EE 579: Wireless and Mobile Networks Design & Laboratory

Lecture 4

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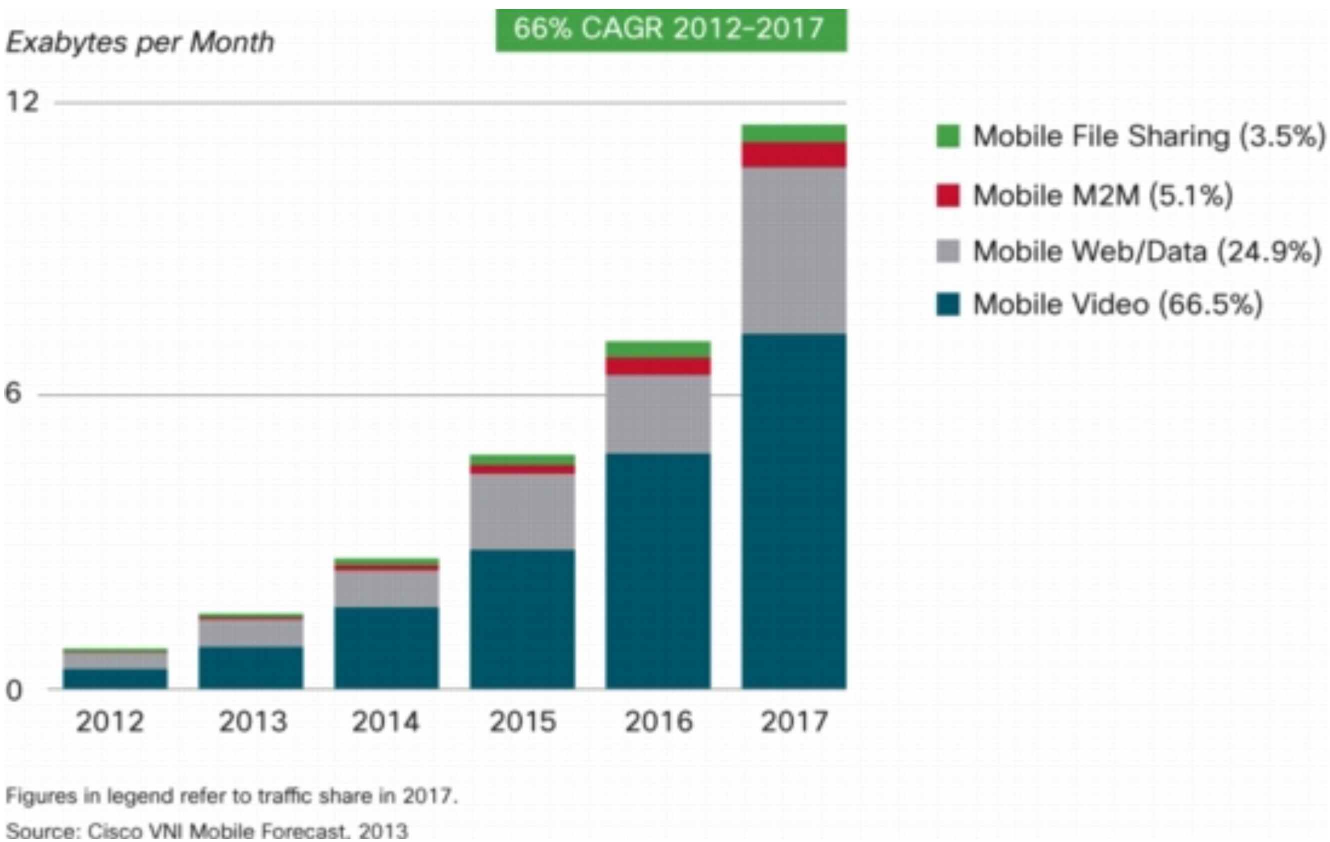
Lecture notes and course design based upon prior semesters taught by Bhaskar Krishnamachari and Murali Annavaram.

Outline

- Administrative Stuff
- Presentation by Professor Kyle Konis (kkonis@usc.edu)
- Lab Assignment 1
- Video over Wireless

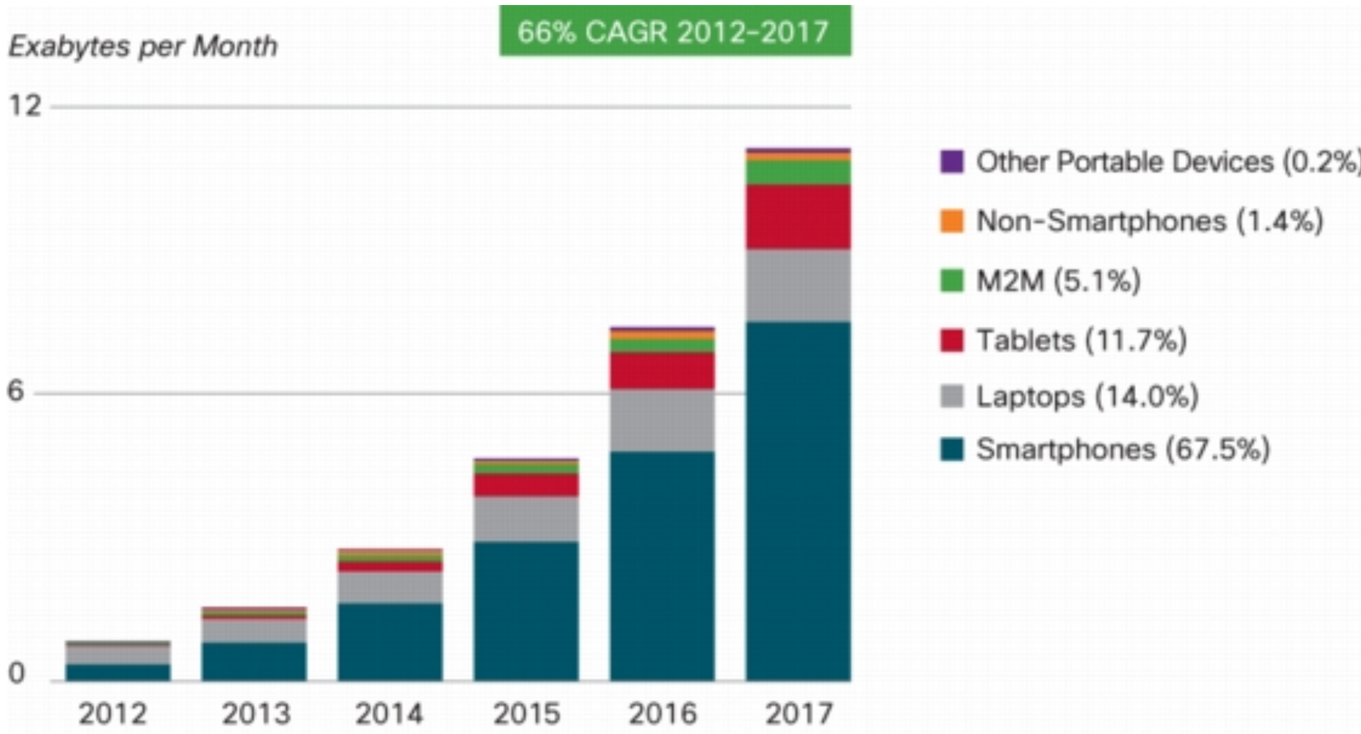
Motivation

- Mobile Video Traffic Projection
  - Over 66% of all mobile data traffic will be from video by 2017
  - 7.4 exabytes (EB) out of 11.2 EB (1 EB = 10^{18} bytes)



Motivation

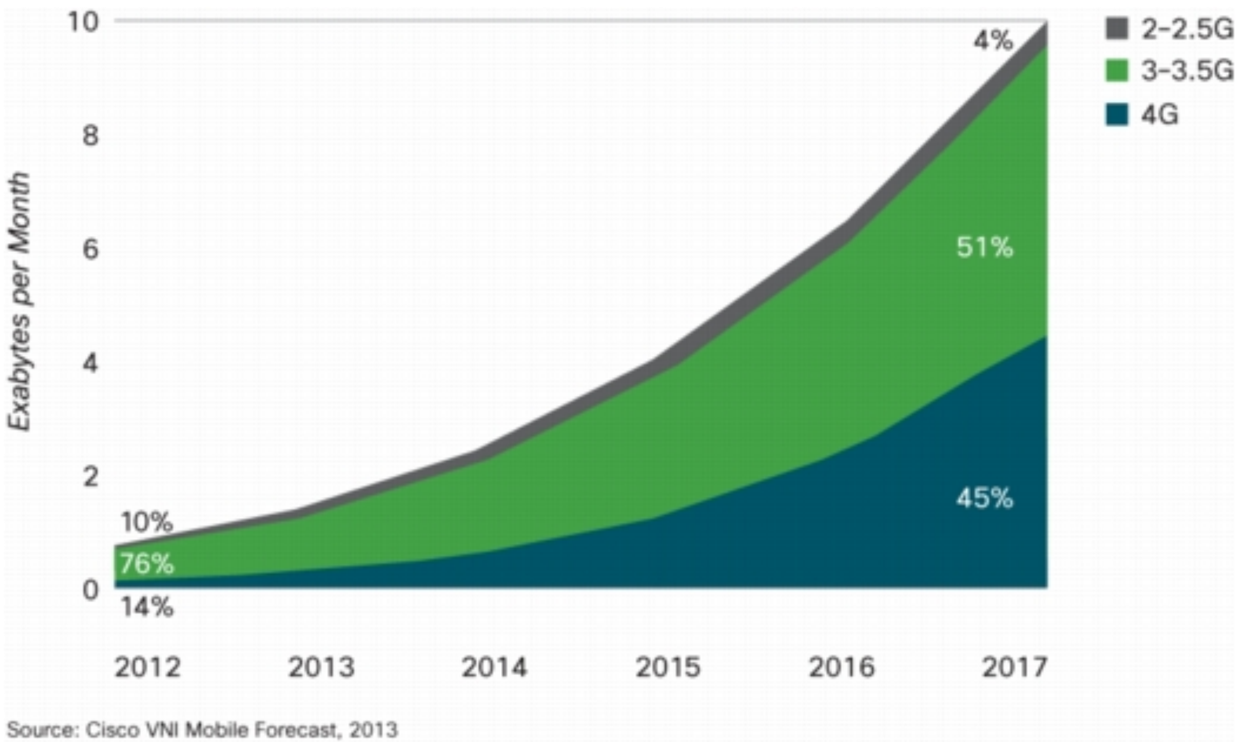
- Evolution of Smart Devices
  - 8.6 billion handheld mobile devices and 1.2 billion M2M by 2017
  - 2.7 GB/month by 2017, as compared to 342 MB/month in 2012



Figures in legend refer to traffic share in 2017.
Source: Cisco VNI Mobile Forecast, 2013

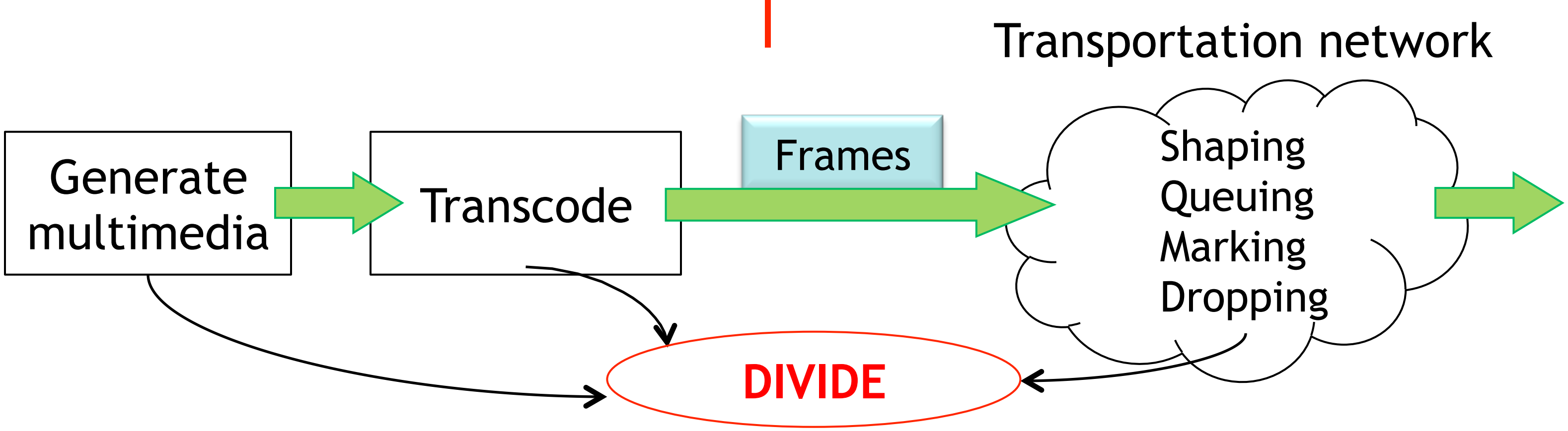
Motivation

- 2G to 3G to 4G and Beyond
  - Higher bandwidth, lower latency, increased security
  - 4G (2012): only 0.9% connections, but 14% of mobile data traffic
  - 4G (2017): only 10% connections, but 45% of total traffic



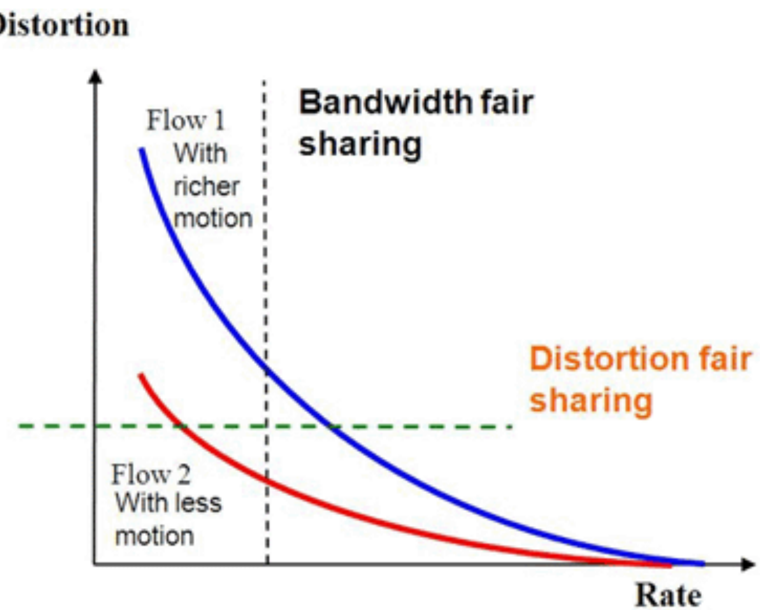
Content-Pipe Divide

- Content Providers
  - Media companies, end-users, operators of CDN and P2P
  - Generate content treating the network as simply a means for communication (dumb pipes)
- Pipe Providers
  - ISPs, equipment & network management vendors, municipalities
  - Treat every content equally as simply bits to be transported between nodes (dumb content)



Content Aware Networking

- Protocol Fairness
  - Rate fair: Each flow gets half the capacity
  - Rate-Distortion fair: Flow1 gets more



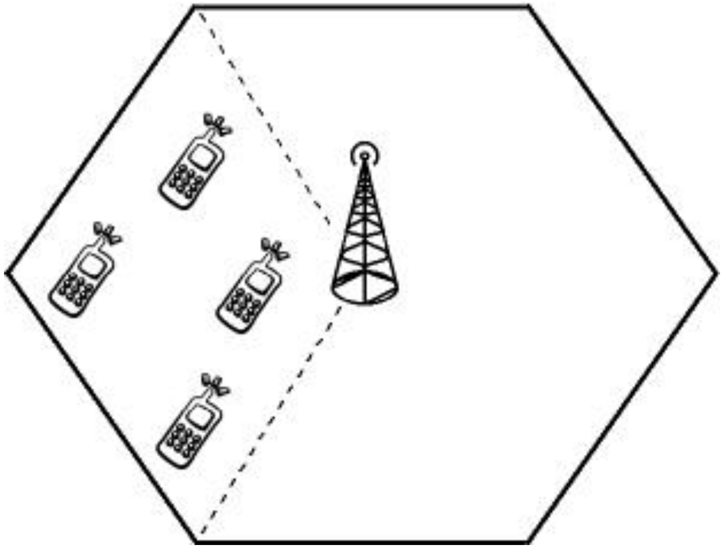
- A New Protocol Design Paradigm
  - Utilize content characteristics
  - Allocate resources based on the optimality criteria that are reflective of the content
  - More adaptive and effective network protocols that are rate-distortion fair

Content Aware Video Delivery over 3G WCDMA Networks

Kartik Pandit, Amitabha Ghosh, Dipak Ghosal, and Mung Chiang, "Content Aware Optimization for Video Delivery over WCDMA," *EURASIP Journal on Wireless Communications and Networking*, July 2012.
URL: http://anrg.usc.edu/~amitabhg/papers/EURASIP-2012.pdf

Network Model

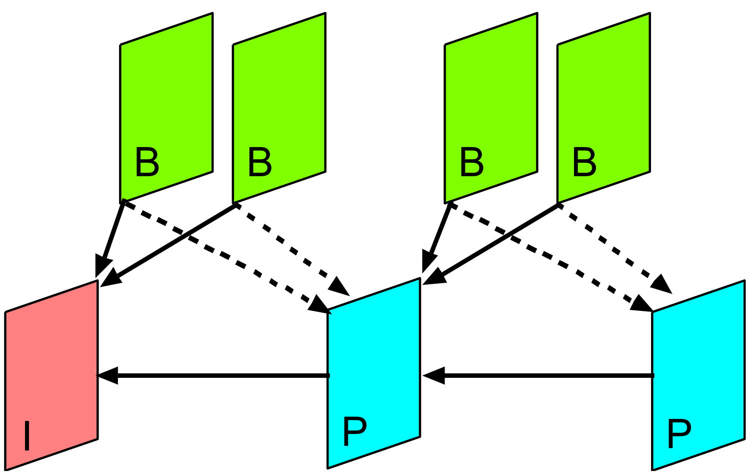
- Cellular Uplink
  - Increasing demand for high data rate
    - EVDO RA (1.8 Mbps), LTE (50 Mbps)
  - A single WCDMA cell, with a base station serving all users
  - Each user transmits a pre-encoded video upstream
  - Videos are encoded as GOP (Group of Pictures) structures



- Degrees of Freedom – Control
  - Scheduling (send or drop frame)
  - Transmission power

Video Model

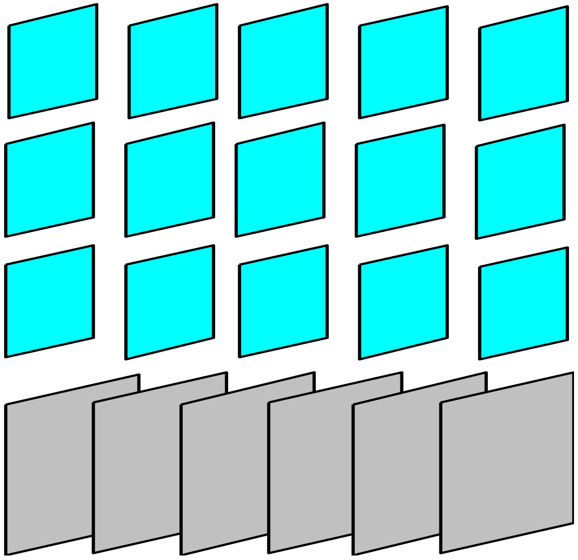
- Group of Pictures (GOP)
  - Successive frames organized into a repetitive structure
    - I frame (intra) – coded independently
    - P frame (predictive) – motion-compensated difference, depends on previous P frame
    - B frame (bipredictive) – depends on previous and following P/I frames
  - Idea: Drop unimportant frames without hurting the quality



GOP: IPBBPBB
Directed acyclic graph
Arrows indicate dependency

Video Model

- Scalable Video Coding (H.264)
  - Base Layer
  - Enhancement Layers
  - Each layer requires more resources
  - Temporal, Spatial, and Quality scalability



Problem Formulation

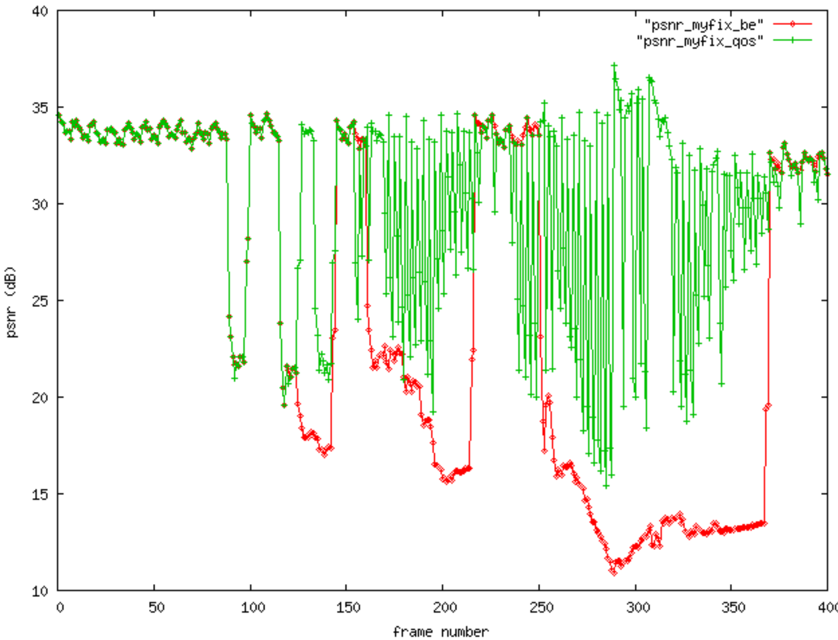
- Use optimization theory to allocate resources
  - Rate
- What do we want to optimize? (Objective function)
  - Some measure of video quality (e.g., PSNR, distortion) $d(f'_{ij}, f_{ij})$
- What are the constraints?
  - Interference (or SINR) γ_{ij}
  - Available power p_{max}
- What are the variables?
  - Transmit power p_{ij} User i frame j
  - Scheduling decision θ_{ij} Binary variable: 0 if frame j of user i is transmitted; 1 if dropped

Objective

- Maximize PSNR / Minimize Distortion
  - PSNR: An objective metric
  - Expressed in decibel (dB)
  - Good values > 20-30 (range: 0-100)

Total distortion per GOP:

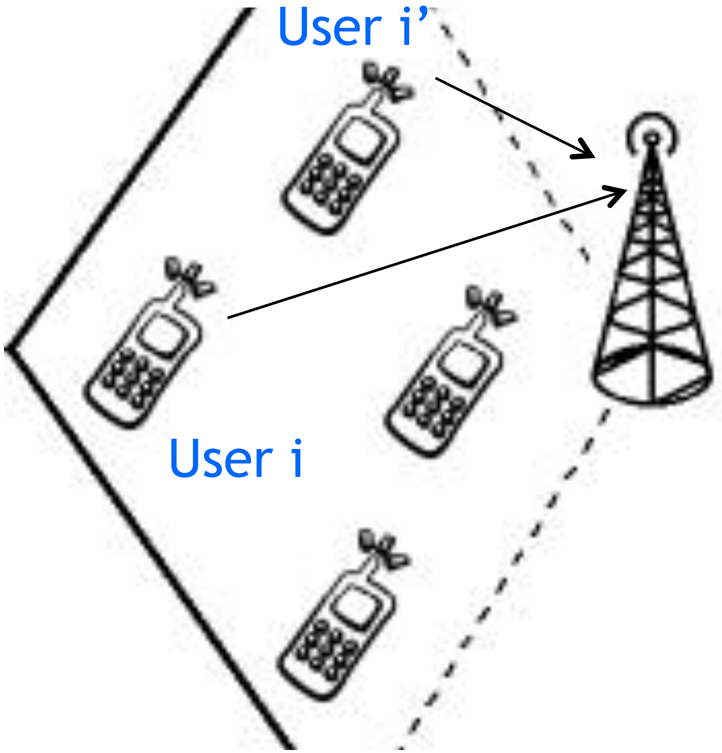
$$D_i(\Lambda_i) = \sum_{j=1}^{n} d(f'_{ij}, f_{ij}), \quad \forall i$$



Constraints

- SINR – signal to interference plus noise ratio
- Achievable rate

$$\sum_{j=1}^{n} d \log\left(1 + c\gamma_{ij}\right)$$



$$\gamma_{ij} = \frac{p_{ij} g_{ii} (1 - \theta_{ij})}{\sum_{i'=1, i' \neq i}^{N} p_{i'j'} g_{i'i} (1 - \theta_{i'j'}) + \eta_0}$$

Constraints

- Set of dropped frames for user i Λ_i
- Required rate to transmit the selected frames $R_i\left(\Lambda_i\right)$
- Achievable rate under SINR
- Constraint: Required rate should be <= achievable rate

Optimization Formulation

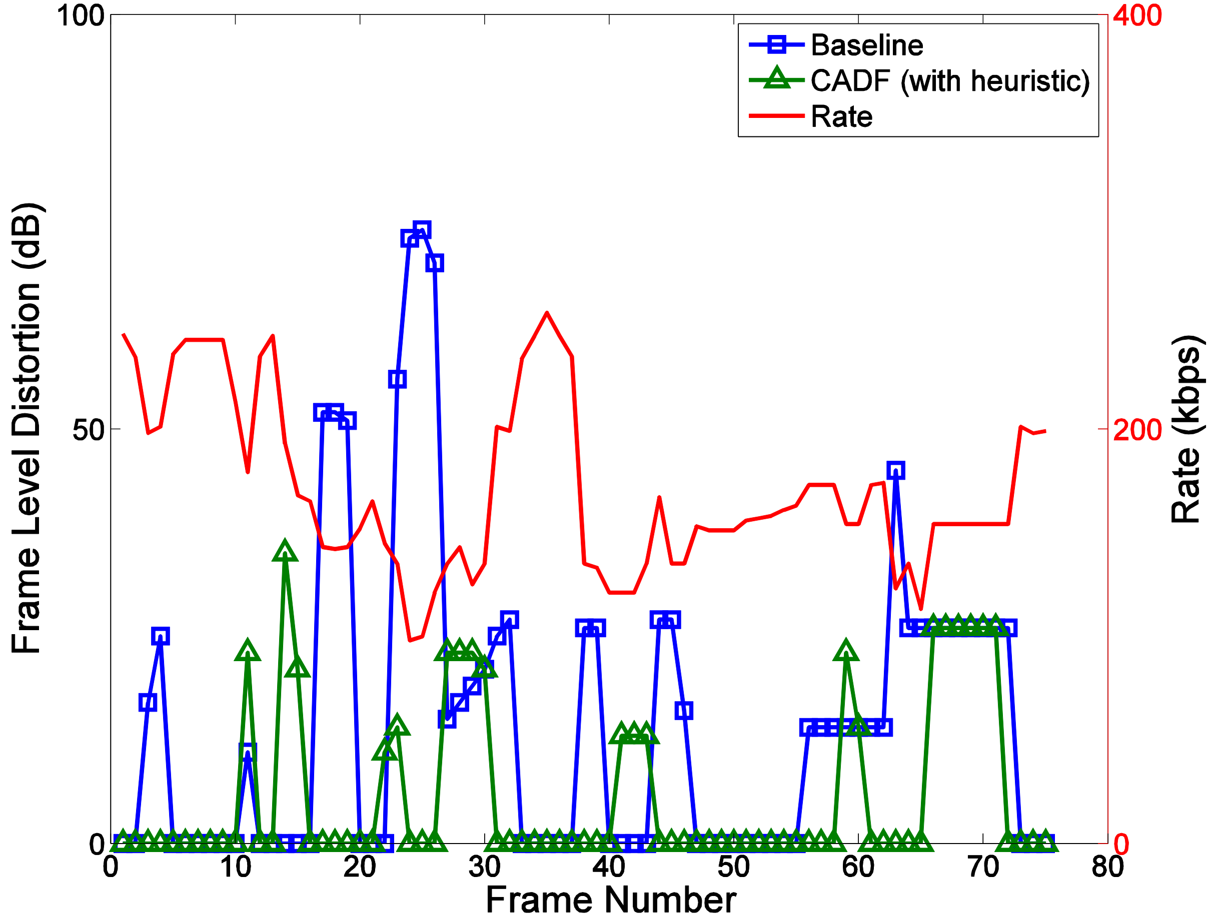
- Content-Aware Distortion-Fair Optimization (CADF)
  - Minimize the sum of distortions over a GOP for all videos subject to SINR constraints

$$\begin{aligned} \text{minimize} \quad & \sum_{i=1}^{N} D_i(\Lambda_i) \\ \text{subject to} \quad & R_i\left(\Lambda_i\right) \leq \sum_{j=1}^{n} d \log\left(1 + c\gamma_{ij}\right), \quad \forall i \\ \text{variables} \quad & 0 \leq p_{ij} \leq p_{max}, \quad \forall i, \quad \forall j \\ & \theta_{ij} \in \{0, 1\} \end{aligned}$$

  - An NP-hard problem (MINLP)
  - Can solve efficiently using heuristics

A Sample Result

- Frame-level distortion: Comparison of CADF scheme with Foschini-Miljanic scheme



QAVA: Quota Aware Video Adaptation

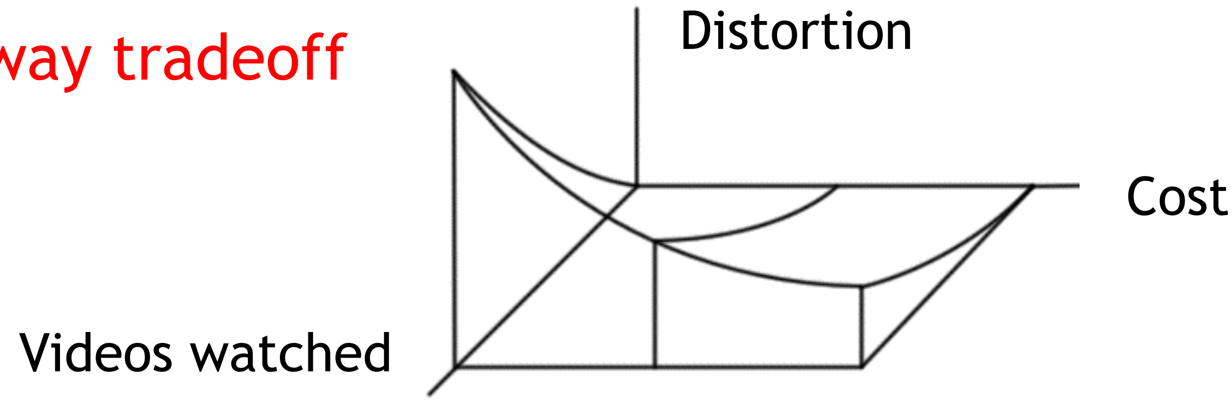
Jiasi Chen, Amitabha Ghosh, Josphat Magutt, and Mung Chiang, "QAVA: Quota Aware Video Adaptation," ACM CoNEXT, pp. 121--132, Nice, France, December 2012.
URL: http://anrg.usc.edu/~amitabhg/papers/CoNEXT-2012.pdf

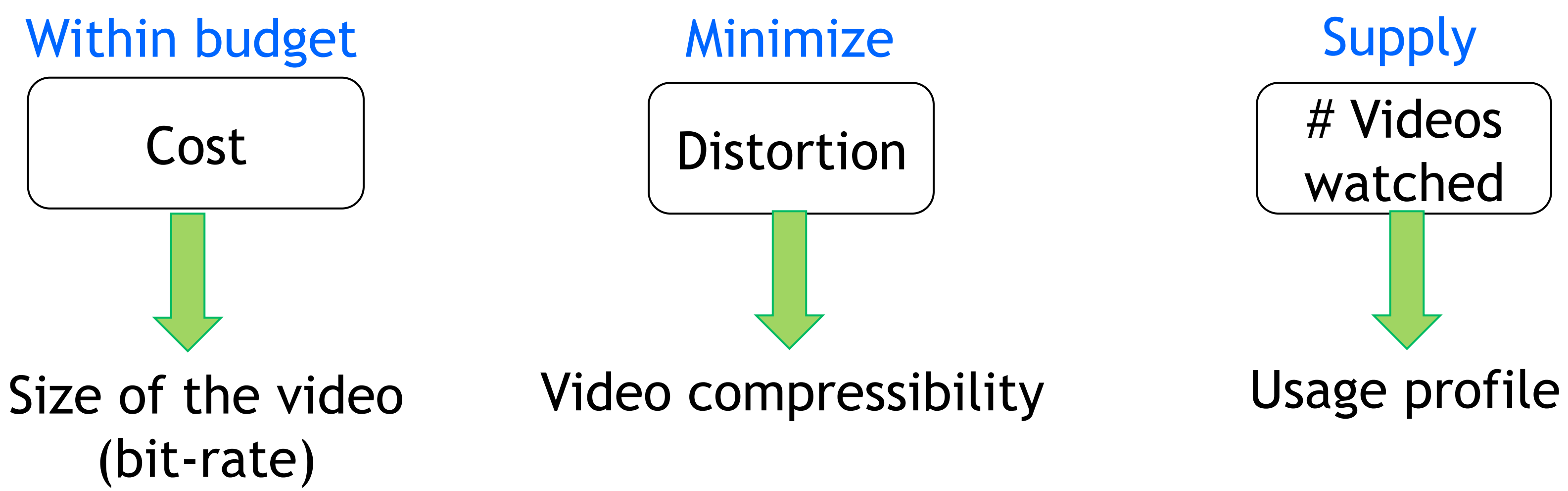
Motivation: The Conflict

- Emerging Trends
  - Video traffic becoming dominant (>66% by 2017)
  - Usage-based pricing becoming prevalent
    - AT&T wireless (Jan 2012): $30/$50 for 3/5 GB (baseline) + $10 per GB
    - Verizon Wireless (July 2011): $30/$50/$80 for 2/5/10 GB (baseline) + $10 per GB
- Can the user consume more content without worrying about the wallet?
- Is every bit needed for everyone at all times?

QAVA: Graceful Tunable Tradeoff

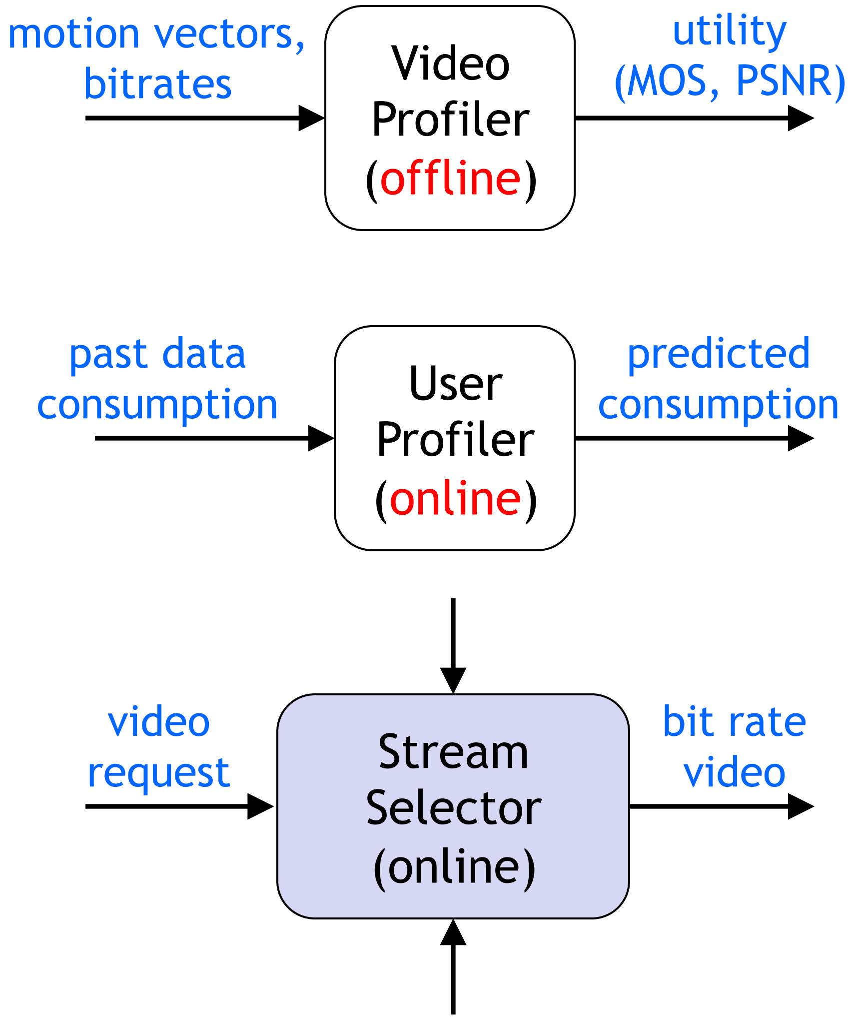
A 3-way tradeoff



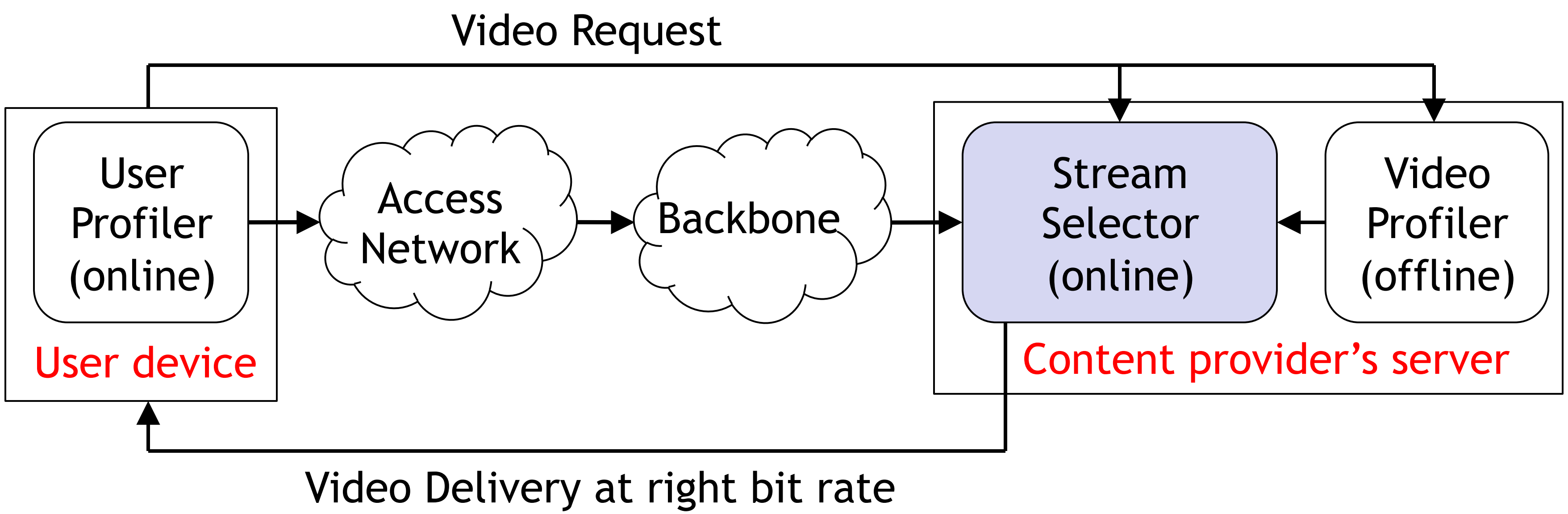


Modular Architecture

- Three Modules
  - Video Profiler
    - Exploit video compressibility from motion vectors
  - User Profiler
    - Predict user's future data consumption from past history
  - Stream Selector
    - Choose the right bitrate to maximize video quality subject to budget



Modular Architecture

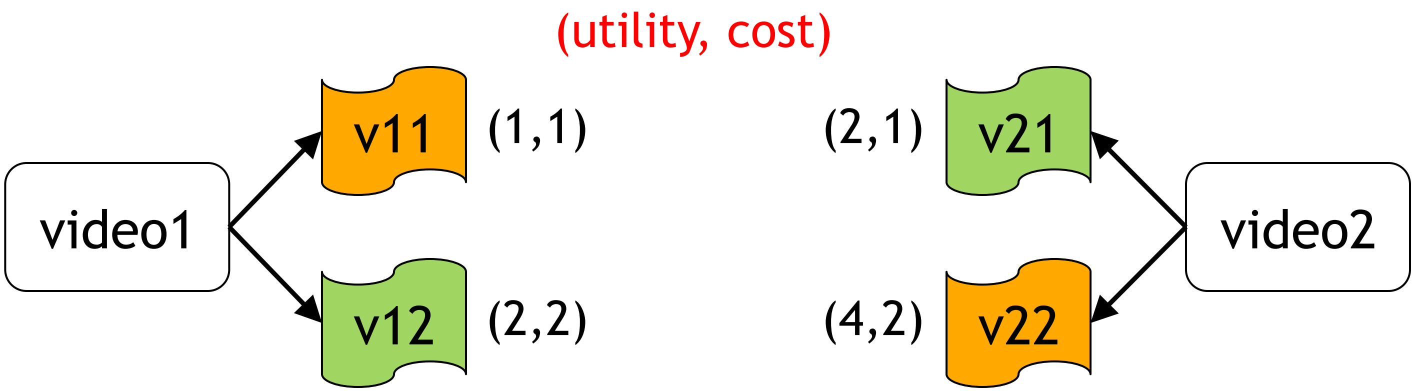


Adaptively choose the right bit rates

Online Stream Selection: An Example

Budget = 3

Goal: Maximize total utility (video quality)



Offline Optimal: v11, v22
Total utility: 1+4 = 5
Total cost: 1+2 = 3

Online Greedy: v12, v21
Total utility: 2+2 = 4
Total cost: 2+1 = 3

Problem Formulation

Maximize the sum of utilities of all the selected videos, subject to

- Exactly one version of each request is granted
- Total cost of all the selected versions must be within budget

$$\underset{x_{ij}\in\{0,1\}}{\text{maximize}} \quad \sum_{i=1}^{N}\sum_{j=1}^{M_i} u_{ij}x_{ij}$$

$$\text{subject to} \quad \sum_{j=1}^{M_i} x_{ij} = 1, \quad \forall i$$

$$\sum_{i=1}^{N}\sum_{j=1}^{M_i} c_{ij}x_{ij} \le B,$$

Online Multi-Choice Knapsack Problem

- B : Budget
- N : # of videos requested
- M_i : # of versions of video i
- u_{ij} : Utility of version j of video i
- c_{ij} : Cost of version j of video i
- x_{ij} : 1 if version j of video i is selected; 0 otherwise

Evaluation: Video Profiler from MOS

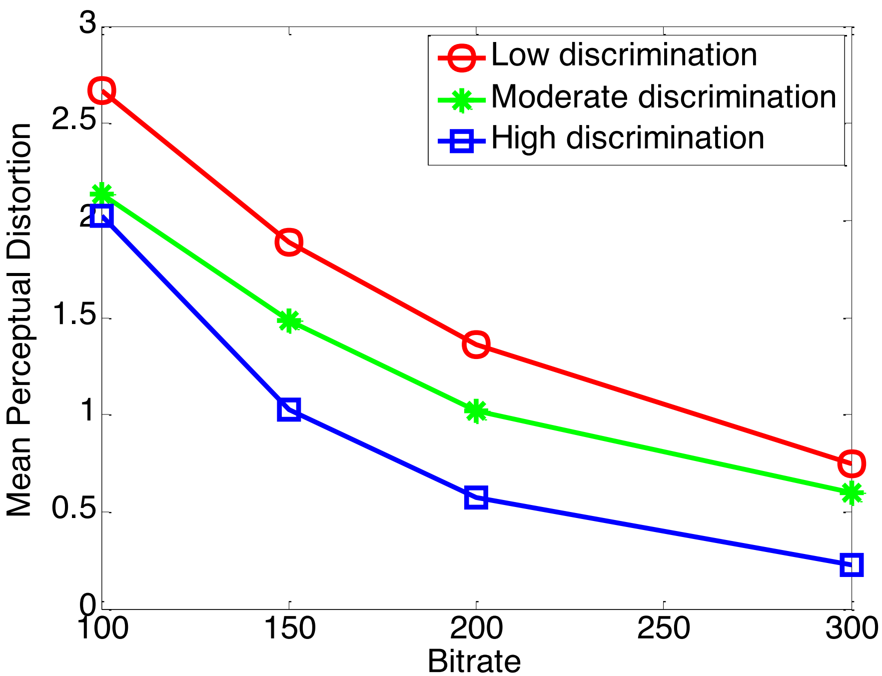
- Videos
  - 20 diverse H.264 clips
  - Resolution 640 x 480
  - Duration 20 sec
  - Each video encoded at 100, 150, 200, 300, Kbps

MOS: Mean Opinion Score (subjective video quality metric)

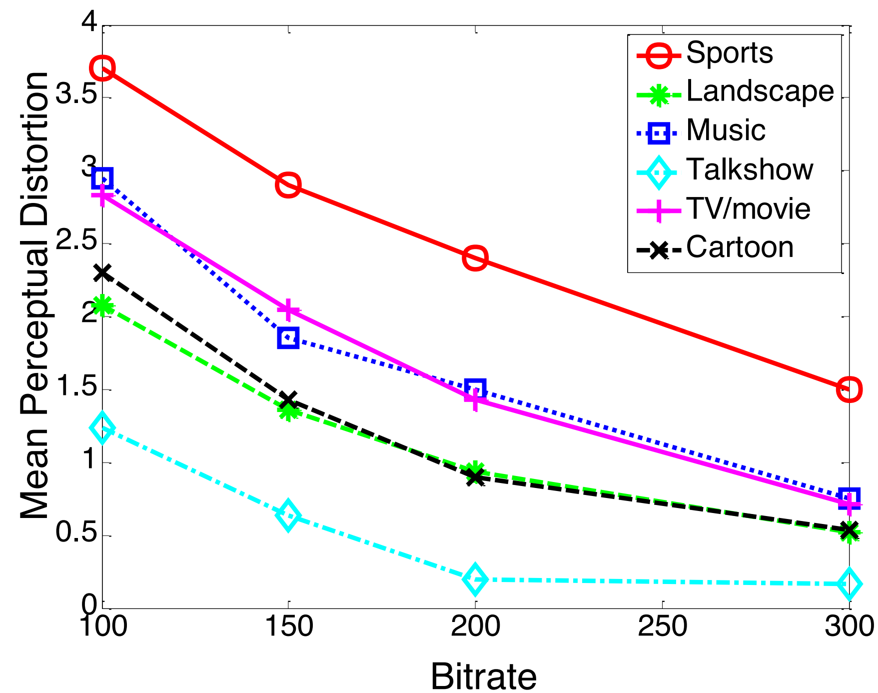
- Shown to 20 participants on iPhone4 held at ~50 cm

- Participants rated in 1-5 MOS scale
  - 1: very good (imperceptible distortion)
  - 5: very annoying

Results



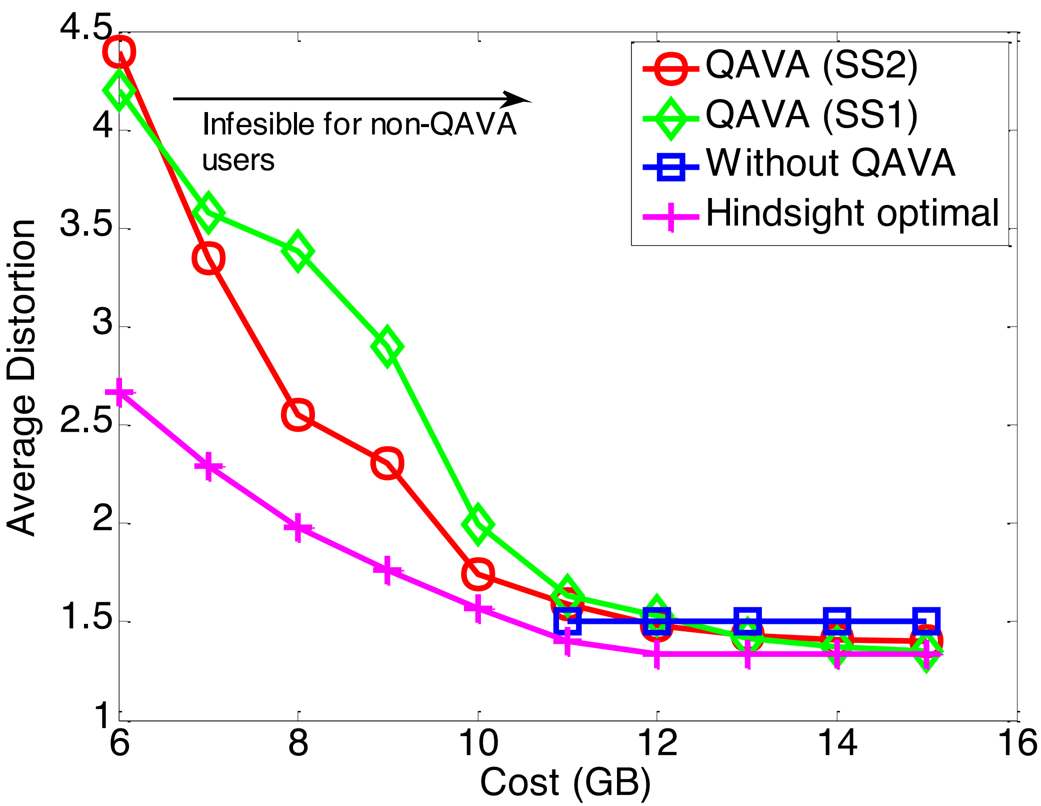
MOS for different types of users
(consistency across user behavior)



MOS for different types of videos
(consistency across motion vector, distortion, rating)

Results: Overall QAVA Benefit

- 1430 video requests randomly generated over 30 days
- Video duration normally distributed with mean 30 sec and s.d. 5 sec



QAVA user can watch all videos at low budget

Benefit of QAVA decreases for sufficiently large budget

Non-QAVA user cannot watch all videos below 11 GB quota

Implementation

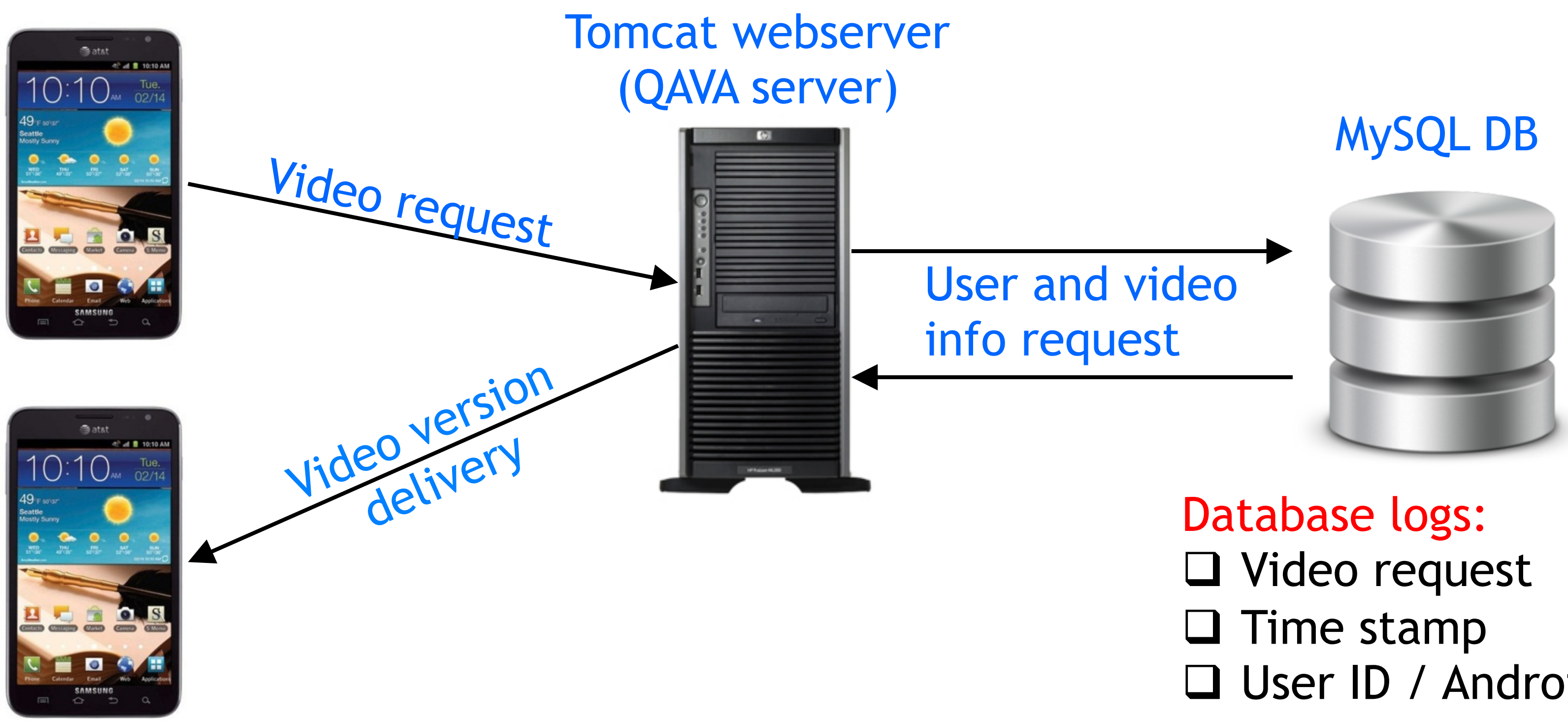
Implementation on Android

Goals

- Understand consumption behavior of real people
- Understand user-perception of video quality
- Evaluate the algorithm
- Fun to run a trial involving real people

Princeton Trial

- Set Up
  - 15 volunteers with Android phones
  - ~500 videos encoded at 25 Kbps granularity (100 Kbps – 500 Kbps)



Database logs:

- Video request
- Time stamp
- User ID / Android ID
- MB of video delivered

Android App Screenshots