Resource Control for the EDCA and HCCA Mechanisms in IEEE 802.11e Networks

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Introduction

- The authors investigate the problem of efficient resource control for elastic (non-real-time) traffic over the EDCA and HCCA mechanisms of IEEE 802.11e.
- They use economic modeling to derive congestion prices and guide the system to its optimal operating point.

EDCA mechanism

- The EDCA (Enhanced Distributed Channel Access) mechanism is an extension of the DCF (Distributed Coordination Function) mechanism.
- The EDCA mechanism supports QoS through multiple access categories (ACs) and different minimum contention window (CWmin) and maximum CW (CWmax).

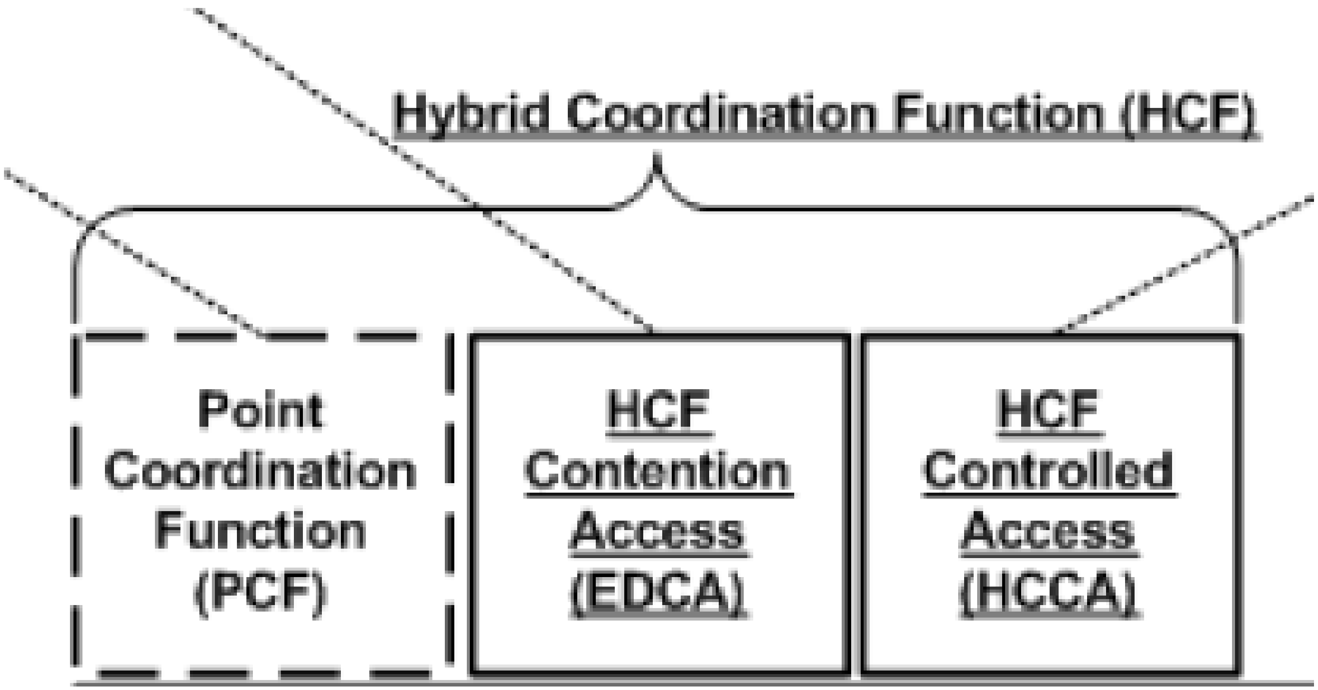
EDCA mechanism

- When a station captures the access of channel, it can deliver data up to a maximum time interval called EDCA TXOP (transmission opportunity).
- The EDCA mechanism is contention-based.

HCCA mechanism

- The HCCA (HCF Controlled Channel Access) mechanism is based on polling, similar to the basic PCF mechanism.
- When a station is polled, it is allowed to deliver data up to a maximum time interval called HCCA TXOP (or polled TXOP).
- The HCCA mechanism is contention-free-based.

MAC architecture of IEEE 802.11e



This figure is captured from IEEE 802.11e standard.

Analytical models for throughput

- The authors study the throughput of IEEE 802.11e networks, and discuss the throughputs of the EDCA and HCCA mechanisms separately.

Throughput model for EDCA

- In a p-persistent model, the probability that a wireless station tries to transmit frames in a time slot is p.
- The transmission probability p in IEEE 802.11 is $\frac{2}{E[CW]+1}$, where E[CW] is the average contention window.

Throughput model for EDCA

- If the probability of a frame being involved in more than one collision is very small, then $E[CW] \approx CW_{min}$.
- In IEEE 802.11e, different wireless stations can have a different CW_{min}, so the transmission probability of a station i in the p-persistent model is

$$p_i = \frac{2}{CW_{min,i} + 1}.$$

Throughput model for EDCA

- In IEEE 802.11, the MAC operation can be viewed in time as a mix of three types of time intervals:
  - a successful transmission interval
  - a collision interval
  - an idle time interval

Throughput model for EDCA

- The average throughput x_i of station i can be expressed as:

$$x_i = \frac{E[X_i]}{E[T]},$$

where E $[X_i]$ is the average amount of data transmitted by station i, and E[T] is the average time interval.

Throughput model for EDCA

- The authors assume that p_i and the aggregate transmission probability are very small, hence x_i is approximately:

$$x_i = \frac{p_i(1-P_{-i})L}{\sum_k p_k(1-P_{-k})T^{suc} + [P - \sum_k p_k(1-P_{-k})]T^{col} + 1 - P}, \quad (1)$$

p_i : transmission probability of station i

T^{suc} : a successful transmission interval, normalized to the idle time interval.

T^{col} : a collision interval, normalized to the idle time interval.

P : $\Sigma_j \, p_j$, the aggregate transmission probability

P_{-k} : $\Sigma_{j \neq k} \, p_j$ L : frame length

Throughput model for EDCA

- Using RTS/CTS and stations having different PHY transmission rate, the average throughput is :

$$x_i = \frac{p_i(1-P_{-i})L}{\sum_k p_k(1-P_{-k})T_k^{suc} + [P - \sum_k p_k(1-P_{-k})]T^{col} + 1 - P} \quad (2)$$

Throughput model for EDCA

- Equation (1) and (2) are used in IEEE 802.11, and considering the situation of the EDCA mechanism in IEEE 802.11e, the throughput for station *i* is :

$$x_i = \frac{p_i(1-P_{-i})R_i o_i}{\sum_k p_k(1-P_{-k})(a+o_k) + [P - \sum_k p_k(1-P_{-k})]T^{col} + 1 - P}, \quad (3)$$

R_i : the PHY transmission rate of station *i*.

a : the physical layer and IFS overhead, and the MAC layer Ack transmission time.

o_i : EDCA-TXOP for station *i*.

Throughput model for HCCA

- A polled station i is allowed to transmit data up to a maximum time interval o_i (polled-TXOP), so its throughput is

$$x_i = \frac{R_i o_i}{\sum_j o_j}.$$

Resource control model

- Suppose the utility for a user i is $U_i(x_i)$, where the average throughput x_i depends on the control parameter q_i.
- The control parameter can be :
  - the transmission probability or the EDCA TXOP in the EDCA mechanism.
  - the polled-TXOP in the HCCA mechanism.

Resource control model

- The global problem is maximizing the aggregate utility in a wireless system with *N* users

$$\text{maximize} \quad \sum_i U_i(x_i)$$
$$\text{over} \quad \mathbf{q} \geq 0\,,$$

where $\mathbf{q} = (\, q_i,\ 1 \leqq i \leqq N\,)$

$U_i(x_i) = w_i \log x_i$, and w_i is willingness-to-pay factor

Resource control model

- If the maximum is achieved for **q** > 0, the necessary conditions are

$$\frac{\partial \sum_i U_i(x_i)}{\partial q_i} = \frac{\partial U_i(x_i)}{\partial q_i} + \sum_{j \neq i} \frac{\partial U_j(x_j)}{\partial q_i} = 0 \quad \forall i \in N \,. \quad (6)$$

- Next, the authors consider the different cases where resource control is based on the different control parameters.

Resource control model

A. Resource control for contention-based access
   1) Control of the transmission probability
   2) Control of the transmission opportunity (TXOP)

B. Resource control for controlled access
   1) Control of the transmission opportunity (TXOP)

A.1) Control of p_i in EDCA

- Substitute

$$x_i = \frac{p_i(1-P_{-i})L}{\sum_k p_k(1-P_{-k})T_k^{suc} + [P - \sum_k p_k(1-P_{-k})]T^{col} + 1 - P} . \quad (2)$$

in

$$\frac{\partial \sum_i U_i(x_i)}{\partial q_i} = \frac{\partial U_i(x_i)}{\partial q_i} + \sum_{j \neq i} \frac{\partial U_j(x_j)}{\partial q_i} = 0 \quad \forall i \in N . \quad (6)$$

A.1) Control of p_i in EDCA

- After some complex mathematical manipulations, the necessary conditions have been reduced to:

$$\frac{\partial U_i(x_i)}{\partial p_i} = L \frac{(1-P)^2 T_i^{suc} + P(2-P)T^{col}}{E[T]^2} \sum_j U_j' p_j \,, \quad 1 \le i \le N \,, \tag{7}$$

And later on, induce :

$$p_i = \frac{w_i}{\sum_j w_j} \frac{(1-P)E[T]}{(1-P)^2 T_i^{suc} + P(2-P)T^{col}} \,.$$

A.2) Control of the EDCA TXOP

- Suppose the transmission probabilities p_i are fixed, and the wireless resource is controlled through EDCA TXOP (o_i).
- Substitute

$$x_i = \frac{p_i(1-P_{-i})R_i o_i}{\sum_k p_k(1-P_{-k})(a+o_k) + [P - \sum_k p_k(1-P_{-k})]T^{col} + 1 - P}, \quad (3)$$

in

$$\frac{\partial \sum_i U_i(x_i)}{\partial q_i} = \frac{\partial U_i(x_i)}{\partial q_i} + \sum_{j \neq i} \frac{\partial U_j(x_j)}{\partial q_i} = 0 \quad \forall i \in N. \quad (6)$$

A.2) Control of the EDCA TXOP

- Then solve the problem

$$\text{maximize} \quad U_i(x_i) - \lambda p_i o_i$$
$$\text{over} \quad o_i \geq 0 \,. \qquad (\, o_i \text{ is the EDCA TXOP })$$

The necessary condition is :

$$\frac{\partial U_i(x_i)}{\partial o_i} = \lambda p_i$$

Finally, solve the λ , and we can find :

$$\lambda = \frac{(1-P)^2}{E[T]^2} \sum_j U_j' p_j R_j o_j \,.$$

B.1) Control of the HCCA TXOP

- Substitute

$$x_i = \frac{R_i o_i}{\sum_j o_j} .$$

in

$$\frac{\partial \sum_i U_i(x_i)}{\partial q_i} = \frac{\partial U_i(x_i)}{\partial q_i} + \sum_{j \neq i} \frac{\partial U_j(x_j)}{\partial q_i} = 0 \quad \forall i \in N . \quad (6)$$

B.1) Control of the HCCA TXOP

- The necessary conditions become

$$\frac{\partial\ U_i(x_i)}{\partial o_i} = \frac{1}{(\sum_k o_k)^2} \sum_j U_j' R_j o_j\ , \quad 1 \leq i \leq N\ . \qquad (13)$$

, and we can find the optimal values of o_i and x_i are

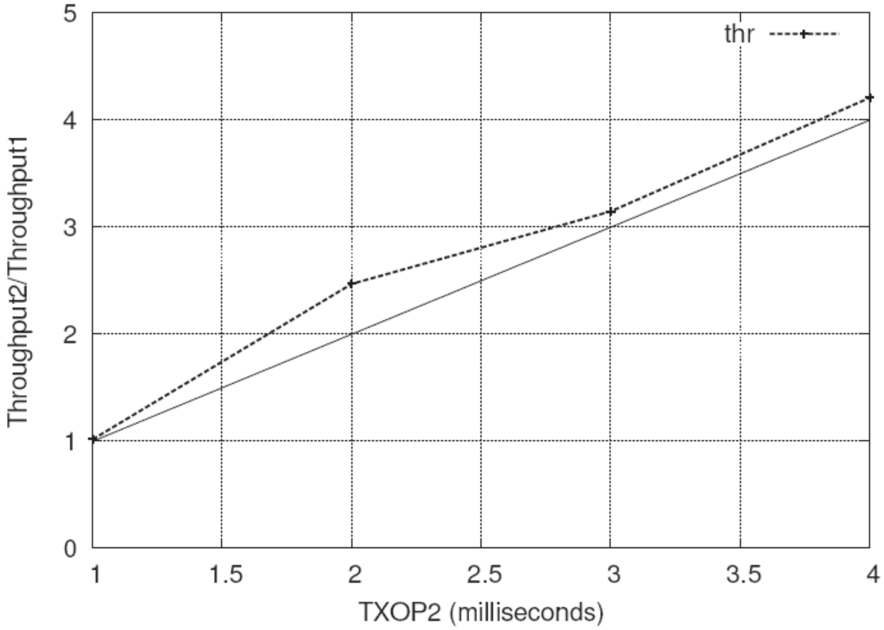
$$o_i = \frac{w_i}{\sum_j w_j} \sum_j o_j$$

$$x_i = \frac{w_i}{\sum_j w_j} R_i .$$

Simulations

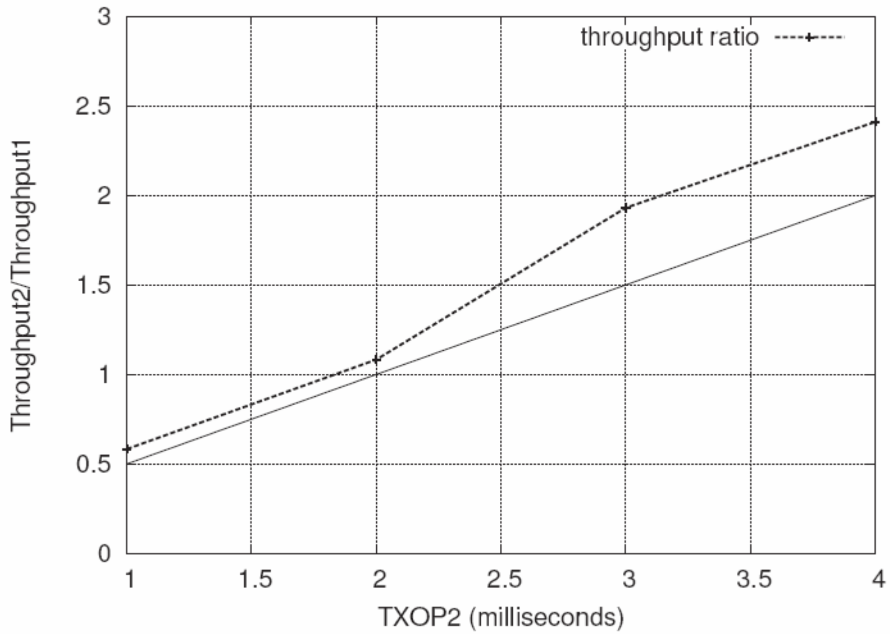
- The simulation experiments 1 and 2 consider five stations in the EDCA mechanism, and two types of parameters control.
- The results are presented as the relation between the ratio of throughput of type2 and type1 and TXOP of type2.

Simulation 1



	Type1	Type2
CWmin	128	128
TXOP	1 ms	variable

Simulation 2

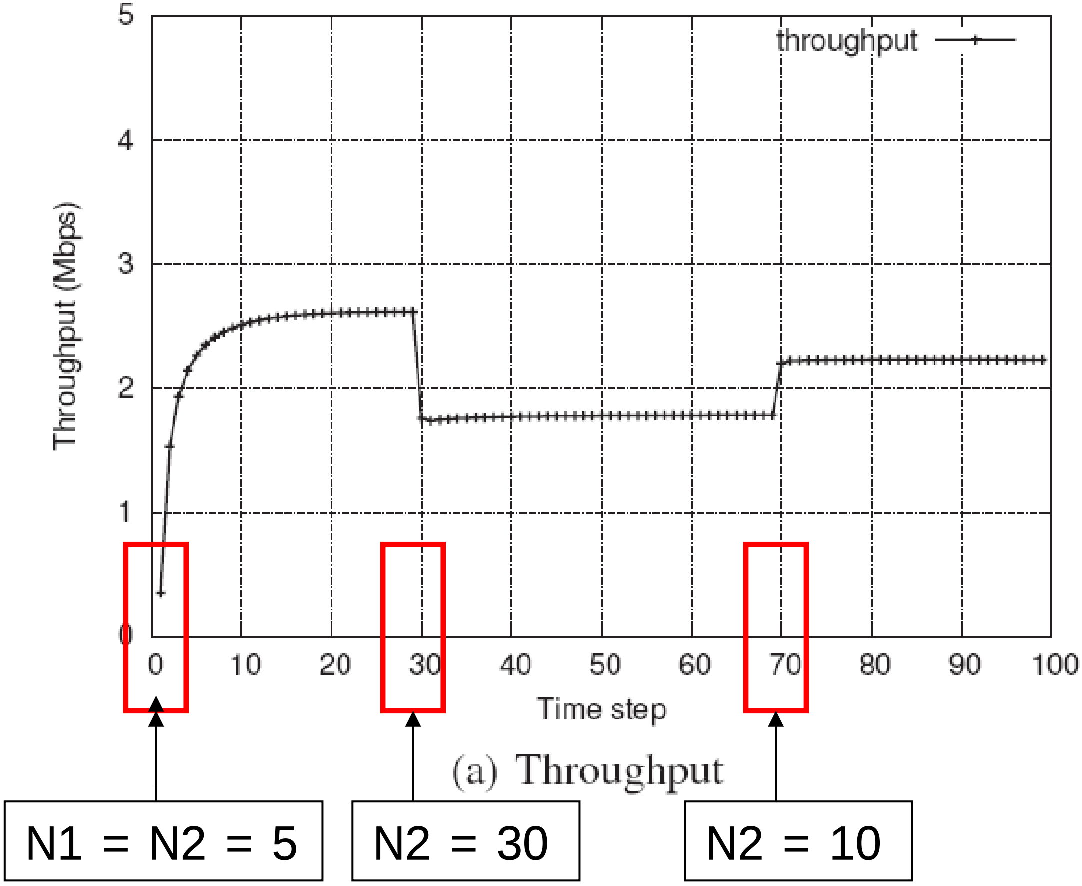


	Type1	Type2
CWmin	128	256
TXOP	1 ms	variable

Simulation 3

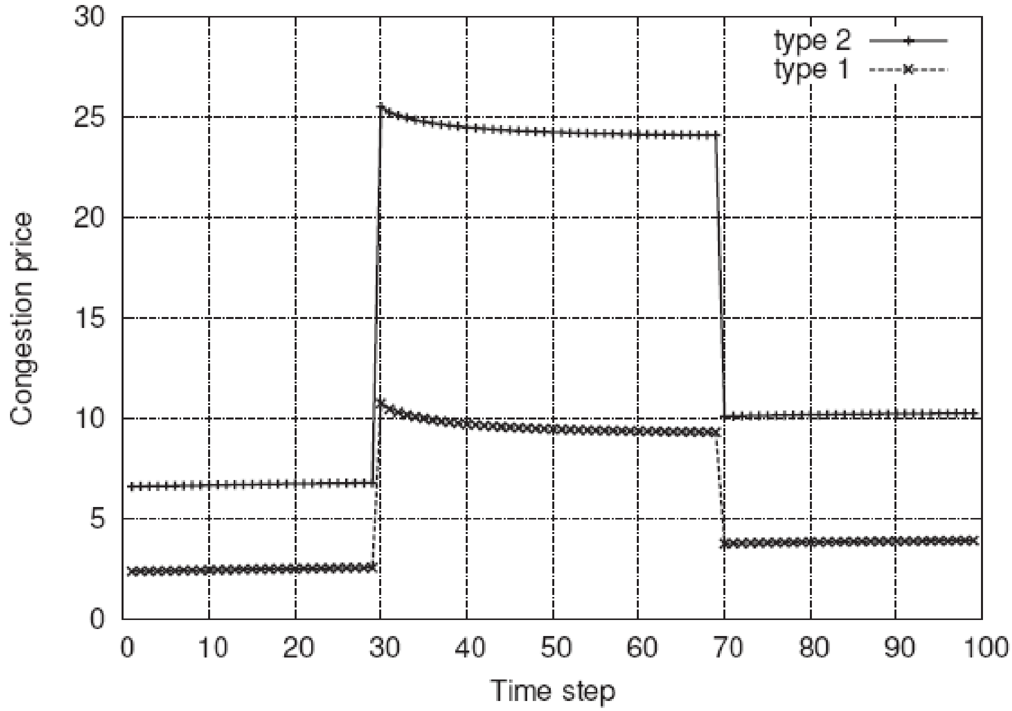
- Simulation 3 considers two types of stations with the same utility but different R_i, 11Mbps(type 1) and 2Mbps(type 2).

Simulation 3



(a) Throughput

Simulation 3



(b) Congestion price

Congestion price $= L \dfrac{(1-P)^2 T_i^{suc} + P(2-P)T^{col}}{E[T]^2} \sum_j U_j' p_j \, , \quad 1 \le i \le N$

Conclusion

- The models can be used through a class-based framework, where different classes have different utility functions and prices.
- The access point (AP) is responsible for optimally selecting the transmission probability, TXOP, and the percentage of contention and contention-free periods.

Problem

- The authors assume the transmission probability $p_i << P = \Sigma_j p_j$ in the resource control models, that implies the number of stations should be large. However, there are only 5 stations in the simulations.