”Incentive-compatible” MAC design for WLANs

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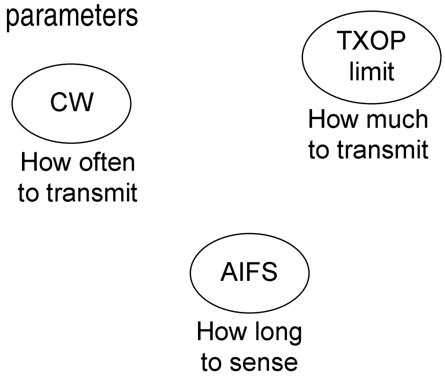
Outline

- MAC QoS provision in WLANs:
  - 802.11e EDCA
    - Problem?
- Some concepts of 802.11e
  - HCCA
  - Admission control
- Some concepts of game theory
  - Game
  - Nash equilibrium
  - Mechanism design
- Current approaches
  - HCCA-based
  - Pricing-based
- Conclusion

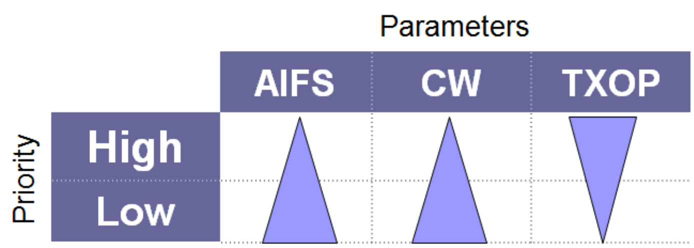
QoS provision in WLANs

- 802.11e EDCA (Enhanced Distributed Channel Access)
  - ☐ contention – based period (CP)
  - ☐ MAC parameters



QoS provision in WLANs

- 802.11e EDCA:



Problem?

- Low priority traffic claims to be of high priority.
  - Improve throughput
  - Hurt delay-sensitive traffic

⇨ **Need for a mechanism which incentivizes low priority to claim their true type.**

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Problem?

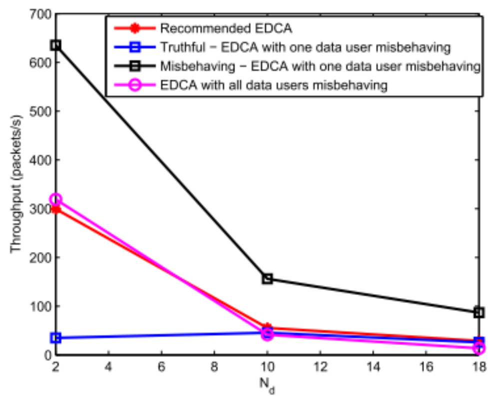

Fig. Throughput of data users

($\lambda = 20$ packets/s, $l_{sat} = 1040$ bytes, $l_{nonsat} = 100$ bytes, $N_u = 4$)

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Concepts in 802.11e

- HCCA (Hybrid coordination function controlled channel access)
  - Polling-based
  - Contention free period (CFP)
- Admission control
  - Guarantee QoS
  - Complicated: require signaling mechanism

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Game

- Components of a game
  - Players
  - Actions
  - Payoffs
    - Payoff of user i: $U_i(a_i,a_{-i})$
    - U_i: utility function of user i
- Nash equilibrium
  - An action profile is a Nash equilibrium if no player can get higher payoff by changing its action while others keep theirs unchanged.

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Mechanism design

- Achieve a desired goal
- Mechanism setting:
  - Individuals: $N = \{1, 2, \ldots, n\}$
  - Type of users: $\theta = (\theta_1, \ldots, \theta_n)$
  - Message: $\widehat{\theta}$
  - Decisions: d
  - Preference
    - Utility function: $v_i(d(\widehat{\theta}), \theta_i)$

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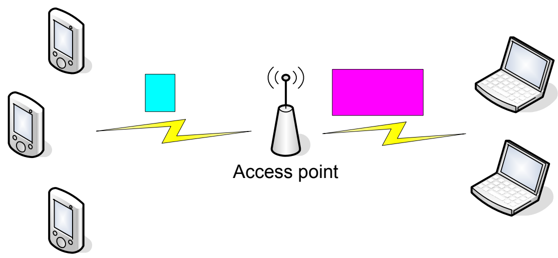
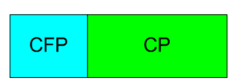
Scenario



HCCA-based

- Idea:
  - polling low priority traffic during contention free period
  - No admission control
  - Let $\alpha = \frac{T_{CFP}}{T_{CFP}+T_{CP}}$.



- Game model:
  - Players: low priority stations
  - Action: claim to be {high priority, low priority} .
  - Payoff
    - Low priority: Throughput
    - High priority: 1/Delay

HCCA-based

- Problem:
  - Find α which incentivizes LP traffic to be truthful.
- Result:
  - Truth telling is a Nash equilbirum if

$$\alpha \geq \frac{nB}{1+nB}$$

$$B = (p-q)(1-q)^{n-1}\left[1 - \frac{\lambda}{(1-q)^n}\right]^m.$$

    - n: number of LP, m: number of HP
    - p: prob. HP attempts to transmit in a given slot.
    - q: prob. LP attempts to transmit in a given slot.

HCCA-based

- Pros
  - LP traffic has no incentive to lie about their type.
- Cons
  - Assumption: AP knows whether a LP station is not claiming their true type
  - Need the cooperation of AP.
  - HCCA: optional feature, not supported in most current hardware.

VCG (Vickrey–Clarke–Groves) mechanism

- Incur payments to players
- Provide players with incentive to declare their private information truthfully.
- Guarantee achieving maximum total utility.

VCG-based mechanism

- Mechanism setting:
  - Individuals: all users
  - Type of a user i: its true traffic class, θ_i
  - Message: $\widehat{\theta}$
  - Decision: $\boldsymbol{p} = (p_i,\ i \in \mathcal{N})$ where p_i: attempt probability of user i.
  - Utility function:
    - Modified α-fair utility function in terms of p_i^{succ} and p_i^{critical}
    - Utility of user i: $u_i(\gamma_i(\boldsymbol{p}), \theta_i)$ where $\gamma_i(\boldsymbol{p})$ is the probability station i successfully transmit in a given slot.

VCG-based mechanism

- Mechanism setting
  - Payment (VCG)

$$t_i(\hat{\boldsymbol{\theta}}) = \sum_{j \in \mathcal{N} \setminus \{i\}} u_j(\gamma_j(\tilde{\boldsymbol{p}}(\hat{\boldsymbol{\theta}})), \hat{\theta}_j) - \sum_{j \in \mathcal{N} \setminus \{i\}} u_j(\gamma_j(\boldsymbol{p}(\hat{\boldsymbol{\theta}})), \hat{\theta}_j),$$

$$\tilde{\boldsymbol{p}}(\hat{\boldsymbol{\theta}}) = \arg \max_{\boldsymbol{p} \in \mathcal{P},\, p_i = 0} \sum_{j \in \mathcal{N} \setminus \{i\}} u_j(\gamma_j(\boldsymbol{p}), \hat{\theta}_j).$$

$$\boldsymbol{p}(\hat{\theta}_i, \hat{\boldsymbol{\theta}}_{-i}) = \arg \max_{\boldsymbol{p} \in \mathcal{P}} \sum_{i \in \mathcal{N}} u_i(\gamma_i(\boldsymbol{p}), \hat{\theta}_i).$$

- Main steps:
  - Type declaration
  - AP calculate attempt probability and payment
  - AP broadcasts these to stations

VCG-based mechanism

- Pros
  - Guarantee minimum throughput
  - No incentive for players to be dishonest
  - Achieve high aggregate utility
- Cons
  - Complicated algorithm
  - Require centralized control
  - It's not clear how pricing can be implemented in reality

Conclusion

- EDCA: vulnerable to the misbehavior of LP traffic.
- Current approaches to prevent this
  - HCCA-based
  - Pricing-based
- Pros:
  - QoS differentation
  - Incentive-compatible
- Cons
  - Require centralized control
  - Complicated implementation