Real-Time Video Quality of Experience Monitoring for HTTPS and QUIC

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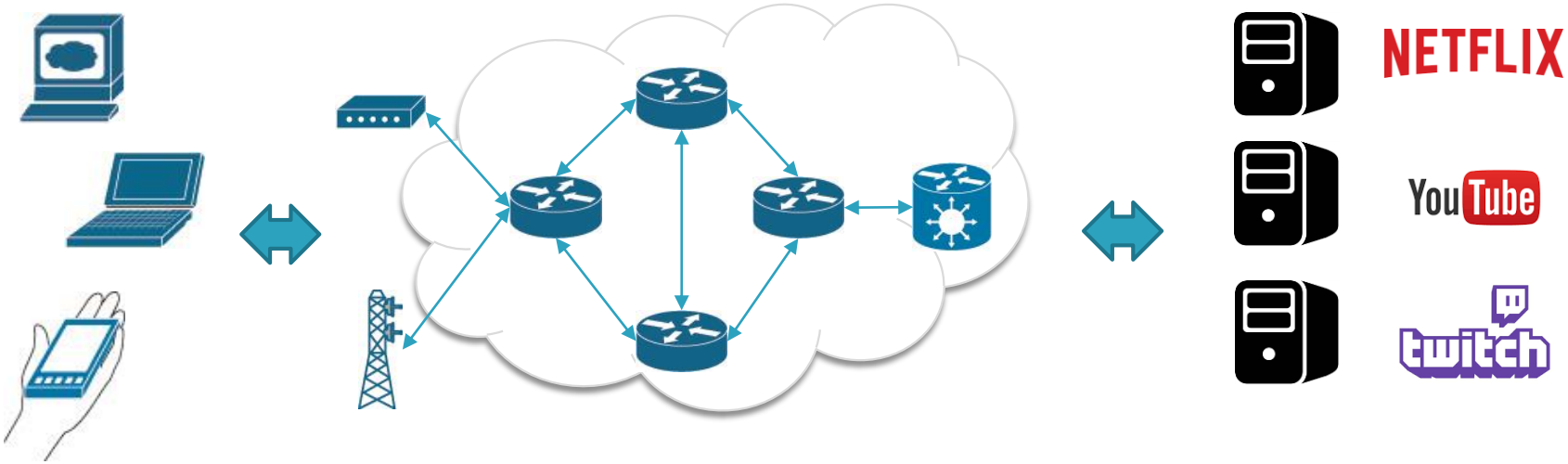
Overview – Video Streaming

- 72% of all consumer Internet traffic was video in 2016
- Forecasted to grow up to 81% by 2021.

Today's Internet is a 'video' Internet

Overview - Ecosystem

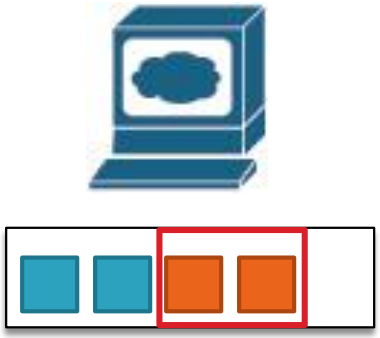


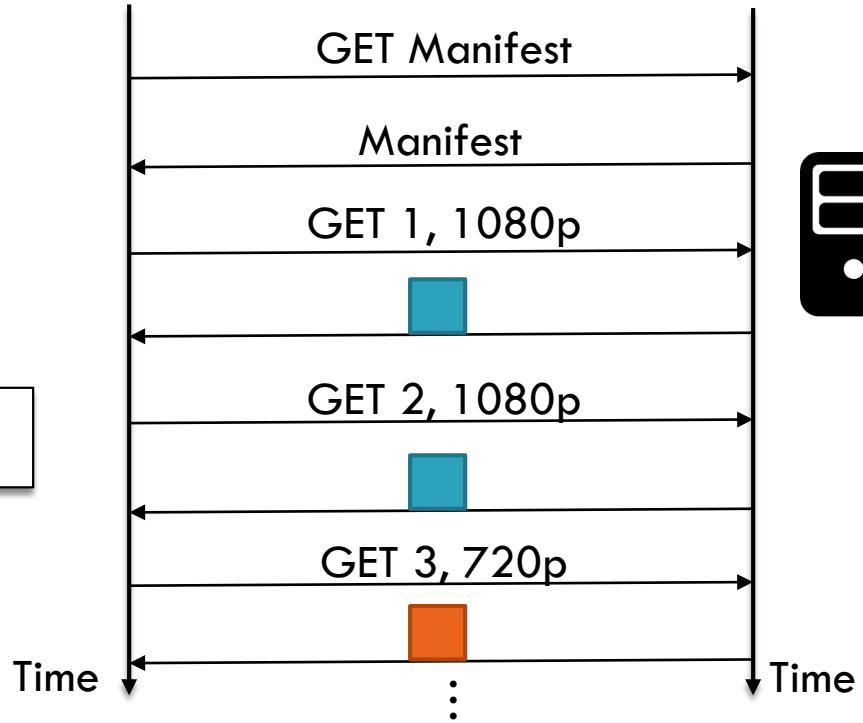
Users

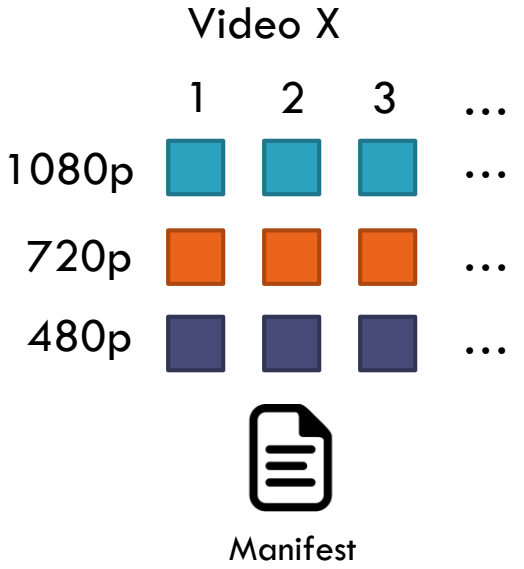
Internet Service Provider Networks

Content Providers

Overview – Adaptive Video Streaming



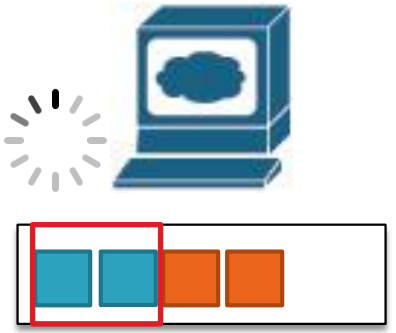




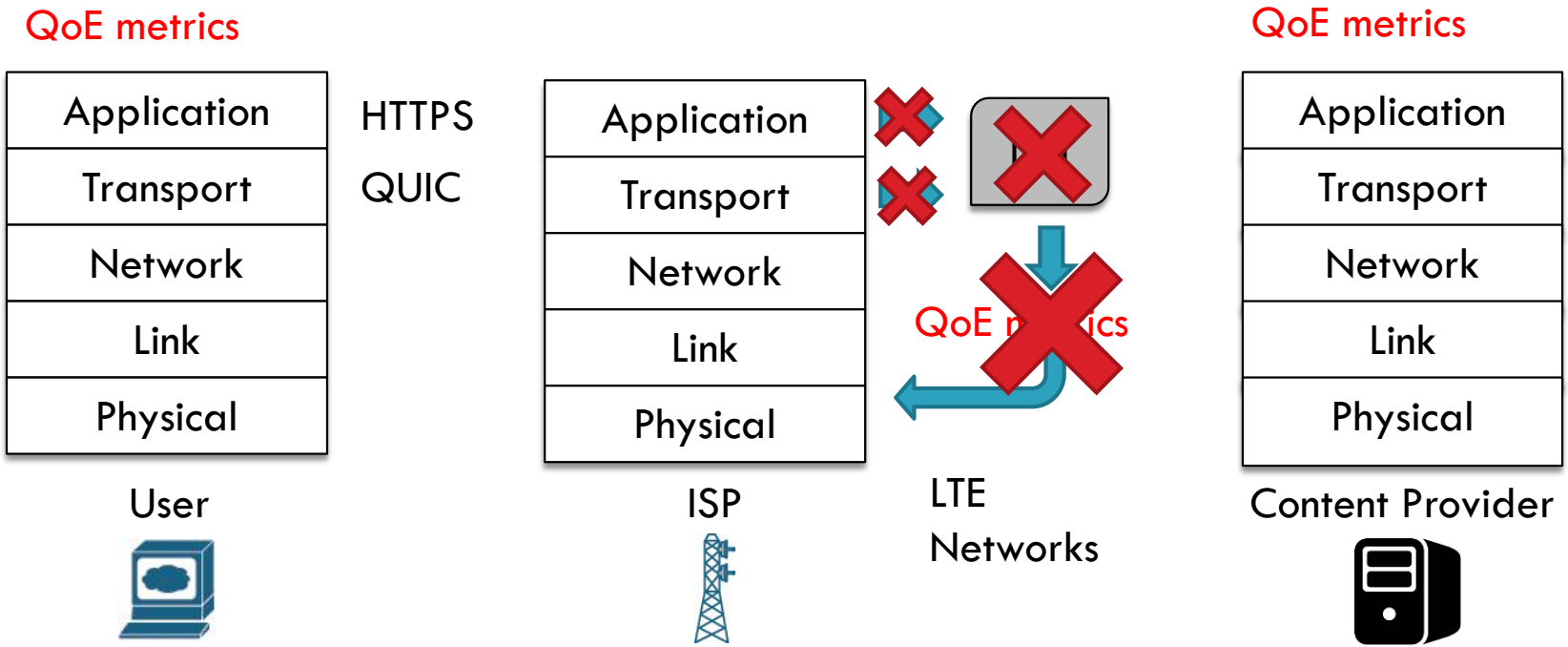
Overview – Quality of Experience Metrics

- Used to objectively measure user experience.
- Startup Delay
- Average Quality =۹۰۸۹p
- Rebuffering

QoE metrics



Overview - Network Management



Challenge - Encryption on the rise

- HTTPS page loads increased from 45% (2016) to 69% (2018).
- YouTube is increasingly using QUIC for mobile video delivery.

End-to-end encryption eliminates QoE monitoring.

Problem Statement

Predict QoE metrics in real-time for encrypted video traffic.

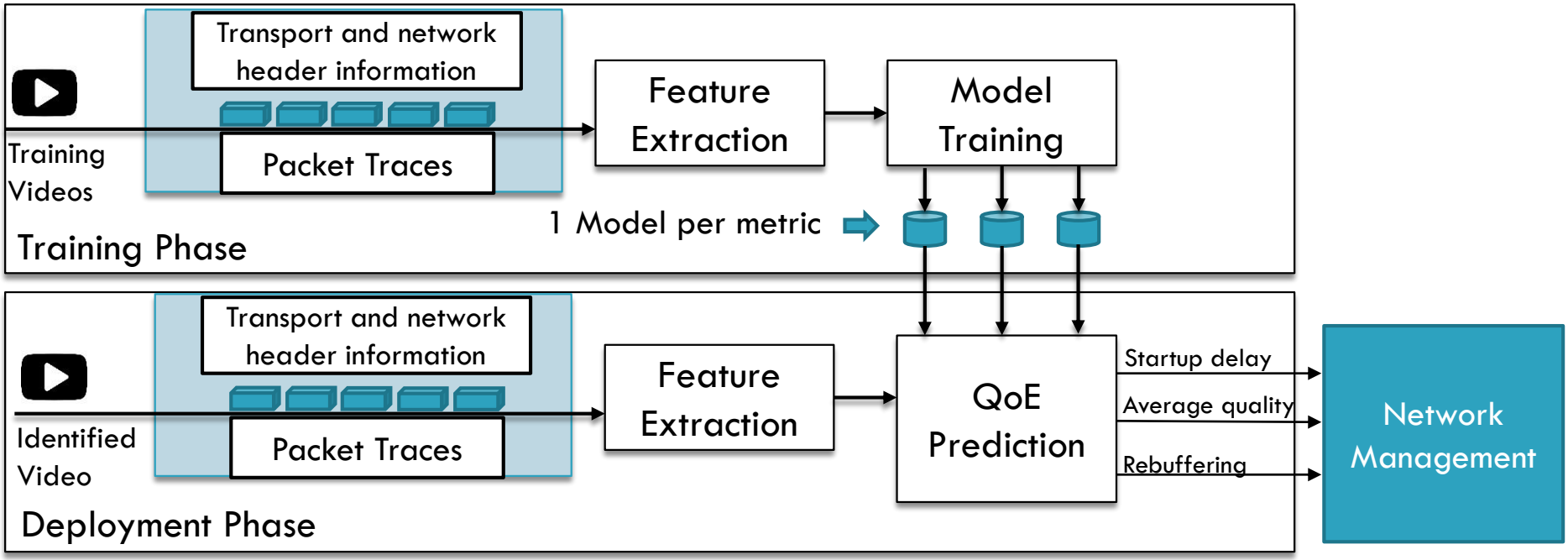
Assumptions:

- Video stream detection on encrypted traffic (machine learning, traffic analysis, etc)
- Network/Transport layer info. collection

Our Contributions

- Machine learning for QoE metric prediction
- Prediction at 10 second time scales
- Network/transport layer features.

Proposed Approach



Features

	Window	Packet
Network Layer	Byte Counts Packet Counts Throughput Idle Time	Packet Inter-arrival times Bytes per packet
Transport Layer	TCP Flag Counts Out-of-order bytes/packets TCP Goodput Retransmission ratio Starting/Ending bytes-in-flight	Retransmissions per packet Receive Window RTT Bytes-in-Flight

QoE Metric Prediction

- We view it as a binary classification problem
- Startup delay: is it below *k* seconds?
- Average Quality: is it above a set resolution?
- Rebuffering: has rebuffering occurred?

Evaluation – Data Collection

- Selenium with Google Chrome for YouTube video streaming.
- Packet capture with `tcpdump`
- Network shaping with `tc` and `netem`
- Ground truth QoE metrics with YouTube IFrame API

Evaluation - Machine Learning

- Supervised machine learning using decision trees.
- Avoid overfitting with AdaBoost ensemble meta-classification.
- Evaluated under 10-fold cross validation.

Results

$$\text{Precision} = \frac{TP}{TP+FP} \qquad \text{Recall} = \frac{TP}{TP+FN}$$

QoE Metric	HTTPS		QUIC	
	Precision	Recall	Precision	Recall
Startup Delay	82%	82%	85%	85%
Average Quality	85%	86%	72%	72%
Rebuffering	90%	90%	80%	80%

More results and insights in paper

Limitations

- Differences across video providers
  - Solution: Unique models per provider
- Sensitive to changes in video delivery for same provider
  - Solution: Online Learning
- Models provide actionable insights, but not root causes

Conclusion

- Machine learning based QoE prediction for encrypted video streams
- Features based on the transport/network layer
- Achieve 90% accuracy for HTTPS, 85% for QUIC

Questions?

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