

Monitoring User-Perceived Quality in an Encrypted Internet AI to the Rescue

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Context: **Quality of Experience (QoE) monitoring** (from passive measurements, at the network side) for multimedia services (video streaming, web browsing, mobile apps) is a daunting yet critical task for Internet Service Providers (ISPs), who need to shed light on the performance of their networks as perceived by their customers, to avoid churn due to quality dissatisfaction.

Problem: While ISPs have traditionally relied on the usage of Deep Packet Inspection (DPI) techniques to understand the performance of web services from the NETWORK SIDE (monitoring at the end-device is out of scope here, as it does not scale and has many associated limitations, in particular strongly limits visibility), **the wide adoption of end-to-end traffic encryption has drastically reduced their visibility.**

Contributions:

- Simple (**payload agnostic**) network-level **traffic features** derived from packet/flow time and size **for AI/ML-driven performance inference.**
- **(Deep) Learning driven approaches to infer application-level QoE metrics** (re-buffering, video resolution switching, speed index, etc.) directly **from the streams of encrypted bytes**, for **video streaming** services, **web browsing**, and **mobile apps.**
- **Evaluations on large and heterogeneous datasets** for different access networks (cellular, mobile, fixed-line), different network QoS (latency, capacity, packet-loss), different end-devices (smartphones, tablets, laptops), different services and players (YouTube HTML5, YouTube Native App, Chrome Browsing, etc.), different ISPs and geolocation of vantage points, and different transport protocols (QUIC/TCP), show that **it is possible to infer QoE related metrics for these services with high accuracy, enabling end-user performance monitoring from encrypted network traffic.**
- **Implementation of corresponding approaches in PDP, P4-based monitoring systems** for AI/ML-driven real-time traffic monitoring at 100G line rate. E.g., the system can **predict video QoE in real-time** (1 second resolution) **for more than 520,000 concurrent flows** (YouTube) at 100 Gbps line rate, on an Intel Wedge100BF-65X P4-enabled Tofino switch.

Related papers:

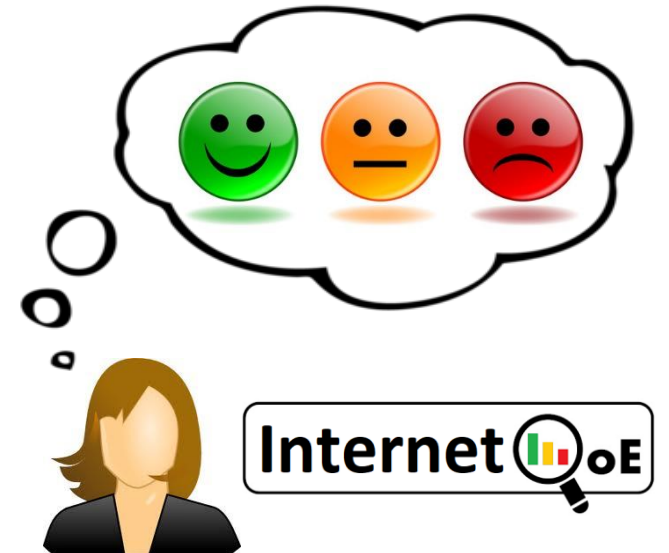
- (1) [**TMA 2022**] X-Ray Goggles for the ISP: Improving in-Network Web and App QoE Monitoring with Deep Learning
- (2) [**IEEE NetSoft 2022**] DeepCrypt: Deep Learning for QoE Monitoring and Fingerprinting of User Actions in Adaptive Video Streaming
- (3) [**IEEE GIS 2022**] Fingerprinting Webpages and Smartphone Apps from Encrypted Network Traffic with WebScanner
- (4) [**IEEE TNSM 2020**] ViCrypt to the Rescue: Real-Time Machine-Learning-Driven Video-QoE Monitoring for Encrypted Streaming Traffic

Decrypting QoE in an Encrypted Internet – AI to the Rescue

Improving in-Network Video Streaming, Web and App QoE Monitoring with Deep Learning

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Nikolas Wehner, Bruno Gardlo, Tobias Hoßfeld

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The Rise of End-2-End Encryption



QoE metrics



Application
Transport
Network
Link
Physical

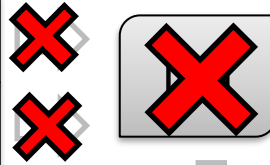
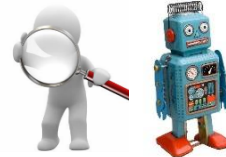
User



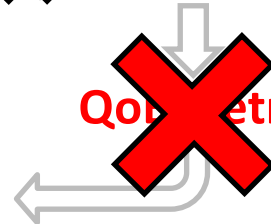
HTTPS
QUIC

Application
Transport
Network
Link
Physical

ISP



QoE metrics



QoE metrics

Application
Transport
Network
Link
Physical

Content Provider



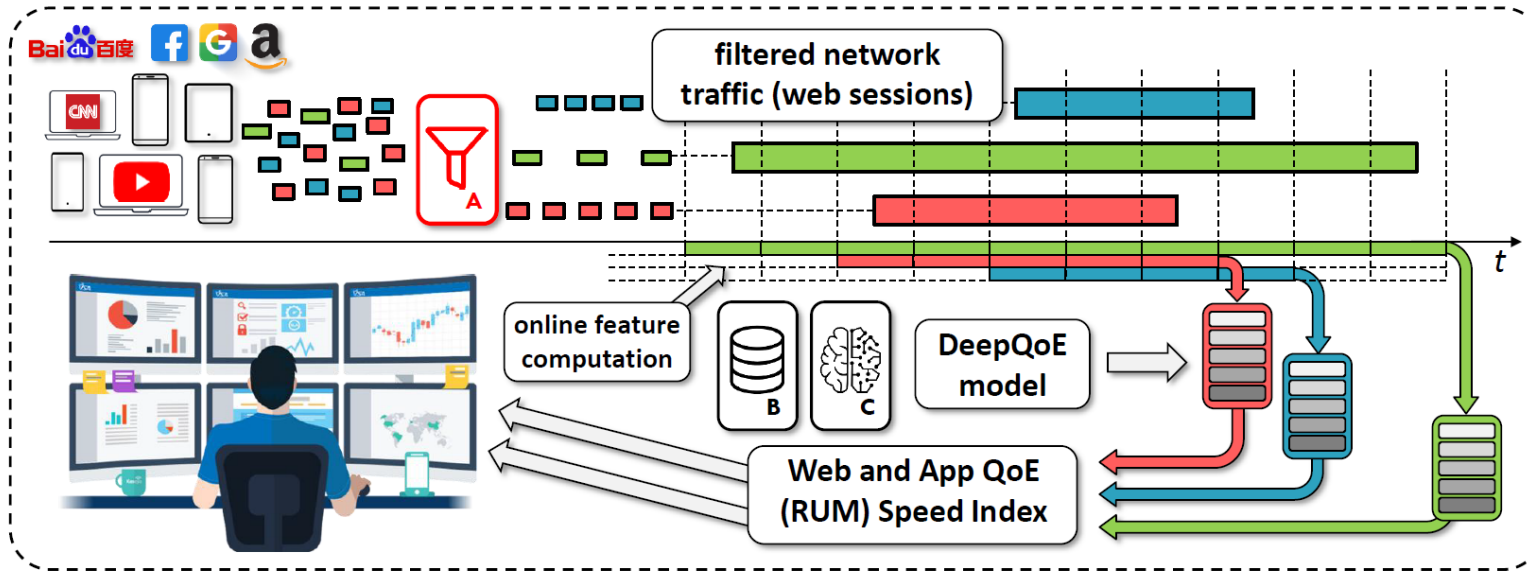
- **HTTPS** and **QUIC** turn previous approaches no longer applicable – **lack of visibility for ISPs**

- Solution I – **monitoring directly at the end devices**

DeepQoE (Deep Learning)

- Solution II – **monitoring at the core, relying on Machine Learning (ML) approaches**

Web, App (and Video) QoE Monitoring with DeepQoE



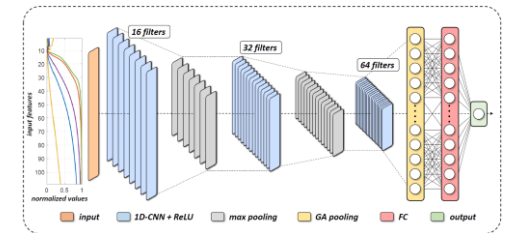
DeepQoE monitoring workflow.

a. Traffic flows identification, filtering, and disentangling *per session*

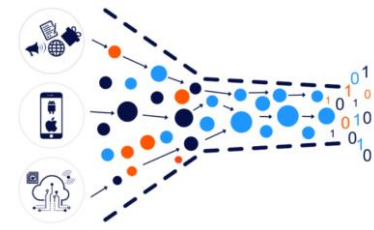
b. *Raw* and lightweight *feature extraction*

c. Deep Neural Networks for *QoE KPIs inference* (*Speed Index, Video QoE metrics*)

- A monitoring platform for QoE inference of multimedia services (web, apps, video streaming)
- Seamlessly operating with *encrypted network traffic*
- Relying on *Deep NNs* to improve inference performance



Contributions



- Mobile Web, App, and Video QoE monitoring and analysis in the wild are complex tasks.
- ***Our approach and contribution: DeepQoE --> Deep Learning-based approach*** capable to ***infer the SI of web browsing sessions and app user actions in smartphone and tablet devices...***
- ...with ***low errors and cross-device, multi-content generalization***, using as input features derived from ***(encrypted) network traffic***
- In ***video streaming, outperforms state-of-the-art ML models by more than 10% in all Video QoE metrics (initial delay, rebuffering, quality switching, video resolution and video bitrate)***
- ***DeepQoE*** also ***properly infers user player actions***, even when mixed-up with QoE events
- And tackles the problem of ***Web and App traffic identification and disentangling from encrypted traffic***, with sufficiently robust and performant results...
- ...such that an end-to-end monitoring solution could be deployed in the practice

Some Associated Papers

"X-Ray Goggles for the ISP: Improving in-Network Web and App QoE Monitoring with Deep Learning"

P. Casas, S. Wassermann, M. Seufert, N. Wehner, O. Dinica, T. Hoßfeld
in 6th IFIP Network Traffic Measurement and Analysis Conference (TMA), Enschede, The Netherlands, 2022.

"DeepCrypt – Deep Learning for QoE Monitoring and Fingerprinting of User Actions in Adaptive Video Streaming"

P. Casas, M. Seufert, S. Wassermann, B. Gardlo, N. Wehner, R. Schatz
in 8th IEEE International Conference on Network Softwarization (NetSoft), Milan, Italy, 2022.

"Not all Web Pages are Born the Same. Content Tailored Learning for Web QoE Inference"

P. Casas, S. Wassermann, N. Wehner, M. Seufert, T. Hoßfeld
in 6th IEEE International Symposium on Measurements & Networking (M&N), Padua, Italy, 2022.

"Mobile Web and App QoE Monitoring for ISPs – from Encrypted Traffic to Speed Index through Machine Learning"

P. Casas, S. Wassermann, N. Wehner, M. Seufert, J. Schüller, T. Hoßfeld
in 13th IFIP Wireless and Mobile Networking Conference (WMNC), Montreal, Canada, 2021.

Best Paper Award

"How are your Apps Doing? QoE Inference and Analysis in Mobile Devices"

N. Wehner, M. Seufert, J. Schüller, P. Casas, T. Hoßfeld
in 17th IEEE International Conference on Network and Service Management (CNSM), Izmir, Turkey, 2021.

"Content Matters: Clustering Web Pages for QoE Analysis with WebCLUST"

L. Jiménez, M. Solera, M. Toril, C. Gijón, P. Casas
IEEE Access, pp. 1-16, 2021.

"Improving Web QoE Monitoring for Encrypted Network Traffic through Time Series Modeling"

N. Wehner, M. Seufert, J. Schüller, S. Wassermann, P. Casas, T. Hoßfeld
ACM SIGMETRICS Performance Evaluation Review, vol. 48, no. 4, pp. 37-40, 2021.

"ViCrypt to the Rescue: Real-time, Machine Learning-driven Video QoE Monitoring for Encrypted Streaming Traffic"

S. Wassermann, M. Seufert, P. Casas, G. Li, L. Kuang
IEEE Transactions on Network and Service Management, vol. 17, no. 4, pp. 2007-2023, 2020.

