Optimized Strategies for Real-Time Multimedia Communications from Mobile Devices

Enrico Masala

Dept. of Control and Computer Engineering, Politecnico di Torino, Torino, Italy

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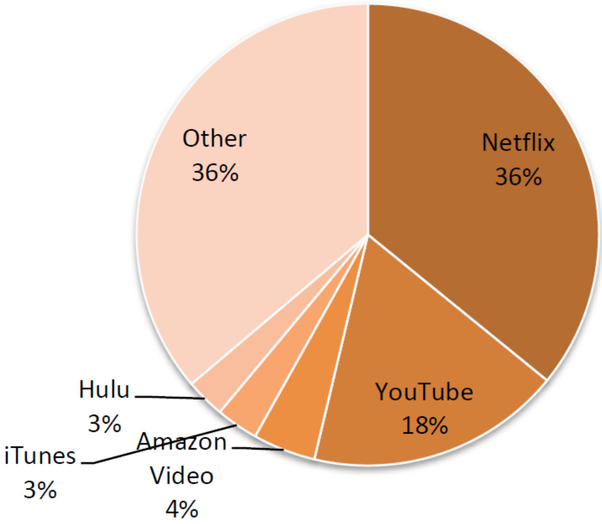
Outline

- Introduction
- Background technologies: SVC, DASH
- Live mobile streaming optimization
  - Problem formulation
  - Proposed solution and results
- Outlook on the mobile live video trend
  - Example: Periscope
- Conclusions

Multimedia Communications

- Dramatically increased in recent years
  - Netflix video accounts for more than 1/3 of traffic in North America at peak hours [1] *(Downstream peak period applications, North America, Fixed Access, Jun 2016)*



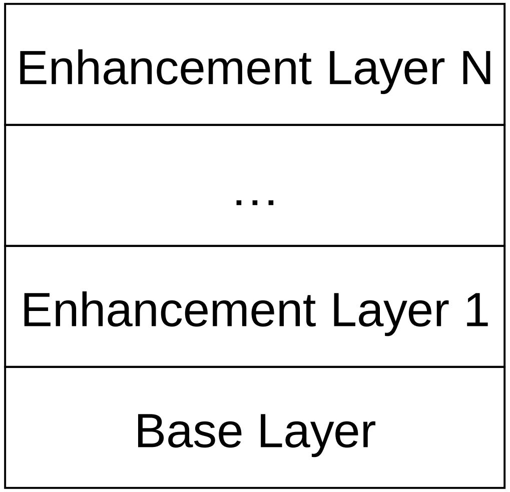
- Anybody can produce content
  - Using, e.g., a mobile device
  - Upload it on streaming platforms (Youtube, etc.)
  - Can even be done live!

Background

- Multimedia encoding and transmission: can be done in many different ways
- We focus on:
  - Scalable coding (different resolution, quality, frame rate)
  - Streaming using HTTP (through the DASH standard)

Scalable Coding

An embedded way to represent a compressed bitstream so that players can extract different versions (layers) of the content using only some portions of the bitstream



Coding example with spatial scalability:

Original image

Base layer

Upsampled base layer

Layered Structure and Advantages

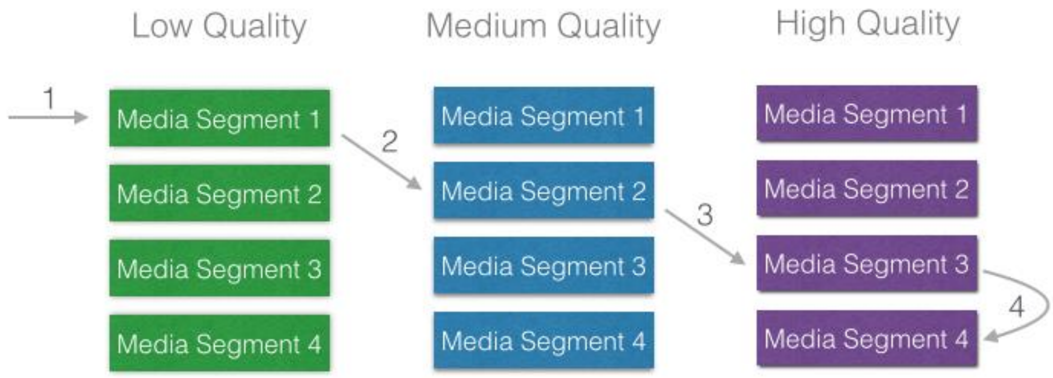
- For efficiency reasons, every layer only adds “refining” information (to improve quality) to the information already present in another layer
  - Other layers are needed to fully decode one layer
  - Only the base layer (the lower one) can be independently decoded
- Advantages:
  - No need to keep more versions of the same content encoded at different qualities: **space savings**
  - No need to process data which are useless to extract a reduced quality version: **complexity savings**

Dynamic Adaptive Streaming over HTTP

- If the network is good, resources can be downloaded in any way, e.g., using HTTP
- How to handle bandwidth variation? → Adaptation
- How to adapt on HTTP?
  - TCP cannot be explicitly controlled

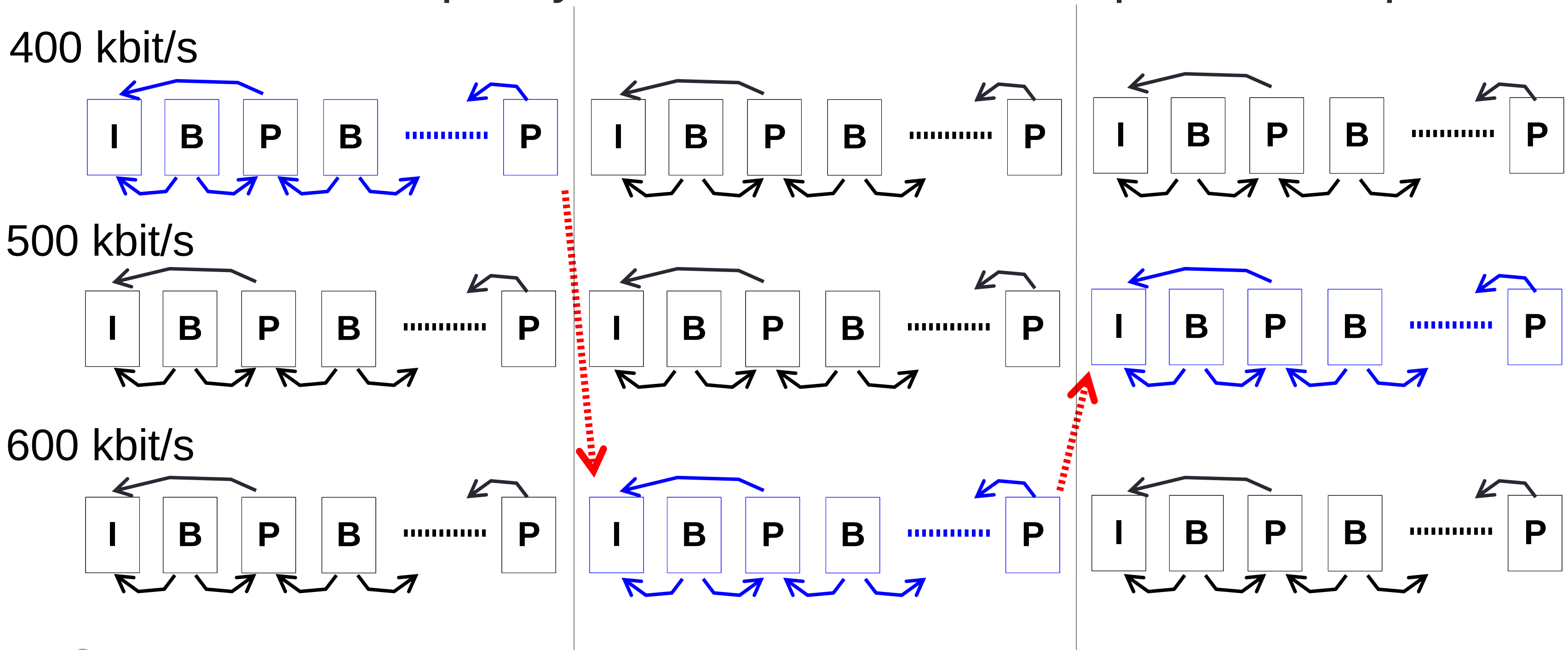
Dynamic Adaptive Streaming over HTTP

- Content is split into “chunk”, temporally aligned, with different characteristics (e.g., bitrate)
- The client requests chunks as **independent** HTTP resources
- The client request different resources over time in order to adapt to the time-varying network conditions
  - The **client drives** the adaptation process



Dynamic Adaptive Streaming over HTTP

- Can switch quality/rate/resolution etc. at predefined points



- Optimized strategies difficult to design (they are not included in the standard)
- Scalable video is supported (more or less layers requested)

Multimedia Communication Optimization

- General problem statement

$$\min_{\{\Pi_i\}} E[D(\Pi_i)] \quad \text{subject to} \quad R(\Pi_i) < R_{max}$$

To be solved for each media segment (e.g., interval between two I frames)

• $E[D(\Pi_i)]$ = **expected distortion** for a given coding and transmission policy i

• **Policies**: set $\{\Pi_i\}$ (for the units – e.g., frames – in the media segment)

• Policy i = (e.g.) an assignment to a certain **coding parameters and channel transmission policies** for each unit (e.g., a frame) in the segment

• $R(\Pi_i)$ = **rate** caused by using the coding and protection level corresponding to the policy Π_i.

(notation from [2])

Difficulties and Possible solutions

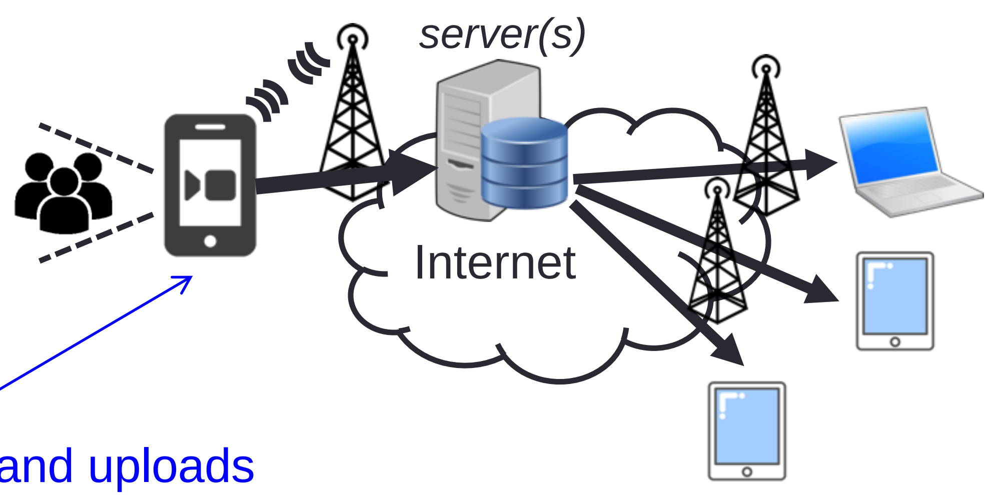
- Estimating the distortion is difficult due to
  - Dependency between coding units (linear additive approximations)
  - Uncertainty in estimating the channel conditions
- The problem grows exponentially in complexity
  - Lagrangian-based solutions (if it is possible to express the terms as sums)
  - Heuristic algorithms

Specific Cases

- The problem needs to be tailored to the specific cases
- Good understanding of the context is essential to adapt and simplify the analytical formulations
- For this presentation, we focus on:
  - upload from mobile devices
  - using stateless HTTP servers
  - that serve multiple clients

Live Mobile Streaming to Many Users

- Constraints
  - Stateless HTTP server (for simplicity and low cost)
  - Support dynamic adaptive streaming, optimized for many users
  - Save, in any case, the maximum quality video and eventually send everything to the server



Captures, encodes, and uploads live video

Results from [3]

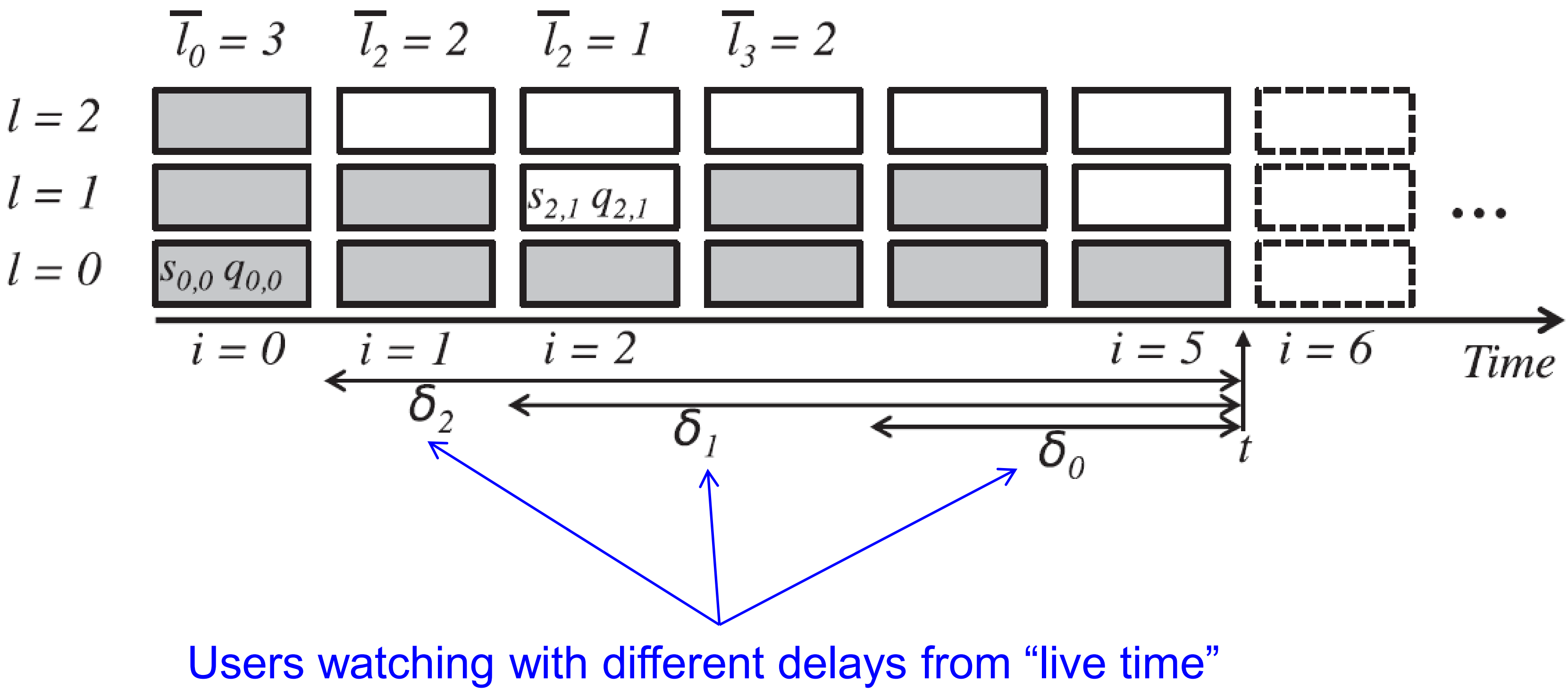
Proposed Solution

- Use scalable video encoding
- Upload scheduling problem: **optimize the order** of chunk uploading, depending on available mobile upload bandwidth, to satisfy the largest number of users watching the video according to their “wishes”
- Use DASH
  - low-cost stateless HTTP server
  - each **user** drives the adaptation, it can choose a **different** delay/quality **tradeoff**
    - The longer the delay from the live point, the better the quality

(from [Siekkinen,Masala17])

Example of Situation

- Chunks in grey have already been uploaded to the server



Analytical Analysis

- Total number of combinations: unfeasible unless number of chunks is very low
- Simple formulation: how can chunks be put into segments?
- Example for constant size chunks: allocate V elements in t bins (multinomial coefficient)

$$\left(\!\!\binom{V}{t}\!\!\right) = \binom{V+t-1}{t} = \frac{(V+t-1)!}{t!(V-1)!}$$

- Optimize for the quality of all clients, while considering the bandwidth constraints

Problem Formulation

- Quality / Distortion of a client, watching the video with a given delay (δ_n) and upload policy (π_k):

$$Q_n^{\pi_k} = \sum_{(i,l)} \left(x_{i,l}^{\pi_k}(i - 1 + \delta_n) q_{i,l} \right)$$

- Optimization

$$\underset{\pi_k \in \Pi}{\text{maximize}} \; f(Q_0^{\pi_k}, \ldots, Q_{N-1}^{\pi_k})$$

$$\text{subject to: } S(\pi_k) \leq \sum_{i=1}^{d+\max\delta_1,\ldots,\delta_N} B_i$$

- Possible combination of client qualities, e.g., average

$$f(Q_0^{\pi_k}, \ldots, Q_{N-1}^{\pi_k}) = \frac{1}{N} \sum_{n=0}^{N-1} Q_n^{\pi_k}$$

General Intuition of the Problem

- It is better a more recent chunk of a lower layer that benefits all clients

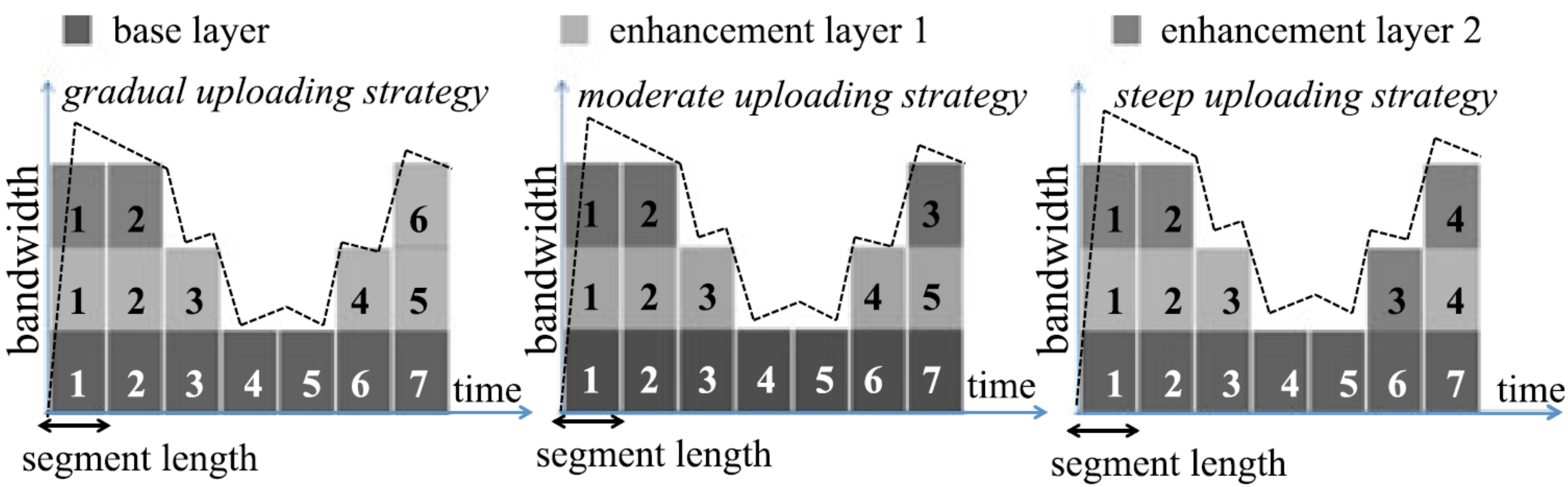
or

- It is better a less recent chunk of a higher layer that improves the quality only for some clients?

- If time allows, 2nd would be better, but channel is uncertain, there might be the risk that important layers are not transmitted for clients with low delay

Possible Strategies

- Example of “naïve” fixed strategies: gradual, moderate, steep
  - Note the different chunks uploaded when bandwidth is available



Other Proposed Strategies

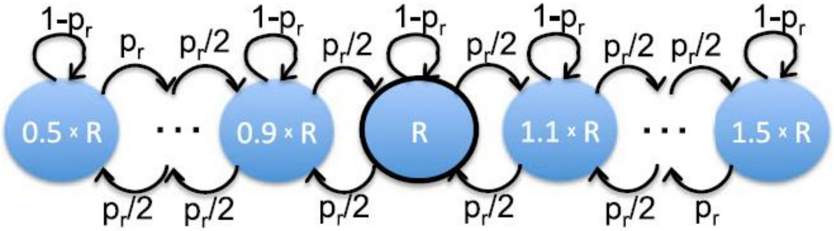
- Greedy approach: send the chunk that has the best quality(increase)/size ratio

$$h_i \leftarrow \frac{q_{i,\bar{l}_i+1} - q_{i,\bar{l}_i}}{s_{i,\bar{l}_i+1}} \qquad \mathcal{O}((t+V)\log t)$$

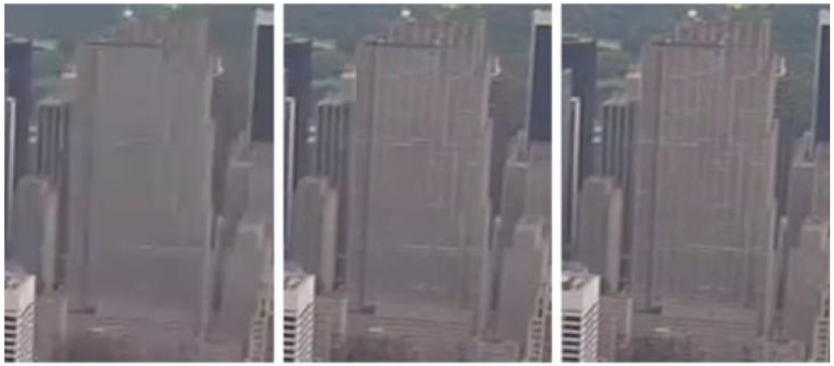
- Dynamic programming for 0/1 knapsack problem
  - Chunks that can be fitted into the available bandwidth
  - One chunk can be used only once (0/1 knapsack)
  - Local knapsack or global knapsack (upper bound, if the channel were known)

Simulation Setup

- Channel: Markov chain of different rates



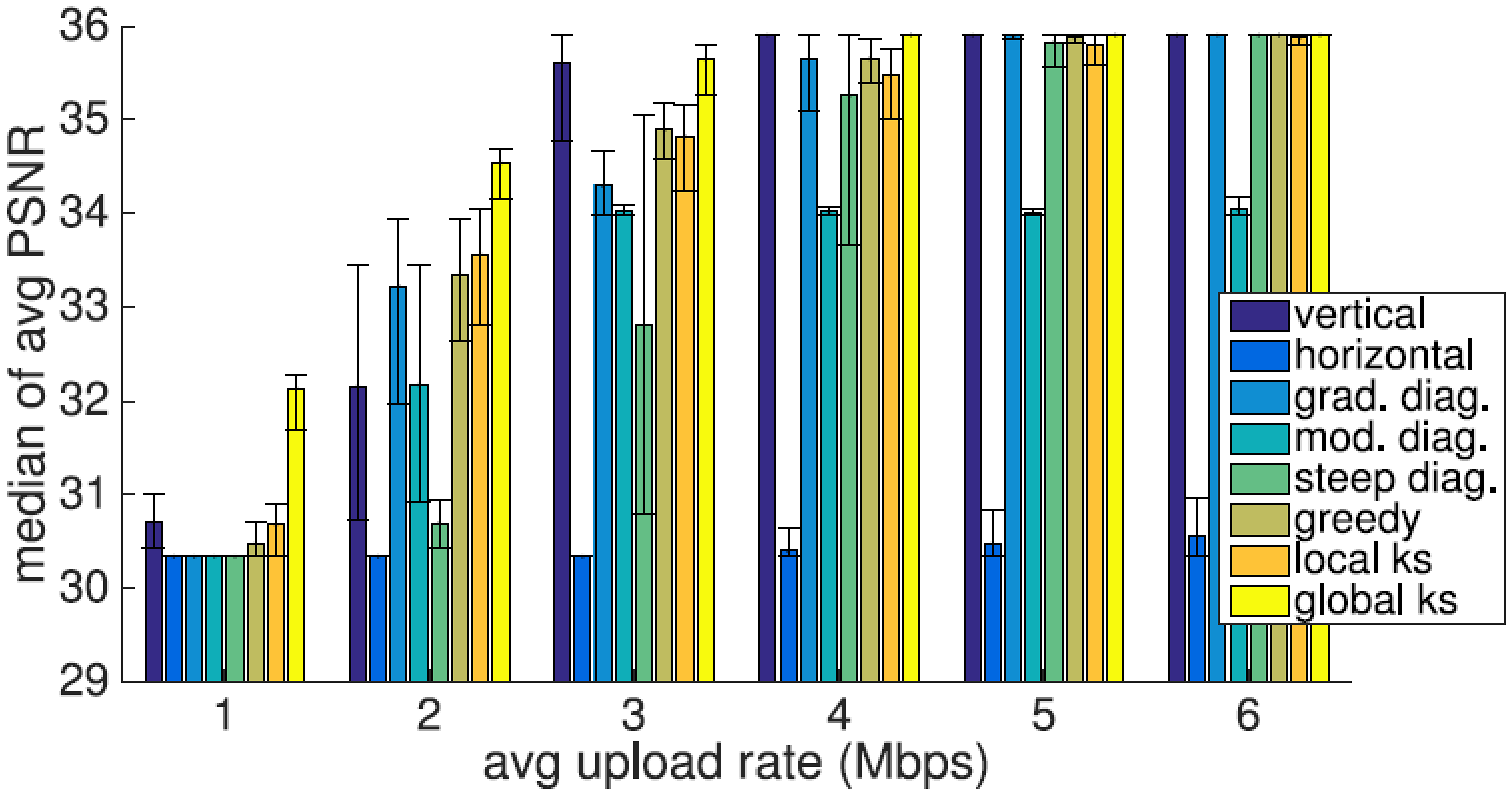
- Spatial and SNR scalability, standard test sequences, from QCIF (176x144) to 4CIF (704x576) resolution



(a) Base layer (L0) (b) Enh. layer #1 (c) Enh. layer #2

Results

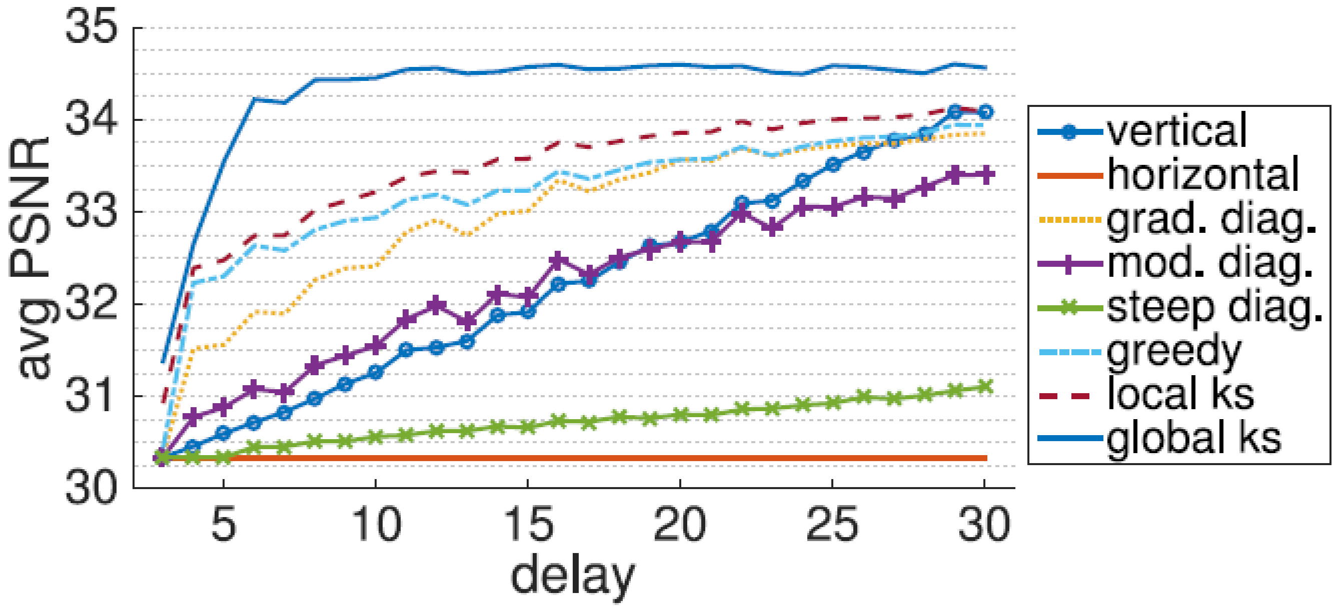
- Quality measured through PSNR (Peak Signal-to-Noise Ratio) w.r.t. the original video sequence at full resolution



Results

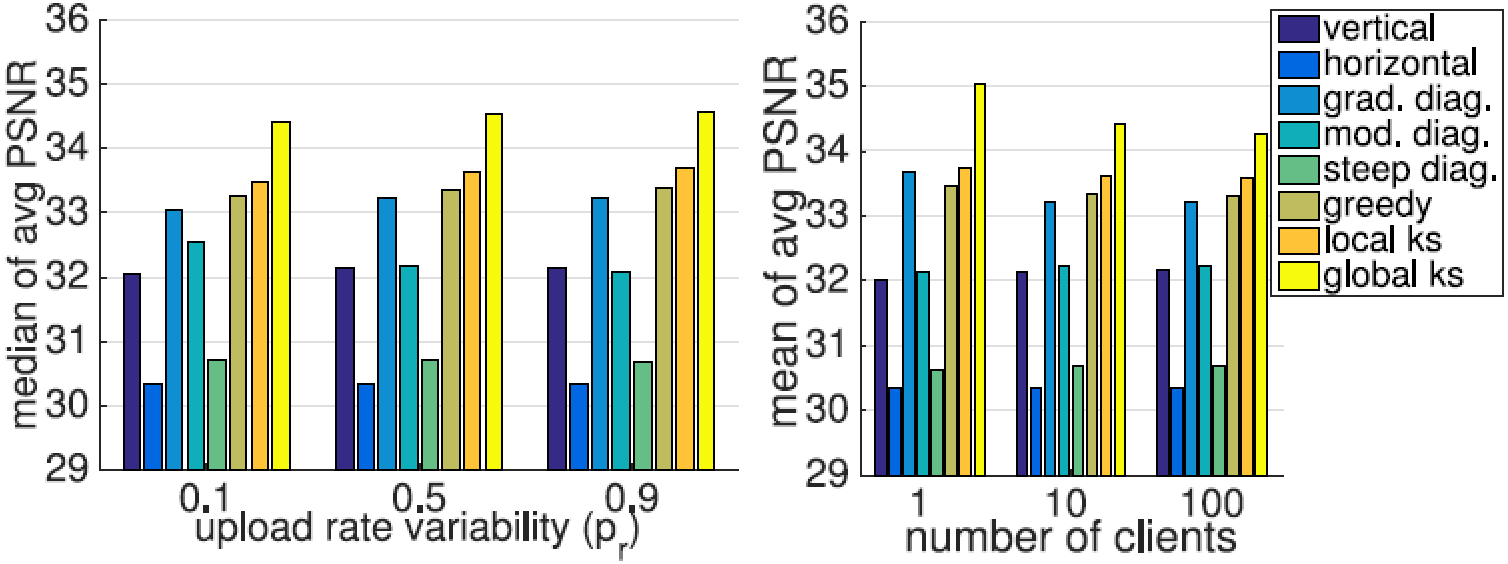
- Tradeoff between quality and delay, for clients

  (2 Mbps upload rate)



Results

- Stability vs simulation parameters



First Conclusions

- Optimized adaptation strategies for live multimedia communications from mobile devices have been designed
- Simple greedy and local optimal algorithms have been provided
- They are shown to perform not far from the global optimum which has channel knowledge in advance
- The algorithms are simple and can be easily implemented in mobile devices

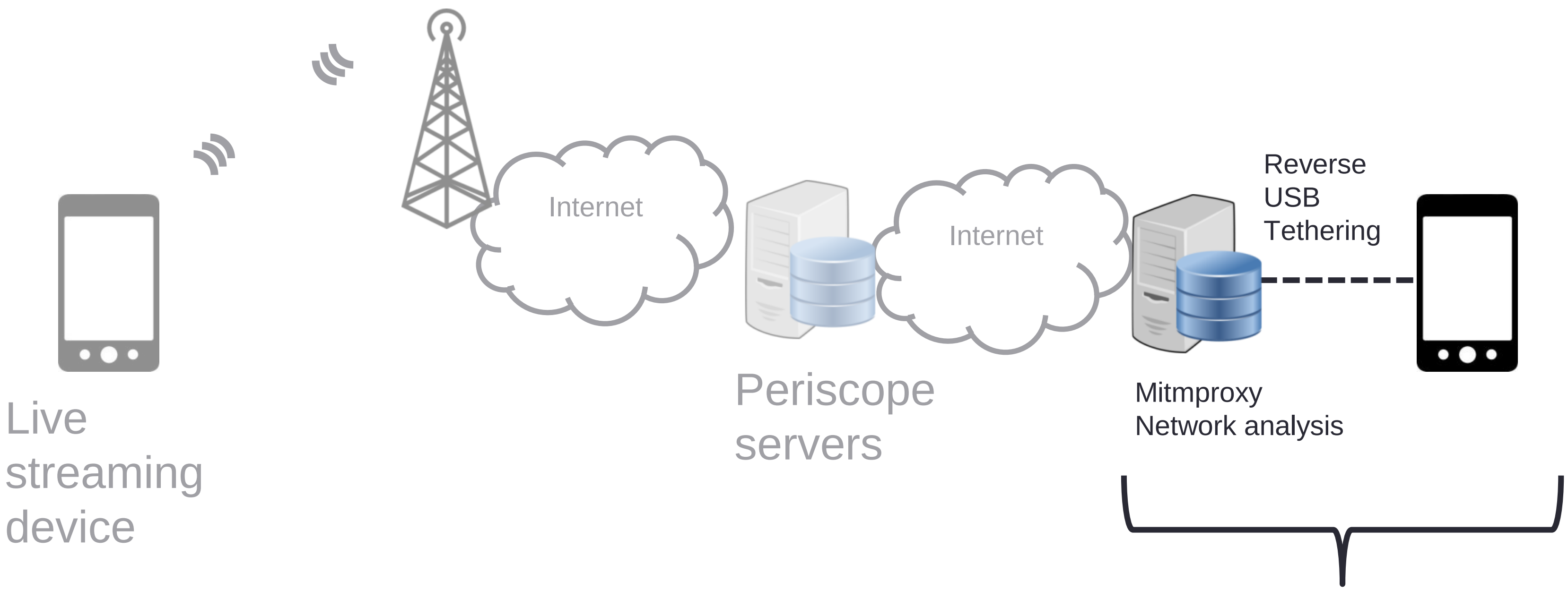
Outlook on the Mobile Live Video Trend

- Mobile live video broadcasting is becoming increasing popular. For instance:
  - App for live streaming from mobile devices:
    - Periscope, Facebook Live, Meerkat, etc.
  - Very popular applications: tens of thousands of users, growing
- Number of receivers per single event can vary significantly
  - Few or 100s / 1,000s

We focused on Periscope

- App for live streaming from mobile devices
  - Similar to Facebook Live, Meerkat, etc
  - Very popular application: tens of thousands of users, growing
- Possibility of selecting a (public) random broadcast through the app “Teleport” button
  - Used for our analysis
- Live streaming with different protocols: RTMP and HLS
  - RTMP: Real Time Multimedia Protocol (Adobe)
  - HLS: HTTP Live Streaming (Apple)

Periscope Analysis Scenario



Our analysis

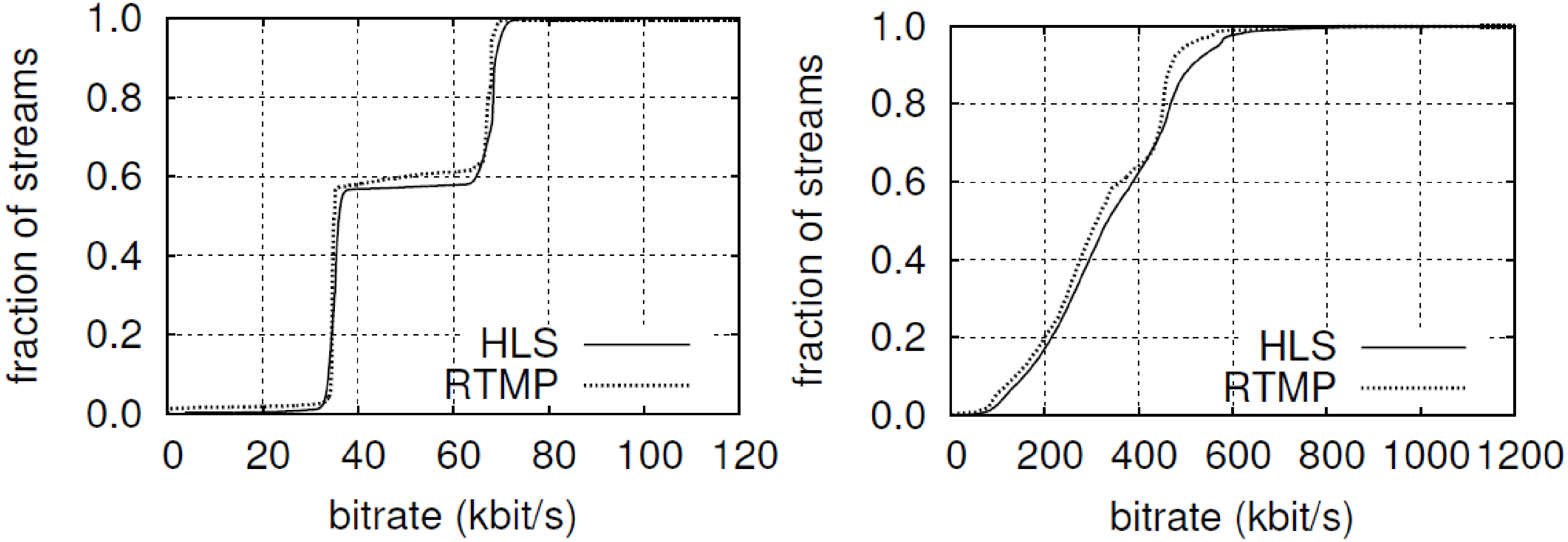
Results from [4] (Sep 2016)

Periscope Challenges

- Mobile upload: unreliability of wireless channel
- Avoid freeze events (rebuffering events) at the receiver side
- Tradeoff: latency vs freeze probability in playback

Media Characteristics

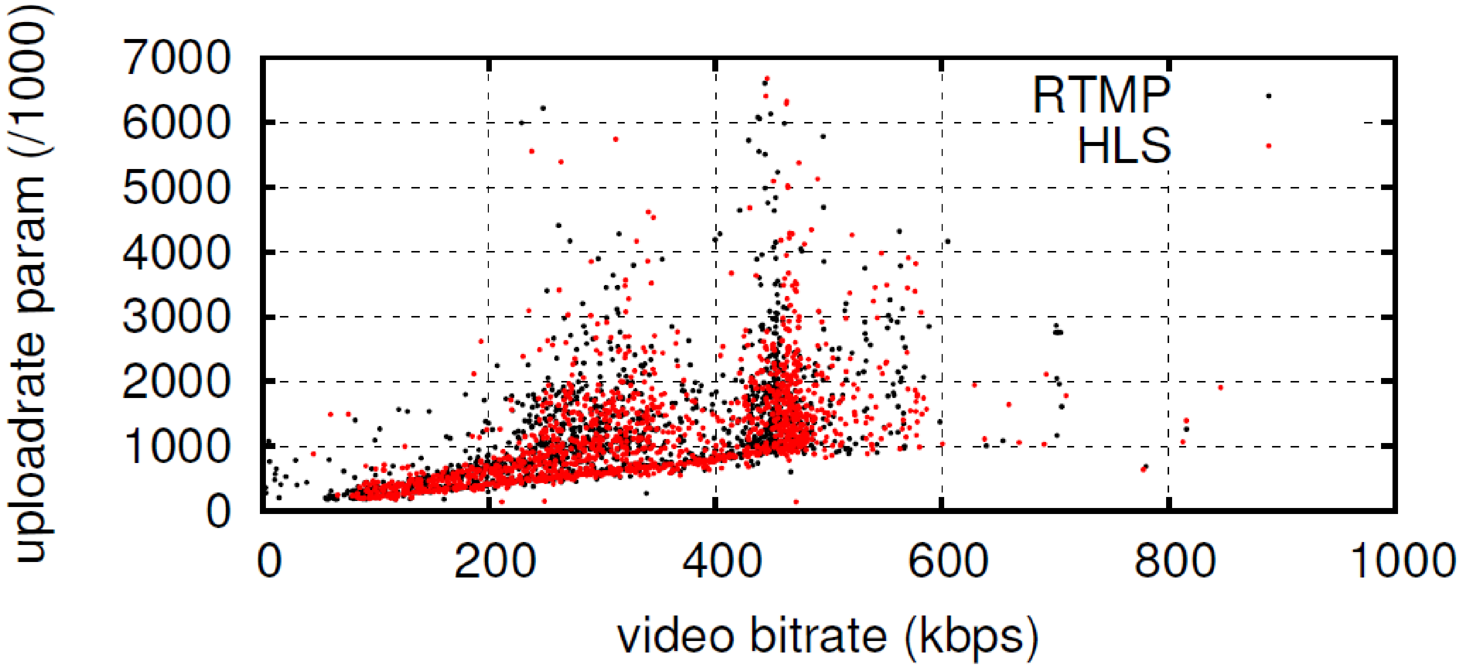
- Audio: 32 and 64 kbit/s
- Video: mostly from 100 to 600 kbit/s, resolution: 320 x 568
- Independent of the protocol: RTMP or HLS



(a) audio (b) video

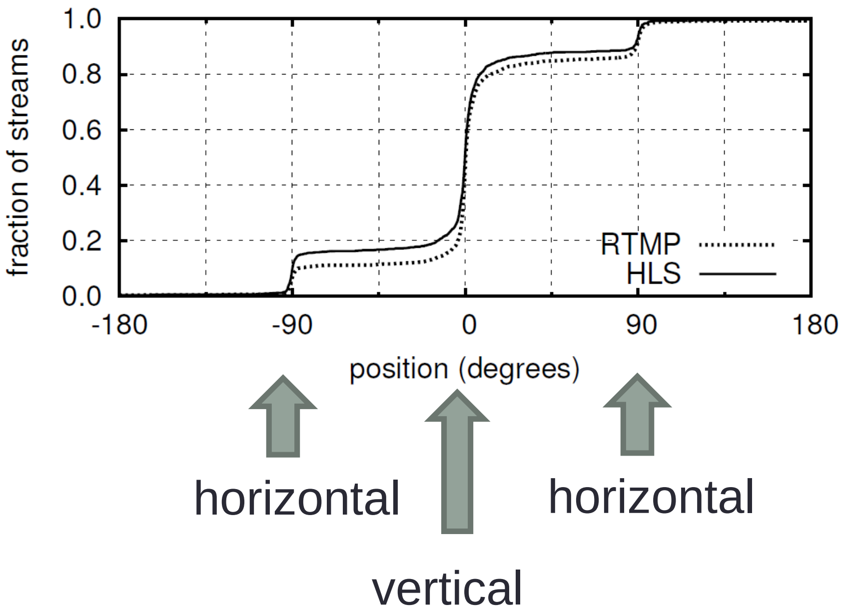
Insights from Embedded Information

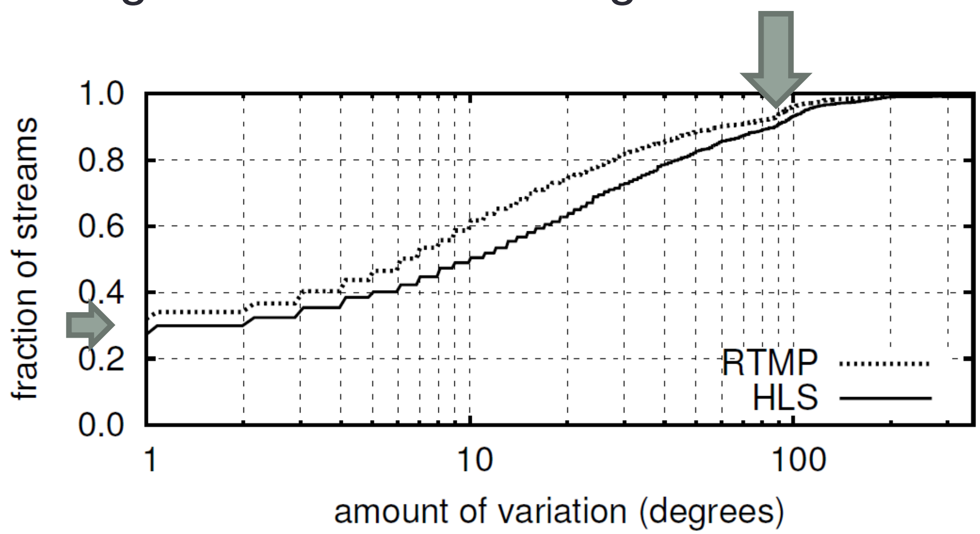
- The stream contains embedded information from Periscope
- Most interesting is *uploadrate* (probably the estimated available upload bandwidth)
- Video rate is capped at about 450 kbps. HLS similar to RTMP



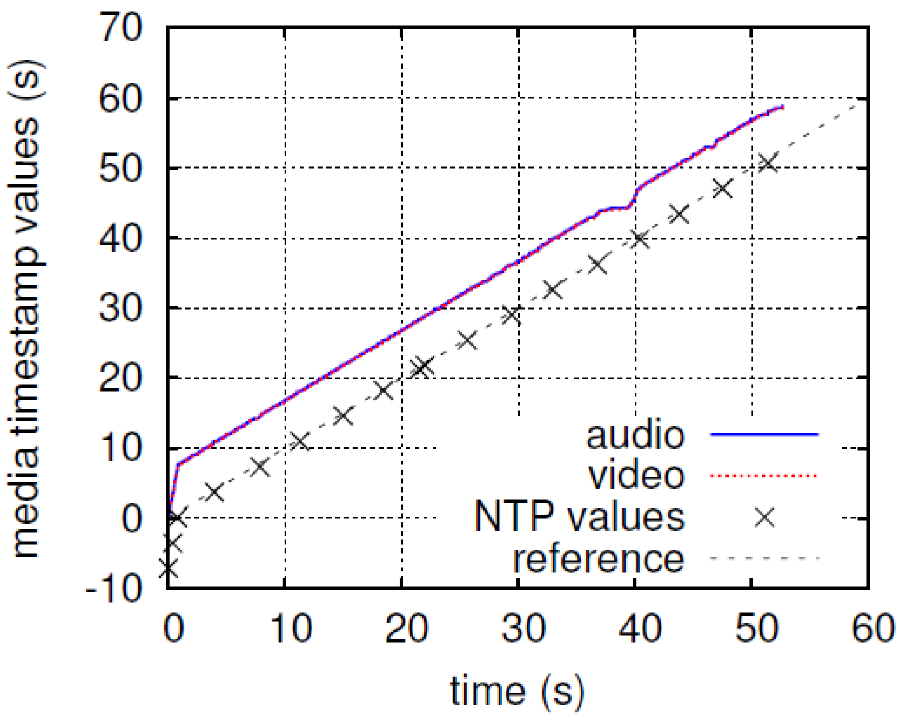
How the Mobile Device is Handled

- From information embedded in the stream:
  - Average position: about 60% vertical
  - 30% of the cases: almost no movements
  - 10% of the cases: rotation > 90 degrees while streaming

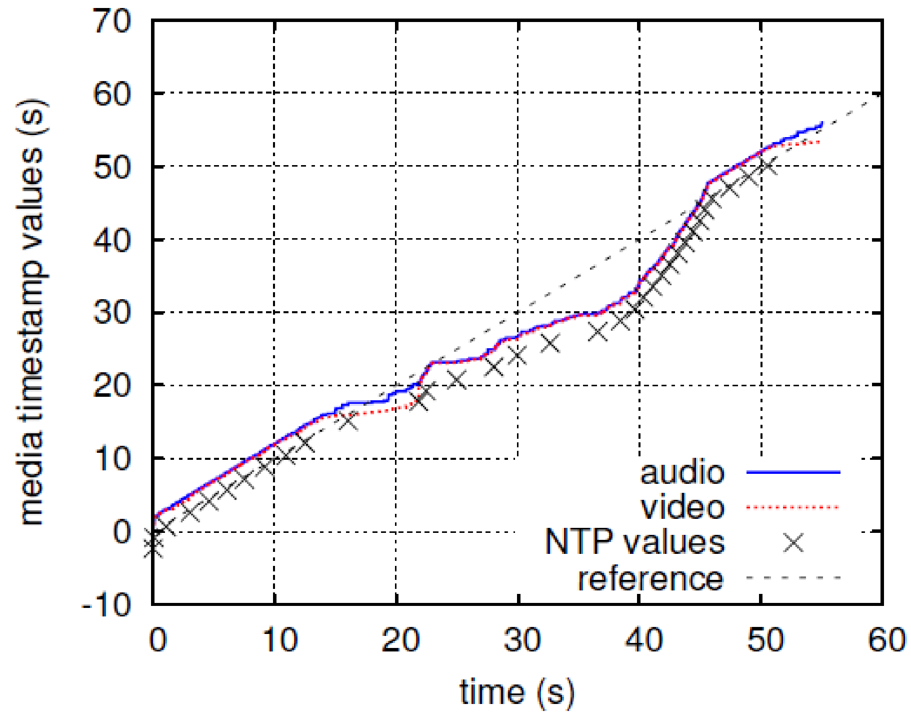




Behavior Over Time: RTMP

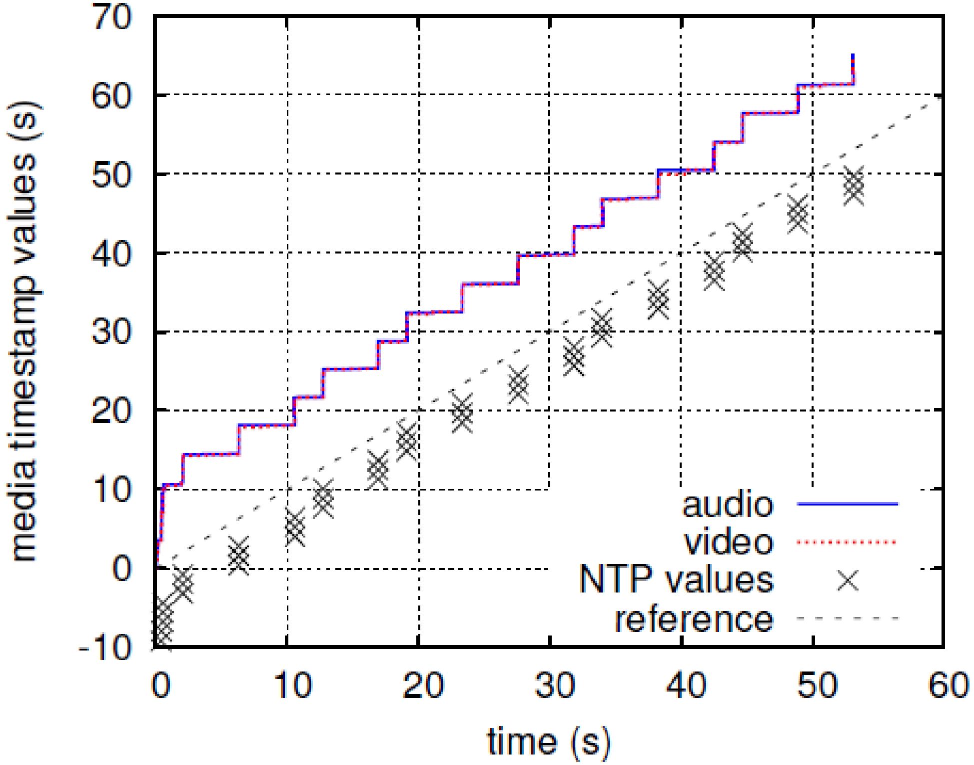


(a) RTMP sample #1



(b) RTMP sample #2

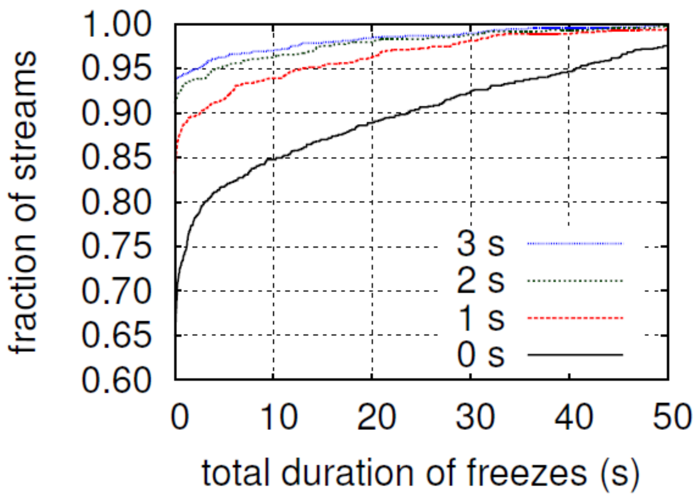
Behavior Over Time: HLS



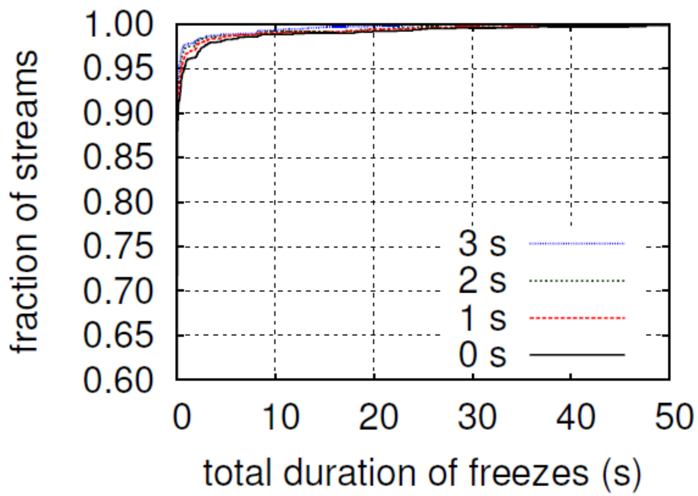
(c) HLS sample #1

Playback Impairments

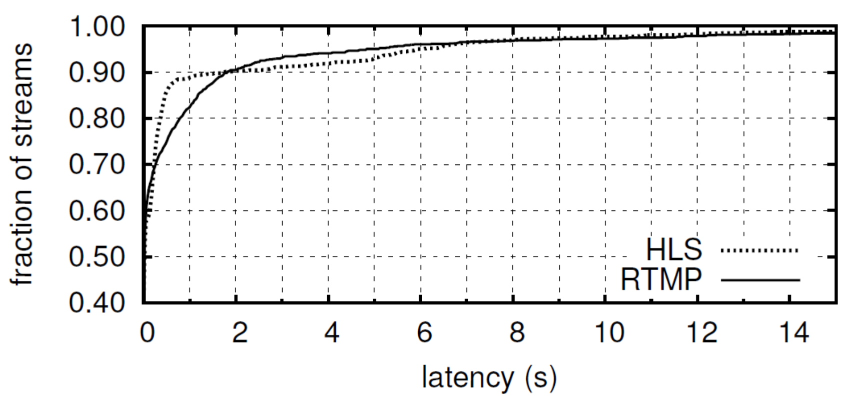
As a function of a simulated initial playout delay (no access to the app…)



(a) RTMP



(b) HLS



1 or 2 s enough for 90% of users, depending on the protocol

Conclusions

- We provided an overview of the status of real-time multimedia communications from mobile devices
- A general framework for multimedia communication optimization has been discussed, with particular reference to optimization strategies for mobile live streaming
- An outlook about current mobile streaming services has been delineated, focusing on the specific characteristics of “Periscope”
- Future work will be devoted to further experiment with adaptation strategies, both in the case of upload and in the case of existing applications

References

[1] Sandvine Global Internet Phenomena Report – Latin America & North America, June 2016, Downstream peak period applications, North America, Fixed Access.

[2] P.A. Chou, Z. Miao, “Rate-Distortion Optimized Streaming of Packetized Media”, IEEE Transactions on Multimedia, vol. 8, n. 2, Apr 2006, pp. 390-404.

[3] M. Siekkinen, E. Masala, J. K. Nurminen, “Optimized Upload Strategies for Live Scalable Video Transmission from Mobile Devices”, IEEE Transactions on Mobile Computing, DOI: 10.1109/TMC.2016.2585138 (ISSN: 1536-1233), Apr 2017.

[4] L. Favario, M. Siekkinen, E. Masala, “Mobile Live Streaming: Insights from the Periscope Service”, IEEE Workshop on Multimedia Signal Processing (MMSP), Montreal, Canada, Sep 2016.