AVIS: A Scheduling Framework for Adaptive Videos over Cellular Networks

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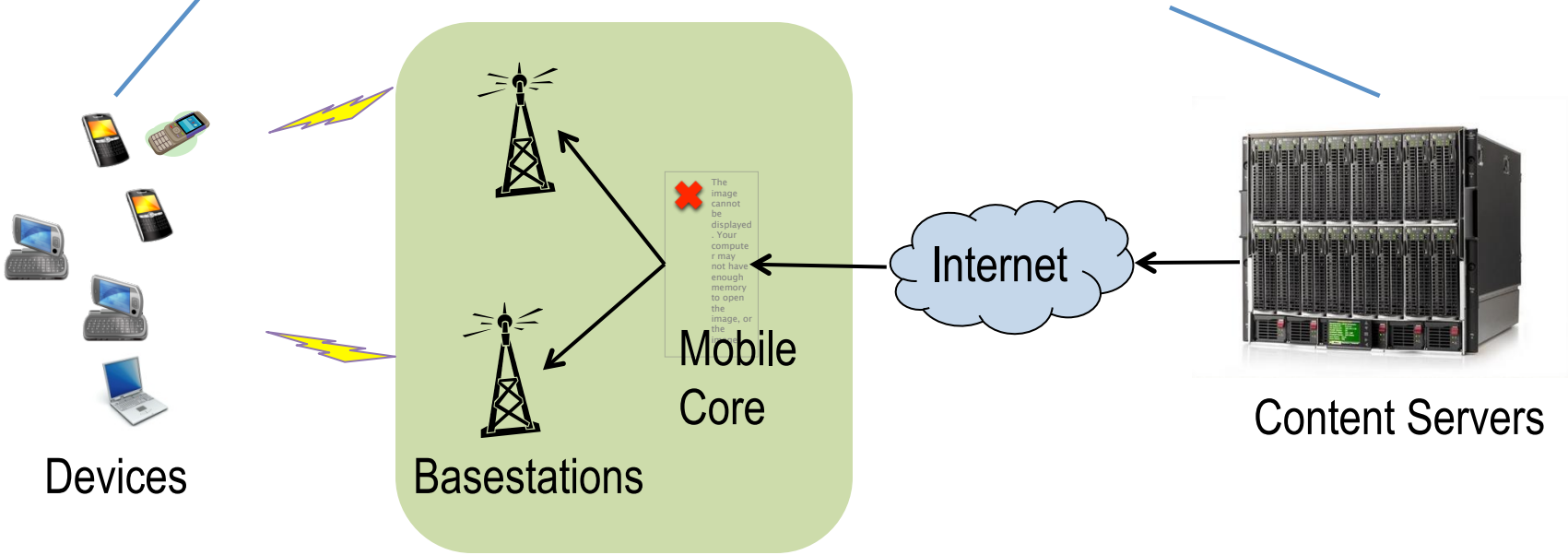
Trends: Video Dominated Mobile Internet

Device Evolution:

- Smartphone sales up 50% in 2Q 2010, predicted: 400 M in 2011
- Capable of HD quality video

Content Evolution:

- Video Content growing: movies, YouTube, Social networking, thin-clients, conferencing
- 64% Mobile content video by 2013 [Cisco]



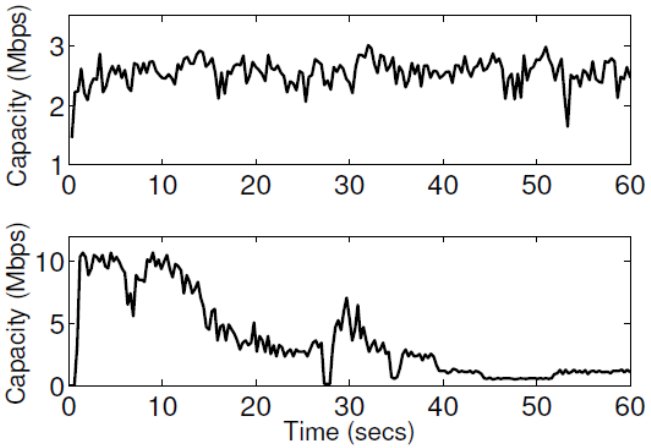
Network Evolution:

- Increasing focus on data: Major LTE rollouts (Verizon, DoCoMo,…), and 3G rollouts (India)
- Mobile network only viable Internet option in many places

Dynamic Adaptive Streaming over HTTP (DASH)

WHAT IS IT?

This delivery method allows the stream to adapt the video experience to the quality of the network and the device's CPU.



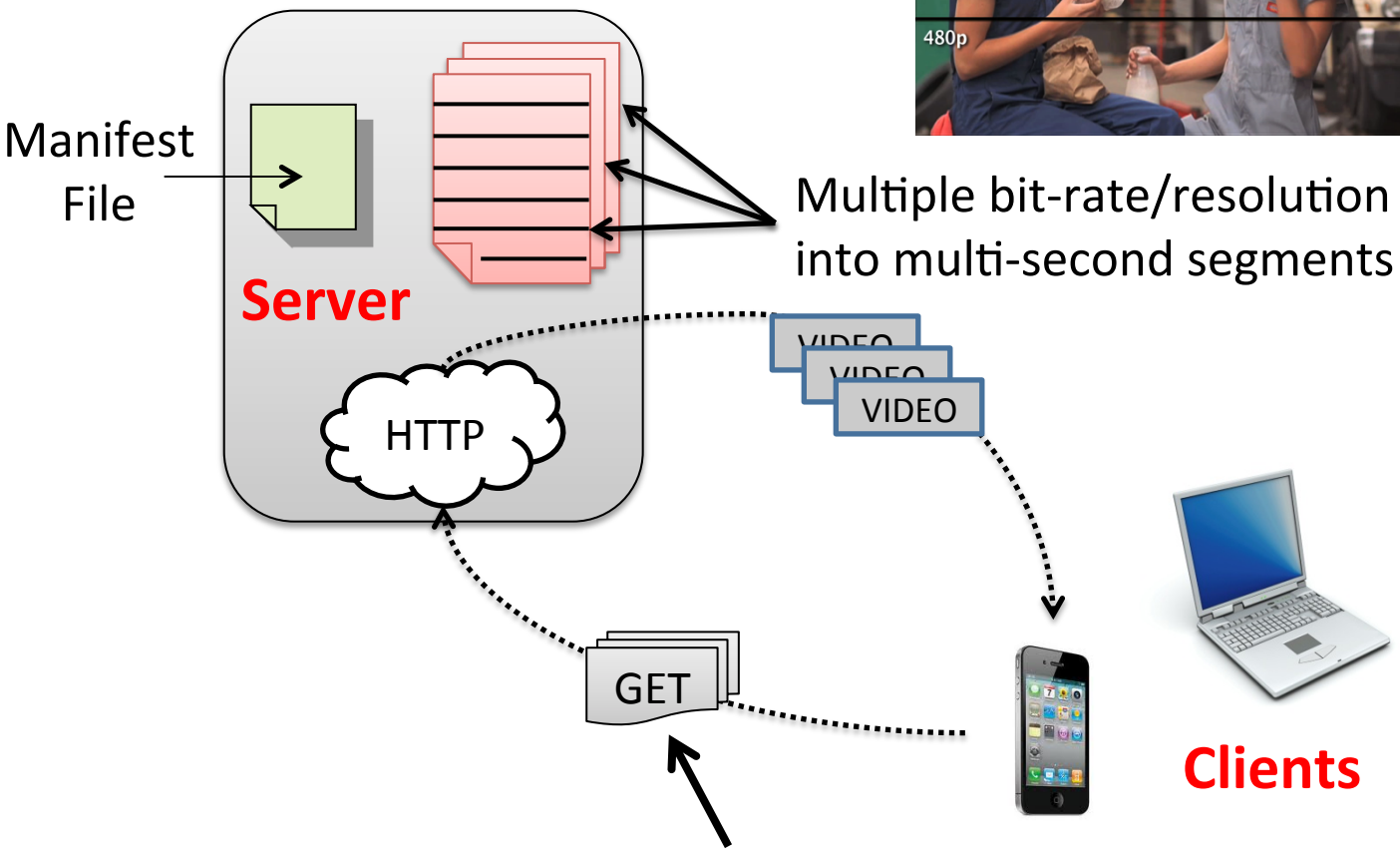
WHY USE IT?

User bandwidth, especially wireless access link bandwidth, can vary significantly over time.

WHO USES IT?

- Netflix uses Microsoft Silverlight.
- Hulu, CBS, etc. deliver video using adaptive streaming technology.
- Apple introduced HTTP live streaming (HLS).
- MPEG recently standardized dynamic adaptive streaming over HTTP (mpeg-DASH)

How DASH Works



Multiple bit-rate/resolution videos divided into multi-second segments

- Clients request a new video segment every ***X*** seconds.
- The bit-rate of the requested segment is based on the average TCP throughput of last ***Y*** segments.

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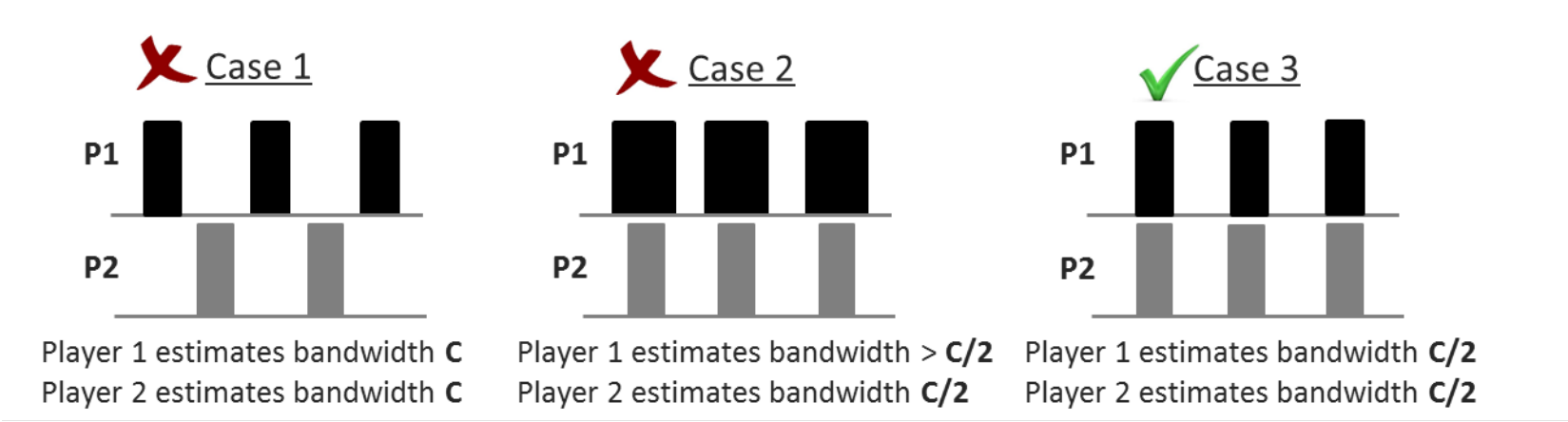
Problem Statement

- Instantaneous TCP throughput may overestimate the actual available bandwidth for the client and may result in instability of chosen video rates



- Although State-of-the-art cellular basestations use sophisticated resource management
  - Proportional fair scheduler to ensure fair resource allocation
  - Per-flow guaranteed minimum bit-rate (eg GBR in LTE) configuration to enable smooth video playback
- However, these techniques are not suitable for DASH videos which have multiple bit-rates available
  - Lack of control for operator to assign video rates to different users based on policies / contracts with the users / content providers
    - With multiple bit-rates available, it is not intuitive how to set LTE scheduler parameters (eg GBR rate)
  - Bit-rate switches over time are not taken into account

Performance Metrics

1. Fairness
   - Users have different link qualities, so basestations perform proportional fair scheduling
   - Proportional fair schedulers strives to achieve resource fairness in longer time-scale

$$\text{Jain's fairness} = \frac{\left(\sum_{i=1}^{N} F_i\right)^2}{N \sum_{i=1}^{N} F_i^2}$$

N: # of users

F_i: resources used by user i

2. Stability (QoE)
   - Frequent bit-rate switches affects user QoE

$$\text{stability} = \frac{\text{number of bit-rate switches}}{\text{time}}$$

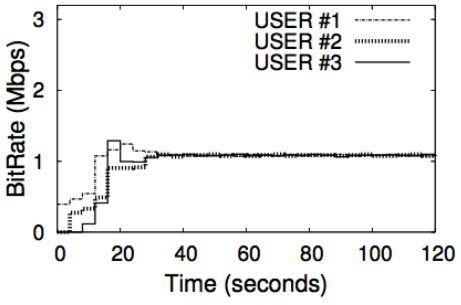
3. Efficiency
   - Due to spectrum scarcity, Operators desire efficient utilization of the wireless link

$$\text{utilization} = \frac{\text{total resources allocated}}{\text{total resources available}}$$

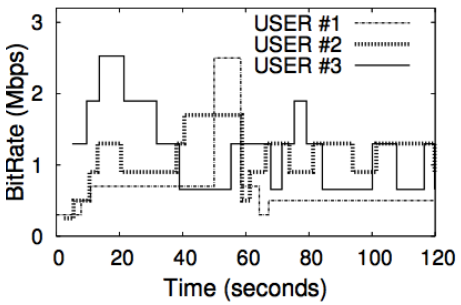
Performance of Current Basestation Schedulers

WiMAX Experiments

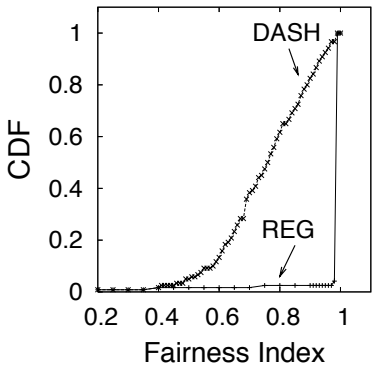
REG

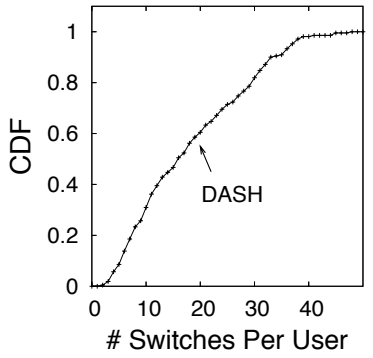


DASH



LTE simulations
(21 basestations, 10 clients each)





REG: single-rate videos DASH: multiple-rate video

State of the Art Basestations schedulers:

→DASH videos' bit-rates do not converge to fair allocation

→DASH videos also experience high frequency of bit-rate switches

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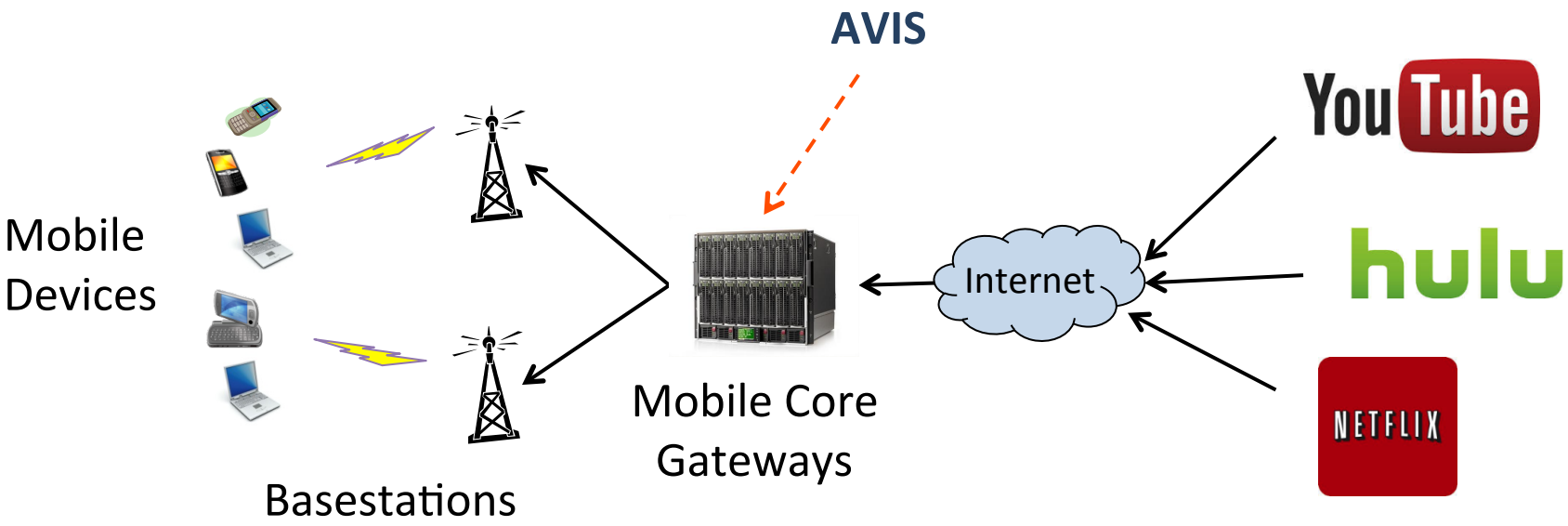
Design Considerations

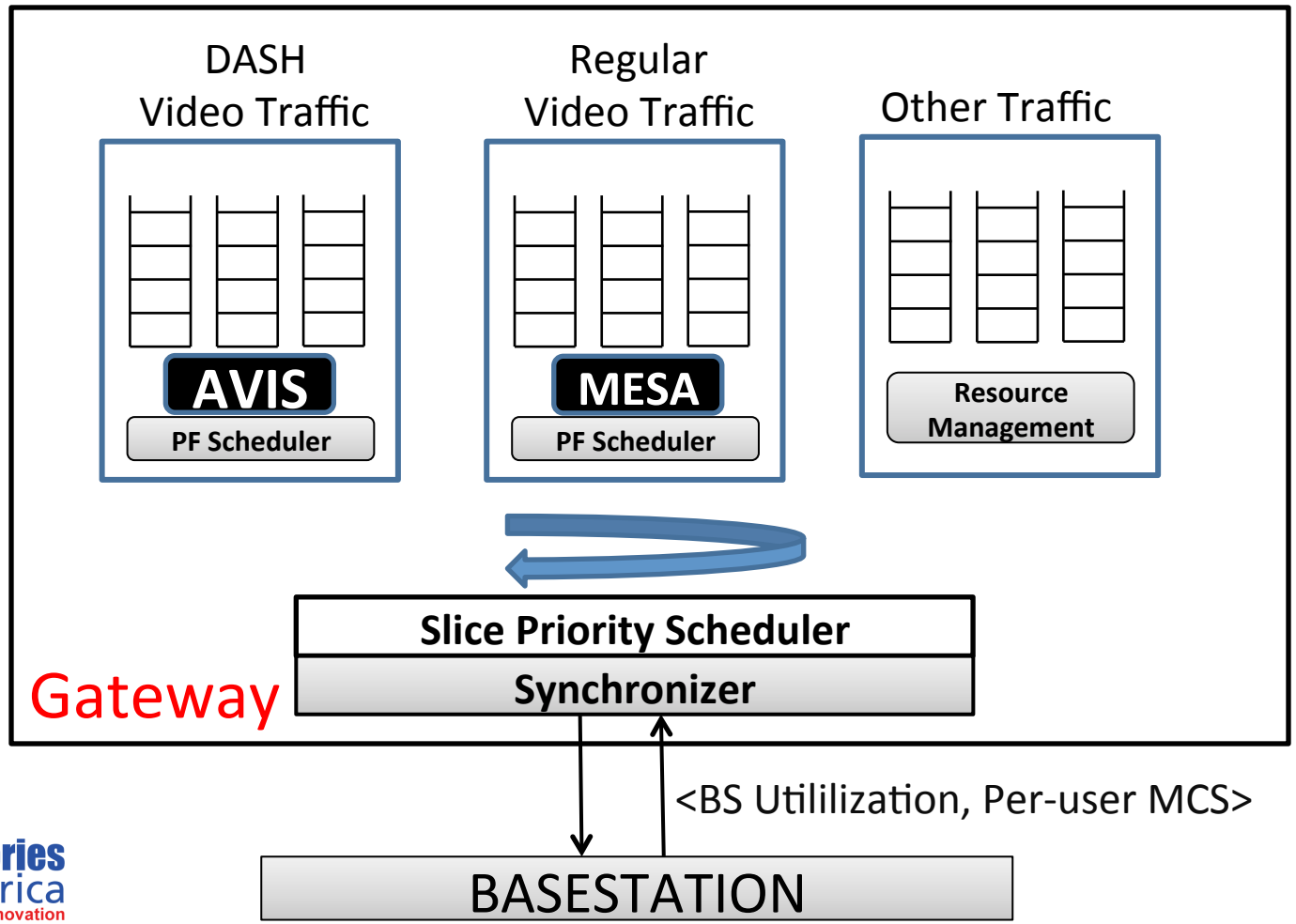
- A network-oriented resource management solution
  - The network is fully aware of the aggregate capacity per basestation
    - Adaptive to wireless link capacity fluctuations due to user arrivals and mobility
  - Faster convergence as opposed to video player based solutions
- Separate regular video scheduler from DASH scheduler
  - Leverages scheduler virtualization
    - Different policies for regular and DASH videos
  - Enables the system to accommodate future innovation
- Gateway – level solution
  - Basestations have minimal computational resources
  - Current Mobile Core network deployments include Deep Packet Inspection (DPI) components that provide meta-information about video flows
- No changes to video players (client) and video servers ensures easier deploy-ability

AVIS deployment

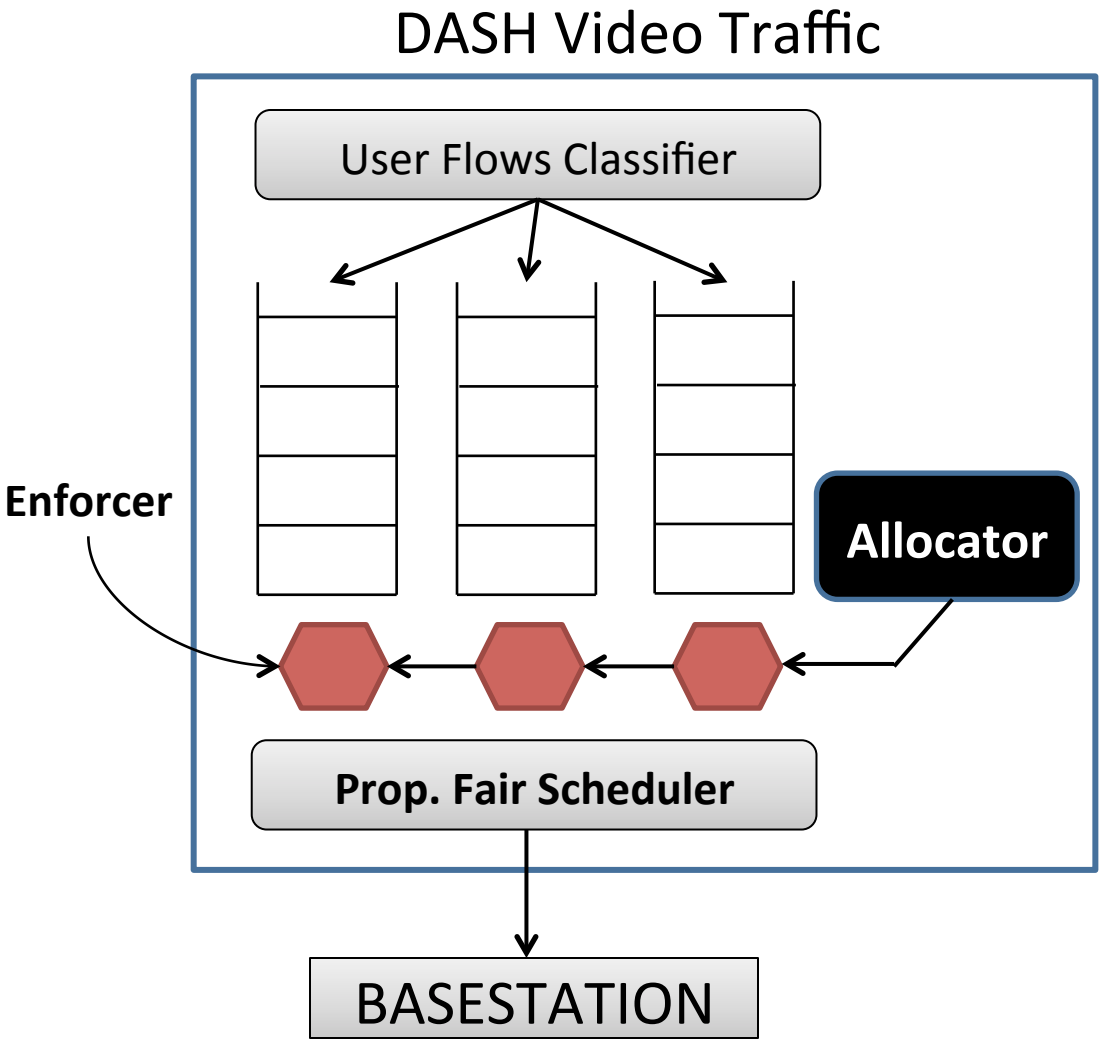


AVIS Architecture

- AVIS builds on the virtualization paradigm
- Separate resource allocation for DASH video flows from other flows
  - Instantiate separate slices using NVS virtualization technology (MobiCom 2010)

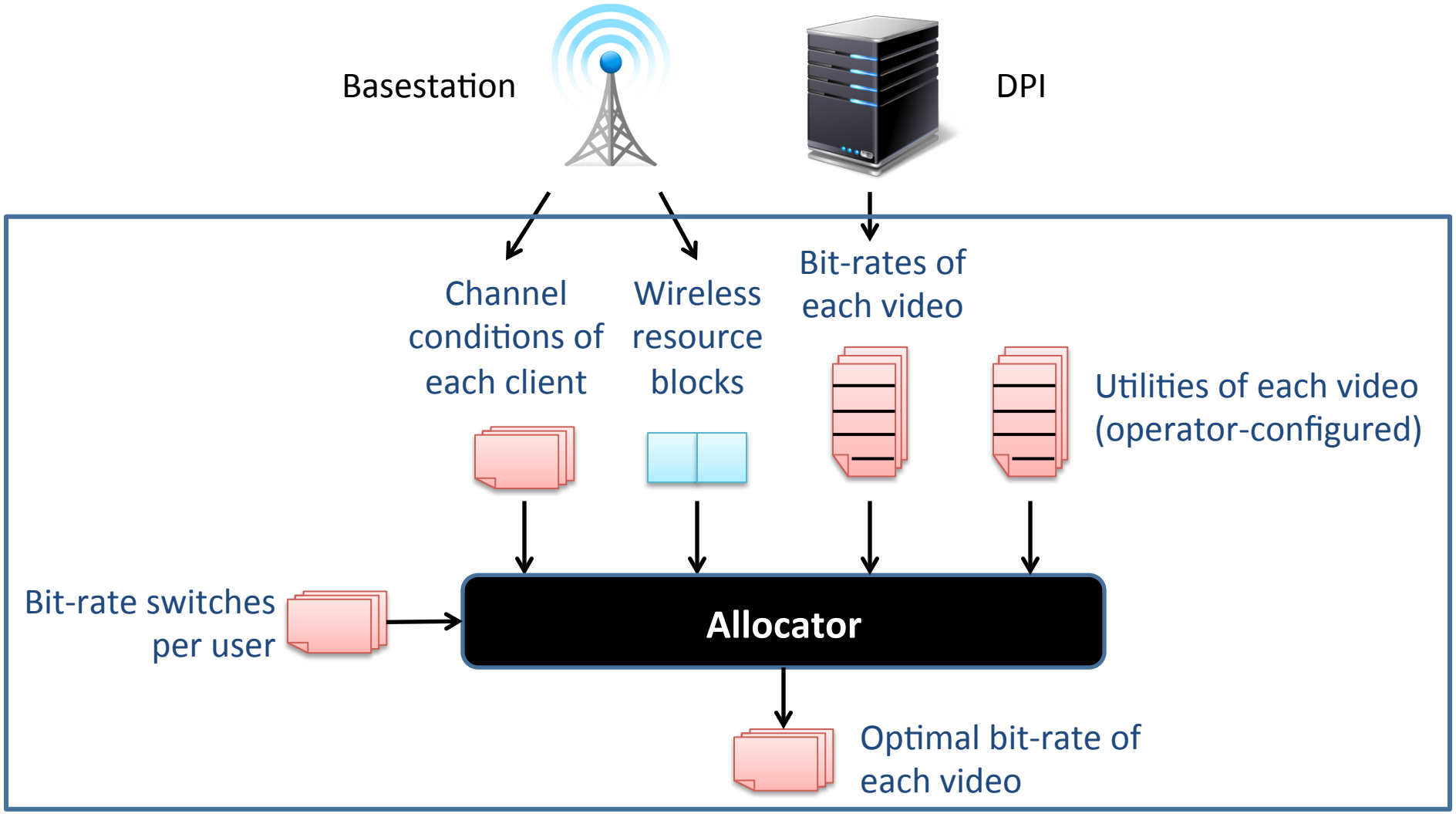


AVIS Design



- The AVIS **allocator** computes the optimal video bit-rate for each flow so as to maximize the aggregate utility for the network operator
- The AVIS **enforcer** indirectly enforces the bit-rates allocated by the scheduler by shaping the rate given to each flow

AVIS's Allocator



User's Utility Function

- Model user's utility as a concave function of video bit-rate

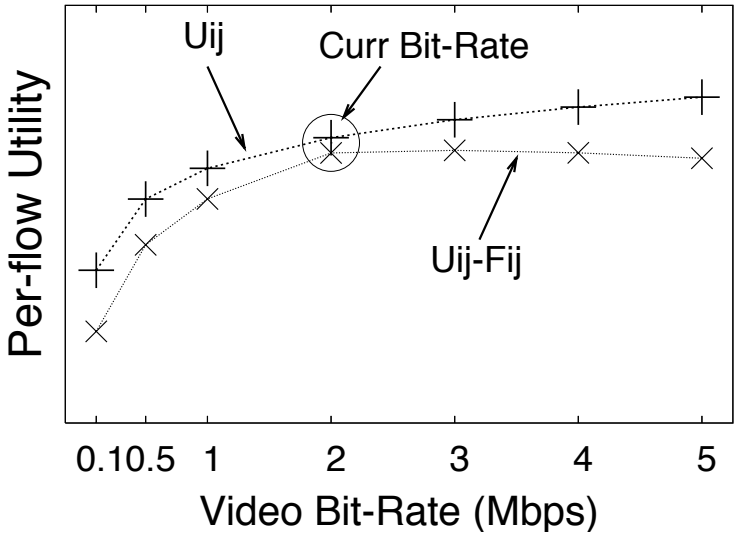
$$u_{ij} = P_i \times \log r_{ij}$$

u_{ij} : utility of version *j* of video *i*
P_i: priority of user *I*
r_{ij} : bitrate of version *j* of video *i*

- QoE: To improve stability, introduce penalty function f_{ij} to penalize bit-rate switches

$$f_{ij} = (|j - j^*| + 1)S_i$$

penalty increases with: difference from current bit-rate; number of switches



$$\text{total utility} = u_{ij} - f_{ij}$$

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AVIS's Allocator

- Maximize the overall utility for the mobile operator
  - Utility can be a pricing contract between operator and user / content provider
- Subject to total basestation wireless resource blocks
  - Video bit-rate depends on channel quality of each user

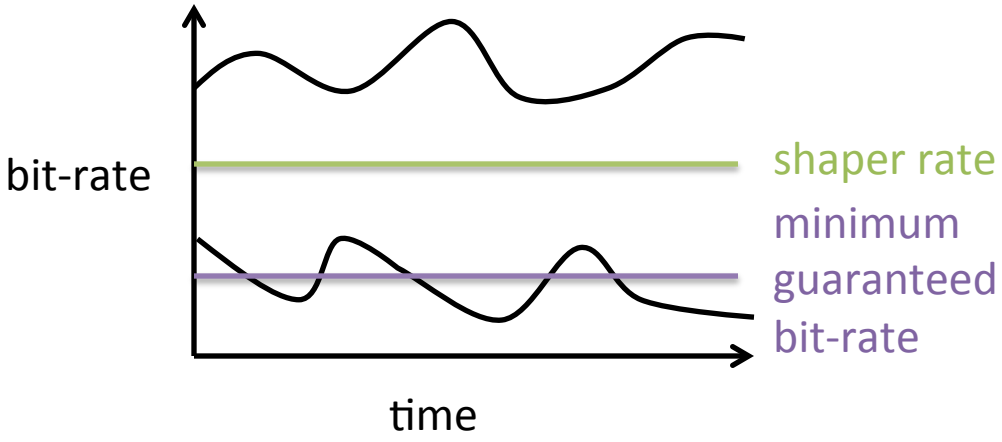
- Discrete solution
  - Multiple-choice knapsack problem
  - Solution by dynamic programming in O(NMT)

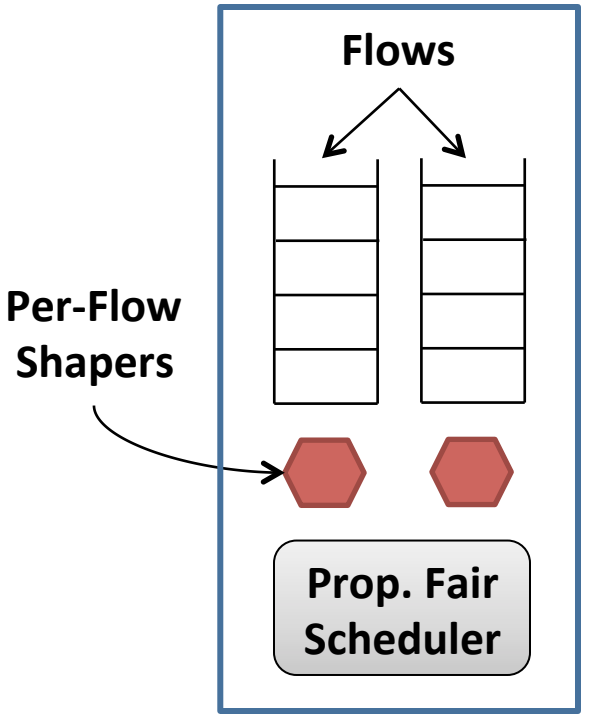
- Continuous solution
  - Can be employed for large-scale system
  - Treat the optimization variable (selected video bit-rate) as continuous
  - To convert to discrete solution, greedily round the optimal solution
    - respect the capacity constraint
    - maximize the resource utilization

AVIS's Enforcer

- Goals
  - Enforce the optimal bit-rate computed by the Allocator for each flow
  - Provide isolation of resources across flows
  - Achieve high utilization and bit-rate stability

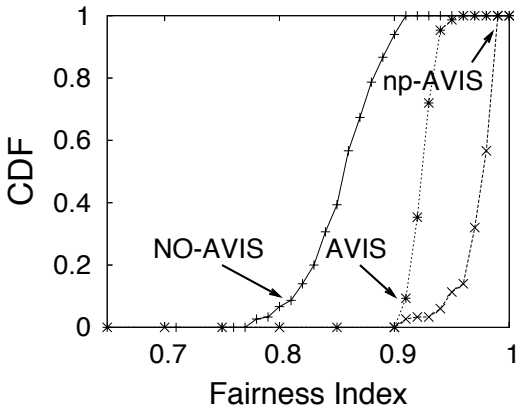
- Challenge: The video bit-rate varies over timw

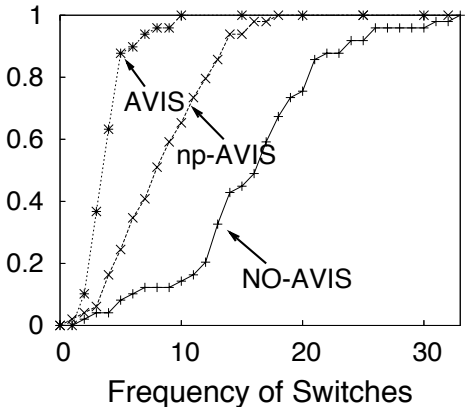


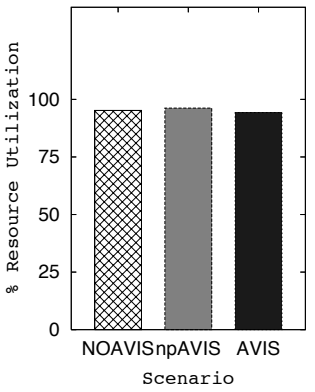


Large-Scale System Evaluation

- We used a 3GPP-compliant system-level LTE simulator to help evaluate AVIS
- 21 basestations with 8 users each streaming a 5-minute video
- Compare against:
  - np-AVIS: no penalty function for bit-rate switches
  - NO-AVIS: set equal GBR values for all users







→ NO-AVIS achieves the worst fairness

→ np-AVIS achieves the best fairness, at the expense of bit-rate switches

→ AVIS balances fairness and switching frequency

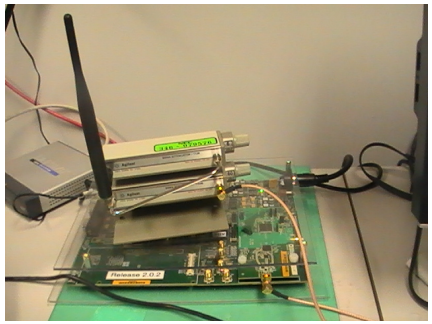
WiMAX Prototype

Akamai Servers hosting HTTP Videos

Internet

AVIS is implemented in the ASN-gateway (1000+ lines of C++)

Picochip WiMAX Basestation



Adobe

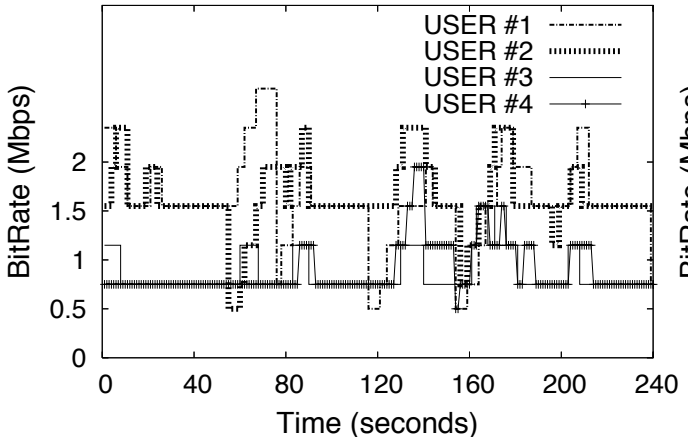
open source media framework

Adobe OSMF player was modified to collect logs on Intel WiMAX mobile clients

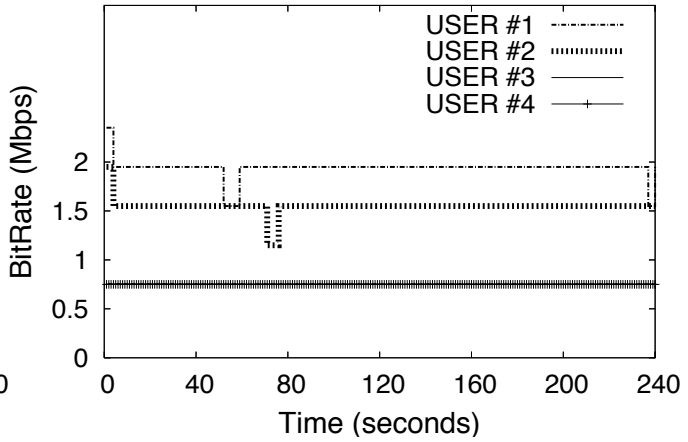
End-to-End Prototype Experiments

- 4-minute videos encoded at multiple bit-rates:
  {0.5,0.75,1.15,1.55,1.95,2.35,2.75,3.25} Mbps
- 4 clients randomly placed in indoor environment
  - Users 1,2 using 16QAM
  - Users 3,4 using QPSK

Without AVIS



With AVIS



→ Without AVIS, users with better channel quality (1,2) don't receive better rate

→ AVIS preserves resource fairness by giving **stable** and **fair** bit-rates

End-to-End Prototype Experiments

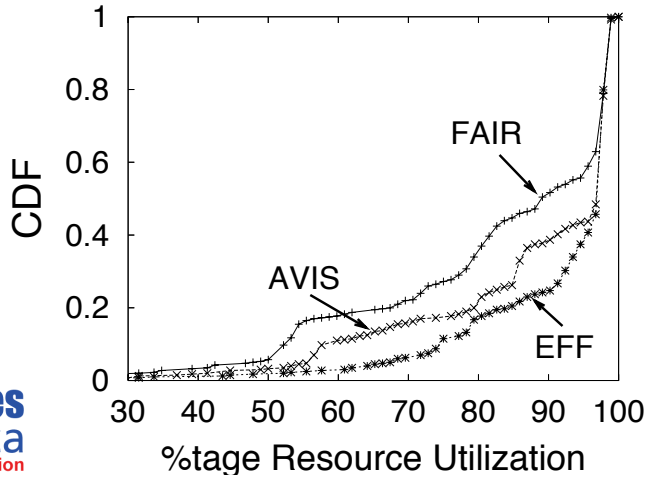
- Two strawman algorithms:
  1. FAIR: Fair allocation of resources
  2. EFF: High utilization of basestation

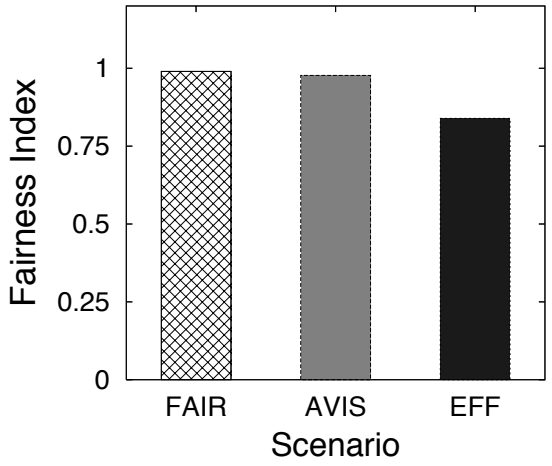
	User 1	User 2	User 3	User 4
FAIR	1.55 Mbps	1.55 Mbps	0.75 Mbps	0.75 Mbps
EFF	2.75 Mbps	1.95 Mbps	0.5 Mbps	0.5 Mbps
AVIS	1.95 Mbps	1.55 Mbps	0.75 Mbps	0.75 Mbps

→ FAIR allocates resources equally, so users with better channel conditions receive higher rate

→ EFF maximizes total bit-rate delivered to all users

→ AVIS strikes a balance in the tradeoff between resource allocation fairness and wireless resource utilization





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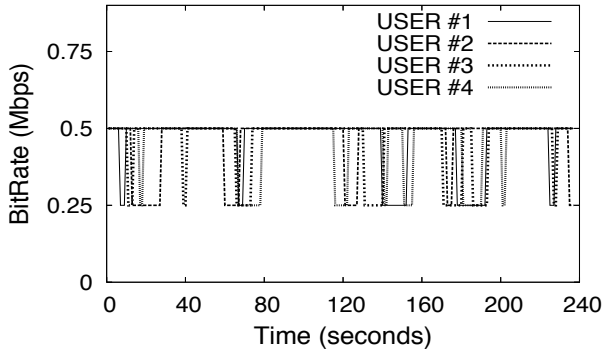
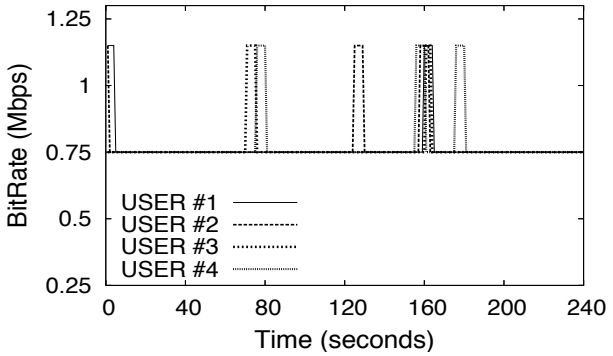
Benchmarking the Enforcer

- Shaper rate = maximum rate for each flow

Set shaper rate to optimal bit-rate

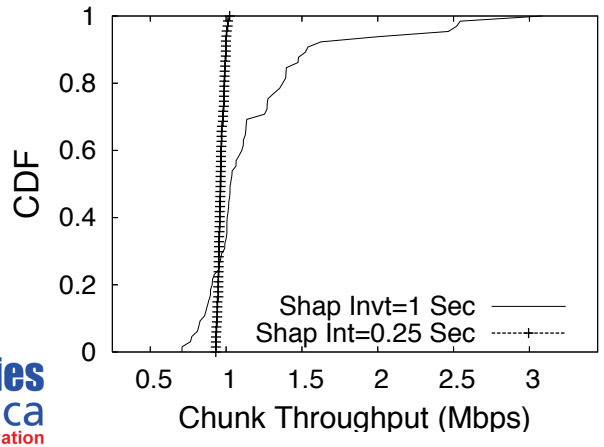


Set shaper rate to next higher bit-rate



→ Set shaper rate to mean

- Shaping interval = time granularity of traffic shaping



→ Small video chunks may be downloaded faster than the shaper interval

→ Set shaping interval smaller for effective enforcement

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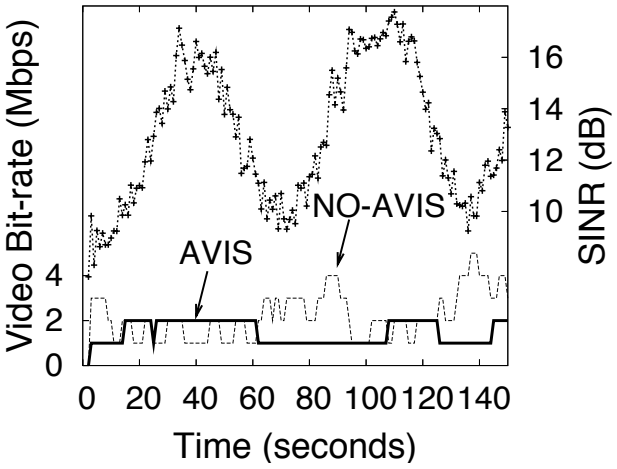
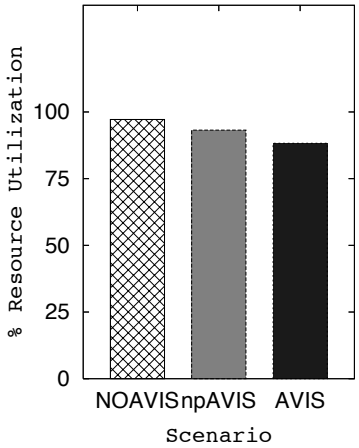
Mobility and Channel Dynamics

- Base station with 8 users, including several vehicular users with time-varying SINR





→ With AVIS, vehicular user has fewer bit-rate switches, at the expense of utilization

Summary

- AVIS is a network-oriented resource management solution for DASH videos on cellular basestations
  - Designed for **fairness**, **stability**, and **efficiency**
  - Allocator to determine optimal video bit-rates
  - Enforcer to schedule and shape traffic for bit-rate stability of each flow

- We implemented AVIS on a WiMAX testbed and large-scale LTE simulator to show its efficacy and scalability

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