Cross-Layer Wireless Multimedia Transmission: Challenges, Principles and New Paradigms

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Overview of Presentation

- Multimedia transmission in wireless networks.

- Part 1: meeting QoS constraints

- Part 2: fairness and "coopetition"

Multimedia Transmission

- Quality of Service (QOS) constraints in multimedia:

    - Can tolerate some errors / dropped packets

    - Sensitive to delay

    - High Bandwidth

Cross-layer Optimization Background

- Link adaptation

- Channel-aware scheduling

- Optimal power control

- Don't consider characteristics of multimedia.

- Redesign existing protocols?

Layers being considered

- Applications (APP)
- Medium Access Control (MAC)
- Physical Layer (PHY)

PART 1: meeting QoS constraints

Definitions

- N_P, N_M, N_A denotes the number of PHY, MAC, APP adaptation and prediction strategies.

- Joint cross-layer strategy is defined as:

$$S = \{PHY_1, ..., PHY_{N_P}, MAC_1, ..., MAC_{N_M}, ..., APP_1, ..., APP_{N_A}\}$$

- Q denotes multimedia quality.

- $\mathbf{x}$ = (SNR, contention) represents the instantaneous channel condition

Cross-Layer Optimization Problem

- Optimal strategy denoted as:

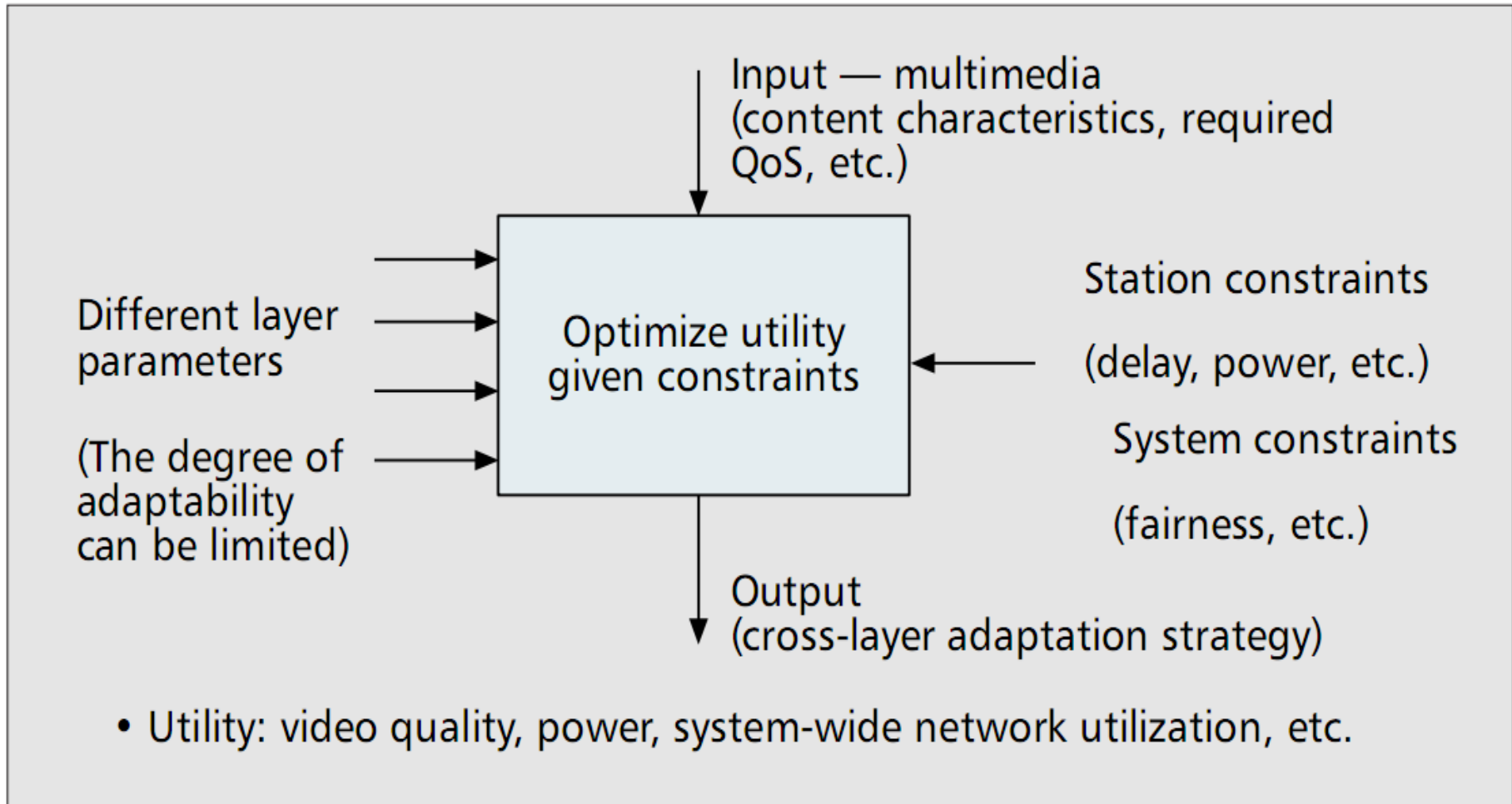$$S^{opt}(\mathbf{x}) = \arg\max_{S} Q(S(\mathbf{x}))$$

  with constraints:
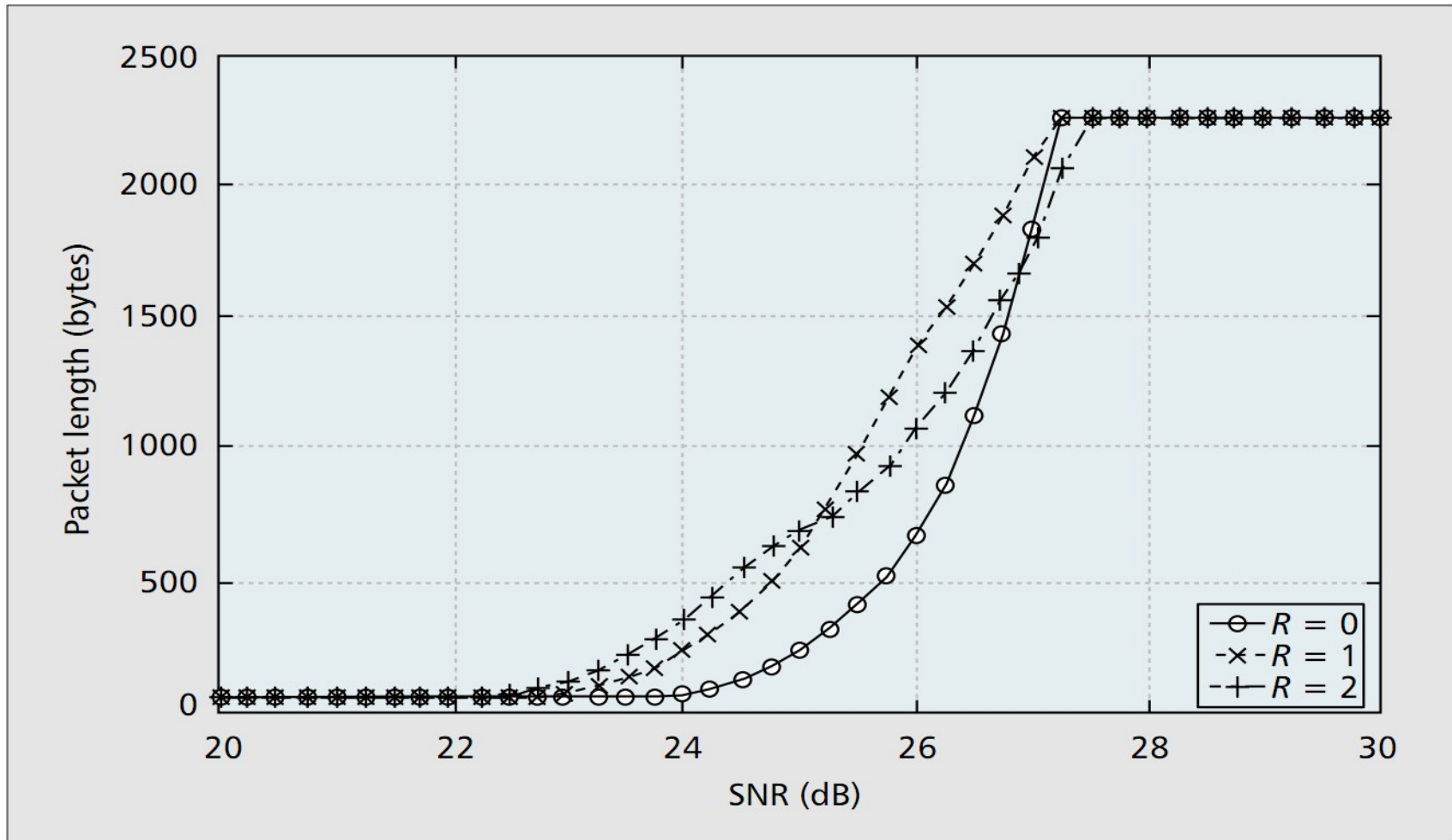
$$Delay(S(\mathbf{x})) \leq D_{\max}$$
$$Power(S(\mathbf{x})) \leq Power_{\max}$$

- Many approaches to this optimization problem.

Cross-Layer Optimization Problem

Input — multimedia (content characteristics, required QoS, etc.)

Different layer parameters

(The degree of adaptability can be limited)

Optimize utility given constraints

Station constraints (delay, power, etc.)

System constraints (fairness, etc.)

Output (cross-layer adaptation strategy)

- Utility: video quality, power, system-wide network utilization, etc.

Minimum required APP-layer packet length as a function of SNR
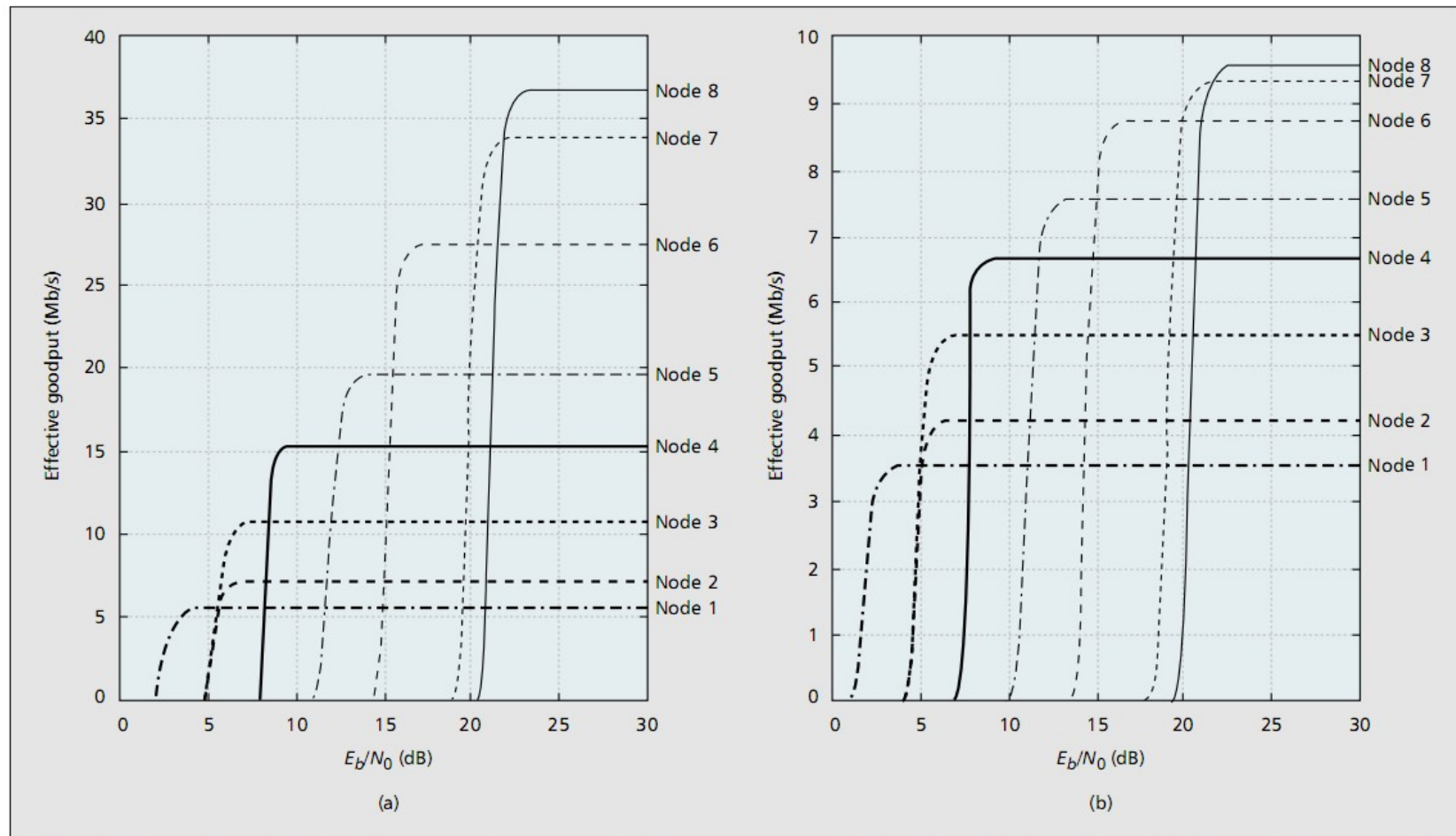

R denotes MAC retry limit

Joint MAC/PHY Optimization

- Use received signal strength indicator (RSSI) via ACK to adapt modulation at PHY.

- Increase throughput.

- But this is not optimal for multimedia.

Joint MAC/PHY Optimization

Figure 3. *Optimal modulation scheme as a function of SNR and frame size decided by the MAC [12]: a) MSDU size 2000 octets; b) MSDU size 200 octets.*

Joint APP/MAC/PHY Optimization

- R_{bl}, R_{el} denote the base layer and enhancement layer rates at the APP.

- P : MAC packet size.

- m : modulation strategy at PHY.

Joint APP/MAC/PHY Optimization

- Optimal strategy becomes:

$$S^{opt}(\mathbf{x}) = \arg\max_{S} Q(S(\mathbf{x}))$$

with $S(\mathbf{x}) = \{R_{bl}, R_{el}, P, m\}$

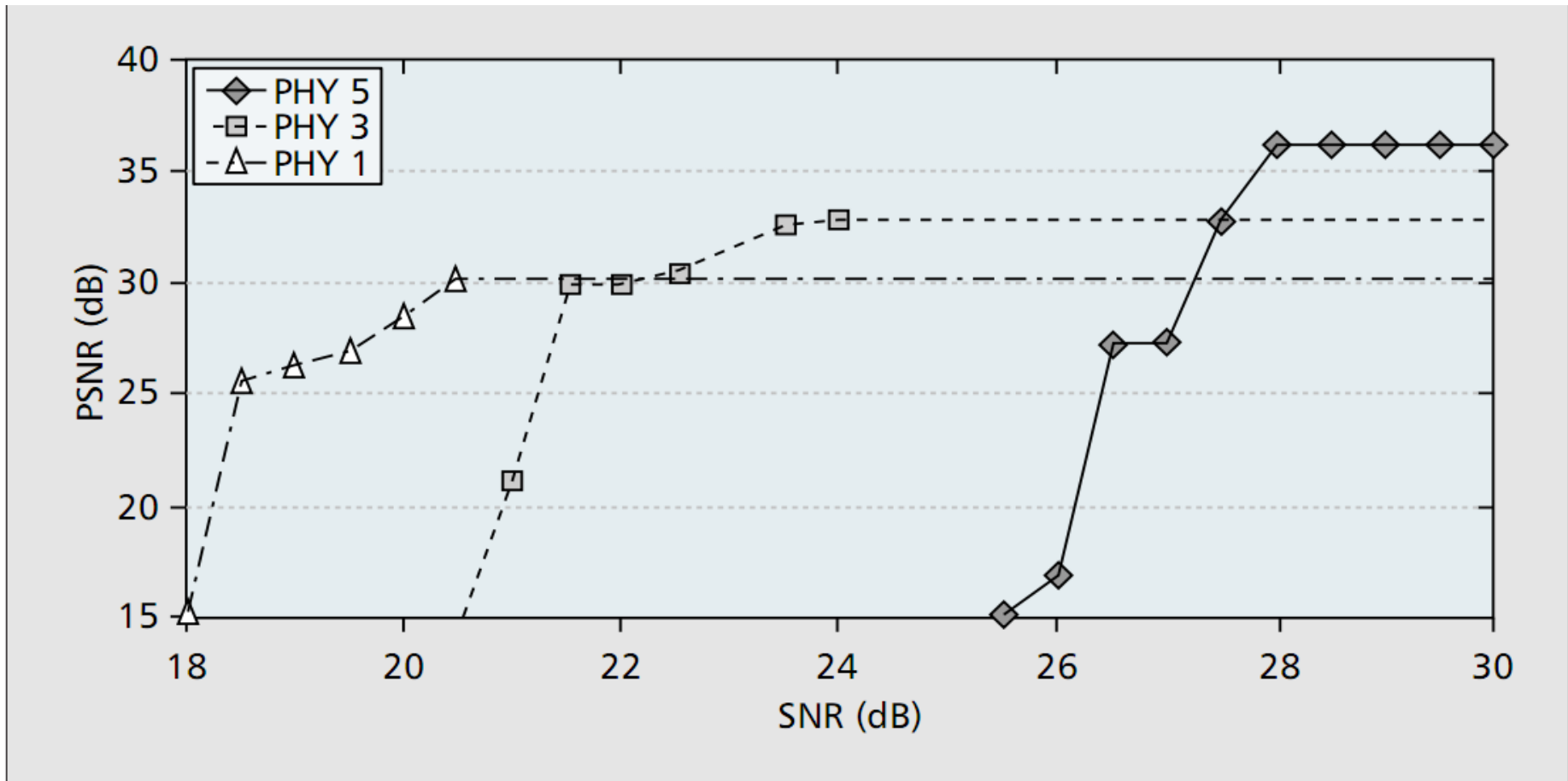# Joint APP/MAC/PHY Optimization

■ **Figure 4**. *Optimal modulation scheme decided by the APP-MAC-PHY as a function of SNR [13].*

Joint APP/MAC/PHY Optimization

Deployed strategies	Visual score
No optimization at MAC and APP	1.4
MAC layer optimization (RTRO)	1.9
APP layer optimization	3.8
Joint APP-MAC optimization	4.6

■ **Table 1.** *Subjective video quality experiment.*

PART 2: Fairness

Ideal Fair Scheduler Based on Generalized Processor Scheduler

- $W_i(t_1, t_2)$: amount of video flow from WSTA i at time interval (t_1, t_2).

- ϕ_i : weight based on requirements.
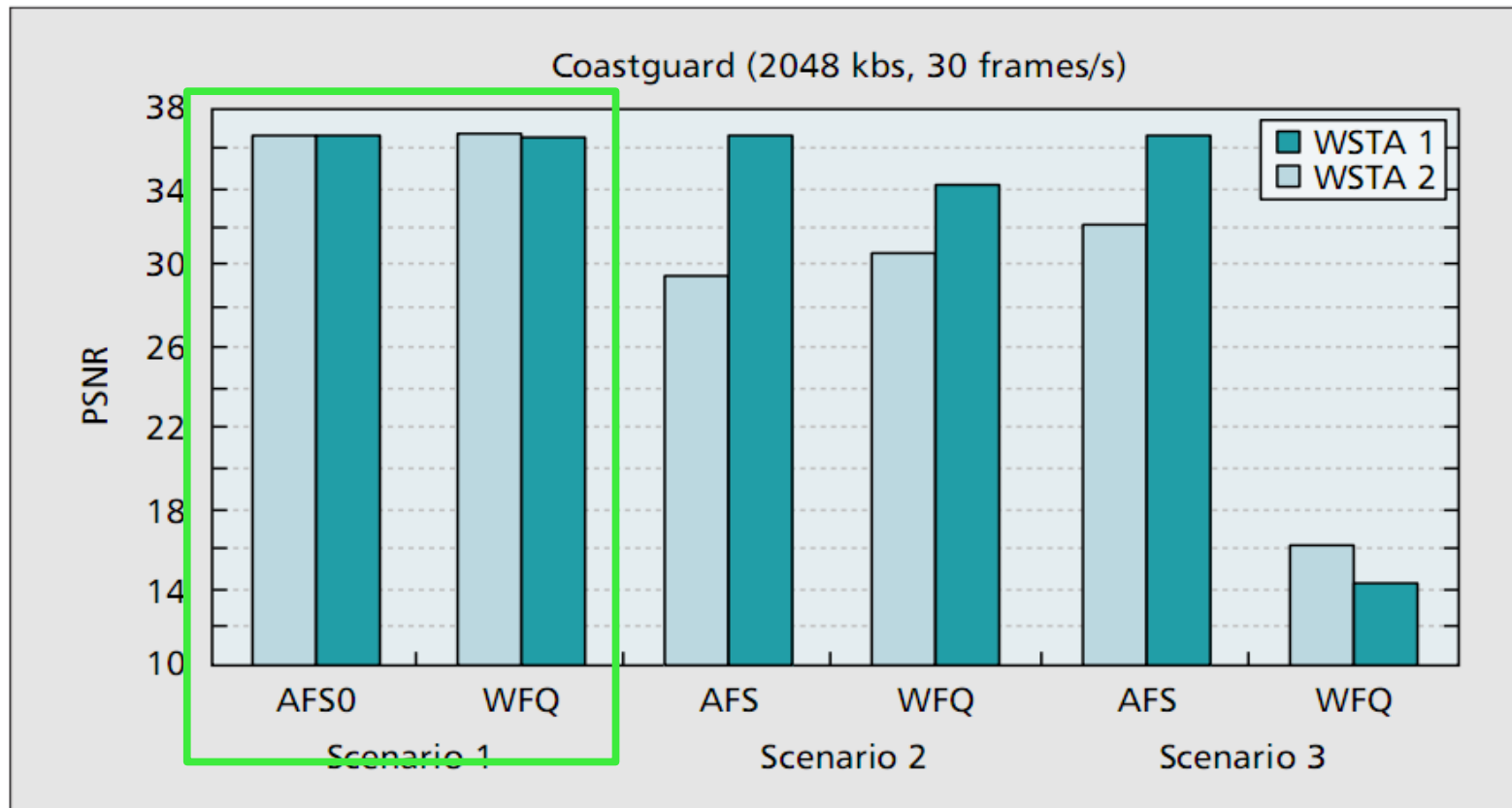
- Optimal policy is

$$\frac{W_i(t_1, t_2)}{W_j(t_1, t_2)} \geq \frac{\phi_i}{\phi_j} \ , j = 1, 2, ..., N$$

Proposed Idea: Time Scheduling

- $T_i(t_1, t_2)$: time allocated to video stream of i during time interval (t_1, t_2).

- ϕ_i : weight based on requirements.
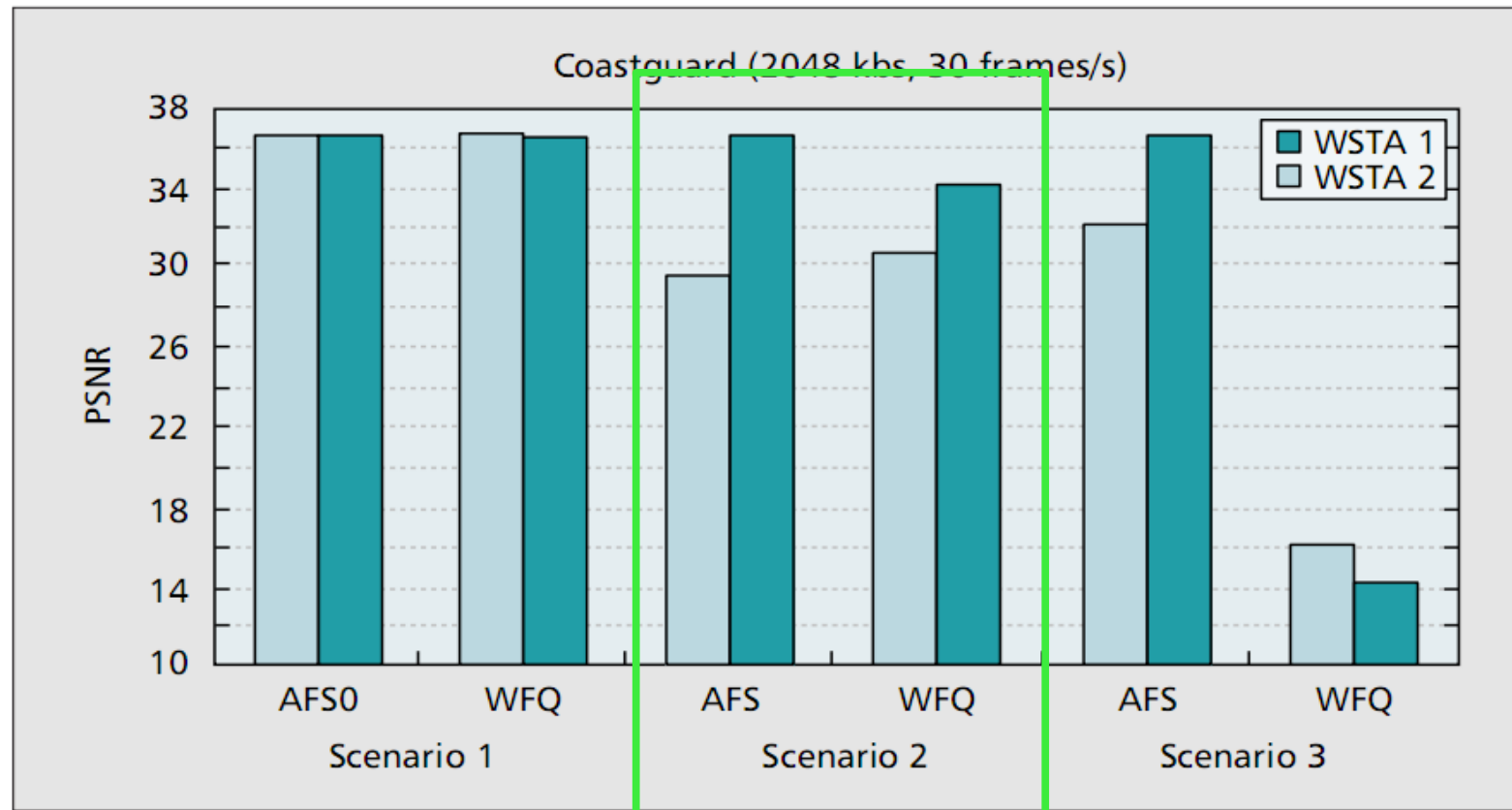
- Fairness policy becomes

$$\frac{T_i(t_1, t_2)}{T_j(t_1, t_2)} \geq \frac{\phi_i}{\phi_j} \, , j = 1, 2, ..., N$$

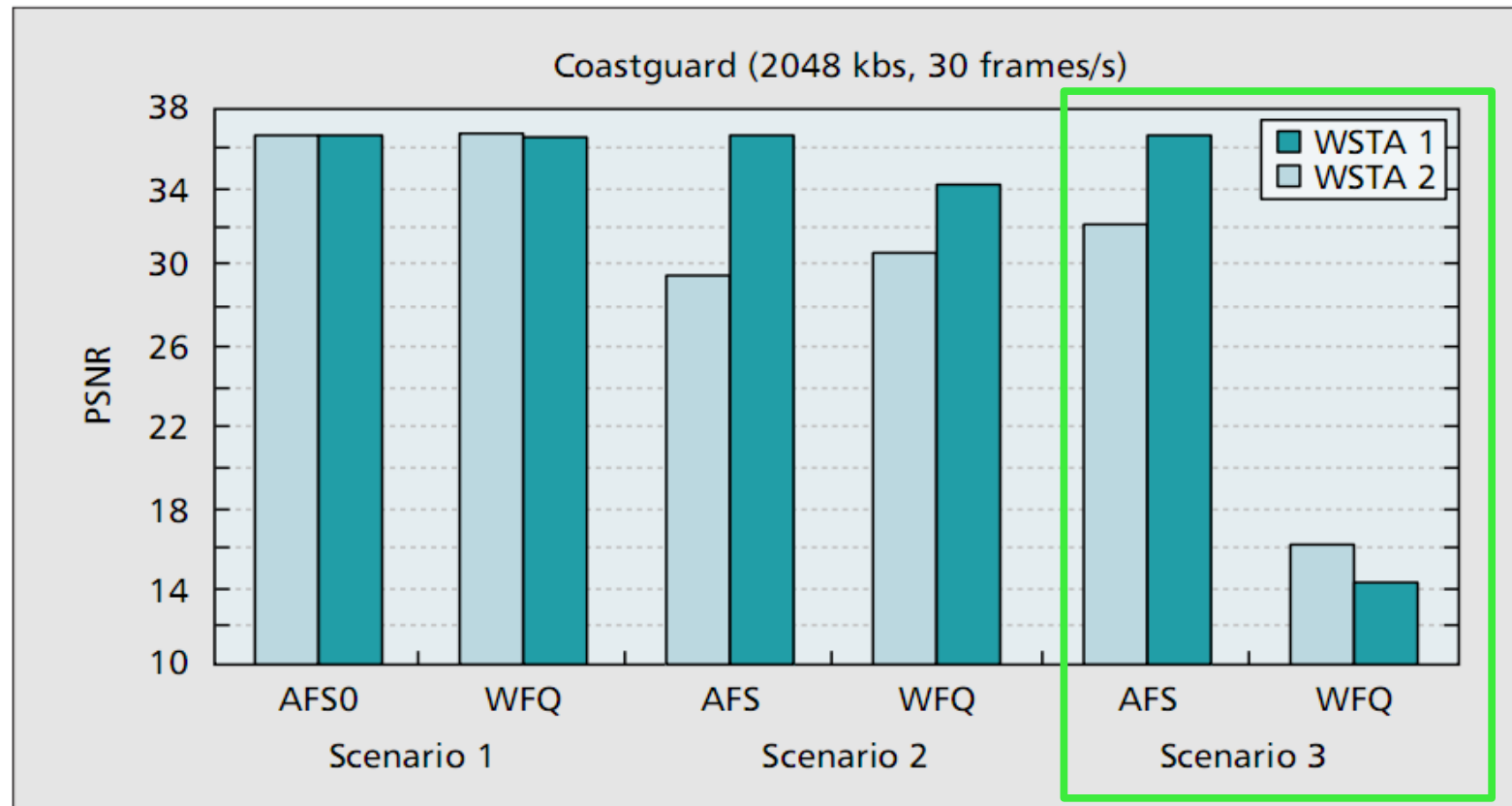# Scenario 1: same cross-layer strategies for both WSTAs

Figure 5. *The PSNR performance of multimedia for different fairness scenarios [20].*

Scenario 2: WSTA1 experiences more severe fading and interference

Figure 5. *The PSNR performance of multimedia for different fairness scenarios [20].*

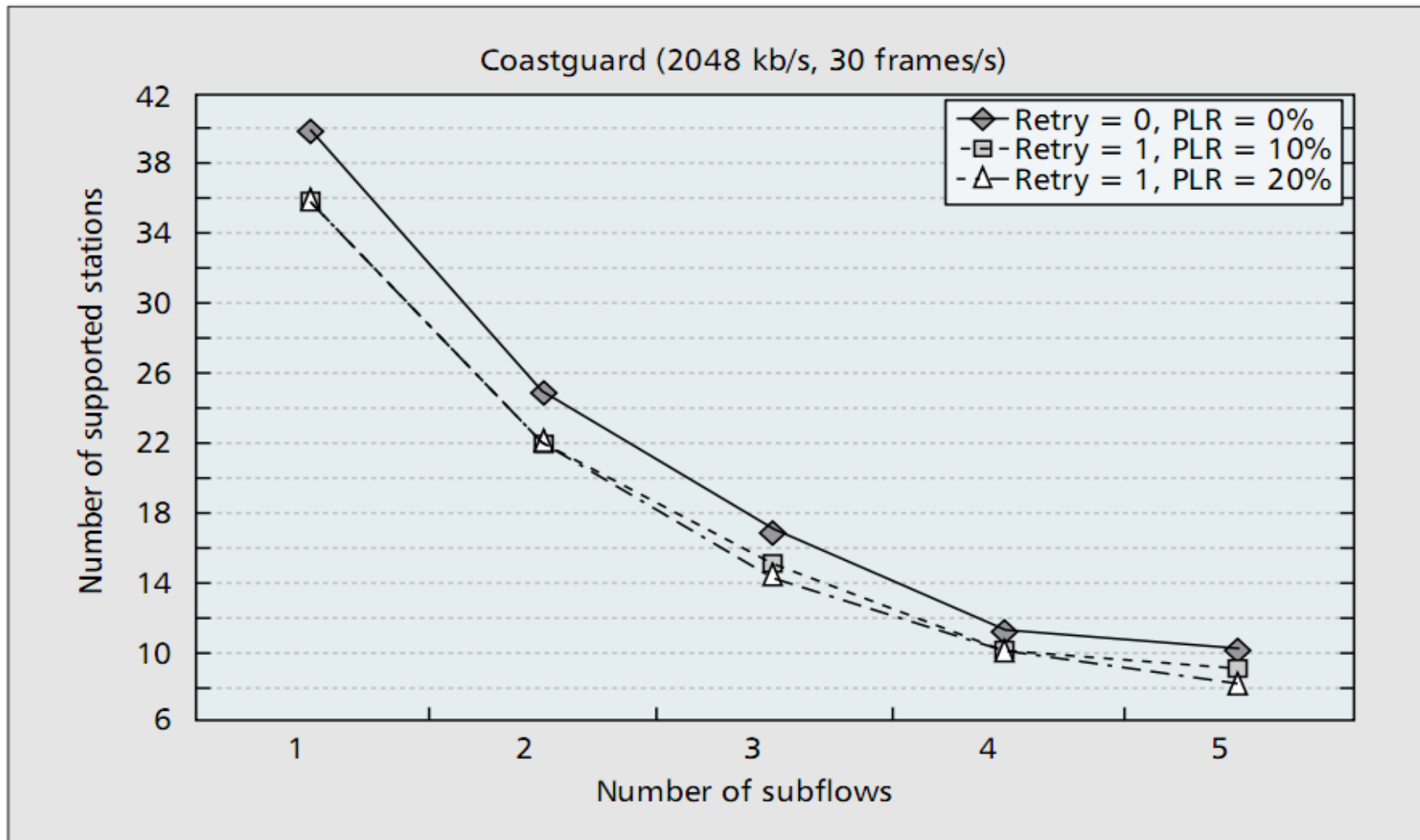# Scenario 3: WSTA1 located further away from access point

Figure 5. *The PSNR performance of multimedia for different fairness scenarios [20].*

Multimedia Quality Fairness

- Use information at APP to partition streams into multiple sub flows.

- Enforce minimum quality constraint for all stations.

Multimedia Quality Fairness

Figure 6. *Number of stations supported as a function of number of subflows [20].*

Conclusions

- Traditional cross-layer paradigms need to be adapted for multimedia transmission.

- Cross-layer optimization problem is exhaustive to solve deterministically.

Questions?