Background: Conviva

- Co-founded with Hui Zhang (CMU) in fall, 2006
- Conviva optimizes video quality for premium content properties
  - E.g., HBO, ESPN, ABC, Disney, and Turner
- Conviva's powered some of the world's largest on-line events
  - E.g., Olympics, FIFA World Cup, NCAA College Basketball March Madness, Major League Baseball, and Academy Awards.
Internet Video Ecosystem: Video Data-plane

Key components: Video Player & CDN

Video Source

Encoders & Video Servers

CMS and Hosting

Content Delivery Networks (CDN)

ISP & Home Net

Video Player
Trends
Trend: CDN Pricing

- CDN pricing has decreased x1.5-2 every year for the last 6 years
Trend: Bitrate for Premium Content

- Average bitrate has increased 20-40% every year
Per-hour streaming cost has decreased 15-30% every year.
HTTP Chunking

- Trends fueled by switching from proprietary streaming technologies (e.g., Adobe’s FMS) to HTTP chunking
  - Move Networks (2005)
  - Apple (2008)
  - Microsoft (2009)
  - Adobe (2011)
How does HTTP Chunking Work?
Why HTTP Chunking?

- **Scale**: more HTTP caches/servers than streaming servers

- **Cost**: HTTP servers cheaper than proprietary streaming protocol

- **Reachability**: HTTP traffic penetrates enterprises firewalls easier than proprietary streaming protocols

- **High bitrate**: can use multiple TCP connections to download subsequent chunks in parallel
What Does this Mean?

- Ad supported premium content
  - CPM (cost per thousand of ad impressions): $20-$40
  - One ad covers one hour of streaming!

- Paid content
  - $0.99 episode, distribution cost < 2%

- Subscription based premium content
  - It costs less than $1/month to stream content to an user watching 2 hour per day

- Production & rights dominate!
Quality Matters
We’ve seen patterns across many sites ... and billions of streams
Video Player Monitoring: Player Model

Player States

- **Joining**
  - Time

- **Playing**
  - Video buffer filled up
  - Video buffer empty

- **Buffering**
  - Buffer replenished sufficiently

Events

- Network/stream connection established
- Video download rate, Available bandwidth, Dropped frames, Frame rendering rate, etc.

Player Monitoring

- **JoinTime (JT)**
- **BufferingRatio (BR)**
- **RateOfBuffering (RB)**
- **AvgBitrate (AB)**
- **RenderingQuality (RQ)**

User action

Stopped/Exit
Video Player Monitoring: Data Collection

- Automatic and consistent monitoring of default streaming modules
  - Flash: NetStream, VideoElement
  - Silverlight: MediaElement, SmoothStreamingMediaElement
  - iOS: MPMoviePlayerController

![Diagram of Video Player Monitoring](conviva.png)
Empirical Study [Sigcomm’11]

- Goal: impact of quality on engagement (play time)
- A week of data from multiple premium video sites
- There genres: Live, Long VoD (LVoD), Short VoD
- Five quality metrics:
  - Buffering Ratio (BR)
  - Rate of Buffering (RB)
  - Join/Start Time (JT)
  - Rendering Quality (RQ)
  - Average Bit rate (AR)
- Two granularities: view/viewers
Highlight of Results [Sigcomm'11]

- Quality has substantial impact on engagement

- Buffering ratio is most critical across genres
  - Highest impact for live: 1% of buffering reduced play time by 3min

- Bitrate more important for live than VoD

- Join time impact engagement at viewer level but less at view level
Buffering ratio correlates with engagement the most
LVoD vs. Live [Sigcomm’11]

Buffering Ratio remains most significant, but Bitrate and Rate of Buffering bigger impact
Engagement vs. Buffering Ratio [Sigcomm’11]

Correlation coefficient (kendall): −0.96, slope: −3.25

1% increase in buffering reduces engagement by 3 min
Engagement vs. Join Time: Viewer Level [Sigcomm’11]

Join time critical for user retention

Correlation coefficient (kendall): -0.74
What about Rendering Quality? [Sigcomm’11]

Why doesn’t play time correlate with rendering quality for Live?
Example Video Site Quality Summary

- 31.68% of views had quality issues
- 32.2% of viewers had recurring quality issues
- Viewers with good quality watched 1.5X more video than viewers with poor quality
- Good video quality for all viewers can add 10.9% more minutes of viewed video
- Good video quality can add $120K more revenue per month*

* Assumes $30 CPM ad every 8 minutes

Total Views = 66,447,919
Total Viewers = 3,291,204
Total Minutes Viewed = 290,260,395
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Viewers Return More When Video Is Not Interrupted by Buffering

1% difference in buffering between two ISPs

68% monthly loss in uniques for ISP with poor performance

1% increase in buffering leads to more than 60% loss in audience
CDN Performance Varies Widely
CDNs Vary in Performance over Geographies and Time

- Used one month aggregated data-set
- Considered 31,744 DMA-ASN-hours with > 100 views in each CDN

There is no single best CDN across geographies, network, and time
CDNs Vary in Performance over Geographies and Time.
CDN Streaming Failures Are Common Events
Opportunities for Improving Quality
Refresh: What is high quality?

- Prevent startup failures
- Start the video quickly
- Play the video smoothly and without interruptions
- Play the video at the highest bit rate possible
Possible Actions to Improve Quality

- **Switch bitrate**
  - \(\downarrow\) Buffering, high frame drops, high start time, ...
  - \(\uparrow\) High available bandwidth, ...

- **Switch CDN**
  - \(\leftrightarrow\) Connection error, missing content, buffering on low bitrate, ...

- **Typically two categories of actions**
  - \(\circ\) Start time selection
  - \(\circ\) Midstream switching
Potential Improvement Example: CDN Switching Only

- Partition clients by (ASN, DMA, CDN)
  - DMA: Designated Market Area
Partition clients by (ASN, DMA, CDN)
  - DMA: Designated Market Area

For each partition compute:
  - Buffering ratio
  - Start time
  - Failure ratio
  - ....
Potential Improvement Example: CDN Switching Only

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

Diagram:
- Akamai (buffering ratio)
- Level3 (buffering ratio)
Potential Improvement Example: CDN Switching Only

Oracle:
- For each partition select best CDN and assume all clients in same partition selected that CDN
- Essentially, pick partition with best quality across CDNs
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Historical:
- For each partition select best CDN in previous epoch, and assign clients to that CDN in next epoch
Potential Improvement Example: CDN Switching Only

Details

- If a partition has not enough clients, use a larger partition.
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.
Potential Improvements: Oracle

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

<table>
<thead>
<tr>
<th>Metric</th>
<th>Customer1</th>
<th></th>
<th>Customer2</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Current</td>
<td>Projected</td>
<td>Current</td>
<td>Projected</td>
</tr>
<tr>
<td>Buffering ratio (%)</td>
<td>6.8</td>
<td>2.5 / 1*</td>
<td>1</td>
<td>0.3 / 0.1*</td>
</tr>
<tr>
<td>Start time (s)</td>
<td>6.41</td>
<td>2.91</td>
<td>1.36</td>
<td>0.9</td>
</tr>
<tr>
<td>Failure ratio (%)</td>
<td>16.57</td>
<td>2.4</td>
<td>1.1</td>
<td>0.7</td>
</tr>
</tbody>
</table>

Between x2.7 and x10 improvement in buffering ratio
Customer1: Start-time vs. Midstream CDN Switching

![Graph showing the comparison of Fraction of sessions against Buffering Ratio (%) for different CDN switching methods, with 90%, 84%, and 78% as key values.]
Customer1: Oracle vs. Historical

![Graph showing Average buffering ratio vs. Epoch (hour) for Current, Oracle, and Use previous epoch.

- **Current**: Red line with stars
- **Oracle**: Green line with crosses
- **Use previous epoch**: Blue line with dotted stars and blue crosses

The graph demonstrates the comparison between the buffering ratios from different sources over time.
A Possible Architecture for Delivering High Quality Video Over the Internet
Three Concepts for High Quality Video Delivery

- Continuous measurement and optimization
- Multi-bit rate streams delivered using multiple CDNs
- Optimization algorithms based on
  - individual client, and
  - aggregate statistics
  at multiple time scales
Possible Optimization Architecture

Continuous real-time measurements from every client

Real-time Global Data Aggregation and Correlation (Streaming Map-reduce)

Historical Data Aggregation and Analysis (Hadoop+Hive+Spark)

Real-time Alerts

Real-time and historical Insights

Global Inference, Decision & Policy Engine

Real-time global optimizations

Localize issues by region, network, CDN, and time

Inference Engine

Decision Engine

Optimize viewer performance by selecting the best option within the set of bit rates and CDNs
Example: Local vs. Global Optimization

Bandwidth fluctuation = (Max Bandwidth – Min Bandwidth)/(Average Bitrate)
Example: Local vs. Global Optimization

ASN/DMA saturated on all CDNs ➔ Don’t switch CDN; reduce bitrates, instead
Reduced views impacted by buffering from 16.13% to 5.56% ...

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

... and raised engagement by 36%
Concluding Remarks

- We are in the middle of a key transition of main-stream video to the Internet

- Video quality presents opportunity and challenge
  - Follow the traffic: 60% Internet traffic today, will be more than 95% in the next 2-3 years
  - Premium video on big screens → zero tolerance for poor quality

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