Control theoretic optimization of 802.11 WLANs: Design, implementation and experimental evaluation of two schemes

Pablo Serrano

Dept. Ing. Telemática
Univ. Carlos III de Madrid (UC3M)
http://www.it.uc3m.es/pablo/

Jointly with…

1. Paul Patras

   THE UNIVERSITY *of* EDINBURGH

2. Albert Banchs

   institute imdea

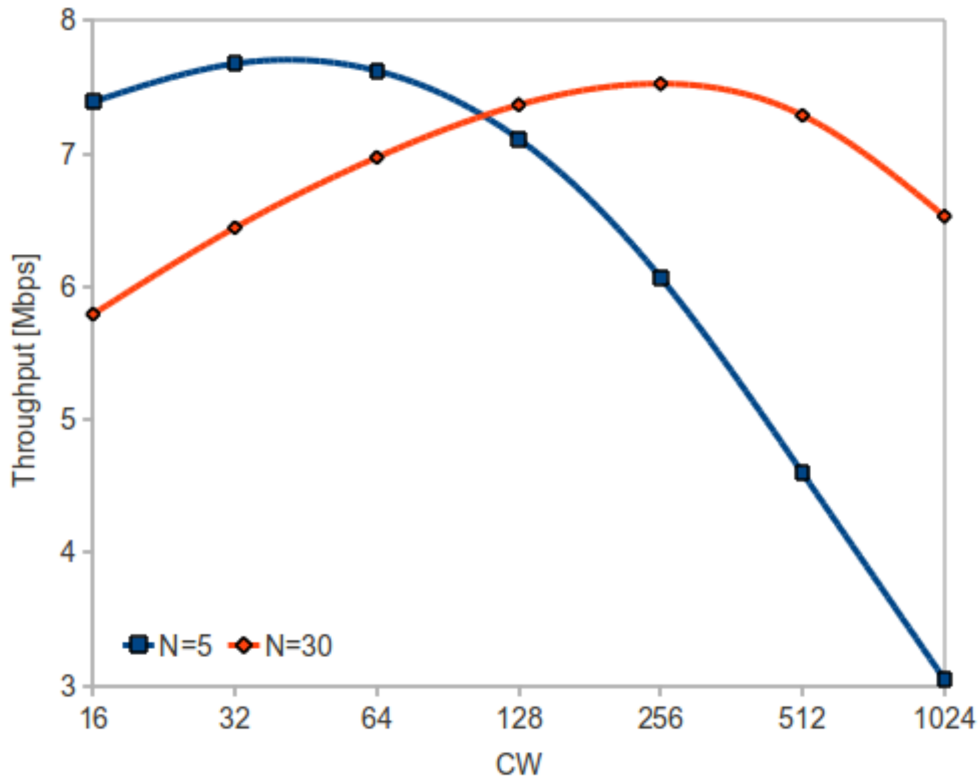
3. Andrea Mannocci

4. Vincenzo Mancuso

   institute imdea

Motivation

- IEEE 802.11: access scheme whose performance depends on the *Contention Window (CW)*
- "Slotted ALOHA": Given the number of stations, there exists a CW* that maximizes performance



Previous works

- Adjust the *CW* based on *conditions*
  - A lot of activity: increase the CW
  - Less activity: decrease the CW
- Two types of solutions
  - Centralized approaches (e.g., [3-5]) – AP computes the configuration and distributes it (now a standard feature)
  - Distributed approaches (e.g., [6-8]) – stations compute their configuration independently → suitable also for ad-hoc mode

(some) Previous works

[1] G. Bianchi, "Performance Analysis of the IEEE 802.11 Distributed Coordination Function", IEEE Journal on Selected Areas in Communications, vol. 18, no. 3, pp. 535–547, March 2000.

[2] P. Serrano, A. Banchs, P. Patras, and A. Azcorra, "Optimal Configuration of 802.11e EDCA for Real-Time and Data Traffic", IEEE Transactions on Vehicular Technology, vol. 59, pp. 2511–2528, June 2010.

[3] A. Nafaa and A. Ksentini and A. Ahmed Mehaoua and B. Ishibashi and Y. Iraqi and R. Boutaba, "Sliding Contention Window (SCW): Towards Backoff Range-Based Service Differentiation over IEEE 802.11 Wireless LAN Networks", IEEE Network, vol. 19, pp. 45–51, July 2005.

[4] J. Freitag and N. L. S. da Fonseca and J. F. de Rezende, "Tuning of 802.11e Network Parameters", IEEE Communications Letters, vol. 10, pp. 611–613, August 2006.

[5] Y. Xiao, H. Li, and S. Choi, "Protection and guarantee for voice and video traffic in IEEE 802.11e wireless LANs", in Proc. IEEE INFOCOM, vol. 3, pp. 2152–2162, March 2004.

[6] G. Bianchi, L. L. Fratta, and M. Oliveri, "Performance evaluation and enhancement of the CSMA/CA MAC protocol for 802.11 wireless LANs", in Proceedings of PIMRC '96, Taipei, Taiwan, October 1996.

[7] M. Heusse, F. Rousseau, R. Guillier, and A. Duda, "Idle Sense: an optimal access method for high throughput and fairness in rate diverse wireless LANs", in Proceedings of SIGCOMM. New York, NY, USA, August 2005.

[8] F. Cali, M. Conti, and E. Gregori, "IEEE 802.11 protocol: design and performance evaluation of an adaptive backoff mechanism", IEEE Journal on Selected Areas in Communications, vol. 18, no. 9, September 2000.

Limitations

- Require modifications of the hardware and/or firmware
- Their performance has not been assessed in real deployment
- Based on heuristics

Motivation, revisited

- Bianchi's seminal work [1]: in **saturation**

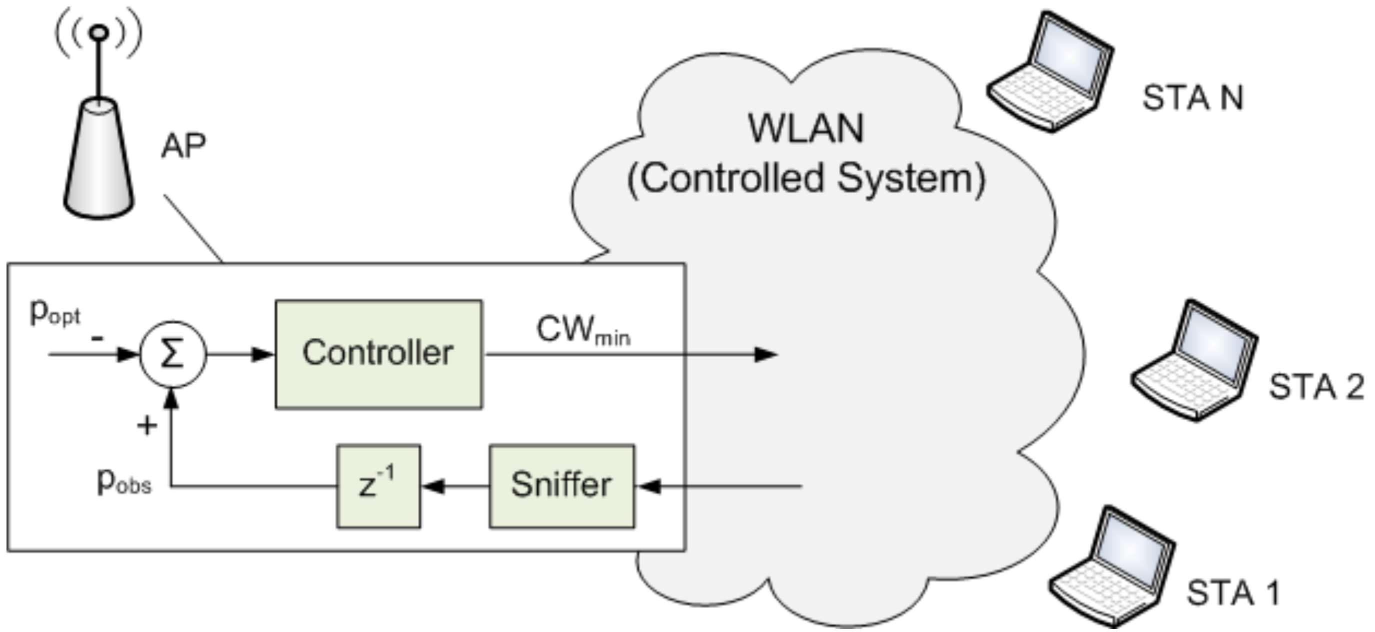
$$\tau_{opt} \approx \frac{1}{n}\sqrt{\frac{2T_e}{T_c}}$$

- This results in a "constant" (conditional) collision probability

$$p_{opt} = 1-(1-\tau_{opt})^{n-1} = 1-\left(1-\frac{1}{n}\sqrt{\frac{2T_e}{T_c}}\right)^{n-1} \approx 1-e^{-\sqrt{\frac{2T_e}{T_c}}}$$

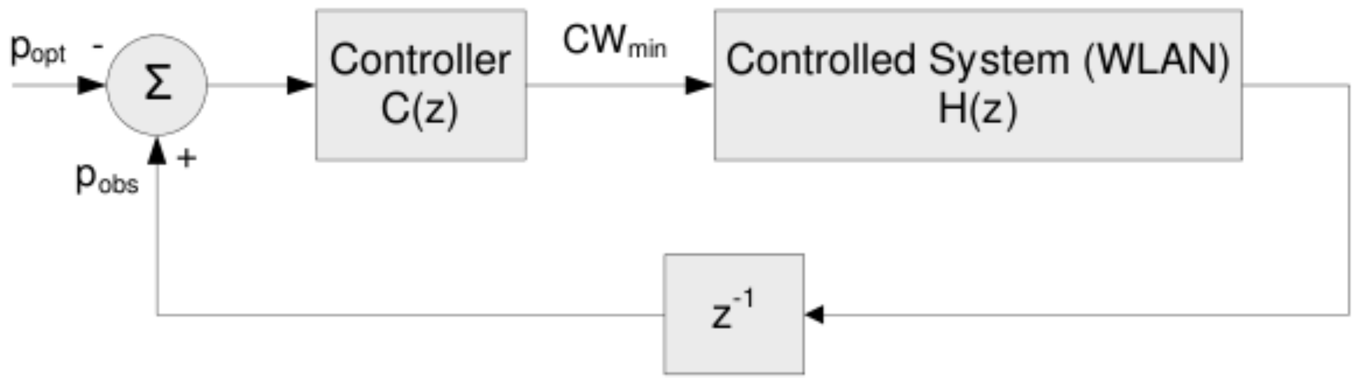
Centralized Algorithm

- Use this p_{opt} as a **reference signal**
  - No need to estimate the number of stations



  - Also for non-sat conditions **?**

Design



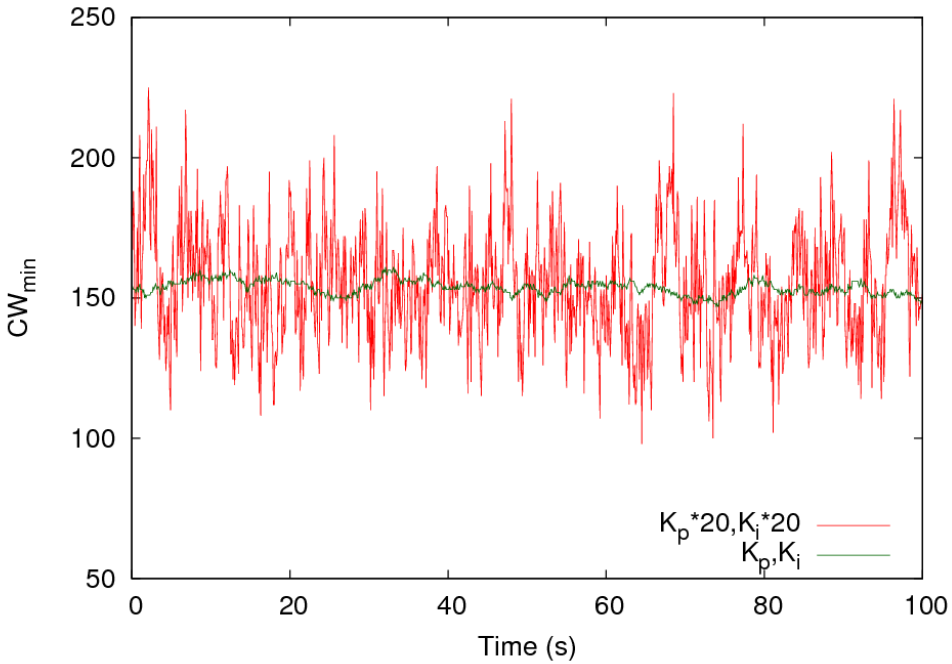
The Controller

- Well established scheme from discrete-time control theory: Proportional Integrator (PI) controller
- Takes as input an error signal
- The AP computes and distributes the CW configuration to the stations

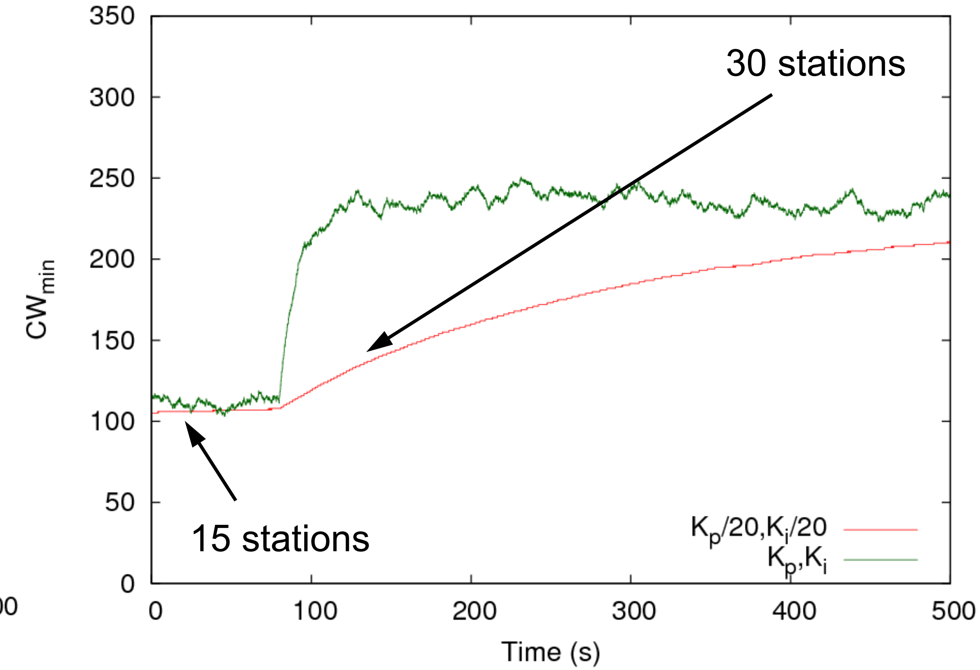
Simulation: it works!

Validation of the designed controller

unstable configuration



slow response to changes



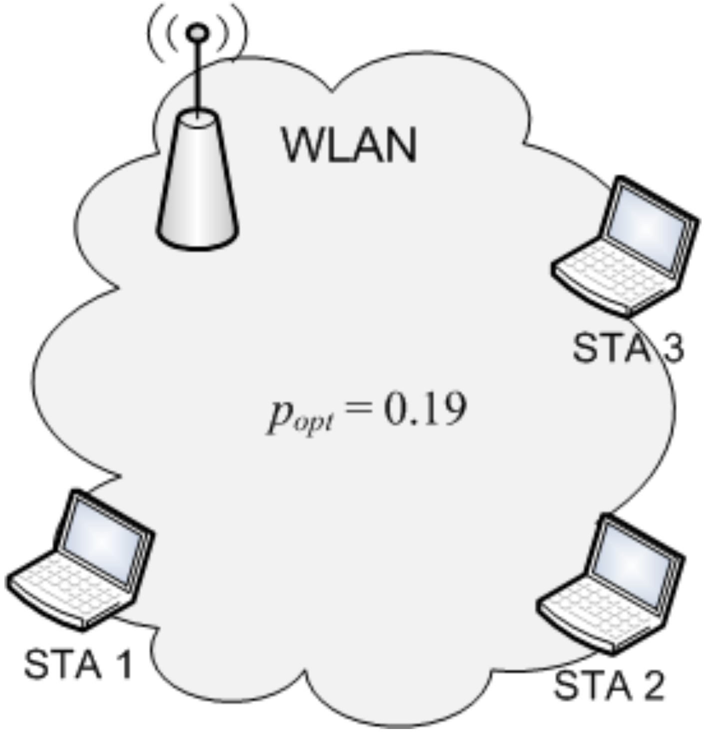
- A large $\{K_p,K_i\}$ setting yields unstable behavior
- A smaller $\{K_p,K_i\}$ setting gains stability but induces slow response

Distributed Approach

- A different (more challenging) approach to performance optimization
  - Each station computes its own configuration by observing the current WLAN conditions (no coordination)
  - Reasons
    - Eliminates single point of failure
    - No need for additional signaling
    - Can operate without an Access Point

Challenge: Short-sightedness

- Driving the WLAN's collision probability to an "optimal" value can result in fairness problems



$$p_1 = 1 - (1 - \tau_2)(1 - \tau_3)$$

CW_1	CW_2	CW_3
48	3	28
9	18	42
19	19	19

Nodes should use the same CW to ensure **fairness**

Restoring fairness: two error terms

- Similar to the centralized solution, first term ensures that the collision probability in the network is driven to the optimal value

$$e_{collision,i} = p_{obs,i} - p_{opt}$$

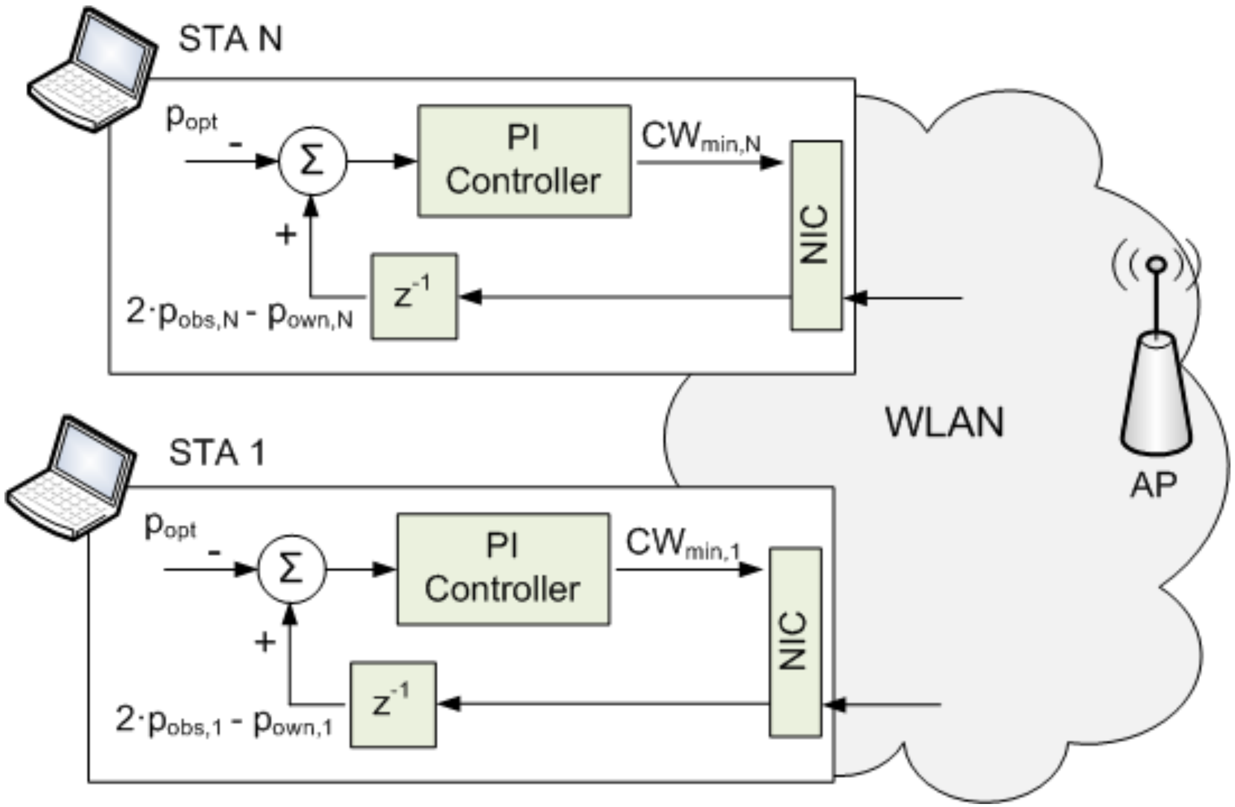
- If two stations do not share the bandwidth fairly due to having different $CW_{min,i}$, the error should be large

$$e_{fairness,i} = p_{obs,i} - p_{own,i}$$

- Hence,

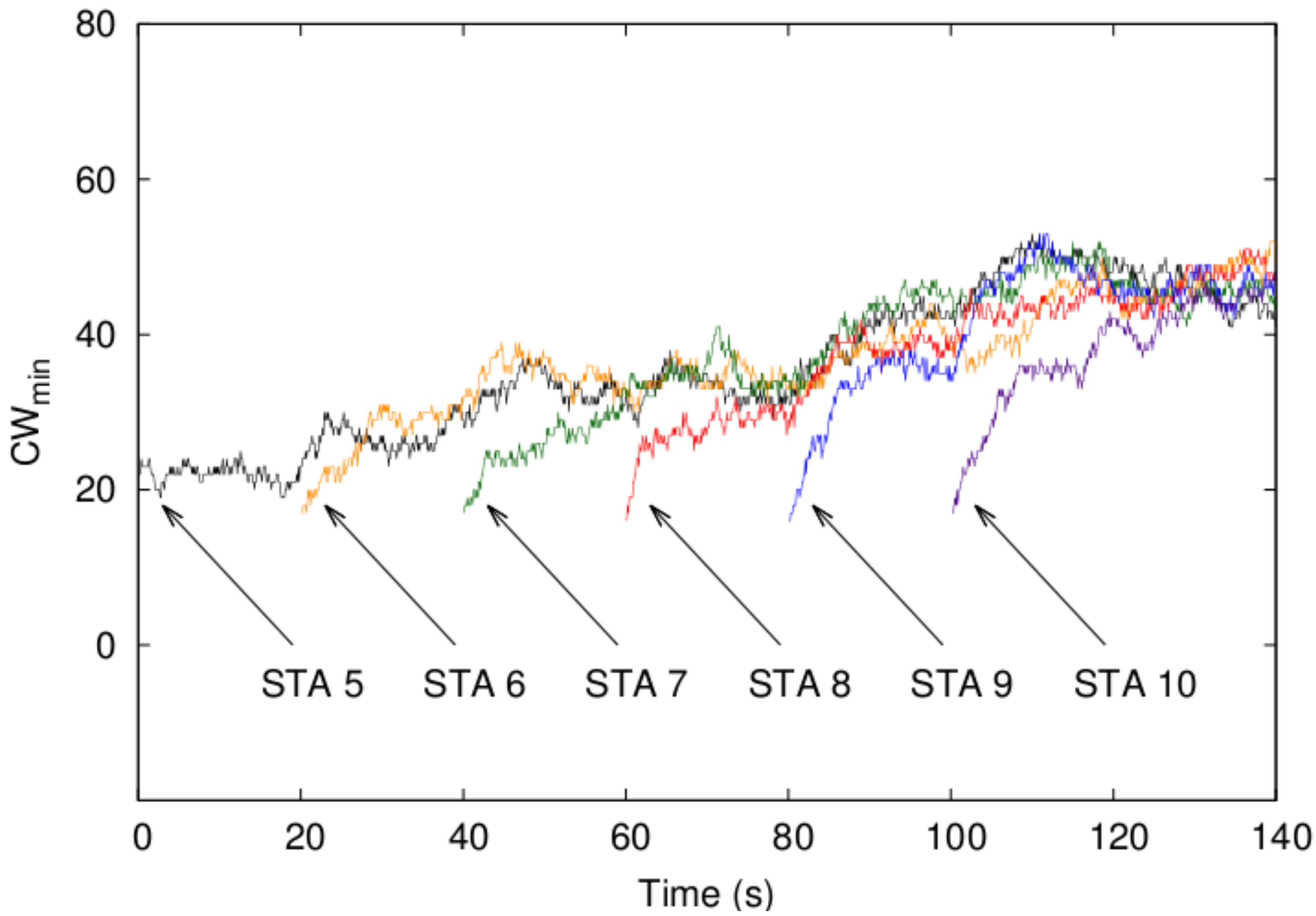
$$e_i = 2 \cdot p_{obs,i} - p_{own,i} - p_{opt}$$

Mechanism



- Distributed implementation, but same vision of the WLAN

Simulation: it also works!



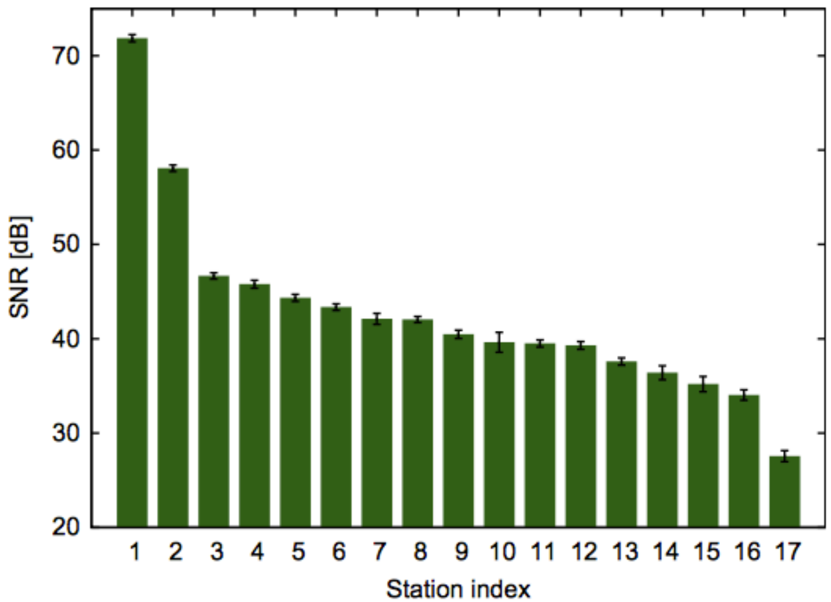
Time for experimentation

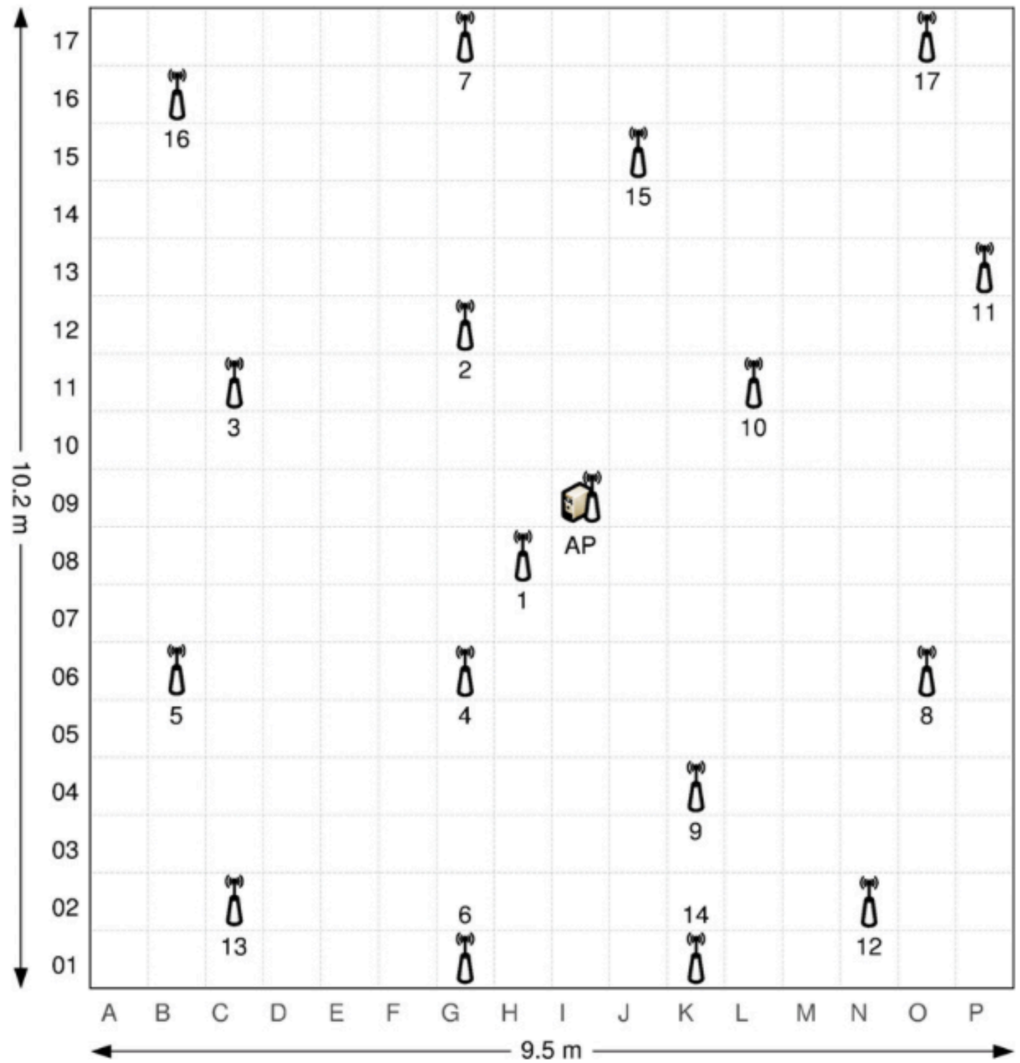
Practice what you know, and it will help to make clear what now you do not know.

Rembrandt

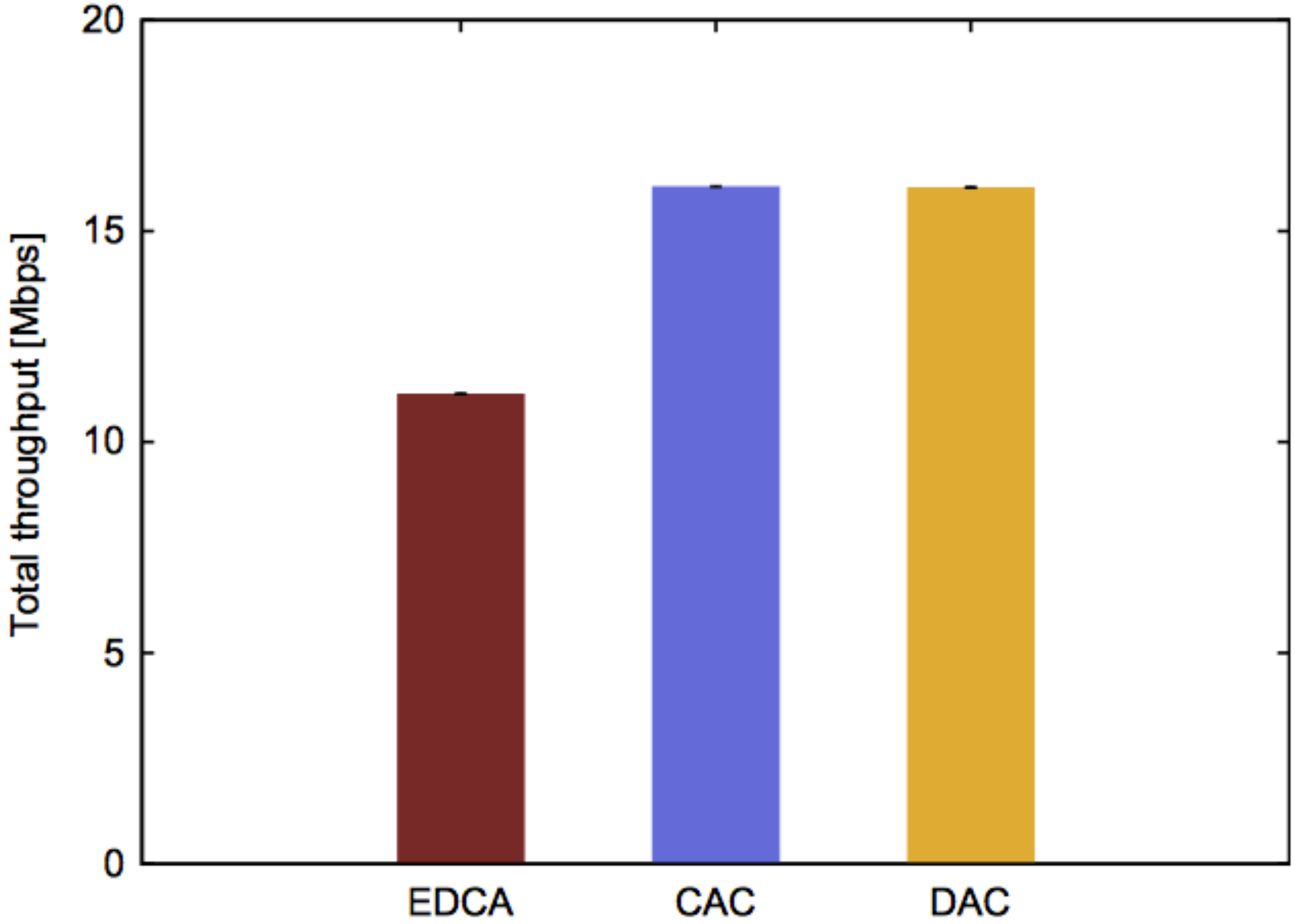
Test-bed

- Under raised floor
- 17 clients, 1 AP
- ≠ link qualities

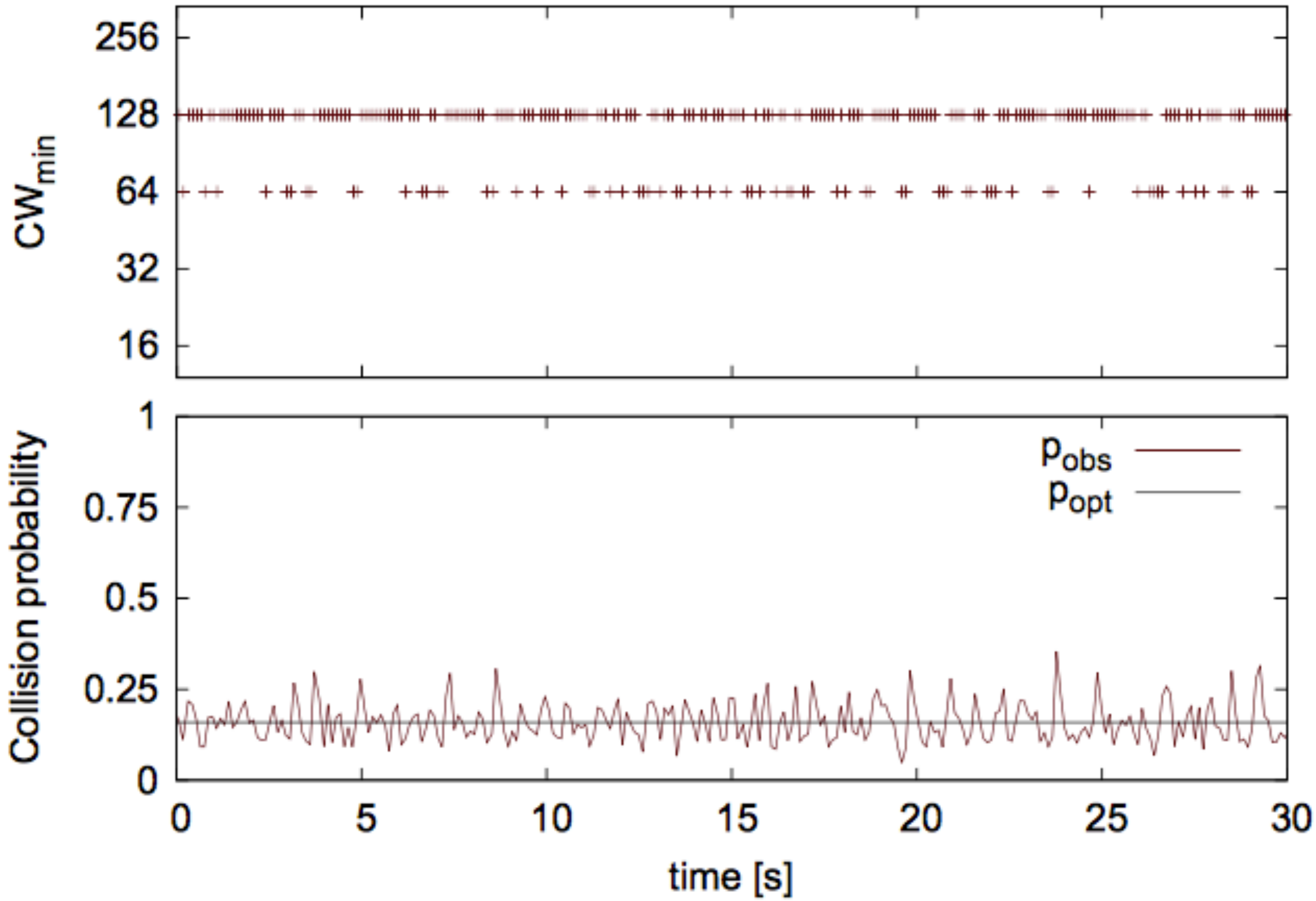




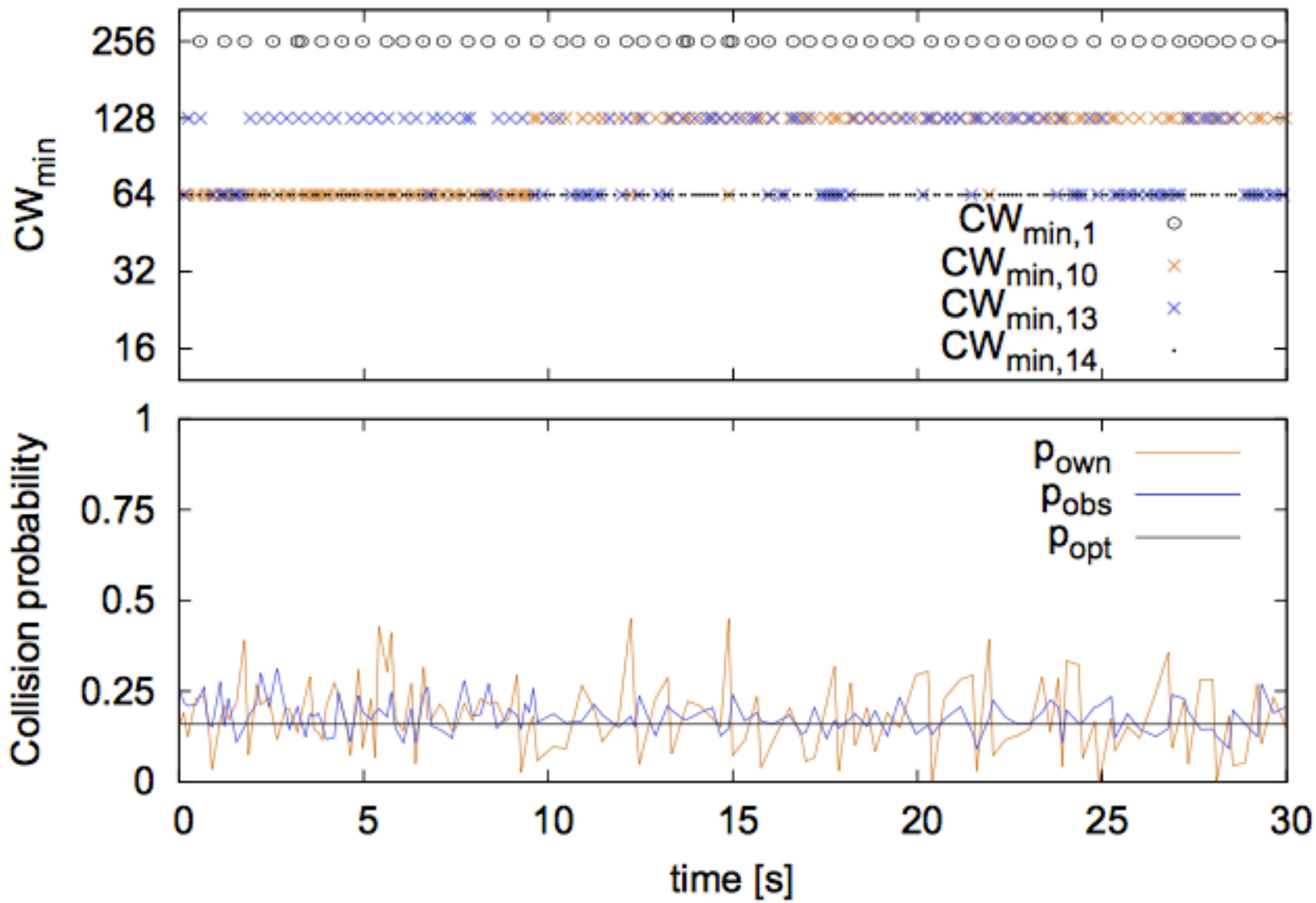
Total UDP throughput



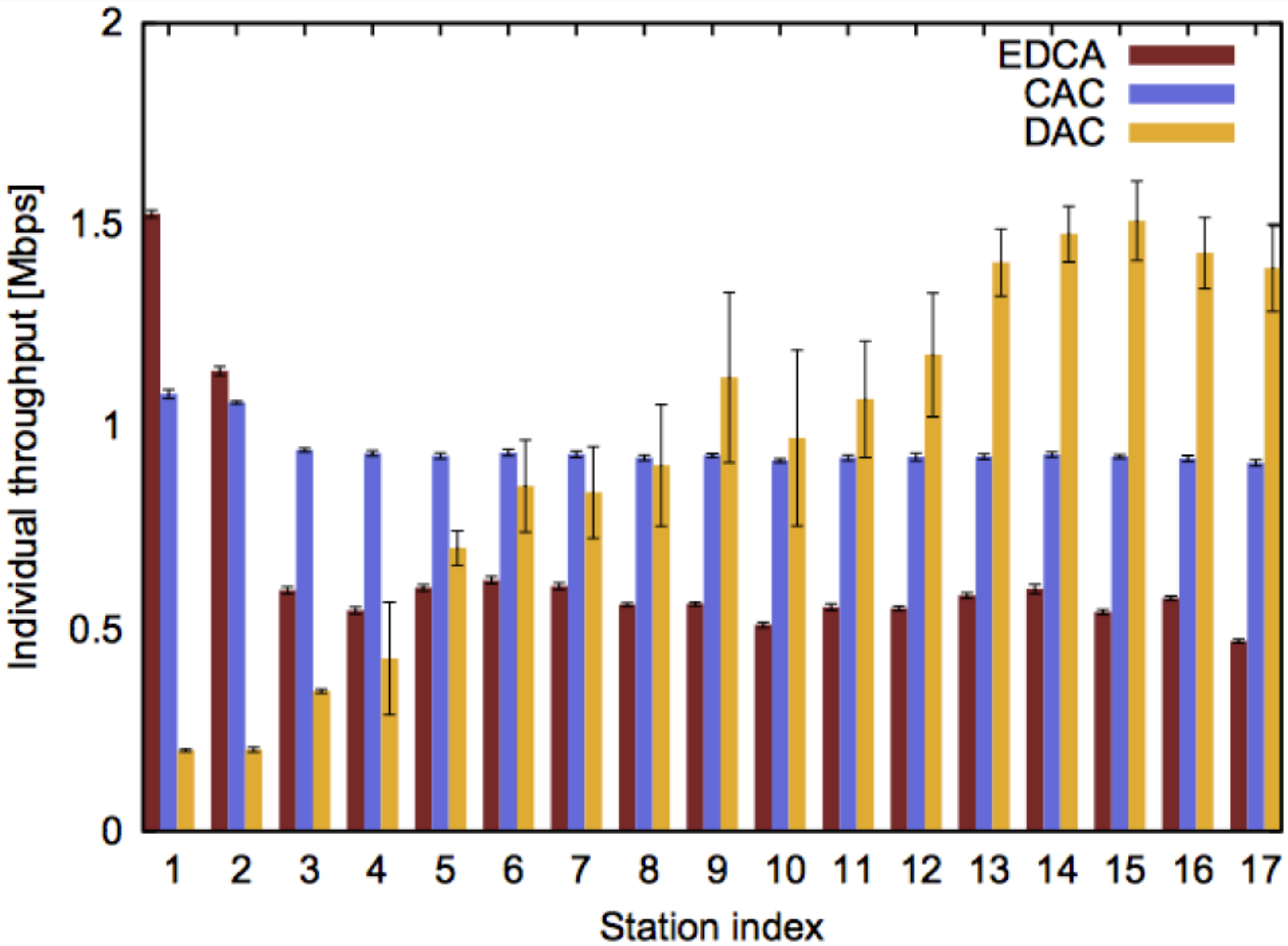
CAC: Validation – real-hw limitations



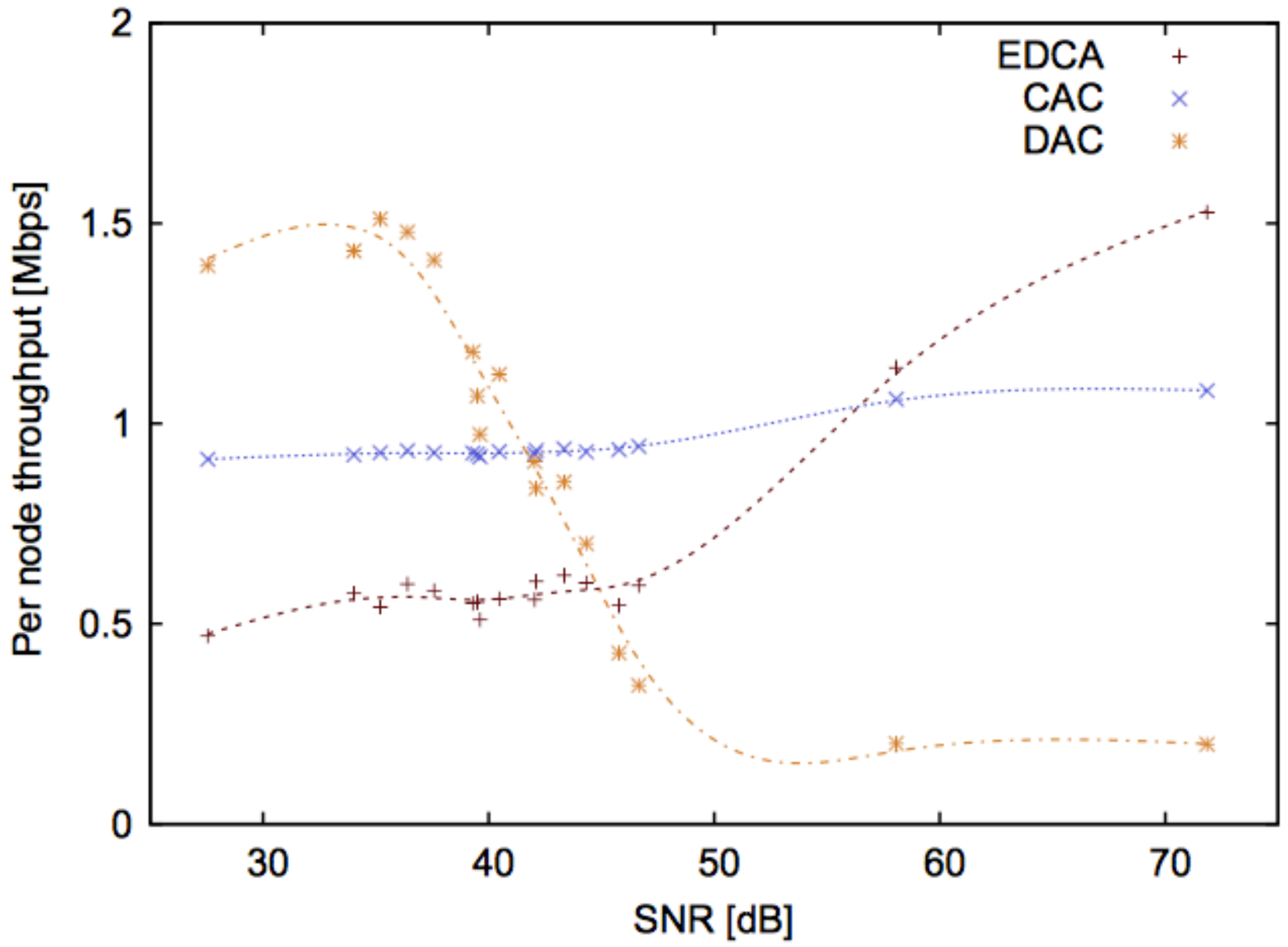
DAC: Validation



Per-station UDP throughput



Throughput vs. SNR

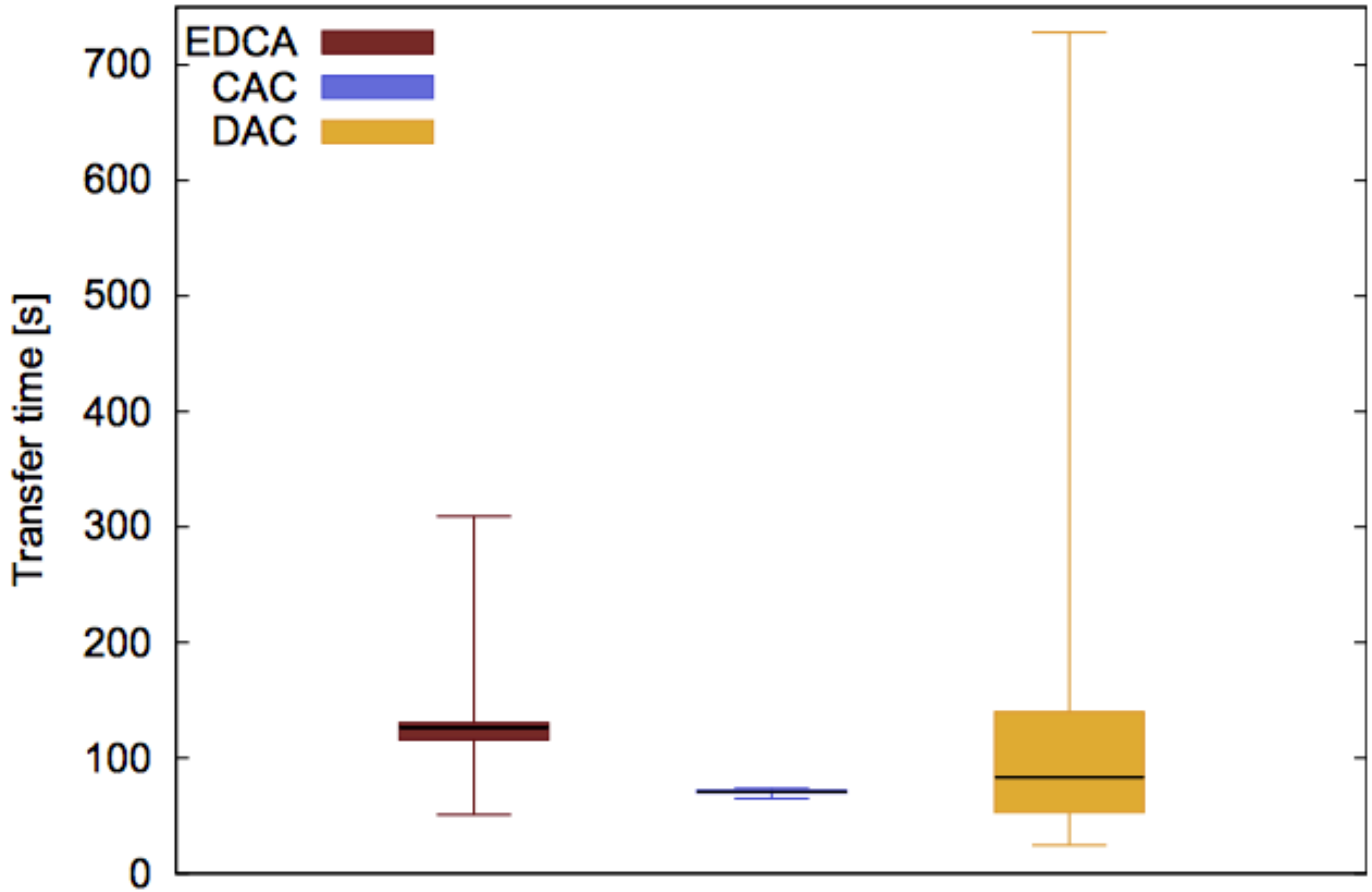


Real-life: Capture effect

- EDCA: Better link quality results in higher throughput.
- CAC: reduces the number of collisions, the impact of the capture effect is reduced.
- DAC: nodes with high capture probability will experience smaller collision rates than the others, acting “more gentle”.

$$e_{fairness,i} = p_{obs,i} - p_{own,i}$$

TCP transfers (10 MB) – non sat. cond.



(a) $\lambda^{-1} = 30$ [s]

Summary

- CAC and DAC: two schemes to adapt the CW to optimize performance
  - Based on analysis (vs. heuristics)
  - Distributed: need to account for fairness
- Tested with real-life devices
  - DAC suffers from link heterogeneity
  - CAC works for sat. & non-sat conditions

Many Thanks!

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