SAP: Stall-Aware Pacing for Improved DASH Video Experience in Cellular Networks

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Motivations

* 49.6% of video sessions experience video problems
* 40-50% of video sessions experience rebuffering events

http://fortune.com/2016/03/01/snapchat-facebook-video-views-2/
Developing Video QoE-aware solutions is crucial to realize a satisfactory streaming performance for all system users.
Dynamic Adaptive Streaming over HTTP (DASH)


- DASH Aware Network Element (DANE) coordinates multiple clients sharing the same network resources
DASH Quality of Experience

Visual Quality issues
- Poor image quality
- Noticeable quality switches

Temporal Quality issues
- Long initial startup delay
- Rebuffering frequency
- Rebuffering duration

Largest Annoyance in Streaming Experience

- Startup delay
- Stalls
- Image quality

Outline

- SAP Design
- SAP Performance Evaluation
- Conclusions
SAP Assumptions

- A group of $U$ DASH clients share a cellular base station (BS)
- Video traffic is assigned a portion of network resources ($C$)
- The BS resource management and video quality control are black-boxes to SAP
- Channel quality information per client is assumed available from the network
SAP-OP: an Optimized QoE-aware decision engine that determines the delivery rates of different streams based on joint application and network states
**SAP Overview**

**SAP-PM**: Pacing manager controls the delivery rate of different streams towards the bottleneck.
**SAP Overview**

**SAP-AL**: an application state logger to maintain relevant application information for different clients

**SAP-NL**: an Network state logger to maintain relevant network information for different clients
SAP QoE-Oriented Pacing Optimizer

- Tunable quality utility inspired by VQM
  \[ \Upsilon_u(x_u) = (1 - e^{-\rho_u x_u / r_q}) \]
  Can Be tuned to accommodate device capability and or user priority.

- Stall penalty identified by the probability of segment stalling based on the segment size distribution
  \[ \pi_u = \text{Prob}(d_u > D_u) = \text{Prob} \left( \frac{S_{\theta u}}{x_u} > D_u \right) \]
  - New segment vs. ongoing segment

- No switching component!
SAP Optimization Program

\[
\max_{x_i} \sum_{u=1}^{U} y_u(x_u) - \beta \pi_u \\
\text{such that} \\
\sum_{u} x_u / \gamma_u < \zeta \\
x_u \in \{\hat{r}_1, \ldots, \hat{r}_Q\}
\]

- Discrete non-linear program

Resource allocation \hspace{1cm} SAP \hspace{1cm} Quality adaptation
(ms) \hspace{1cm} (250–1000ms) \hspace{1cm} (4+ seconds)

Real-time performance is achieved by using \textit{separable programming}
Collaborative vs. Non-collaborative SAP

- **Collaborative SAP**
  - SAP–AL implements a DASH Assisting Network Element (DANE) interface that receives status messages from the client

- **Non–collaborative SAP**
  - **Unencrypted session:**
    1. Extract relevant information from MPD file
    2. Estimate the buffer level
  - **Encrypted session:**
    1. Buffer–level estimation
    2. Educated arbitrary discrete rates
    3. Segment duration estimation
Collaborative vs. Non-collaborative SAP

Collaborative SAP

Non-collaborative SAP

Unencrypted session:
1. Extract relevant information from MPD file
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Encrypted session:
1. Buffer-level estimation
2. Educated arbitrary discrete rates
3. Segment duration estimation
Performance Evaluation Setup

- Real end-devices streaming over a simulated network
- Real content using the public iVID video dataset
- Each video client is connected to a corresponding user equipment in the simulated network using a combination of virtual and real switches
- STATIC IP addresses and routes are defined in both physical and simulated nodes
- Master controller orchestrates the experiment and implements the traffic managers
Performance Evaluation Setup

- GPAC client is extended with multiple algorithms including BBA2, FESTIVE, CONV, ARBITER.
- GPAC is modified to allow configurable buffer size, initial buffering and rebuffering behavior.
- LTE scheduler in ns3 is modified to report the channel quality information to traffic managers.
- Clients report application information to the master controller.
Performance Evaluation

- We compare the performance of three schemes including SAP, no traffic control (noTc), and AVIS [Mobicom 13]
- Traffic manager optimization programs are implemented using C and LINDO API
- Key performance metrics
  - $r_{av}$: The average received quality rate per session
  - $n_{st}$: The average number of stalls per session
  - $t_{st}$: The average stall duration per session
  - $n_{sw}$: The average number of switches per session
  - $l_{sw}$: The average switching level
  - $x_{q}$: objective QoE metric
    \[
    x_{q} = \max(0, 0.17 + 5.67 \frac{q_{av}}{qQ} - 6.72 \times \frac{q_{std}}{qQ} - 4.95\varphi)
    \]
  - $\varphi$: standard deviation of user QoE
Scenario 1: Collaborative Clients with Diverse Link

- Six clients located at incremental distances from an LTE eNodeB with 6 resource units (RU)
- Clients initiate video streaming with a one second gap

![CDF Graph](image)

CDF

Achievable RU Rate (Kbps)
Scenario 1: SAP improves stall performance

SAP reduces the number of stalls and stall duration
Scenario 1: SAP improves stall performance

SAP significantly reduces the stall QoE penalty

\[ \varphi = 0.875 \times \max(0, 1 + \ln(f_{st})/6) + 0.008333 \times \min(t_{st}, 15) \]
How SAP improves stall performance?

SAP reshuffles resources to support clients to avoid stalls when necessary.

AVIS behavior is stall agnostic.
SAP impact on quality rate and switching frequency

Traffic control reduces the average quality rate

SAP has limited impact on representation switching
SAP ensures QoE fairness

While avoiding QoE extremes, the average QoE of all users drops

SAP noticeably reduces the QoE variation among users.
Collaborative vs. Non-collaborative SAP

SAP performs equally well when the buffer level estimator is used in the non-collaborative case.
Conclusions

- The independent operation of client–based quality control and the base station downlink scheduling leads to a distinct QoE among users in cellular systems.

- SAP indirectly integrates the quality control and scheduling loops using a QoE–aware framework based on joint network and application states.

- SAP leads to a dramatic reduction, up to 90%, in the stall QoE penalty for different DASH client adaptation algorithms in a wide variety of operating conditions.

- SAP reduces the QoE diversity by up to 40% leading to a fair QoE for video users operating in distinct channel conditions.

- SAP achieves similar performance in both collaborative and non–collaborative scenarios.

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