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
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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
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)

Transportation network

Generate multimedia → Transcode → Frames

Shaping, Queuing, Marking, Dropping

DIVIDE
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

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) \( \gamma_{ij} \)
  - Available power \( p_{max} \)

- What are the variables?
  - Transmit power \( p_{ij} \)
  - Scheduling decision \( \theta_{ij} \)
    - User i frame j
    - 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:

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

- **SINR** - signal to interference plus noise ratio

- Achievable rate

\[
\sum_{j=1}^{n} d \log (1 + c \gamma_{ij})
\]

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

- Set of dropped frames for user $i$ $\Lambda_i$
- Required rate to transmit the selected frames $R_i(\Lambda_i)$
- Achievable rate under SINR
- Constraint: Required rate should be $\leq$ 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

\[
\text{minimize} \quad \sum_{i=1}^{N} D_i(\Lambda_i)
\]

subject to

\[
R_i(\Lambda_i) \leq \sum_{j=1}^{n} d \log (1 + c\gamma_{ij}), \quad \forall i
\]

variables

\[
0 \leq p_{ij} \leq p_{max}, \quad \forall i, \forall j
\]

\[
\theta_{ij} \in \{0, 1\}
\]

- 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

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

Distortion

Cost

Videos watched

Within budget

Cost

Minimize

Distortion

Supply

# Videos watched

Cost

Size of the video (bit-rate)

Video compressibility

Usage profile
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

User Profiler (online) → Access Network → Backbone → Stream Selector (online) → Video Profiler (offline) → Video Delivery at right bit rate

Adaptively choose the right bit rates
Online Stream Selection: An Example

Budget = 3
Goal: Maximize total utility (video quality)

(utility, cost)

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

Mathematical formulation:

\[
\text{maximize} \quad \sum_{i=1}^{N} \sum_{j=1}^{M_i} u_{ij} x_{ij} \\
\text{subject to} \quad \sum_{j=1}^{M_i} x_{ij} = 1, \quad \forall i \\
\sum_{i=1}^{N} \sum_{j=1}^{M_i} c_{ij} x_{ij} \leq B,
\]

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

- **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

**MOS**: Mean Opinion Score (subjective video quality metric)
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 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