Xatu: Richer Neural Network Based Prediction for Video Streaming

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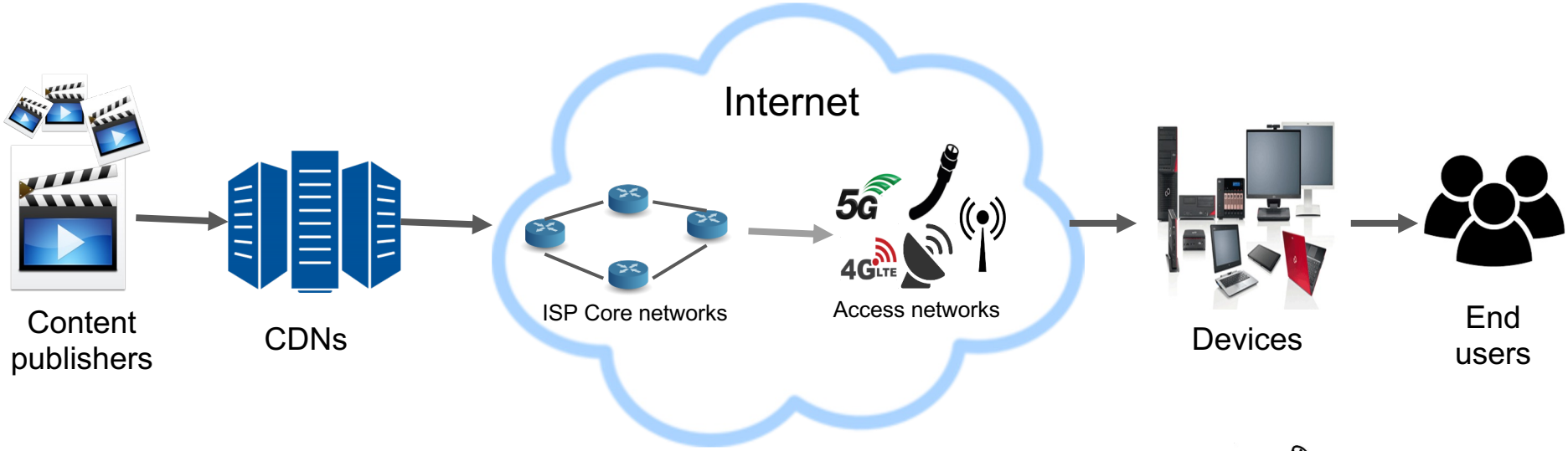
[1]Purdue University, [2]Conviva, *Google

This work was done when Yun Seong Nam was at Purdue University.

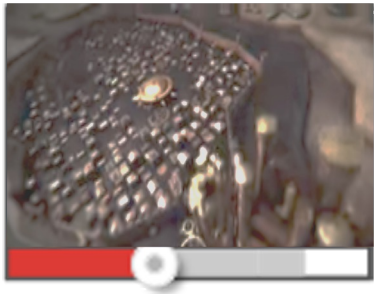
Internet video delivery ecosystem



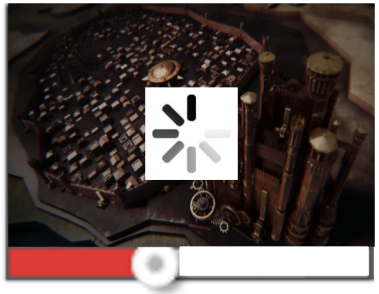
- Internet video is delivered over:
  - Heterogeneous networks: WiFi, wired, 3G/4G LTE
  - Highly varying or challenging network conditions

Internet video streaming today

- Quality of experience(QoE) issues are common place.
- Many factors constitute QoE
  - Avoiding rebuffering
  - Ensuring as high a quality as possible



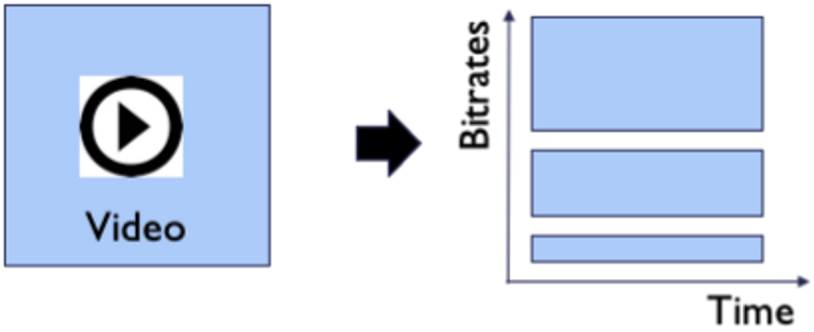
Low quality



Rebuffering

Low QoE adversely impacts user engagement and revenue

Background: Adaptive Bitrate Streaming



A video clip is encoded
with multiple qualities (bitrates)

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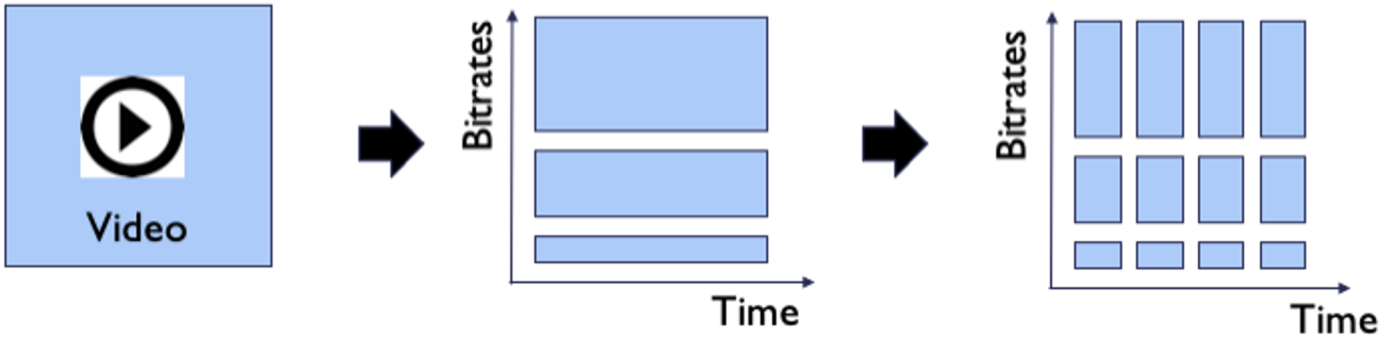

Video encoded at each bitrate is split into chunks

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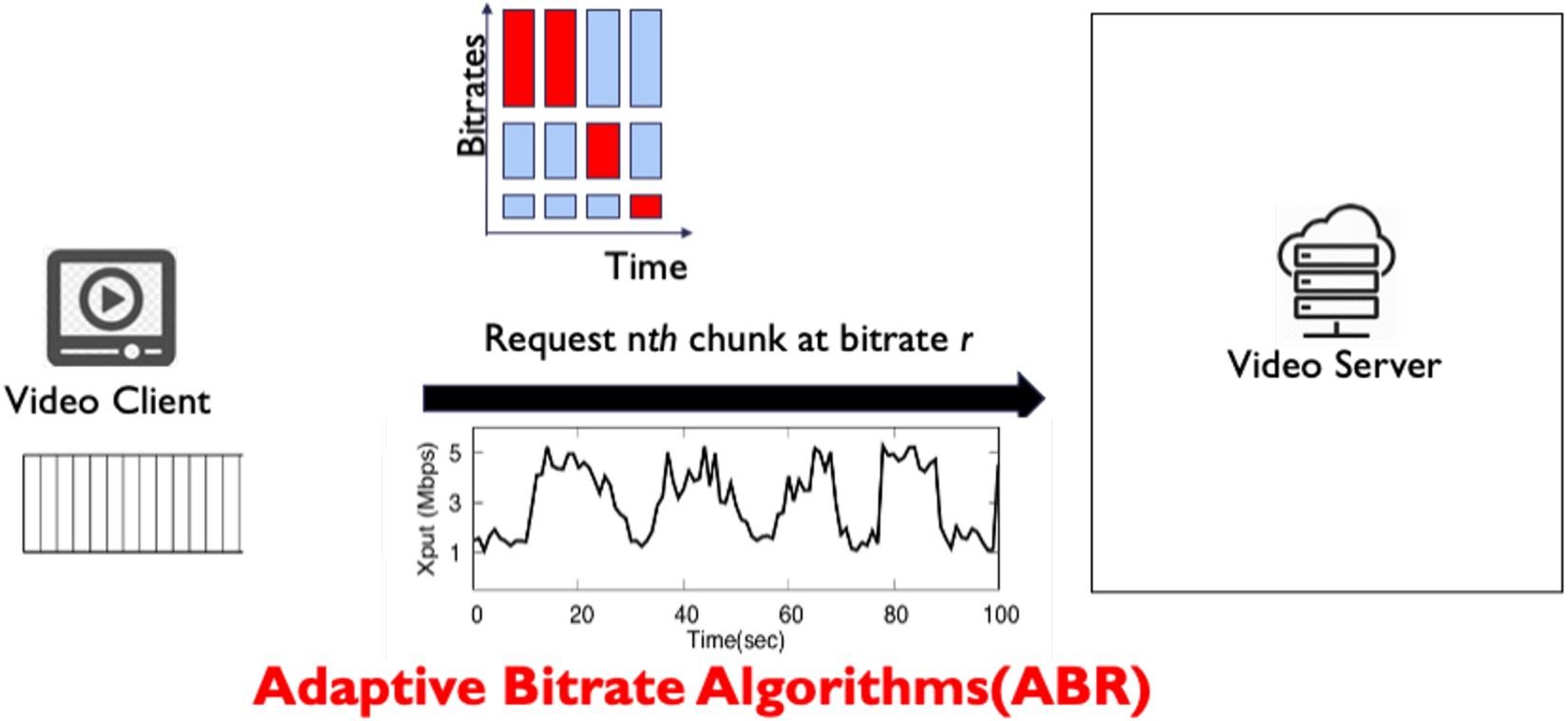

Adaptive Bitrate Algorithms(ABR)

ABRs critically rely on predictions

Bitrate Decision

4 sec of chunks in the player buffer

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4 sec of chunks in the player buffer

Predicting chunk download time

2.1 sec — **Low quality!**

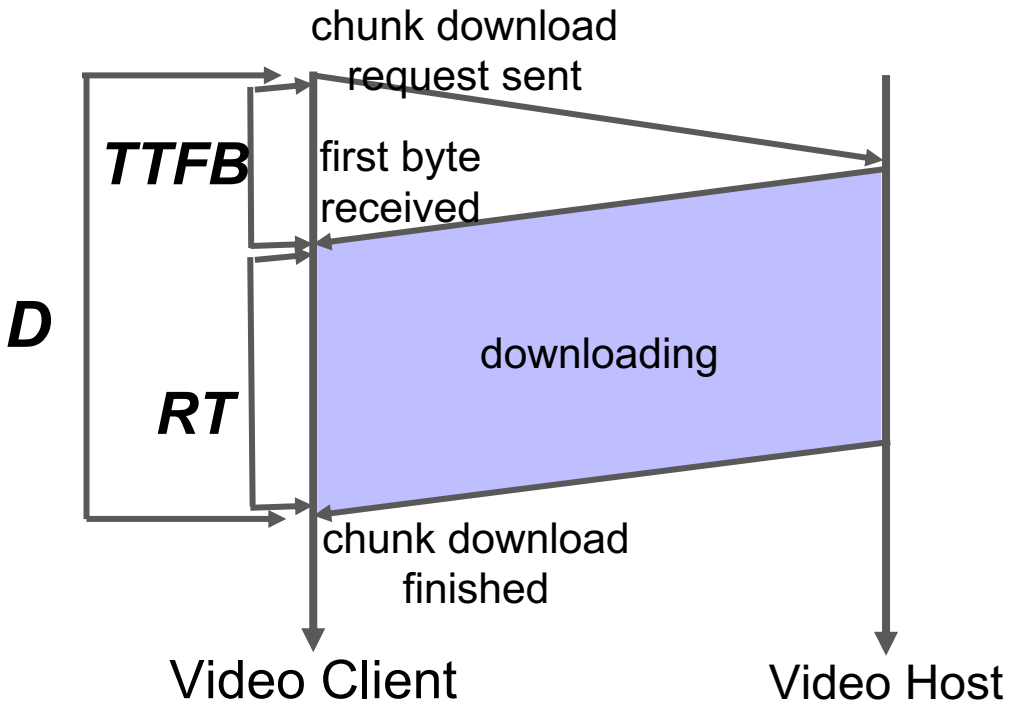
3.5 sec

5.3 sec — **Rebuffering!**

Contributions

- Expose limitations of existing approaches to predicting chunk download times.
  - Based on insights from video sessions of real users.
- Xatu, novel prediction approach based on a customised neural network.
- Evaluations showing Xatu's promise:
  - 24% reduction in prediction error relative to state of the art. (CS2P, SIGCOMM 2016)
  - Integration with multiple ABRs with substantial performance improvement.

Existing prediction approaches



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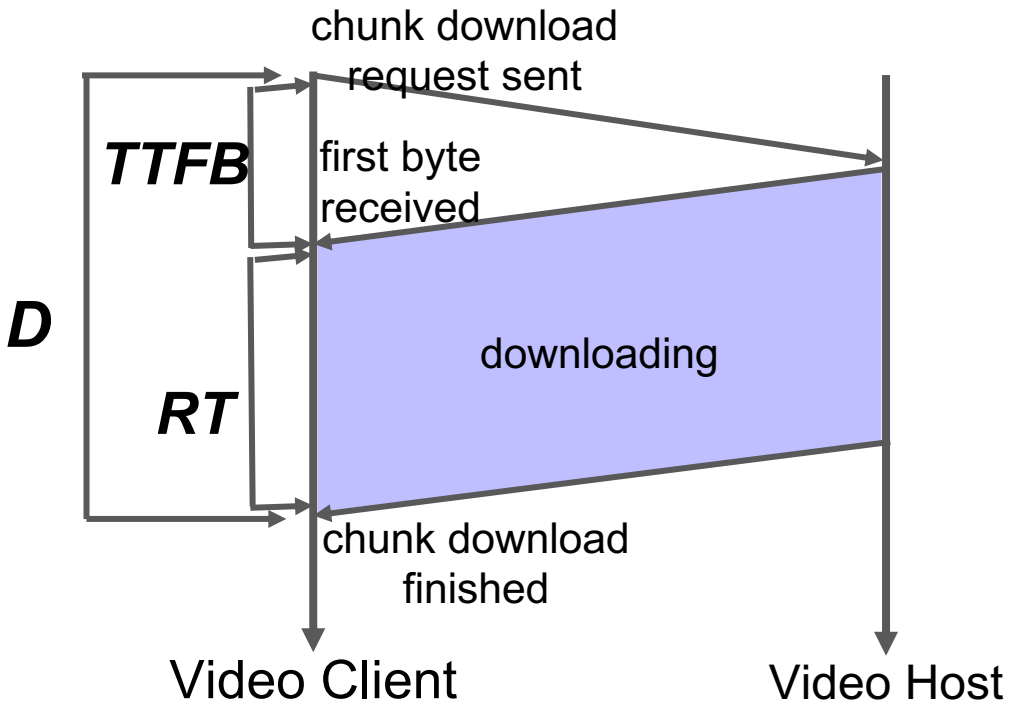

- Neglects TTFB (Time to First Byte).
- Assume chunk download times mainly depend on network throughput.
- Assume throughput independent of chunk size.

Existing prediction approaches

- State-of-the-art: CS2P [Sigcomm 2016]
  - Learns from prior video sessions.
  - Considers features such as ISP, CDN, access technology, and time of day.
  - Partitions video sessions based on these features, and uses a Hidden Markov Model for each combination of features.

What our data analysis reveals..

- 100K video sessions from real users
  - Collected over three months in 2017 from a content publisher in US.
  - Sessions spread over 89 ISPs, 1406 cities, and 2 CDNs.

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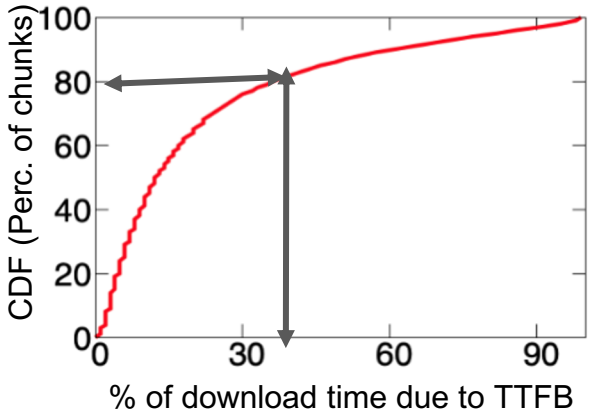

TTFB contributes more than 40% of download times for 20% of the chunks.

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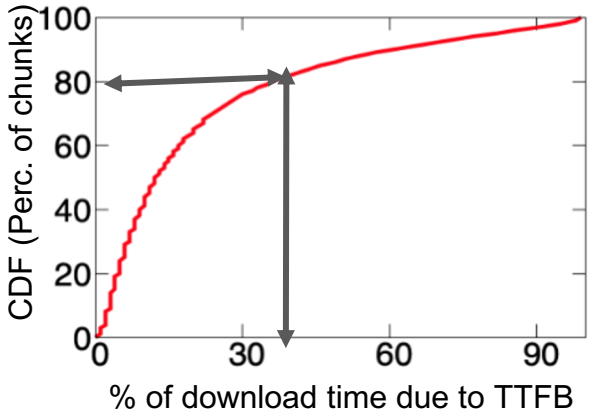

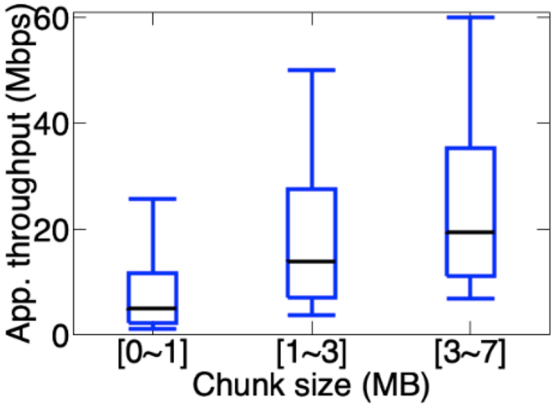

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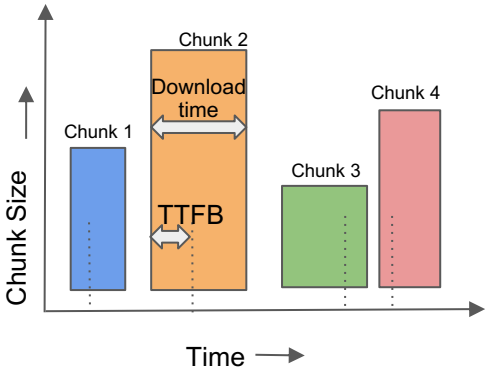
Throughput tends to be higher for larger chunk size

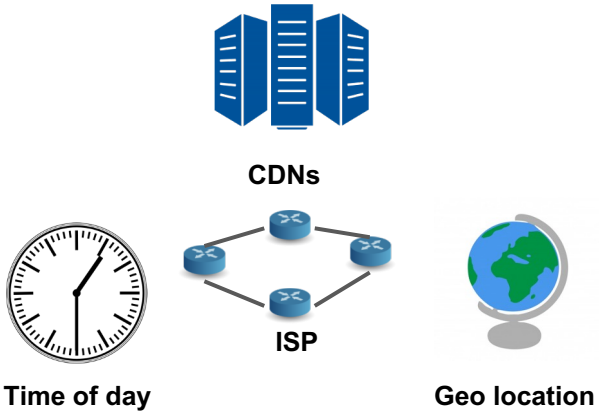
Does clustering improve prediction accuracy?

- CS2P: Per-cluster HMM; Global-CS2P: HMM on sessions across all data.
- What our data shows:
  - In about 35% of clusters, CS2P shows similar or even worse prediction error than Global-CS2P.
  - Using features such as ISP, CDN etc. not always helpful and can even hurt.
- Why?
  - Apriori clustering reduces data-set to learn from.
  - Assumes sessions in the partition have similar network performance: not always true!

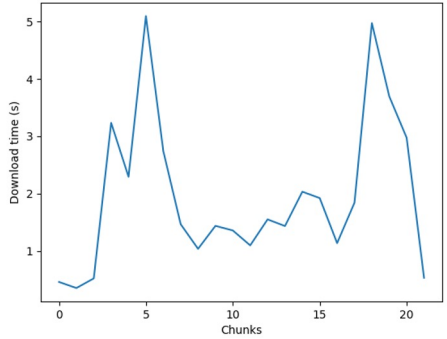
Xatu: Motivation

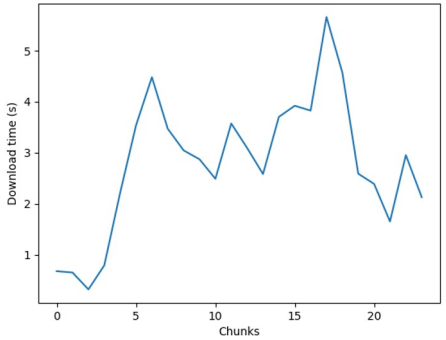


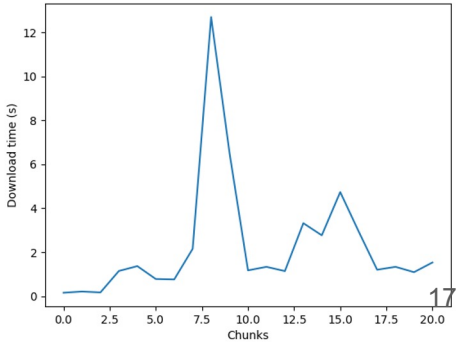
Temporal features



Static features



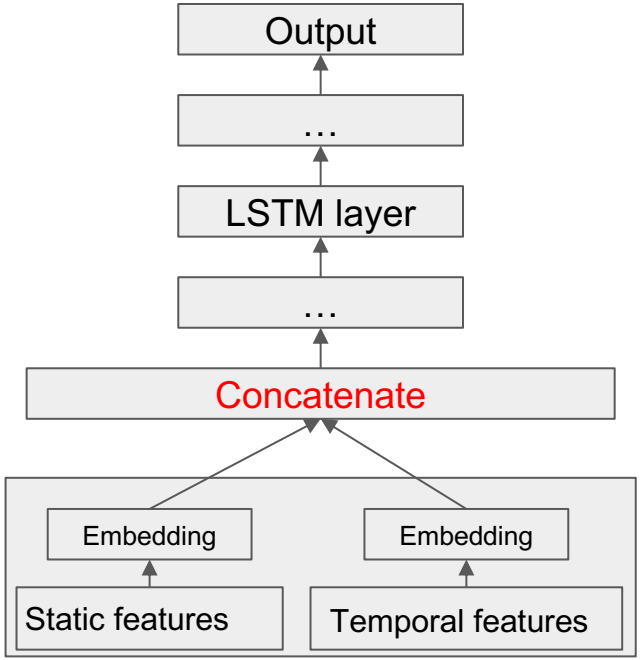




- Model sequences with multiple chunk-dependent features, not just throughput.
- Learn from similar sessions without pre-partitioning.

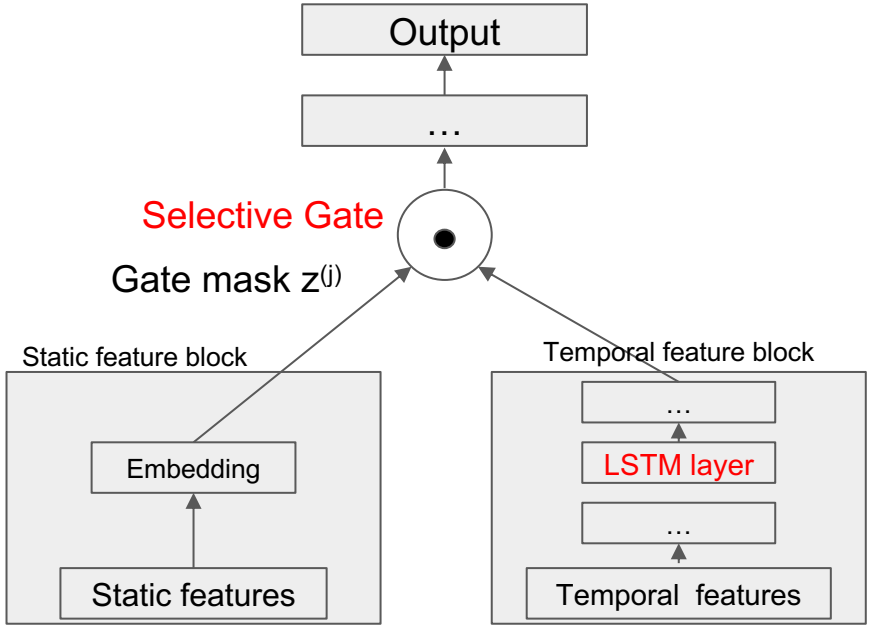
Xatu: Custom Architecture

Xatu: Conventional vs Custom Architecture



Conventional approach

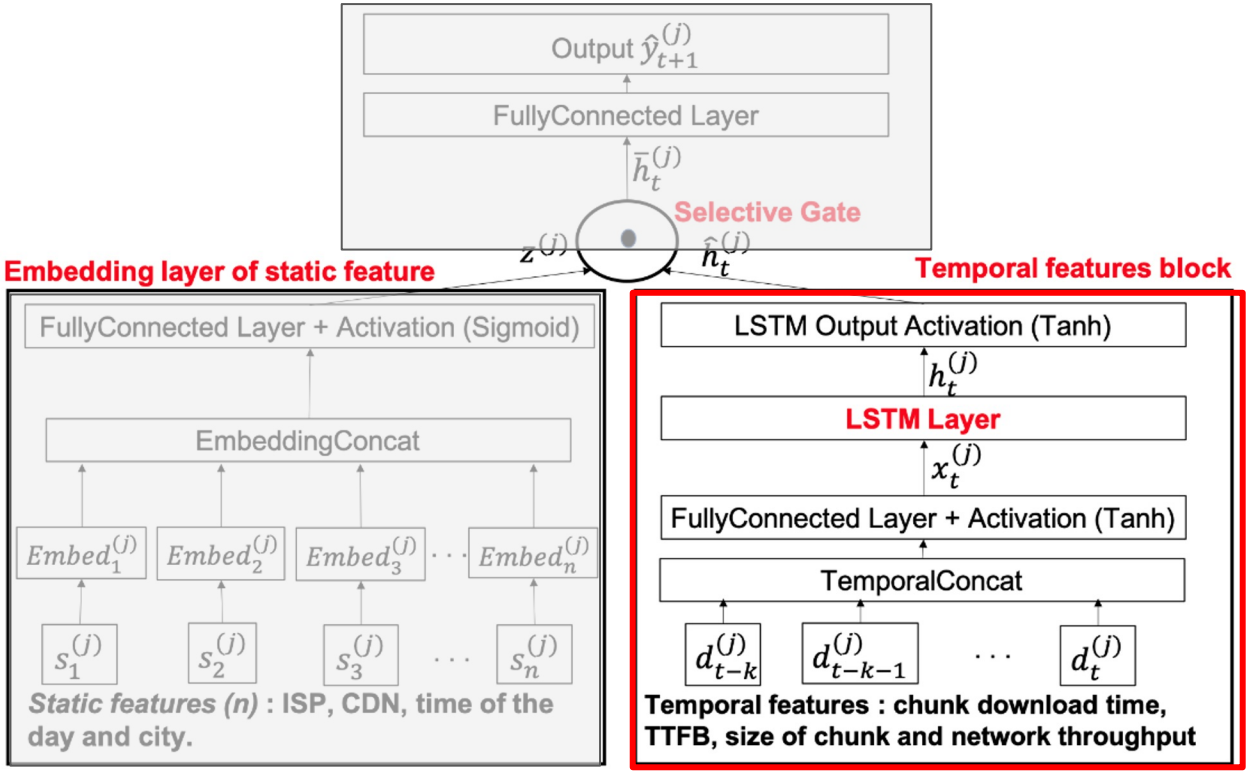
- Difficult to interpret which sessions are considered similar.



Xatu's custom approach

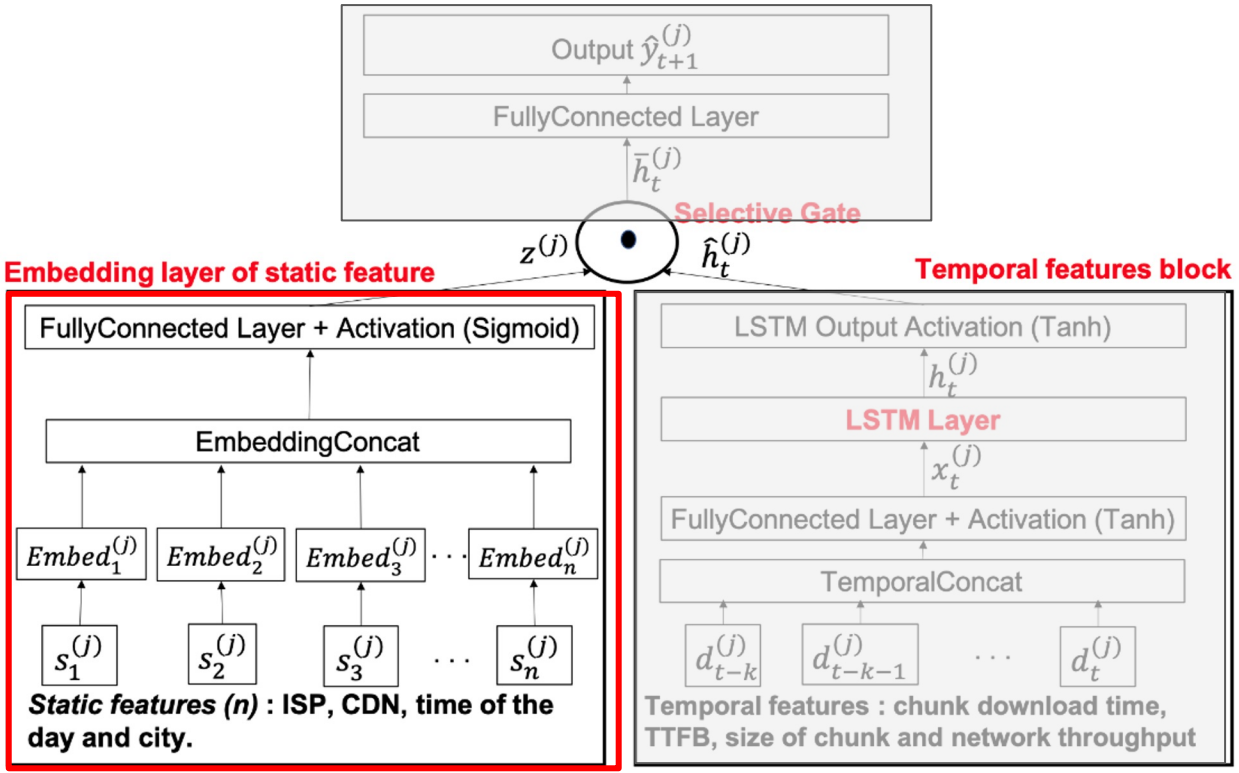
- Gate mask helps in interpretability.

Xatu Architecture - Temporal feature block



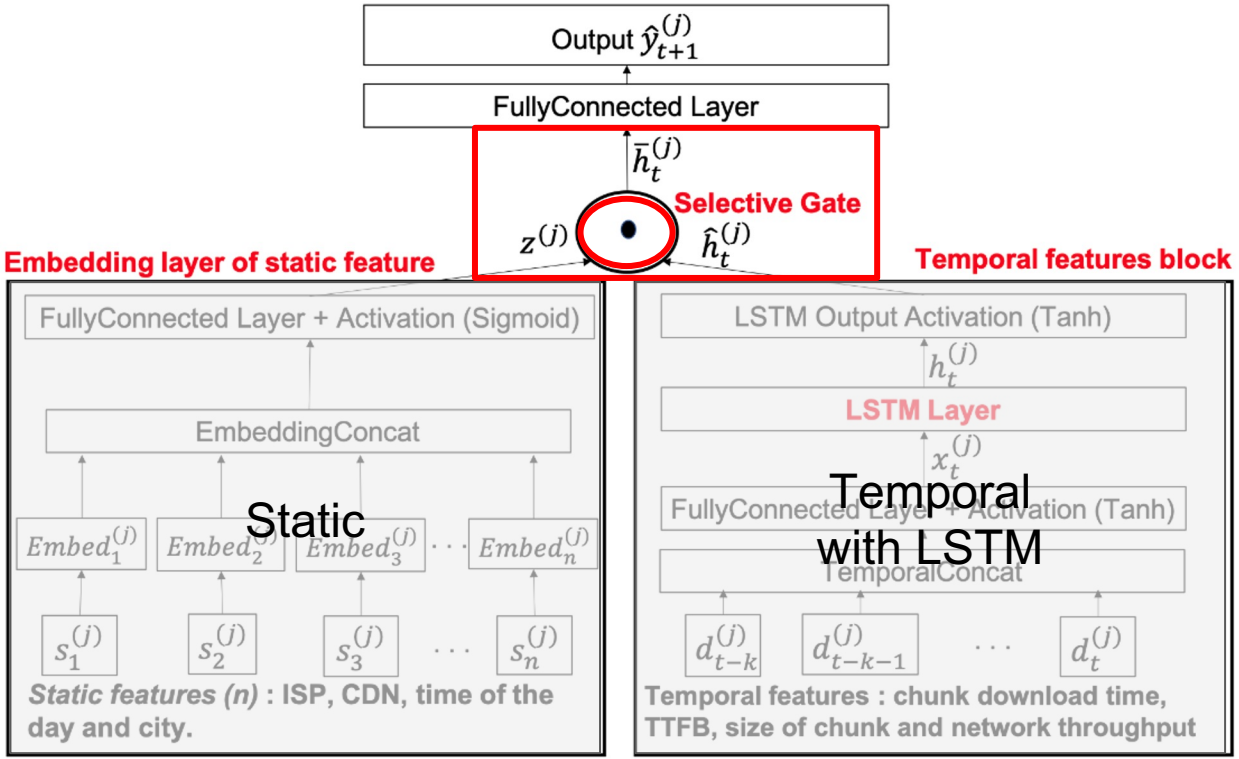
- Temporal features of past ‘k’ chunks: $d_{t-k}^{(j)}$ ... $d_t^{(j)}$: size, TTFB, download time, throughput.
- Sequence modelled using LSTM to predict next value(s) in a time series.

Xatu Architecture - Static feature block



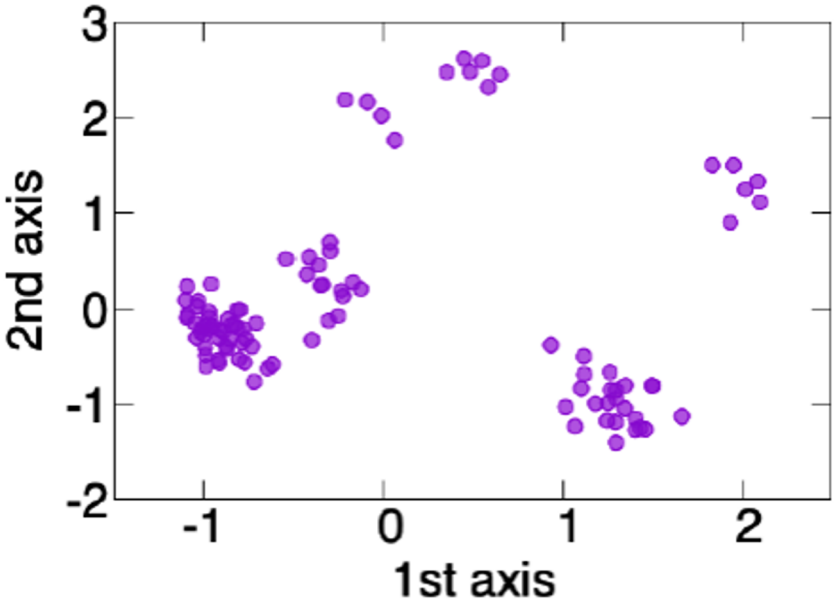
- Video session ‘j’ with ‘n’ static features.
- Static features: $s_n^{(j)}$
- Output: gate mask, $z^{(j)}$

Xatu Architecture - Selective Gate



- Selective gate combines the static and temporal blocks.

Xatu is interpretable



- Gate mask output from static block: $\mathbf{z}^{(j)}$
- Using PCA[3], project gate masks into 2D space.
- Closer dots indicate Xatu identifies corresponding sessions have similar performance.

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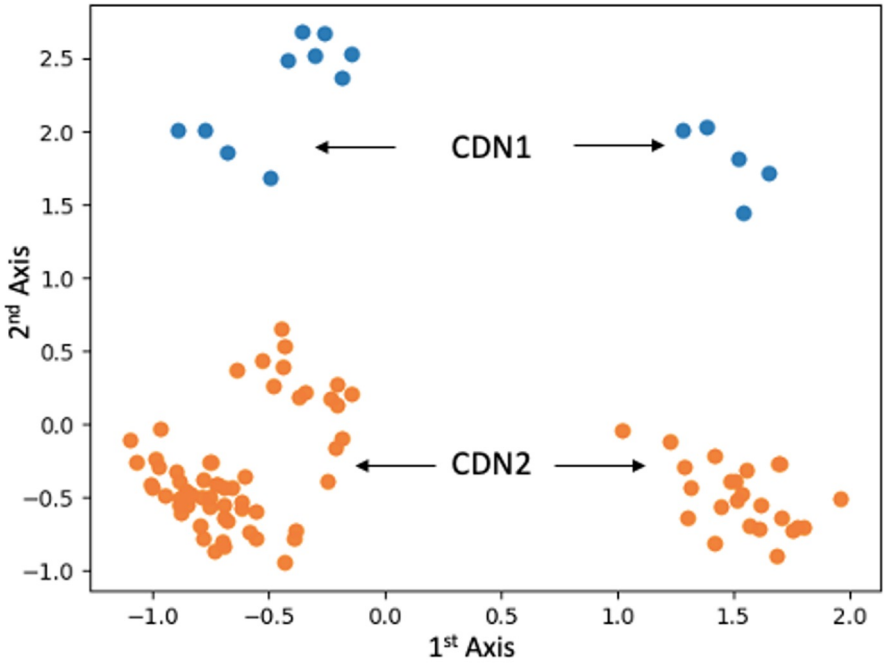

Sessions with same CDN tend to have similar performance

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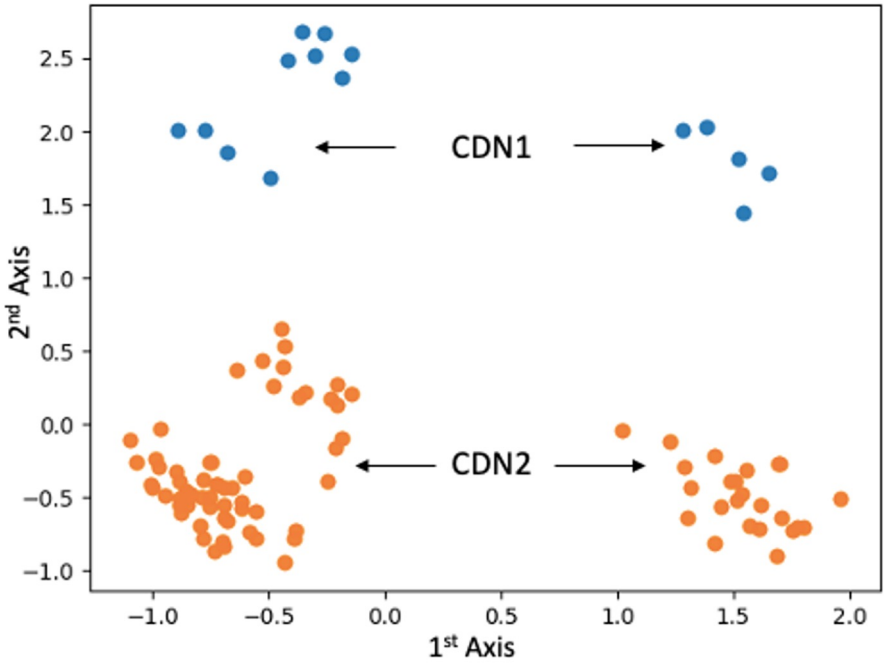

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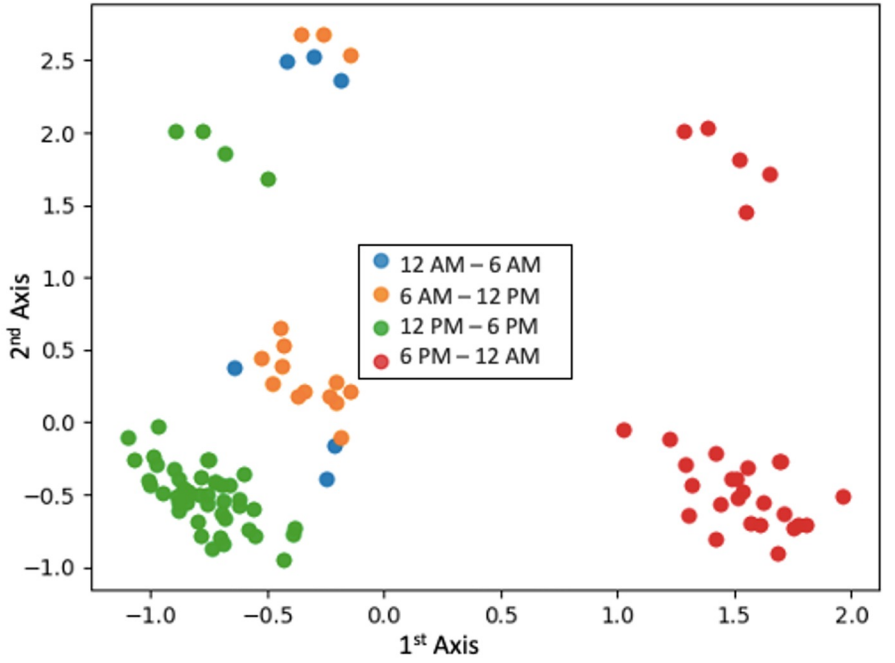


Time of day also plays a noticeable role

Evaluation Methodology

- How effective is Xatu in achieving better prediction accuracies than CS2P?
- How do better predictions translate into better performance for video streaming algorithms?
  - Integrate Xatu with well known ABR algorithms.

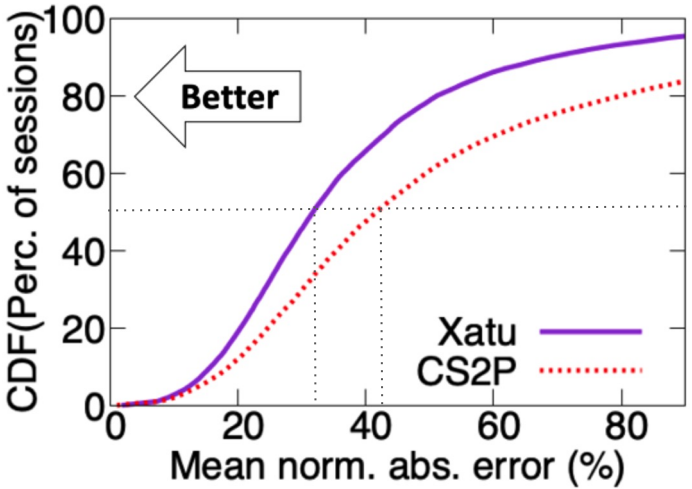
Prediction accuracy - Xatu vs. CS2P

y_t: Actual throughput,
$\hat{y}_t$: Predicted throughput,
$C^{(j)}$: # of chunks in video session, j.

Mean Normalised Absolute Error (NAE) per session:

$$\frac{1}{C^{(j)}} \sum_{t=1}^{C^{(j)}} \left| \frac{y_t^{(j)} - \widehat{y_t^{(j)}}}{y_t^{(j)}} \right|$$

Prediction accuracy - Xatu vs. CS2P



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Reduce median and 90%ile of mean NAE by 23.8% and 41.8%

Does Xatu benefit ABR algorithms?

- Integrate Xatu with 2 representative ABR algorithms: MPC and FuguABR
  - MPC: Well studied algorithm based on Model Predictive Control.
  - FuguABR: Recent algorithm that uses a stochastic controller.

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FuguNN

*Fully connected neural network.
*Predicts probabilistic distribution of download times
*Only temporal features and does not model TTFB.

FuguABR

*ABR algorithm with stochastically optimal controller.

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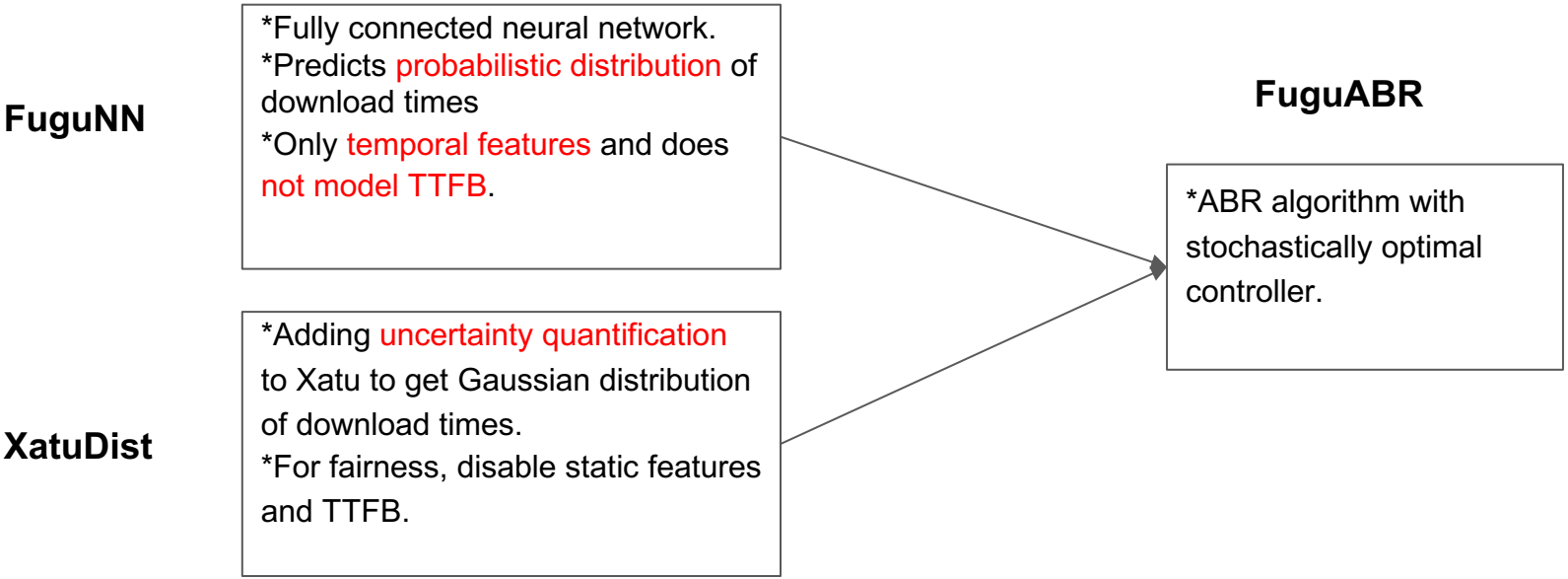
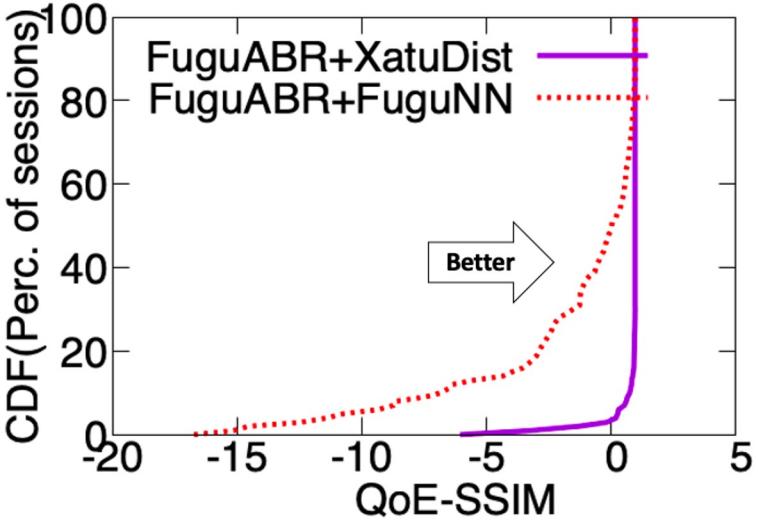


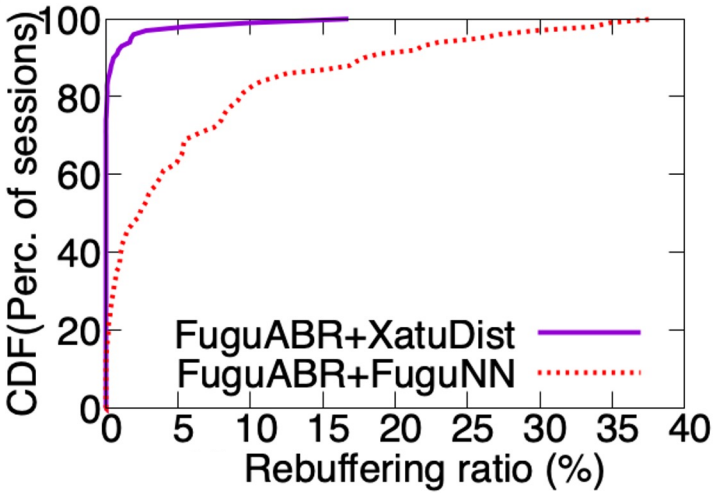
FuguABR + XatuDist v/s FuguABR + FuguNN



- QoE-SSIM (Linear combination of three metrics)
  - Average SSIM
  - Rebuffering Ratio
  - SSIM change magnitude

XatuDist observes higher QoE.

FuguABR + XatuDist v/s FuguABR + FuguNN



XatuDist achieves lower rebuffering ratio, median ~ 0 while FuguNN has median rebuffering of 2%.

Summary of other results:

- Relative to Pensieve (reinforcement learning approach), Xatu+MPC improves the median and 90%tile QoE by 29.2% and 5.8% respectively.
- Compared with CS2P+MPC, Xatu+MPC reduces the rebuffering events by 26% and improves the median average bitrate change magnitude by 17.4%.

Extensibility of Xatu to new information

- Generalize Xatu to other datasets and extend with new features.
- Collect a smaller data-set through controlled experiments which includes information about which CDN layer [Edge or Remote] each chunk is served from.

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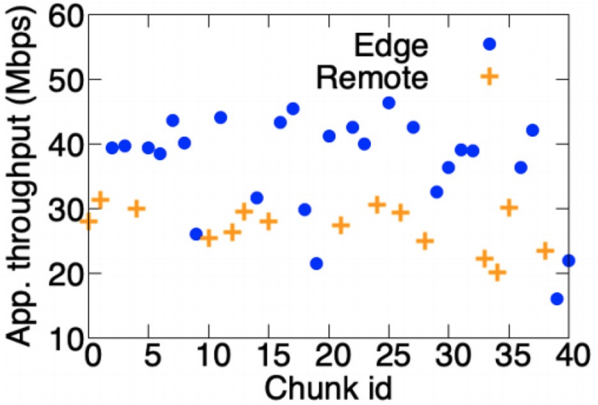

Throughput depends on where a video chunk is served from

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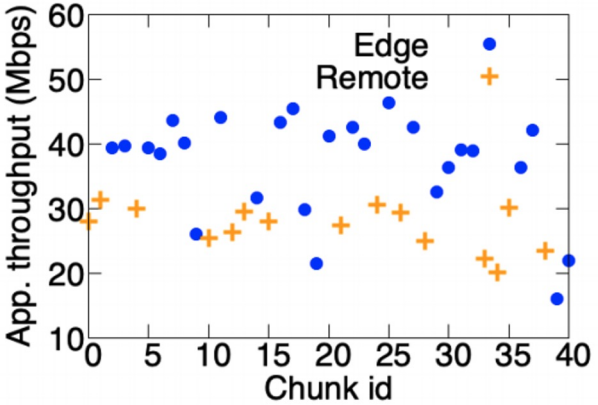

Throughput depends on where a video chunk is served from

New feature (CDN layer) improves the median and 90%ile prediction error by 13.1% and 31.5%.

Conclusion

- Xatu achieves 24% reduction in prediction error relative to state of the art, CS2P, Sigcomm 2016.
- Xatu's custom architecture helps in interpretability and reduces prediction error by 9.4%.
- Xatu integrates with multiple ABRs and achieves significantly better performance.
- Xatu is extensible and adding new features reduces prediction error by 13%.
- Dataset available at: https://github.com/Purdue-ISL/XatuDataset

Thanks!

Q & A