ViCrypt: Real-time, Fine-grained Prediction of Video Quality from Encrypted Streaming Traffic

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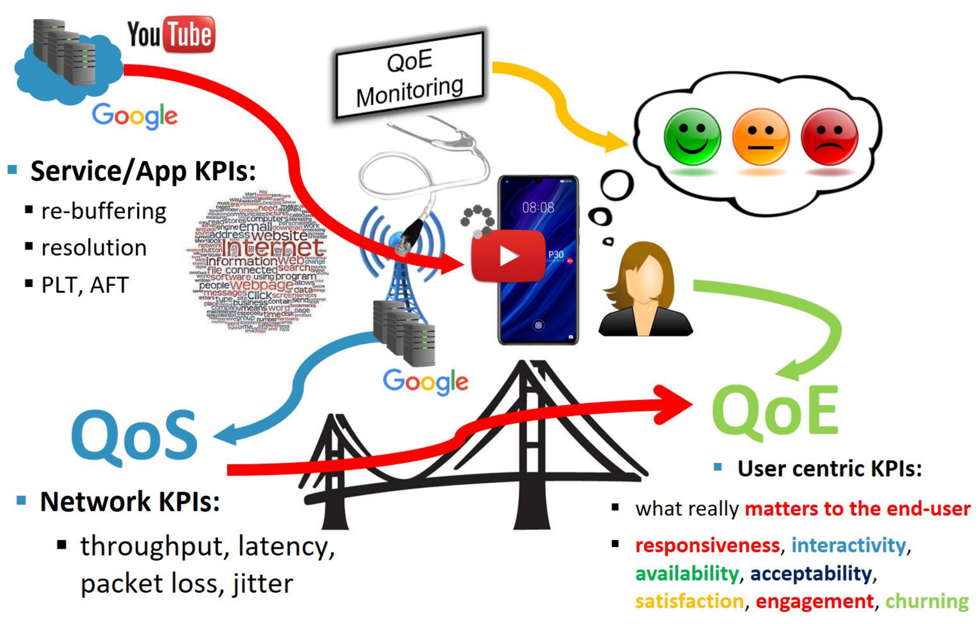
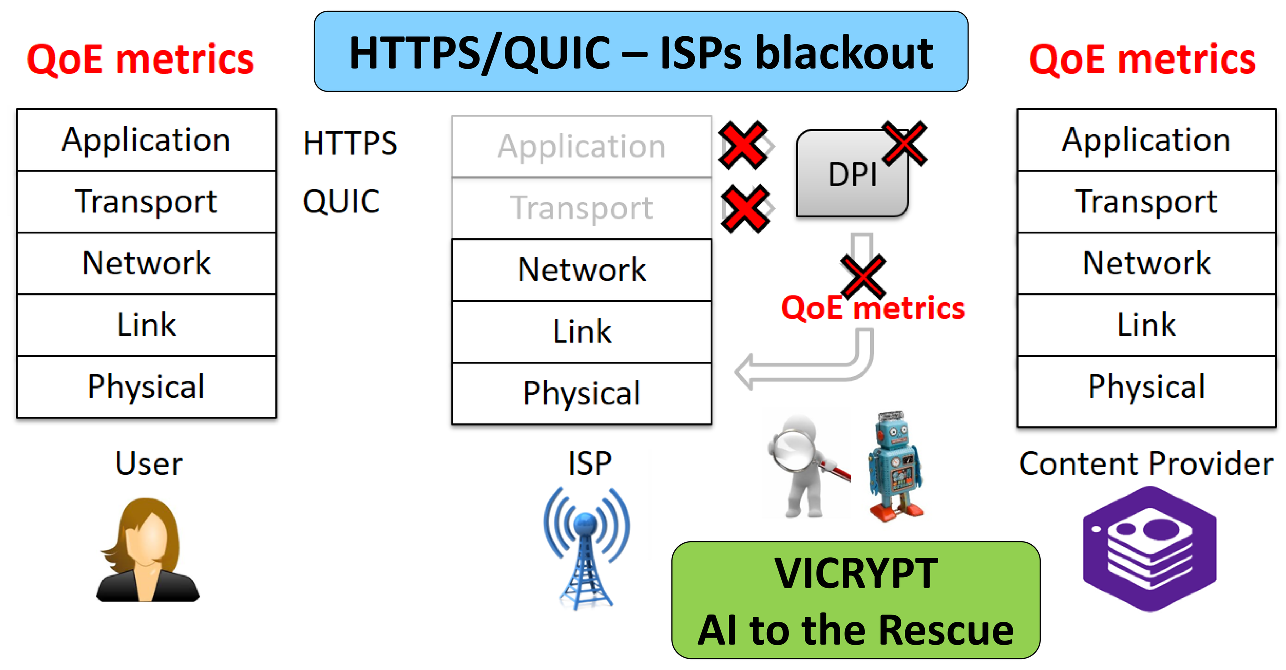
QoE–BASED NETMON (QoE–MON)



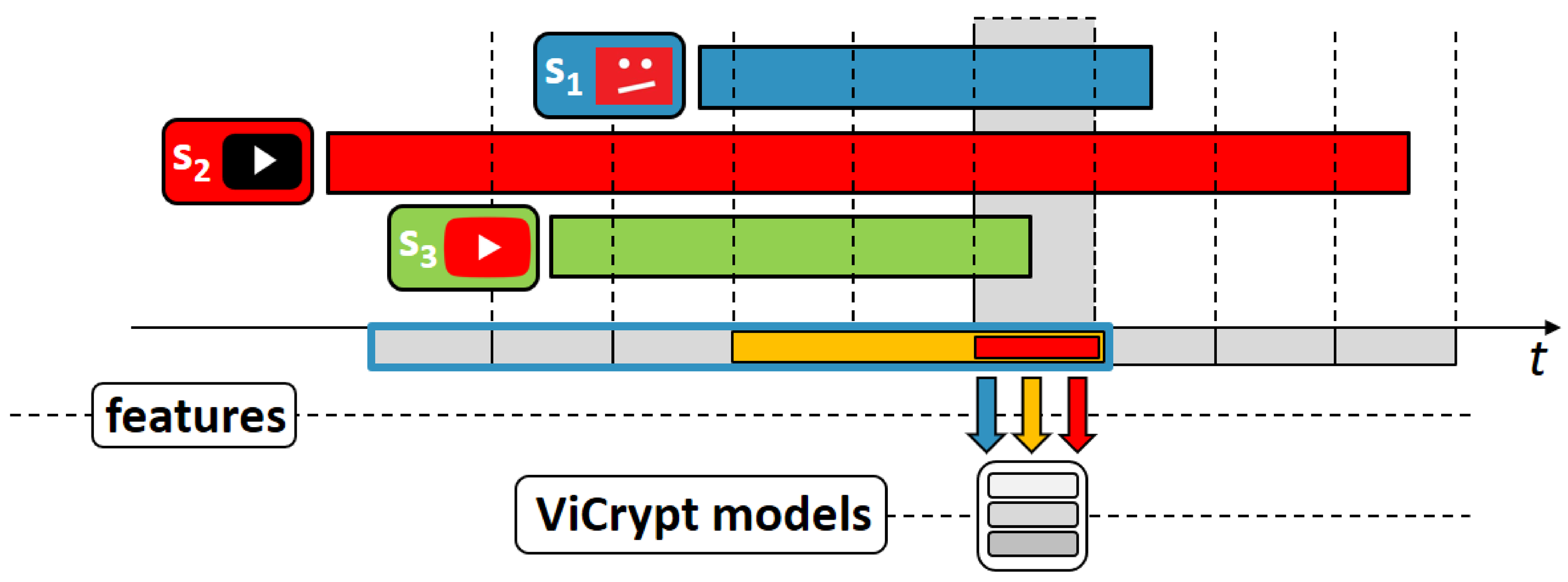
MOTIVATION & CHALLENGE



VICRYPT: ML–BASED QoE–MON

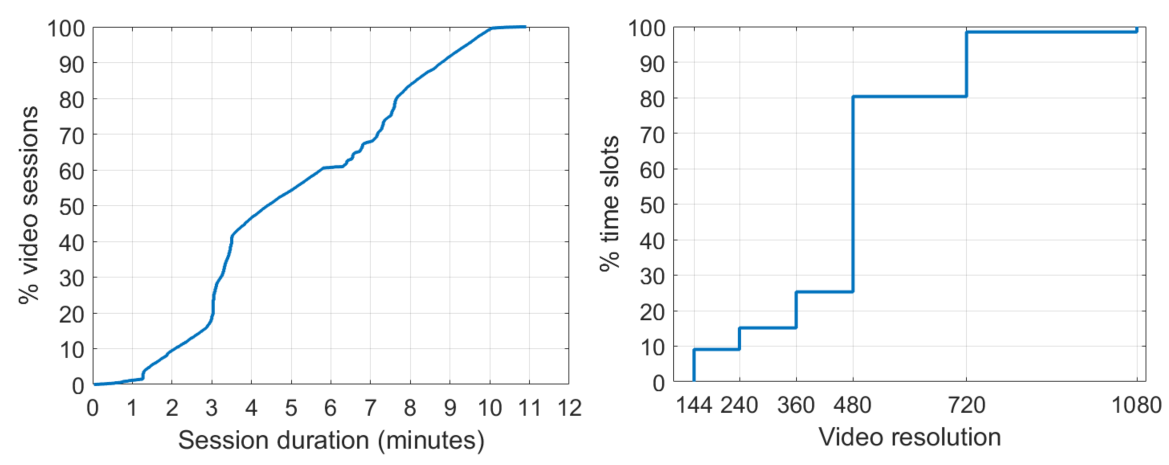
- **Real-time** (1-sec resolution) **prediction of KQIs** for video streaming
- **Video chunk detection NOT NEEDED** features are packet size/time based
- ML models for prediction of **instant, per-sec**:
  - re-buffering events
  - video resolution
  - video bitrate

STREAM-BASED PREDICTION OF VIDEO KQIs

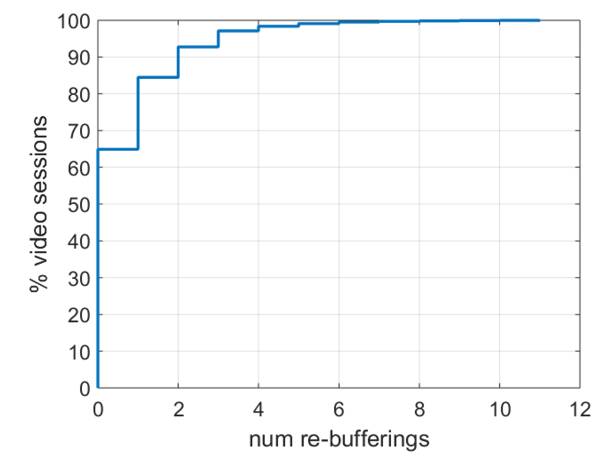


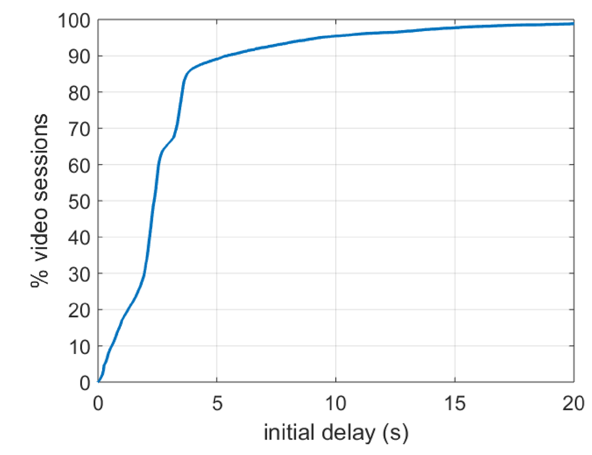
- **Video stream-based analysis,** using multiple sliding windows, capturing different temporal phenomena (**current time**, **short-term trend**, **session-aggregated**)
- **Analysis is done in real time:** for every video session and **for every new time slot of 1 second**, we consider the following set of **207 features**:
  - Features extracted from **current time slot (C) – 69 features**
  - Short-memory (trend) based features, extracted from **last T (3) slots (CT) – 69 features**
  - Cumulative based features, extracted from **all past traffic for this video session (CS) – 69 features**
- **Feature computation** is done **continually**, in **constant-memory** boundaries, ***using sketches***

YouTube DATASET FOR TRAINING & VALIDATION



- Data generation through **semi-controlled testbeds**
- **15.000+ YouTube video sessions** streamed and recorded in late 2018/early 2019
- **Different ISPs**, different **geographic locations** (Austria, Italy, Germany, China)
- Home/corporate **WiFi** networks, **LTE** networks
- **QUIC and TCP sessions**
- **Bandwidth limitations**: 20Mbps, 5Mbps, 3Mbps, 1Mbps, 300kbps + fluctuations
- JavaScript-based monitoring script to **measure ground truth at the player**



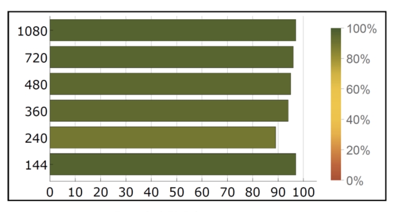


ONLINE PREDICTION OF VIDEO RESOLUTION

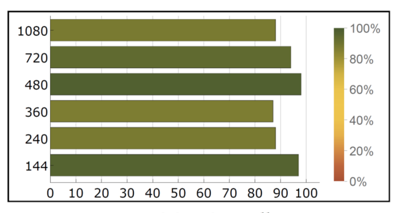
- Training multiple ML models over more then 4.6M individual, 1 sec. slots (***5-fold cross validation***) – here using all 207 inputs
- **Classification task:** per second video resolution, ***6-classes:*** 144p, 240p, 360p, 480p, 720p, 1080p

	Training time (min)	Accuracy (%)
DT	43	92
RF10	2	92
ADA	125	68
ERT10	1	90
BAGGING	37	95
BAYES	1	42
KNN	9	73
NN	507	58
SVM	194	54

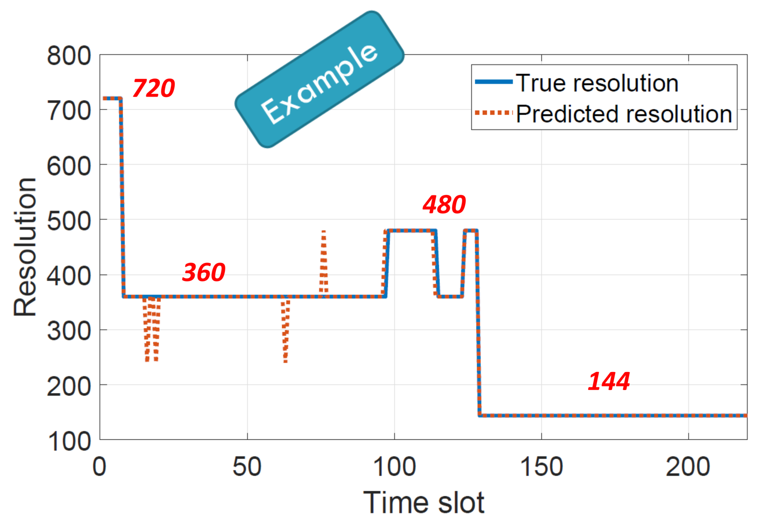
Benchmarking of different ML models



BAGGING precision



BAGGING recall

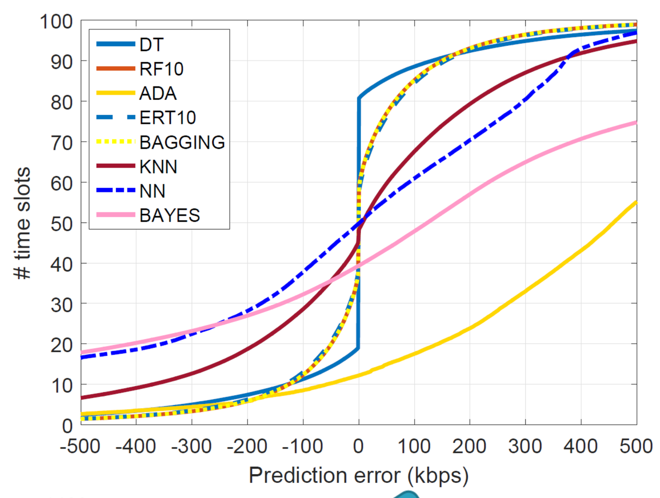


Video-resolution prediction.

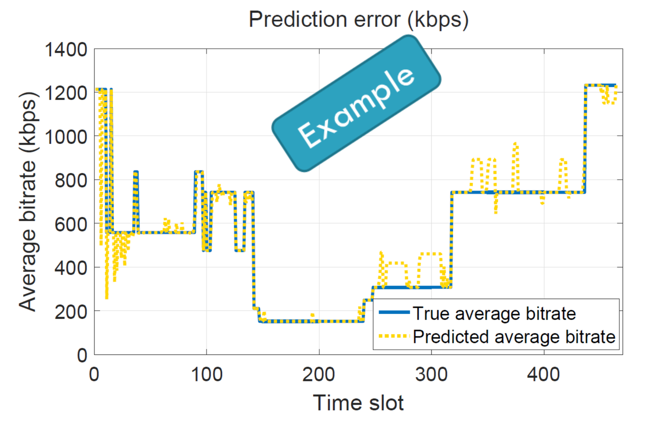
ONLINE PREDICTION OF VIDEO BITRATE

- **Regression task:** estimation of per second average video bitrate

	5-CV time (minutes)	MAE (kbps)	RMSE (kbps)	MRE (%)	PLCC
DT	31	94	246	18	0.88
RF10	36	89	179	18	0.93
ADA	126	492	573	130	0.59
ERT10	7	93	182	19	0.93
BAGGING	22	89	179	17	0.93
BAYES	3	2,540	6,530	545	-0.14
KNN	6	229	353	42	0.70
NN	305	333	489	70	0.20
SVM	143	10^{23}	$2 \cdot 10^{23}$	$2 \cdot 10^{23}$	0.12



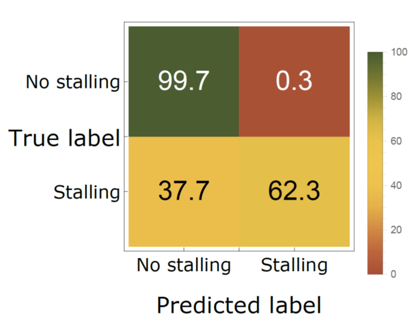
- ERT10 & BAGGING realize **MAE below 100kbps**, and **RMSE below 190kbps** (penalizes larger errors)
- **80% of the slots** are estimated with **errors below 100kbps**
- Predictions are ***highly correlated*** with the target (***PLCC = 0.93***)

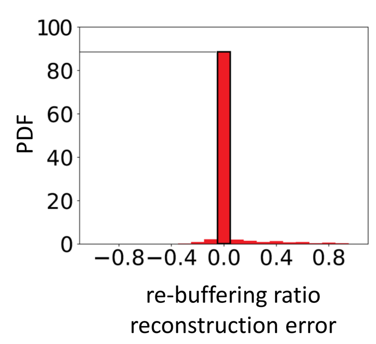


ONLINE PREDICTION OF STALLING

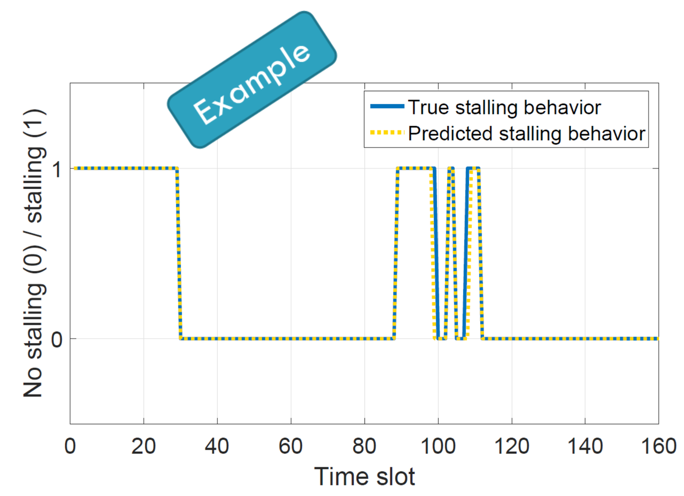
- **Binary classification task:** playback stalled/not-stalled at every new slot

	Accuracy (%)	Recall (%)	Precision (%)	5-CV time (minutes)
DT	96	64	68	57
RF10	97	55	88	3
ADA	95	29	61	154
ERT10	97	54	88	1
BAGGING	97	65	87	63
BAYES	50	86	9	1
KNN	96	48	71	10
NN	94	0	0	600
SVM	84	62	21	36
ISO10	86	13	8	4
LOF	86	11	6	46



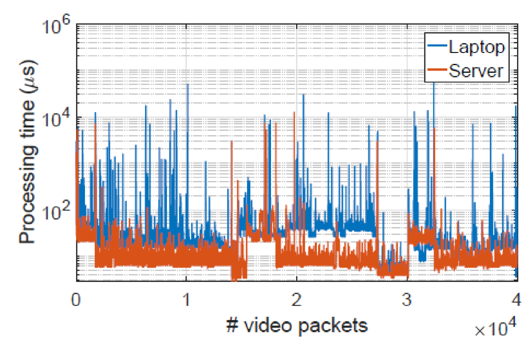


- **per-slot re-buffering** estimation errors are high, **stalling slots under-estimated…**
- …but **estimation of re-buffering ratio** is ***perfect for almost 90% of the videos***

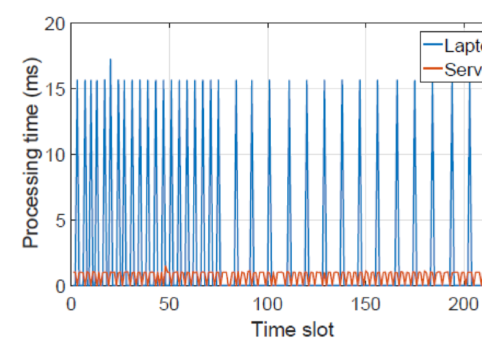


COMPUTATIONAL TIME & IMPACT OF FEATURE SELECTION

- Evaluation of ***full feature set update time*** (done at every new incoming packet) and ***prediction time*** (done for every 1s slot), using an upper bound **with all 207 features**
- ***laptop*** (i5 CPU, 8GB RAM) vs. ***server*** (Xeon Silver, 48 cores, 128GB RAM)
- server: avg. **duration of full feature set update is 13 µs, prediction time below 1.4ms**
- Laptop: **avg. feature update takes 37 µs, prediction time below 16ms**



Features update time at each new packet.



Prediction time.

Features	Accuracy (%)
All	92
F_C	70
F_T	73
F_S	96
F_{DOWN}	90
F_{UP}	90
F_{TOP20}	95

Features	MAE [kbps]	RMSE [kbps]	MRE [%]	PLCC
All	93	182	19	0.93
F_C	275	407	55	0.58
F_T	253	377	51	0.64
F_S	68	157	14	0.95
F_{DOWN}	105	195	21	0.92
F_{UP}	106	198	21	0.92
F_{TOP20}	81	175	16	0.93

Features	Accuracy (%)	Recall (%)	Precision (%)
All	97	54	88
F_C	96	10	30
F_T	97	17	51
F_S	99	72	91
F_{DOWN}	98	41	87
F_{UP}	98	47	74
F_{TOP20}	97	56	86

- Automatic Feature Selection – **CS features (F_S)** alone provide the best results (69 features), improving overall performance. **Top 20 features (F_{TOP20})** provide ***similar improvement with much less features***