Cross-Layer Optimization for Video Streaming in Single-Hop Wireless Networks

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Video Optimization in Wireless Networks

Resource Allocation Problem
-- shared air medium
Video Optimization Problem

- **Goal:** maximize video quality for stations by properly allocating shared resources
- **Challenge:** stations have diverse constraints
  - channel conditions
  - processing powers
  - energy levels
  - video characteristics
- **Approach:**
  - propose a cross-layer optimization framework
  - then, instantiate the framework for 802.11e WLANs
Video Optimization Framework

The Optimization Algorithm

- P-R-D Characteristics
- Opt. Coding Rate

Complexity Scalable Video Coder

QoS-Enabled Controller

Radio Module

APP

LINK

PHY

MAC Parameters
- Opt. Bandwidth
- Share Allocation
- Channel Rate
P-R-D models related distortion as a function $D(.)$ of $r_s$ (coding rate), $p_s$ (coding power), and $V$ (video characteristics).
QoS Enabled Controller

- Link Layer
  - achieves/enforces QoS differentiation
  - allocates bandwidth \( b_s \) to station \( s \), s.t.
    \[ \text{where } B(.) \text{ is the link capacity} \]

- Physical Layer
  - diverse channel rate \( (\gamma_s) \)
Find Opt. policy such that

\( \text{s.t.} \)

- Capacity \( B(.) \) is a function of
  - \# of stations, link protocols, channel rates
- Distortion \( D(.) \) is a function of
  - coding rate, coding power, video characteristics
General Formulation (cont.)

- Formulation $PG$ is general
  - any $D(.)$ and $B(.)$ can be adopted
  - can be numerically or analytically solved

Different objective functions
- MMSE: minimizing average mean-square error
- MMAX: minimizing maximum distortion
Instantiate PG for 802.11e WLAN

- 802.11e is a supplement for supporting QoS
- Why 802.11e?
  - widely deployed, QoS differentiation, more challenging than TDMA networks
- 802.11e supports two modes
  - **EDCA**: distributed contention-based
  - **HCCA**: polling-based contention-free
- Why EDCA?
  - simple, commonly implemented, higher b/w utilization
EDCA Overview

- QoS differentiation: several Access Categories (ACs)
- Each AC is assigned different back-off parameters

<table>
<thead>
<tr>
<th>AC</th>
<th>Voice</th>
<th>Video</th>
<th>Best-Effort</th>
<th>Background</th>
</tr>
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<tbody>
<tr>
<td>AIFS</td>
<td>2</td>
<td>2</td>
<td>5</td>
<td>7</td>
</tr>
<tr>
<td>CWmin</td>
<td>3</td>
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<td>CWmax</td>
<td>7</td>
<td>15</td>
<td>1023</td>
<td>1023</td>
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<tr>
<td>TXOP</td>
<td>4096</td>
<td>2048</td>
<td>1024</td>
<td>1024</td>
</tr>
</tbody>
</table>
EDCA Overview (cont.)

- AIFS: Arbitration Inter Frame Space
- CW: Contention Window
- TXOP: Transmission Opportunity
Per-Station QoS Differentiation

- Assign different EDCA parameters to stations
  - CW, AIFS ↓, then frequency ↑ and bandwidth ↑
  - TXOP ↑, then transmission time ↑ and bandwidth ↑

- But, how we choose the EDCA parameters to achieve a given bandwidth share?
- More importantly, how can we estimate overhead & collisions
Airtime and Efficient Airtime

- Bandwidth allocation == airtime allocation
- **Airtime**: let $\alpha_s$ be the fraction of time allocated to station $s$
  - $r_s$: application (streaming) rate
  - $y_s$: channel rate
- **Effective Airtime**: the fraction of time when the shared medium transmits real data
  - overhead and collisions are deducted
Our Effective Airtime Model

- *p*-persistent EDCA Analysis [Ge et. Al 07]
  - wireless station draws the back-off time from a geometric distribution with parameter *p*
  - stateless, so more tractable
  - analysis can be mapped to EDCA using

- We develop a closed-form EA model
Effective Airtime Model (cont.)

where $t$ is a function of several 802.11 parameters, such as AIFS.

$\geq 1$
Effective Airtime Model (cont.)

It is indeed small and can be dropped
802.11e Formulation

\[ s.t. \]

\[ \text{where} \]

- But, what is \( D(.) \)?
MPEG-4 P-R-D Model [He et al. 05’]

- Distortion
  - : video sequence variance
  - : coder efficiency
  - : power consumption

- For convenience, we let
Optimal Solution

- Solve it using Lagrangian method for closed-form solutions
Optimal Allocation Algorithm

Base Station

Wireless Station 1
Compute and adjust TXOP

Wireless Station 2

Wireless Station 3
Compute and adjust TXOP
OPNET Simulations

- Implement log-normal path loss model
  - more realistic simulations
  - OPNET uses free space model by default
- Implement resource allocation algorithms on two new wireless nodes
  - base station, wireless station
- Implement two algorithms
  - EDCA (current algorithm), and OPT (our algorithm)
Simulation Setup

- deploy 6~8 of wireless stations
- wireless stations stream videos to base station
- each wireless station periodically (every 5 secs) reports its status to base station
- base station computes the allocation
- each wireless station configures its TXOP limit
- base station collects stats, such as receiving rate and video quality
Validation of our EA Model

The empirical Effective Airtime follows our estimation (69%)
Potential Quality Improvement

About 28% Distortion Reduction
Dynamic Channel Conditions

OPT works in dynamic environments
OPT outperforms opt. algms in ind. layers.
Real 802.11e Testbed

- Use Atheoros AR5005G 802.11e chip
- Implement OPT and EDCA algorithms in its Linux driver
- Configure a base station and two wireless stations
- Wireless stations report status every 10 sec
Sample Result from the Testbed

Quality improvement:
up to 100% in MSE, or 3 dB in PSNR
Conclusions

- Proposed a general video optimization framework
- Instantiated the problem for 802.11e networks
- Presented models for 802.11e and developed an effective airtime model
- Analytically solved the optimization problem
- Evaluated the solution using OPNET simulator and real implementation. Both show promising quality improvements.