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

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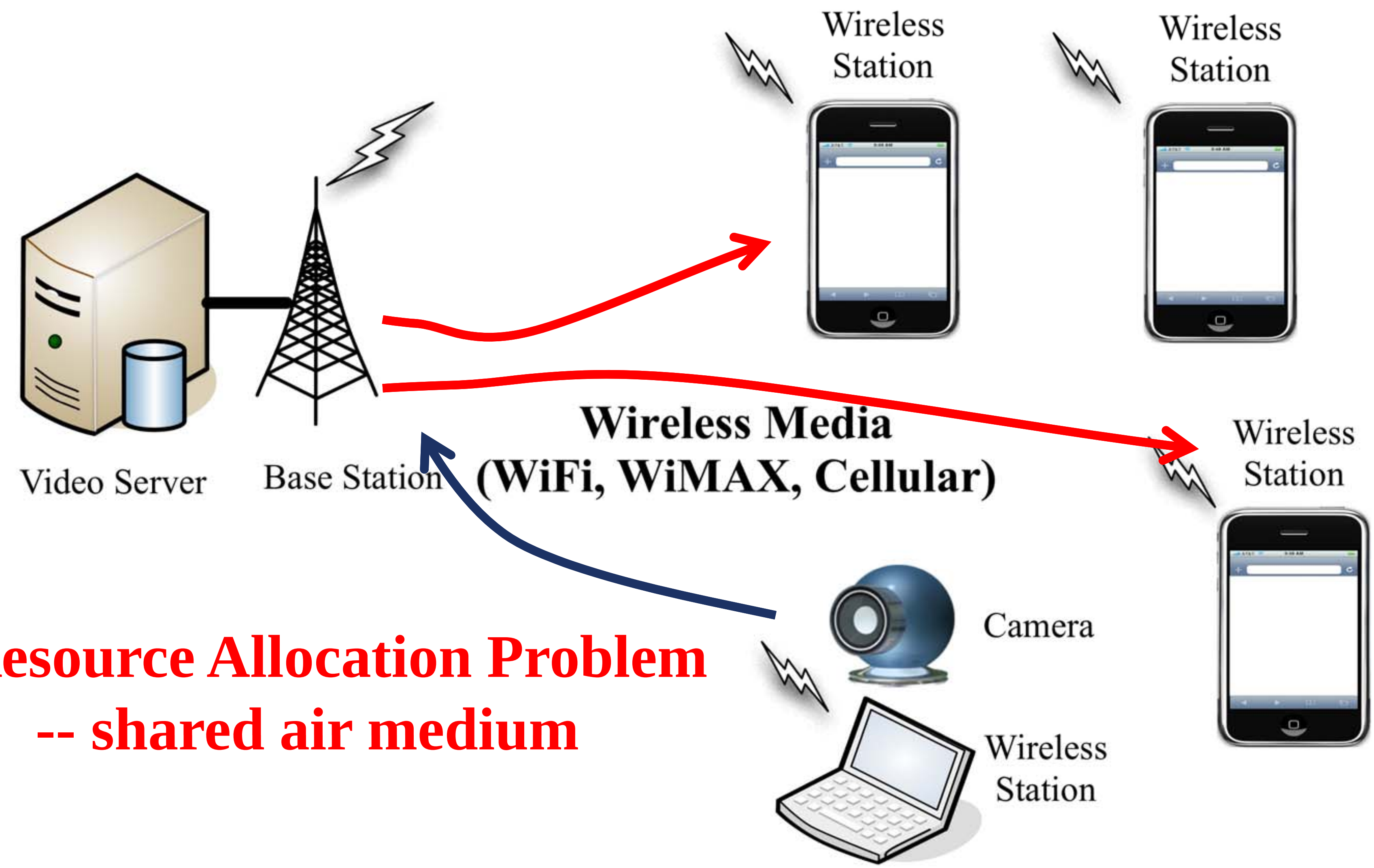
Video Optimization in Wireless Networks

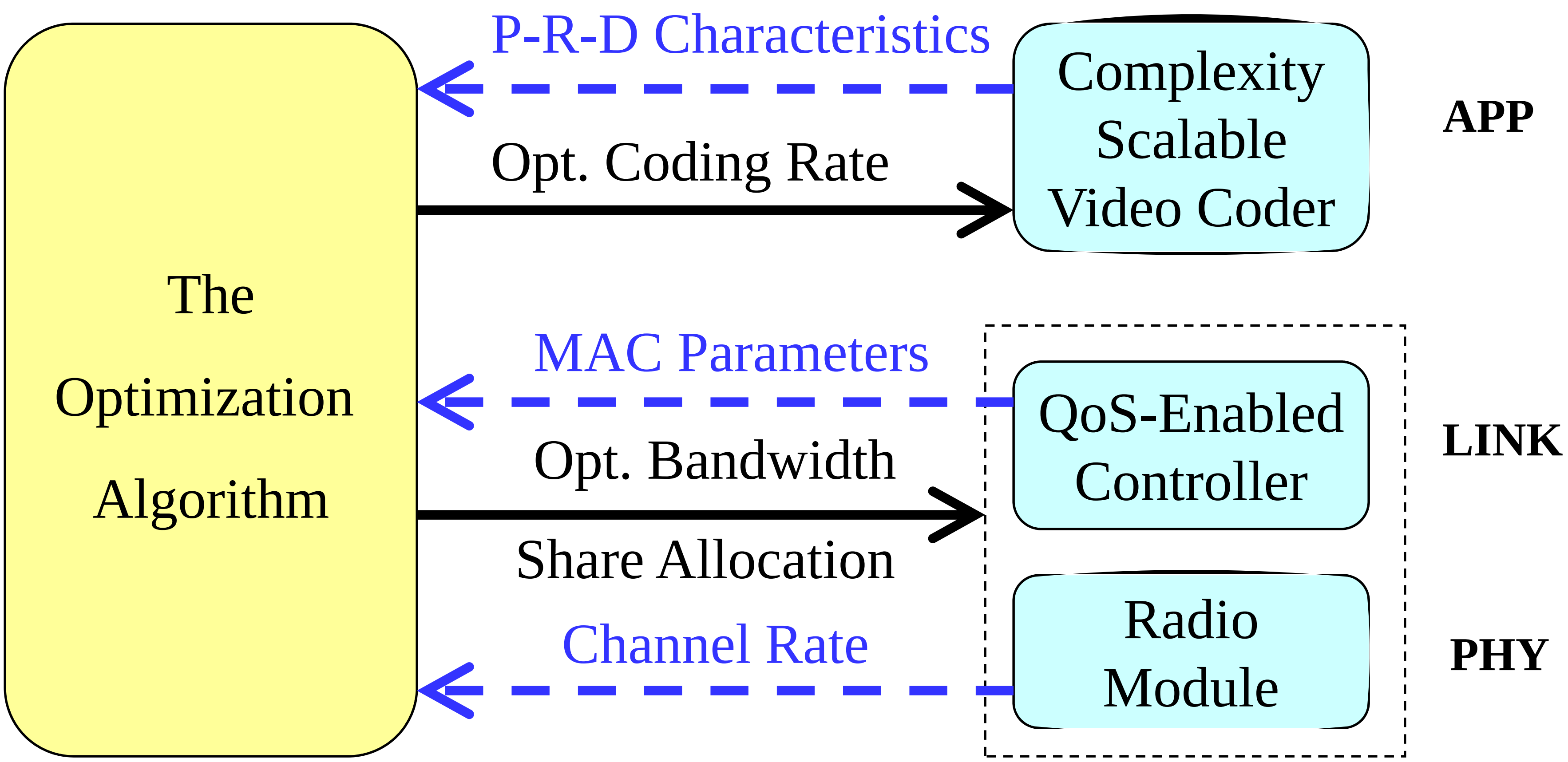


Resource Allocation Problem
-- shared air medium

Video Optimization Problem

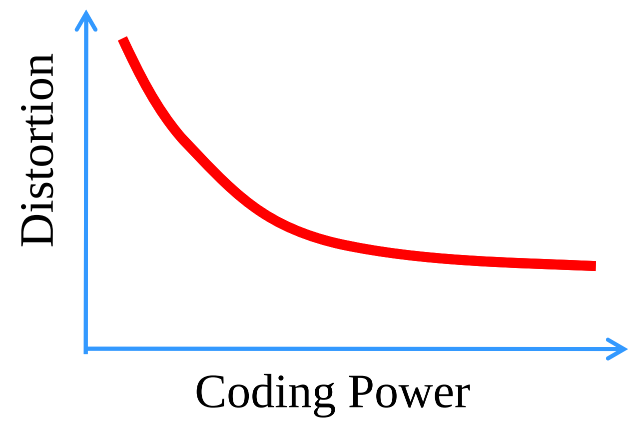
- **Goal:** maximize video quality for stations by properly allocating shared resources
- Challenge: stations have diverse constraints
  - channel conditions
  - processing powers
  - energy levels
  - video characteristics
- Approach:
  - propose a cross-layer optimization framework
  - then, instantiate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

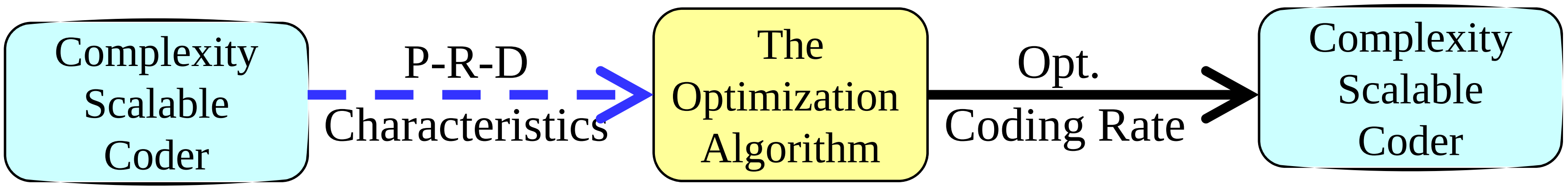
Video Optimization Framework



Complexity Scalable Video Coders

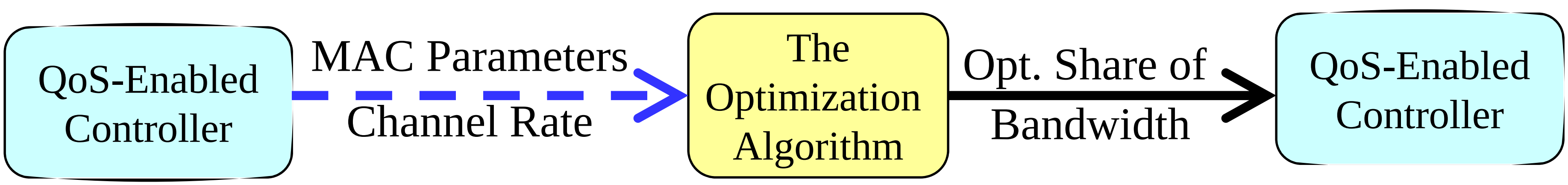
P-R-D models relatedistortion as a func**D(.)** **of r_s (coding rate), p_s (coding power), and V (video characteristics)**





QoS Enabled Controller

- Link Layer
  - achieves/enforces QoS differentiation
  - allocates bandwidth (b_s) to station s, s.t. ,
    where $B(.)$ is the link capacity
- Physical layer
  - diverse channel rate (y_s)



General Formulation

r_s: coding rate
b_s : b/w share

- Find Opt. policy

  such that

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

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

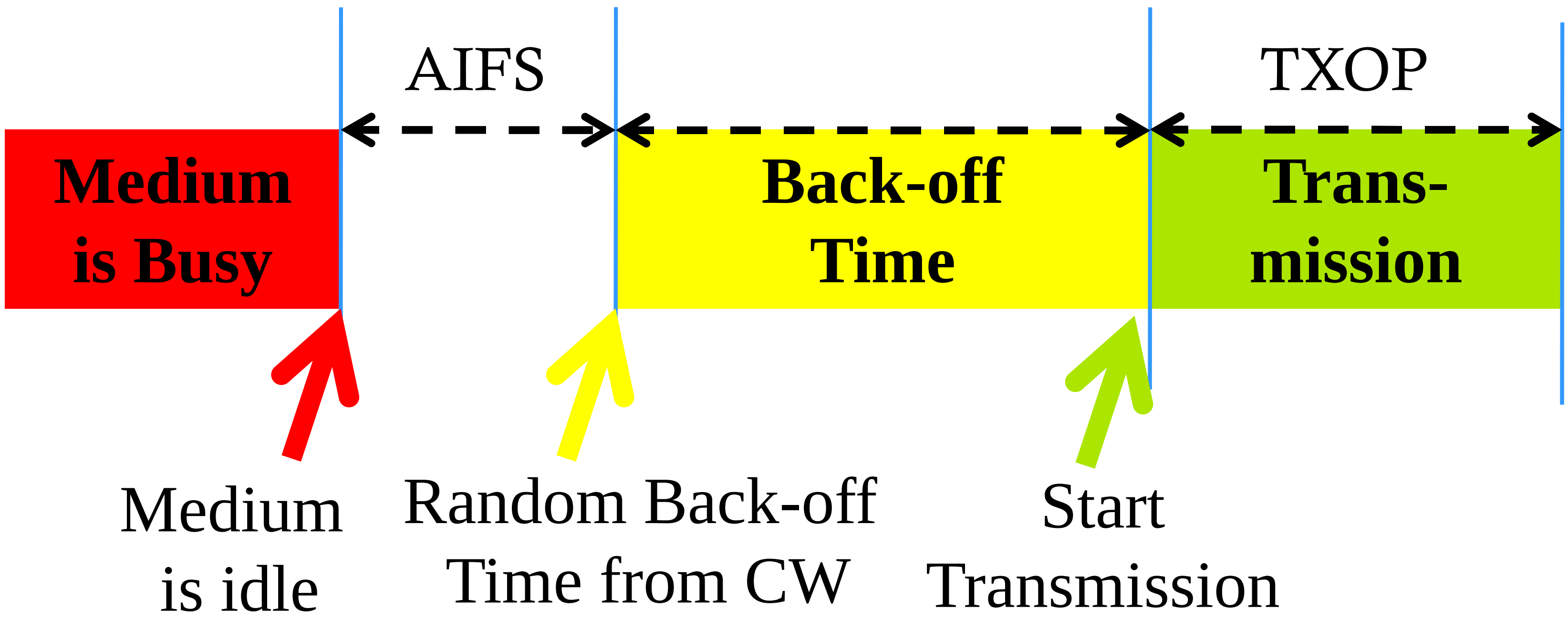
EDCA Overview

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

AC	Voice	Video	Best-Effort	Background
AIFS	2	2	5	7
CWmin	3	7	15	15
CWmax	7	15	1023	1023
TXOP	4096	2048	1024	1024

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 ↑

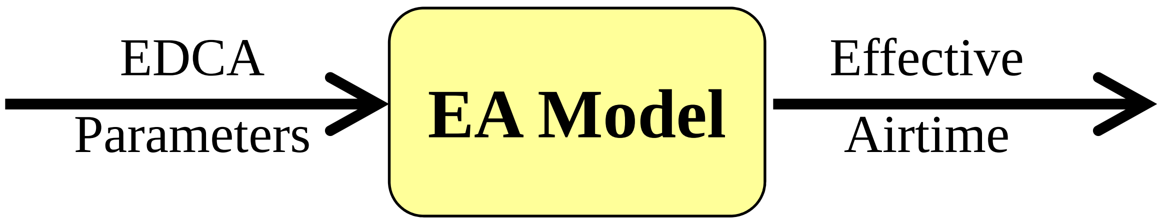
- But, how we choose the EDCA parameters to achieve a given bandwidth share?
- More importantly, how can we estimate overhead & collisions

Airtime and Efficient Airtime

- Bandwidth allocation == airtime allocation
- **Airtime**: let 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



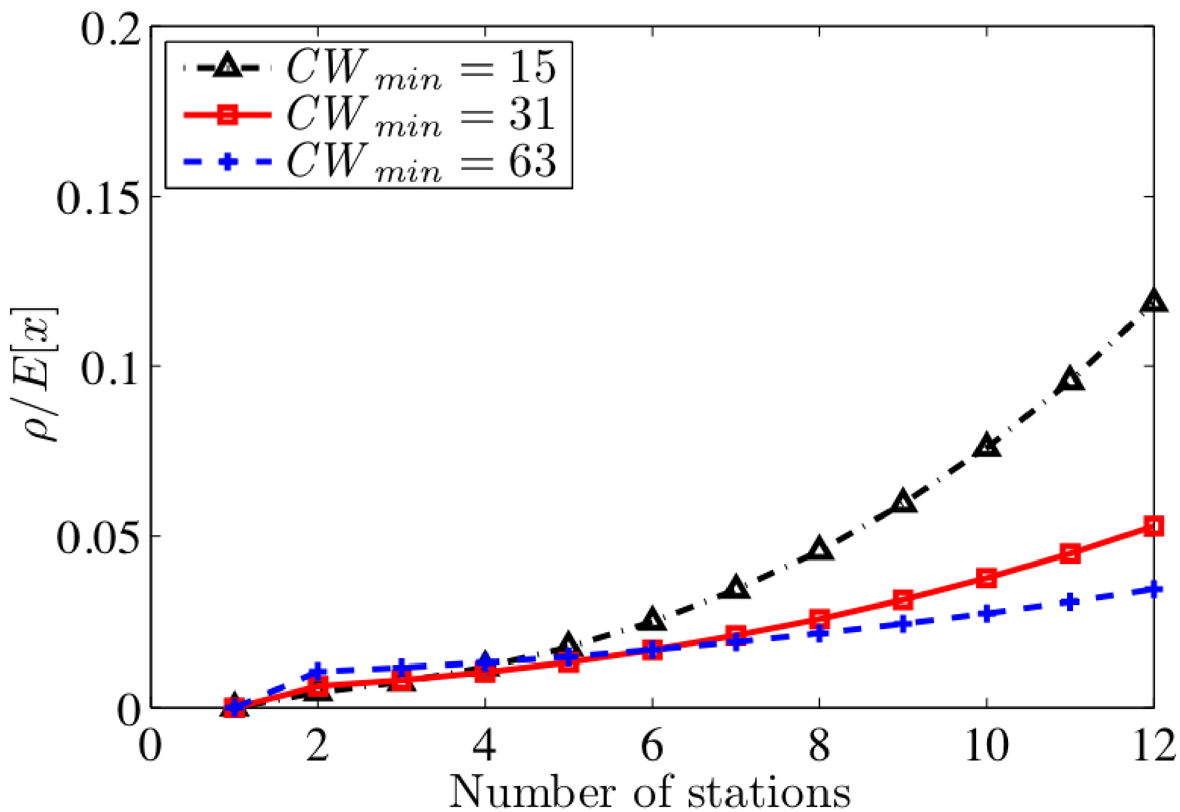
Effective Airtime Model (cont.)

↑

>= 1

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

Effective Airtime Model (cont.)



It is indeed small and can be dropped

802.11e Formulation

s.t.

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

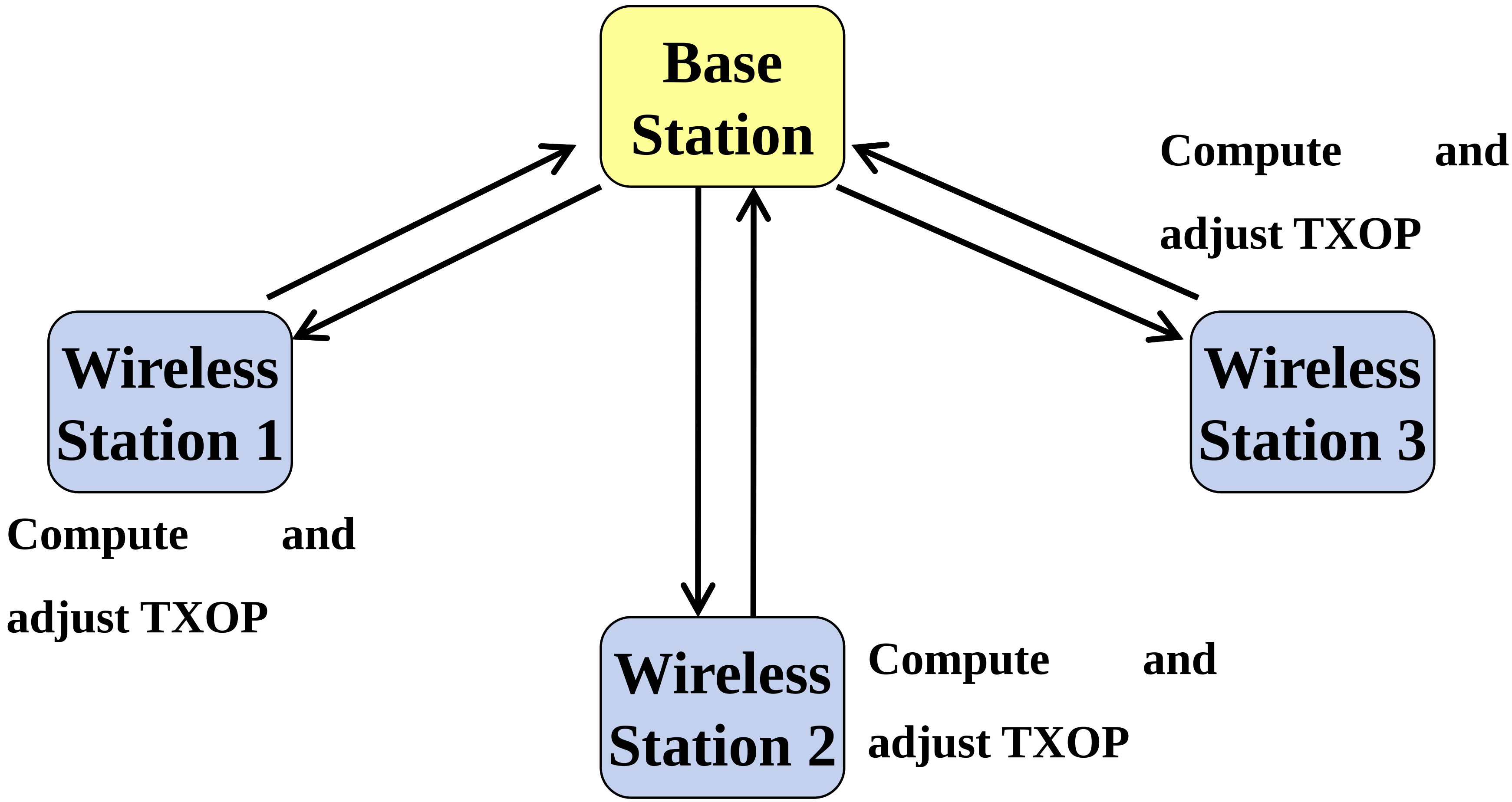
Optimal Solution

- Solve it using Lagrangian method for closed-form solutions

at base station

at wireless station

Optimal Allocation Algorithm



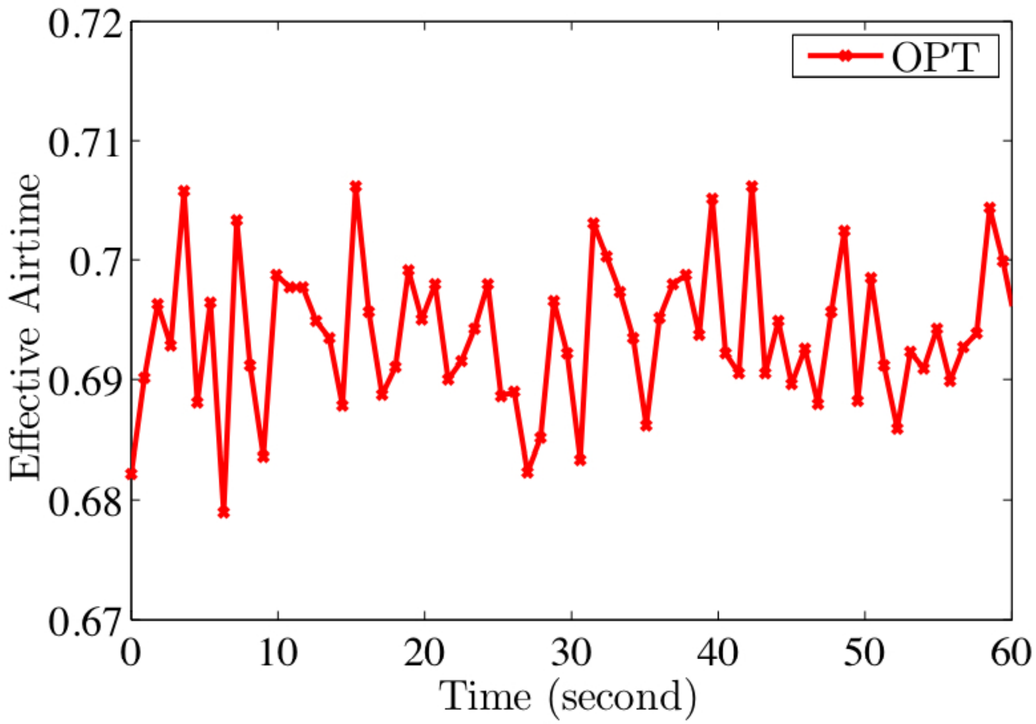
OPNET Simulations

- 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

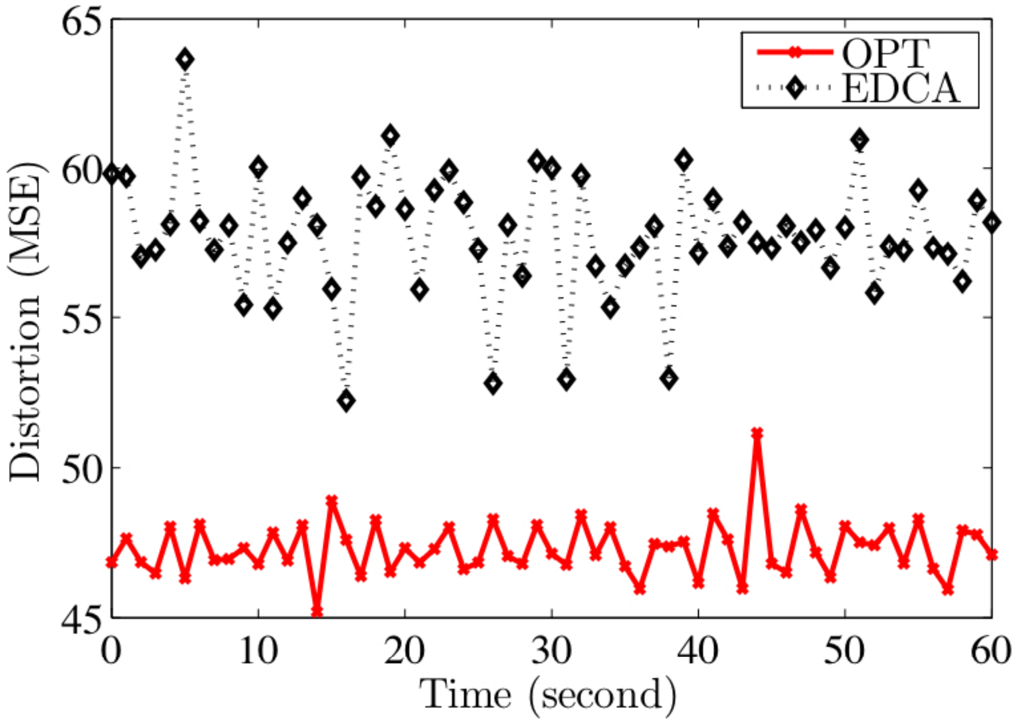
- deploy 6~8 of wireless stations
- wireless stations stream videos to base station
- each wireless station periodically (every 5 secs) reports its status to base station
- base station computes the allocation
- each wireless station configures its TXOP limit
- base station collects stats, such as receiving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

Validation of our EA Model



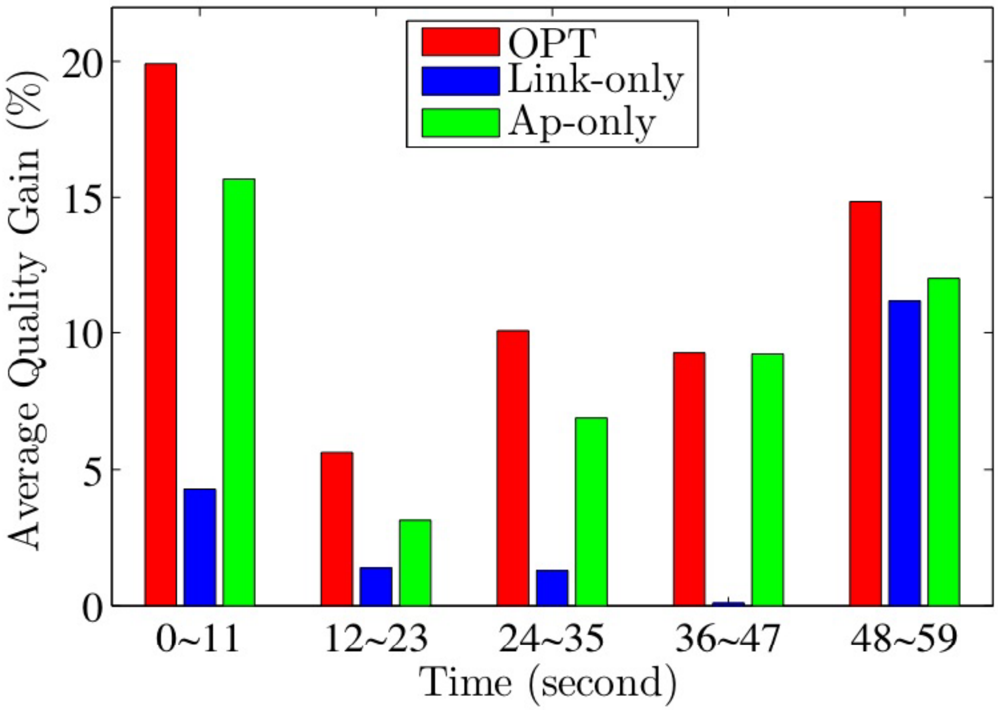
The empirical Effective Airtime follows our estimation (69%)

Potential Quality Improvement



About 28% Distortion Reduction

Dynamic Channel Conditions



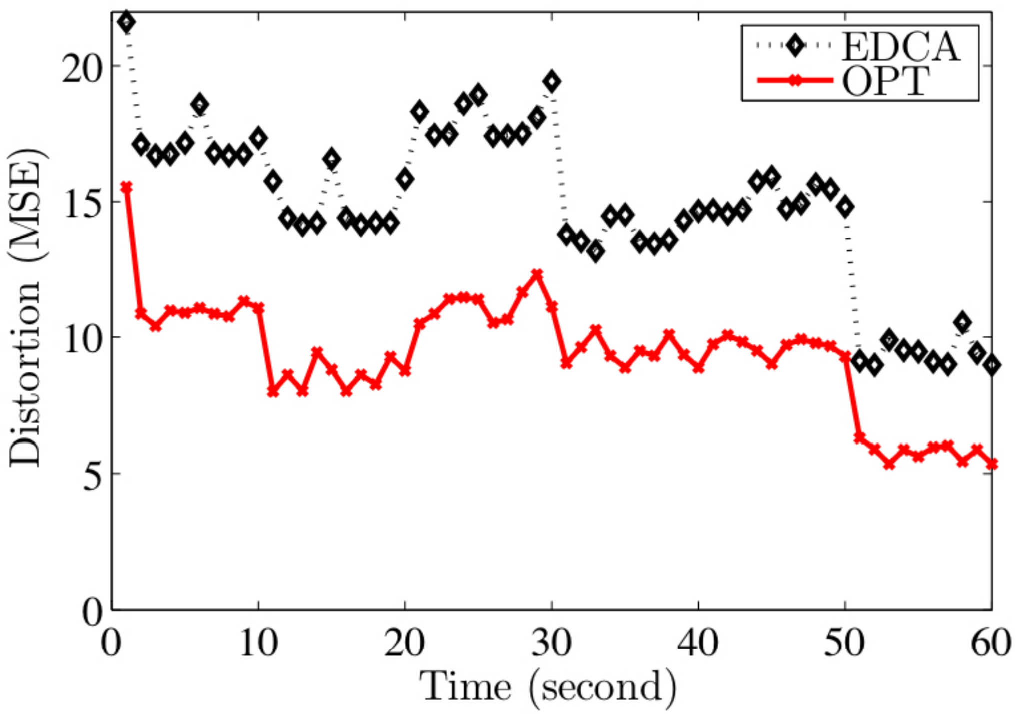
OPT works in dynamic environments

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.