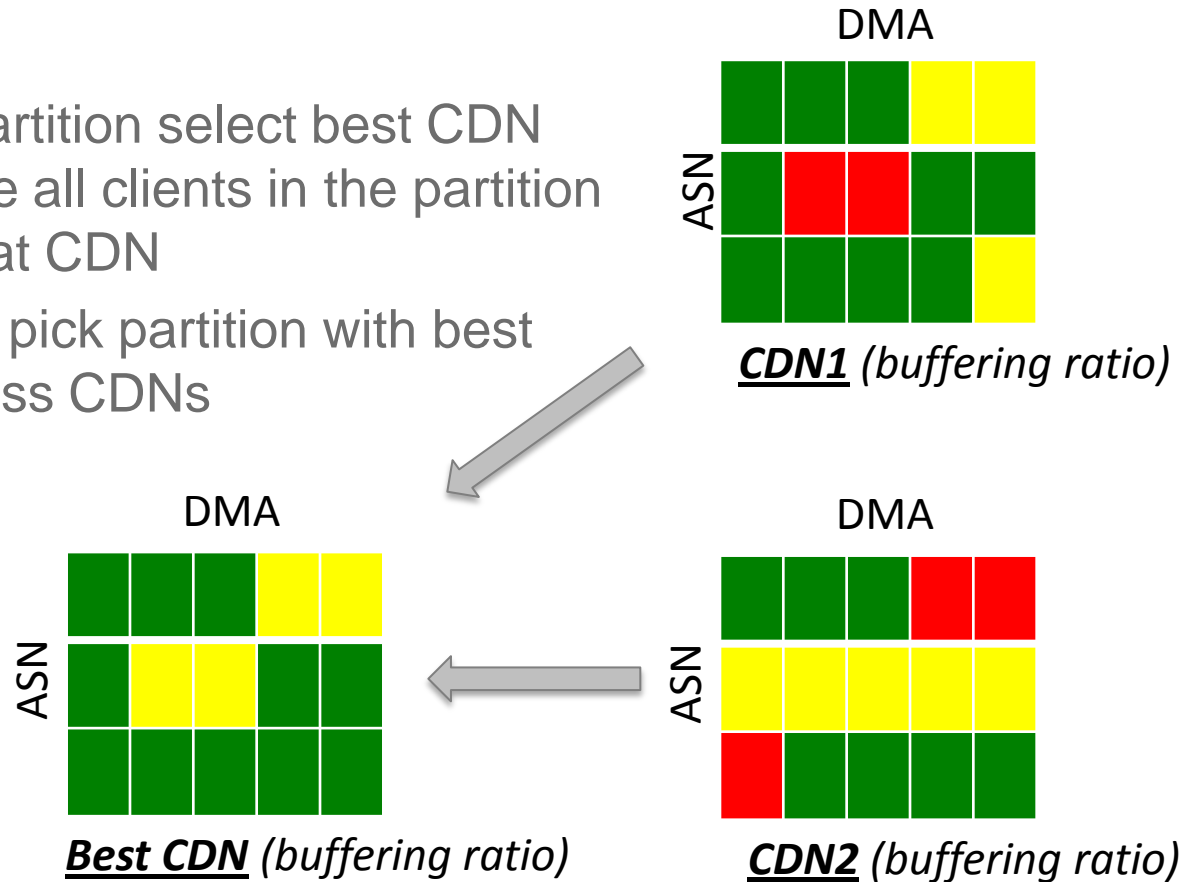# Customer1: Start-time vs. Midstream CDN Switching

Provider1: Oracle vs. Historical

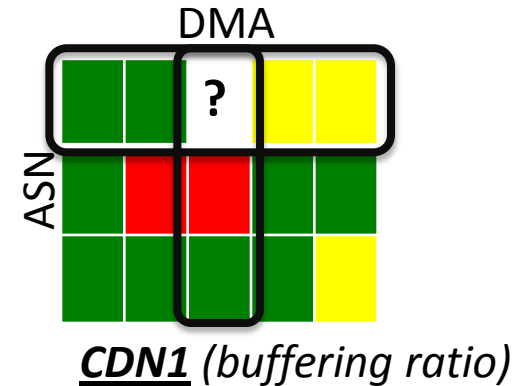# Potential Improvement Example: CDN Switching Only

- Oracle:
  - For each partition select best CDN and assume all clients in the partition selected that CDN
  - Essentially, pick partition with best quality across CDNs

DMA

ASN

CDN1 *(buffering ratio)*

DMA

ASN

CDN2 *(buffering ratio)*

DMA

ASN

Best CDN *(buffering ratio)*

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Potential Improvement Example: CDN Switching Only

- Details
  - If a partition has not enough clients use a larger partition
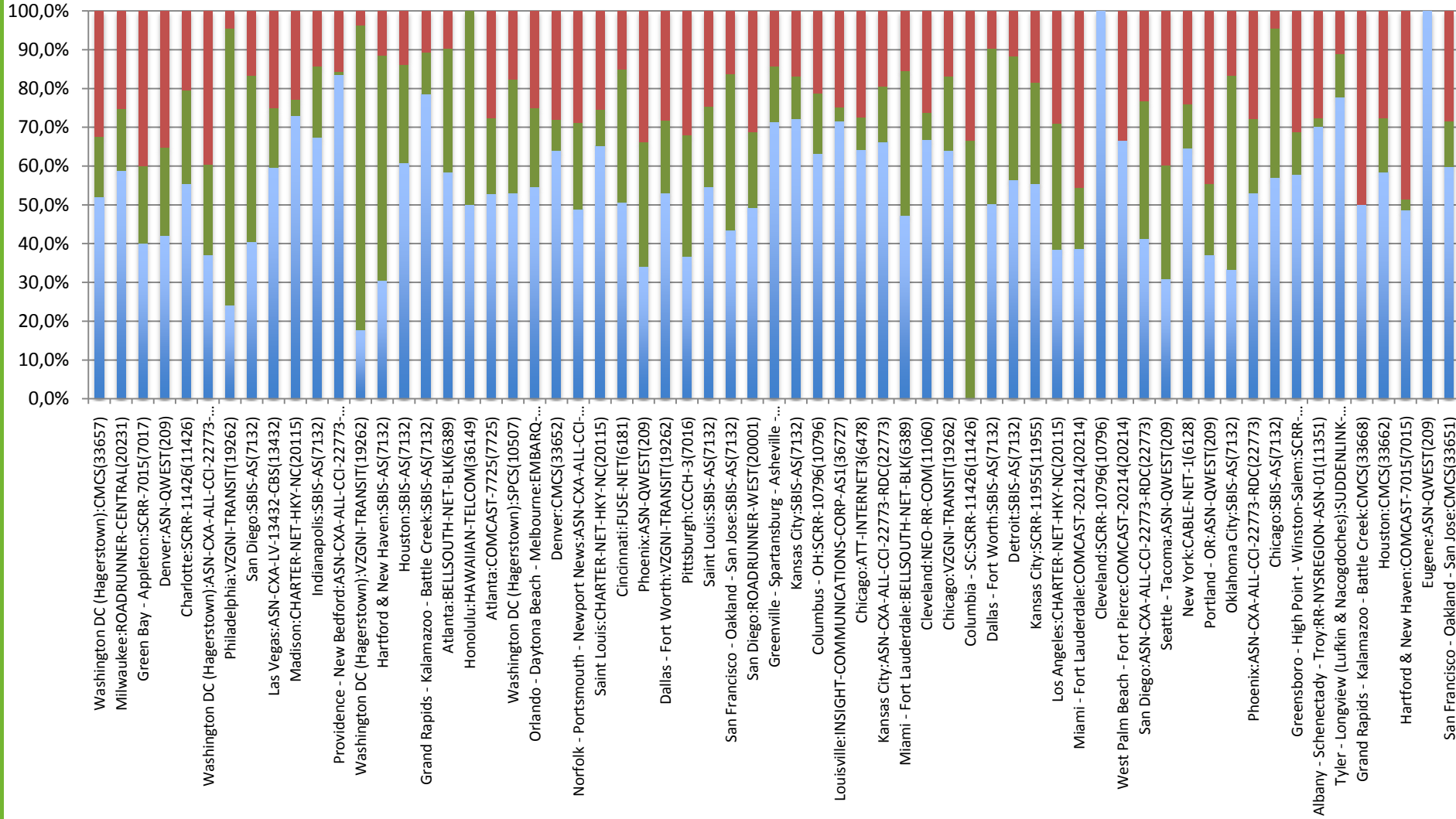

DMA

ASN

CDN1 *(buffering ratio)*

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Potential Improvement Example: CDN Switching Only

- Details
  - If a partition has not enough clients use a larger partition
  - Use quality metric distribution to predict quality of a client on new CDN
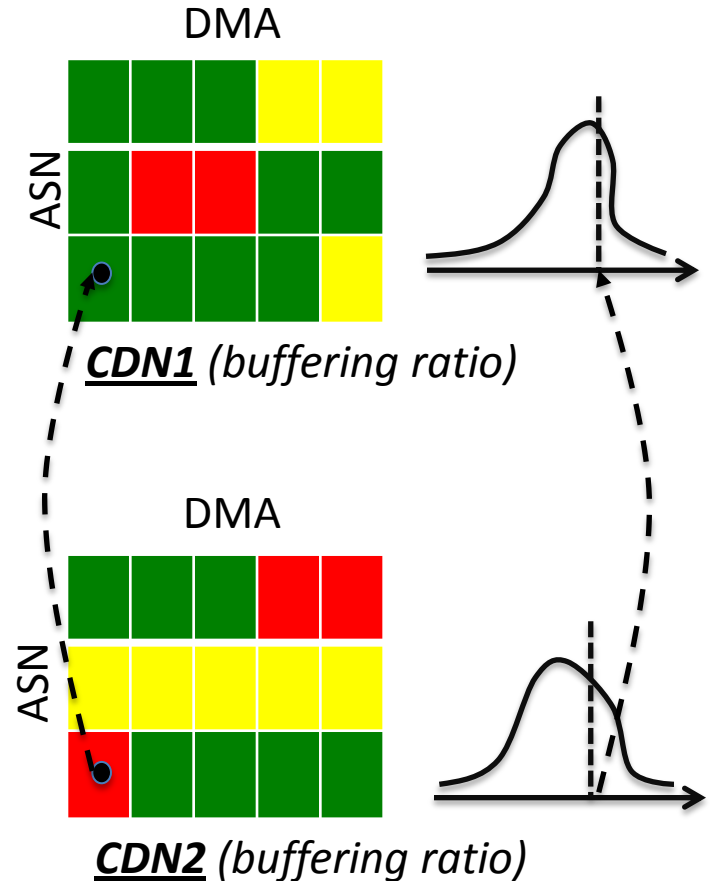
DMA

ASN

CDN1 *(buffering ratio)*

DMA

ASN

CDN2 *(buffering ratio)*

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CDNs Vary in Performance over Geographies and Time

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Potential Improvement Example: CDN Switching Only

- ⟳ Oracle:
  - ⟳ For each partition select best CDN and assume all clients in the partition selected that CDN

- ⟳ Historical:
  - ⟳ For each partition select best CDN in previous epoch, and assign clients to that CDN in next epoch

DMA

ASN

***CDN1** (buffering ratio)*

DMA

ASN

***CDN2** (buffering ratio)*

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