Control theoretic optimization of 802.11 WLANs: From theory to practice

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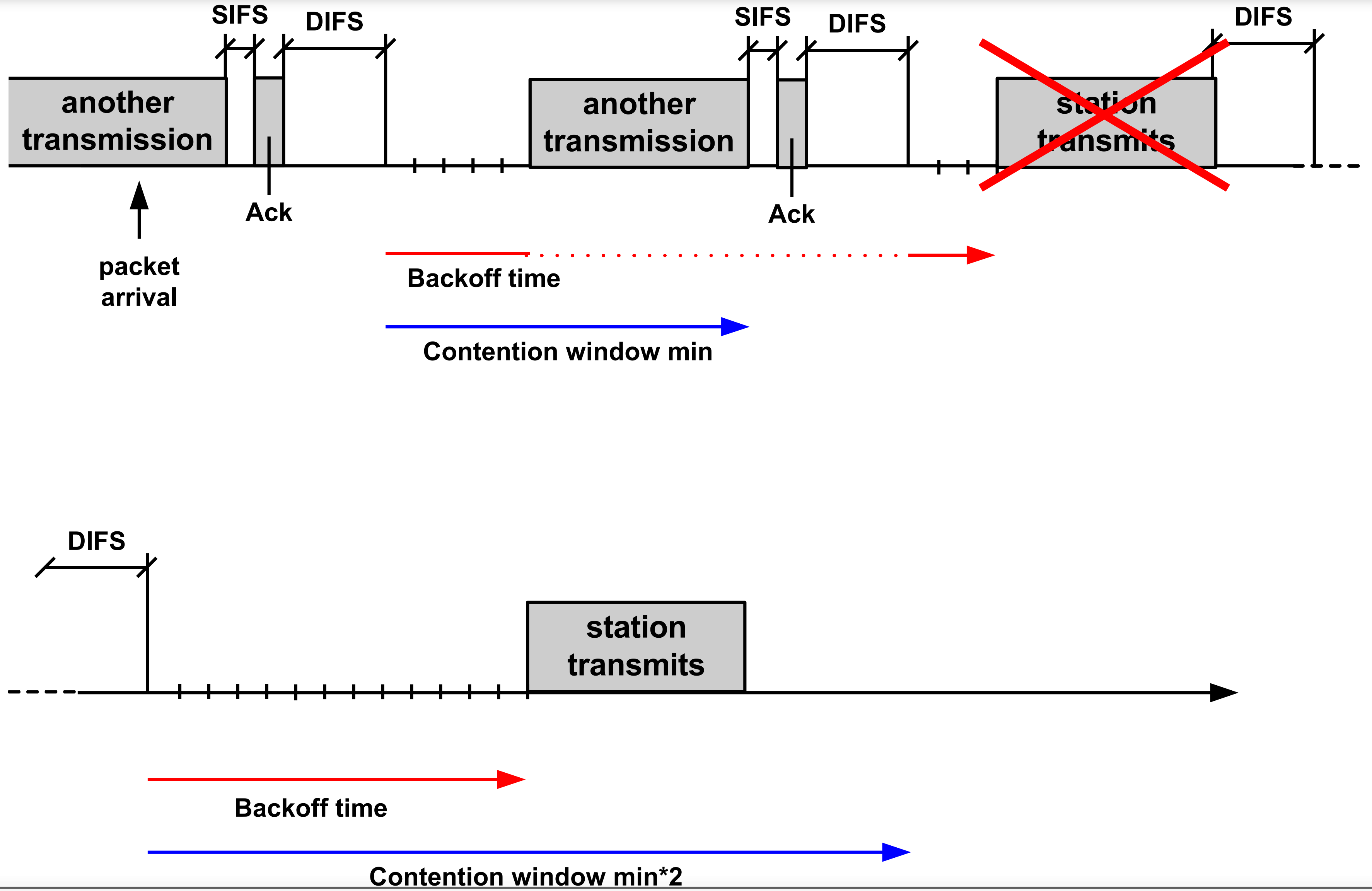
Background

IEEE 802.11 MAC: DCF



Based on a throughput Model…

- Following Bianchi's model [1]

$$\tau = \frac{2}{1 + W + pW\sum_{i=0}^{m-1}(2p)^i}$$

Per slot, per-station tx prob.

- Were W is CM_{min}, *m* is defined such that $CW_{max} = 2^m CW_{min}$, and *p* is given by

$$p = 1 - (1-\tau)^{n-1}$$

(Conditional) collision prob.

Number of stations

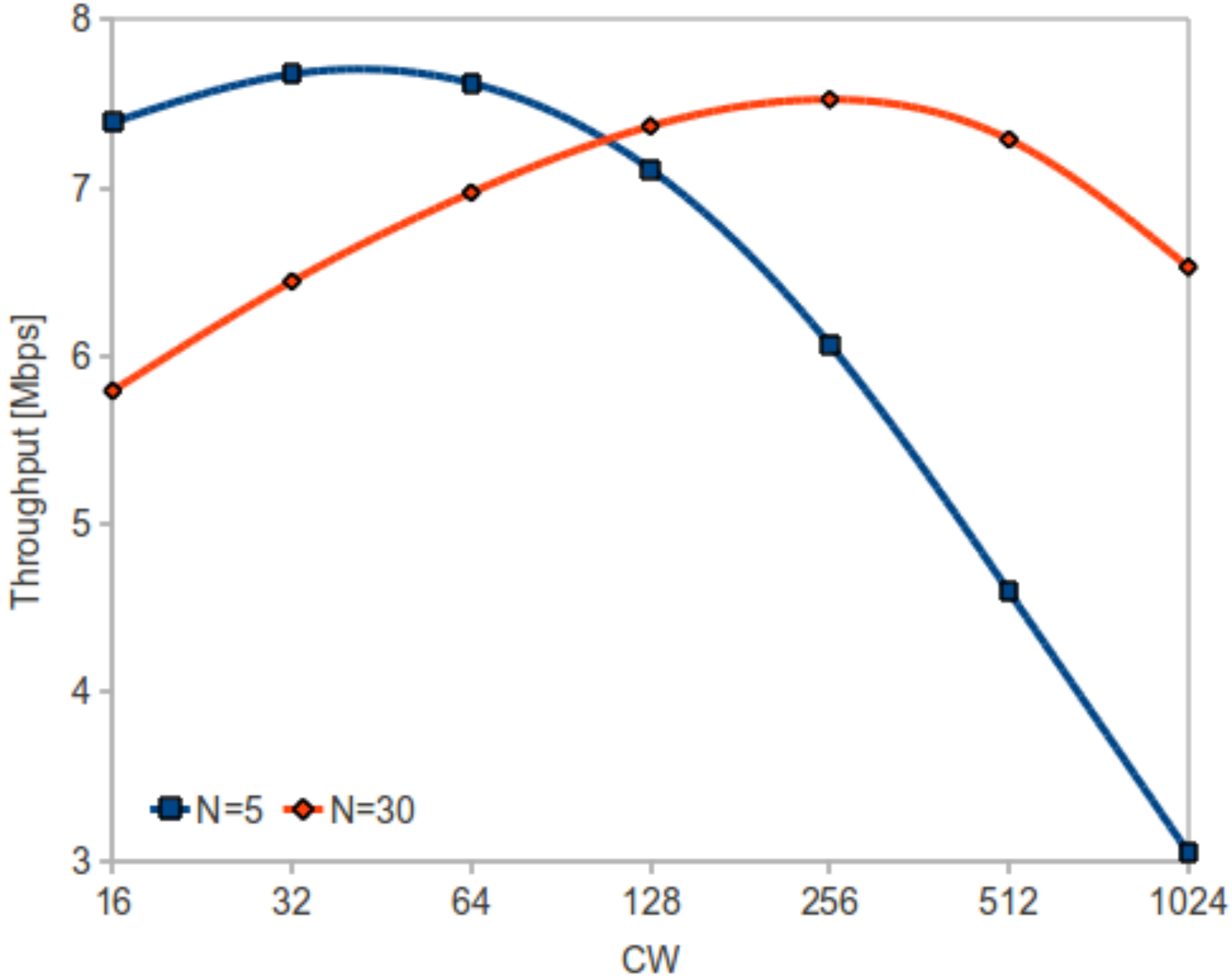
There is an optimal point of operation

- Bianchi's seminal work: in saturation

$$\tau_{\text{opt}} = \frac{1}{n}\sqrt{\frac{2\,T_e}{T_c}}$$

- Optimal tx probability depends on
  - Number of stations
  - Empty slot length
  - Busy slot length

Performance (802.11b, 1500 B)



Previous works

- Adjust the *CW* based on conditions
  - Many stations: increase the CW
  - Few stations: 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

- Based on heuristics

- Their performance has not been assessed in a real deployment

Control Theoretical Schemes

CAC and DAC

Motivation, revisited

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

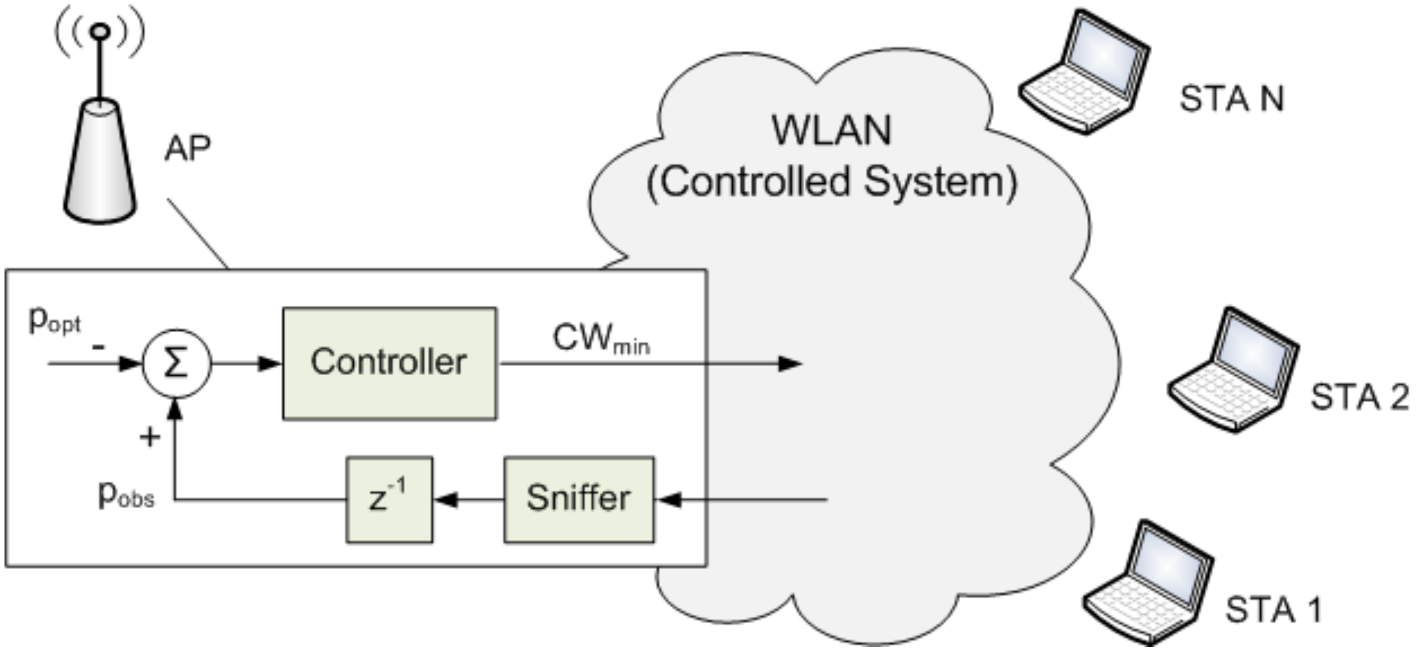
$$\tau_{\text{opt}} = \frac{1}{n}\sqrt{\frac{2\,T_e}{T_c}}$$

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

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

Centralized Algorithm: CAC

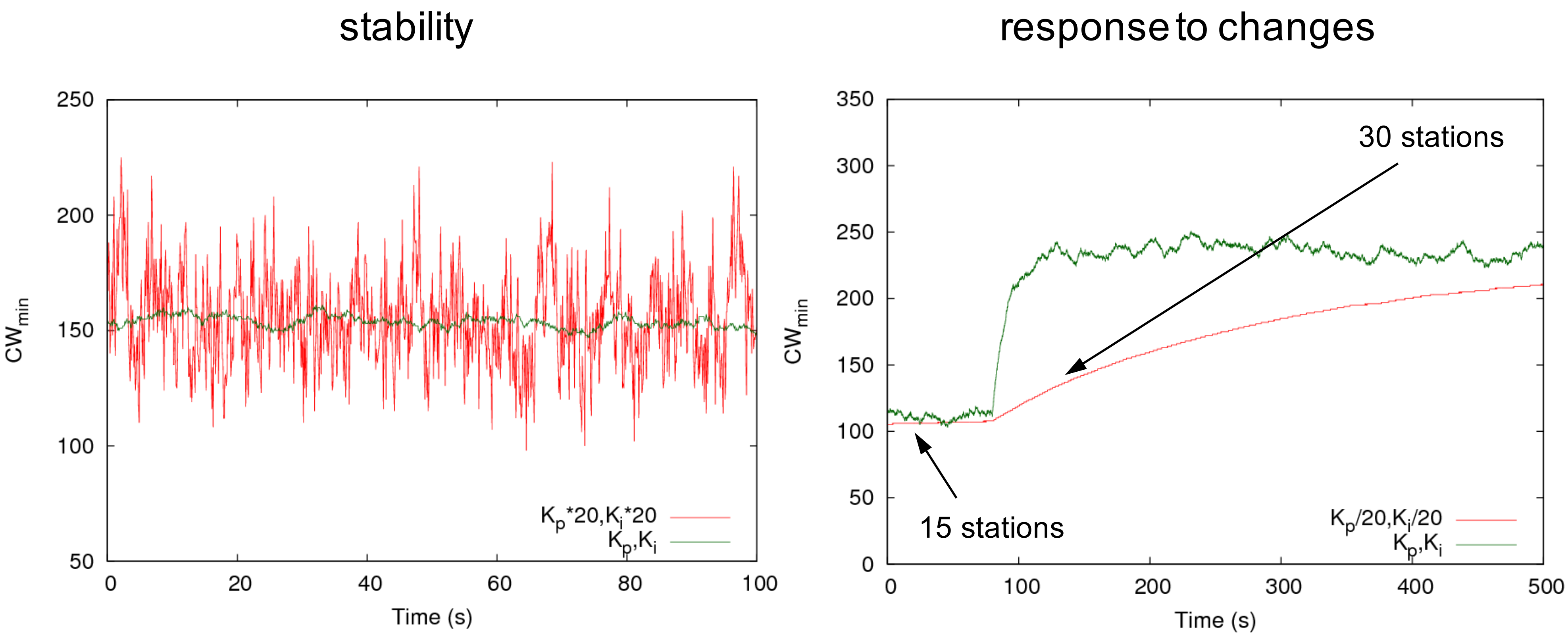
- Use this p_{opt} as a **reference signal**
  - No need to estimate the number of stations



"If collision rate is higher than in ideal case, everyone then increases the CW –> decrease activity"

Simulation: it works!

Validation of the designed controller

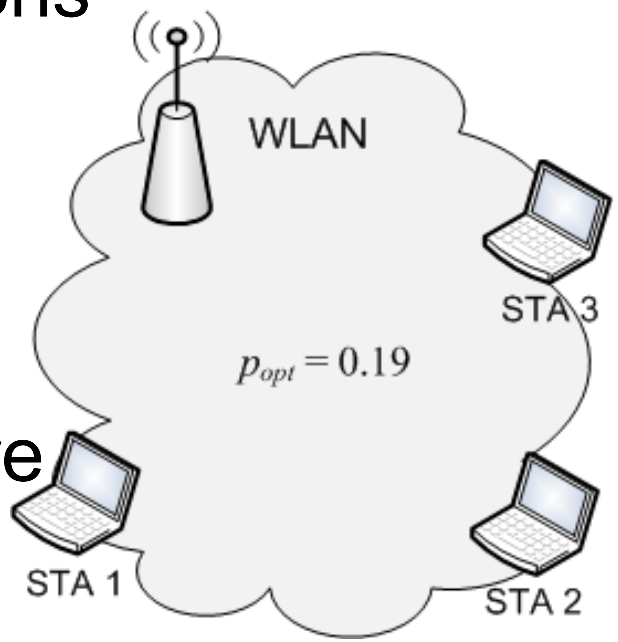


- A large $\{K_p,K_i\}$ setting yields unstable behavior
- A smaller $\{K_p,K_i\}$ setting gains stability but induces slow response

Distributed Approach: DAC

- A different (more challenging) approach to performance optimization
  - Each station computes its own configuration by observing the current conditions

- Motivation
  - No need for signaling
  - Eliminate single point of failure
  - Can operate without an AP



Challenge: fairness at risk

- Target solution

CW_1	τ_1	CW_2	τ_2	CW_3	τ_3	p_{col}
19	0,1	19	0,1	19	0,1	0,19

- One CAC per station: $CW(i) \propto e(i) = \hat{p}(i) - p_{\text{opt}}$

CW_1	τ_1	CW_2	τ_2	CW_3	τ_3	p_{col}
9	0,2	18	0,105	42	0,046	0,192
	p(1)		p(2)		p(3)	
	0,147		0,237		0,284	

DAC: two error terms

- First term ensures that the collision probability in the network is driven to the optimal value:

$$e_{\text{opt}}(i) = \hat{p}(i) - p_{\text{opt}}$$

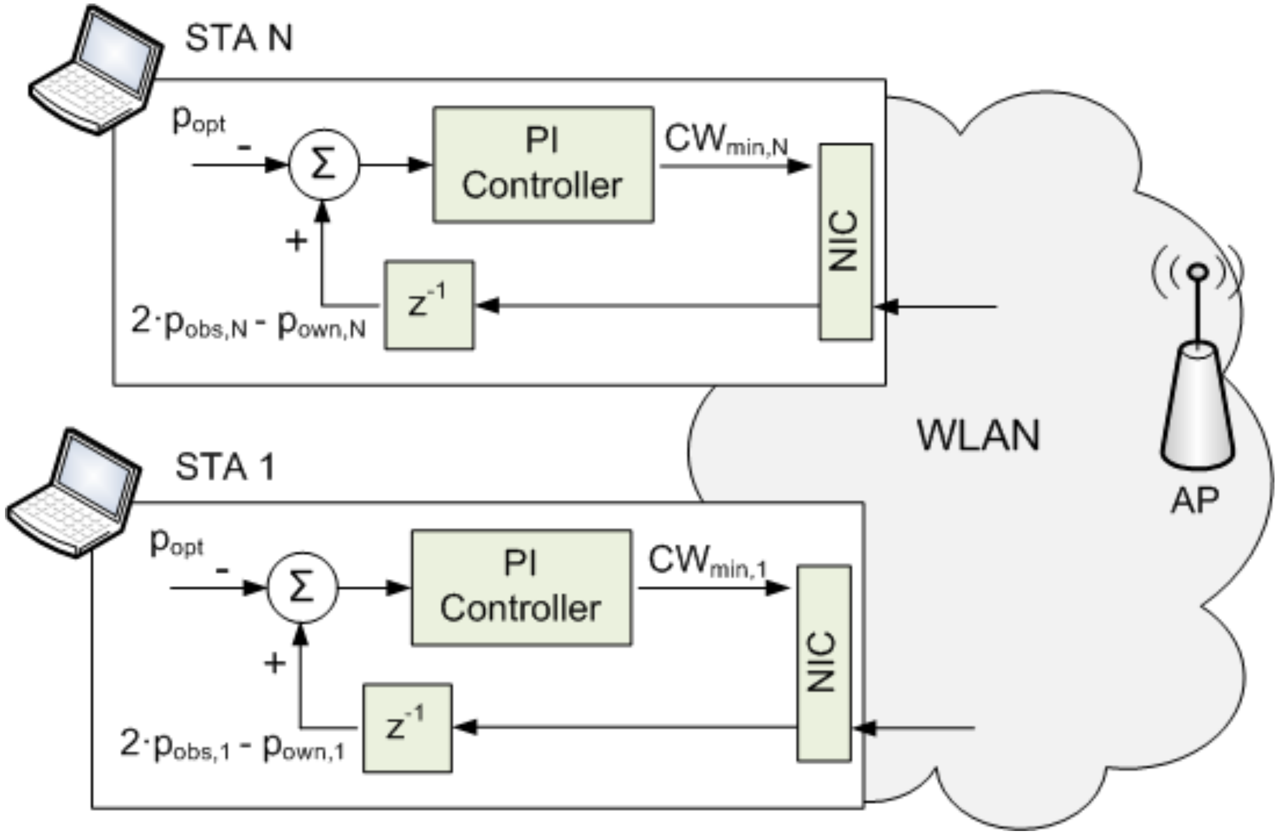
"If the collision rate that I see is higher than the ideal, increase the CW -> contribute to decrease the total activity rate"

- Second term ensures that each station suffers the same collision probability:

$$e_{\text{fair}}(i) = \hat{p}(i) - p(i)$$

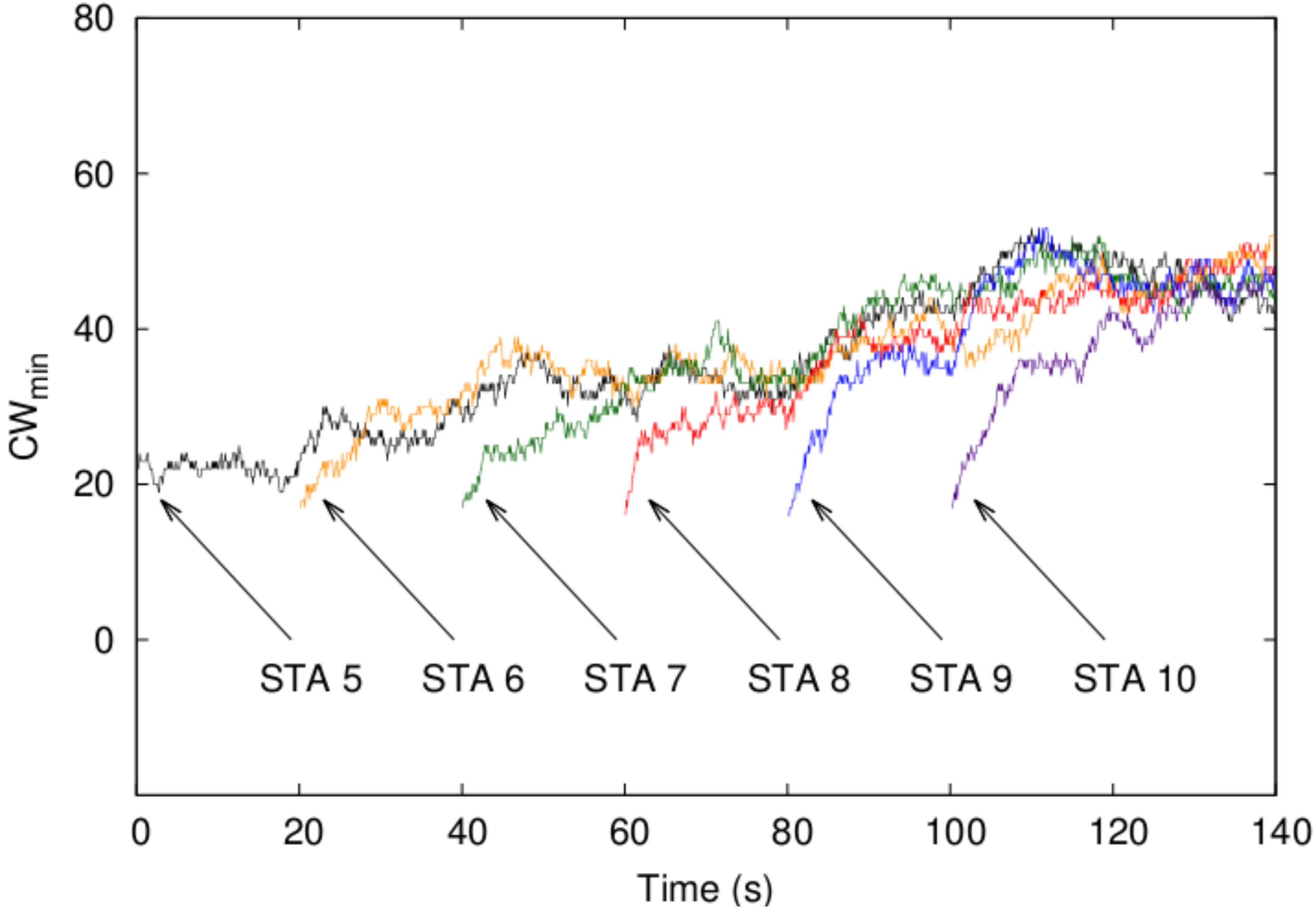
"If other's collision rate is higher than mine, increase my CW -> decrease my activity rate (other's collisions)"

Distributed Approach: DAC



- Distributed implementation, but building on the same vision of the WLAN

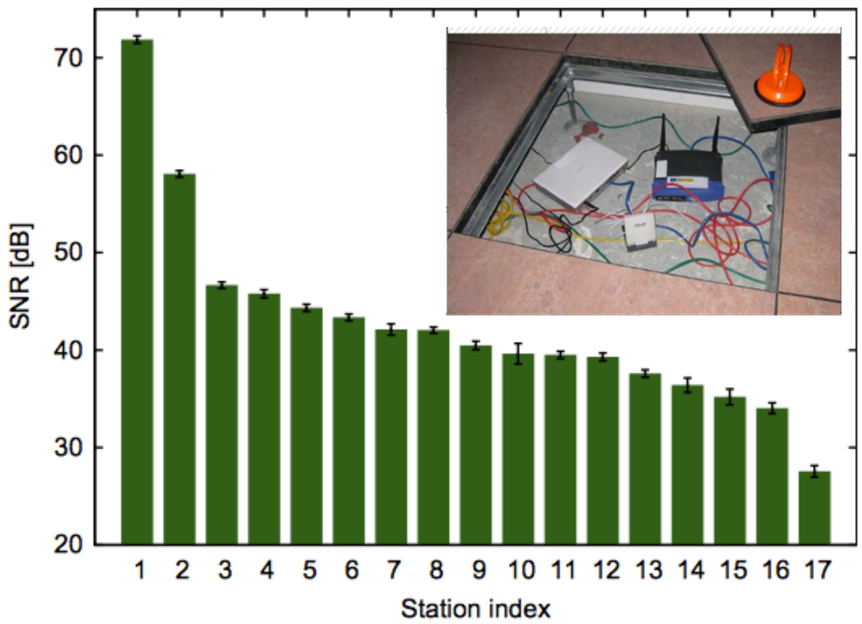
Simulation: it also worked

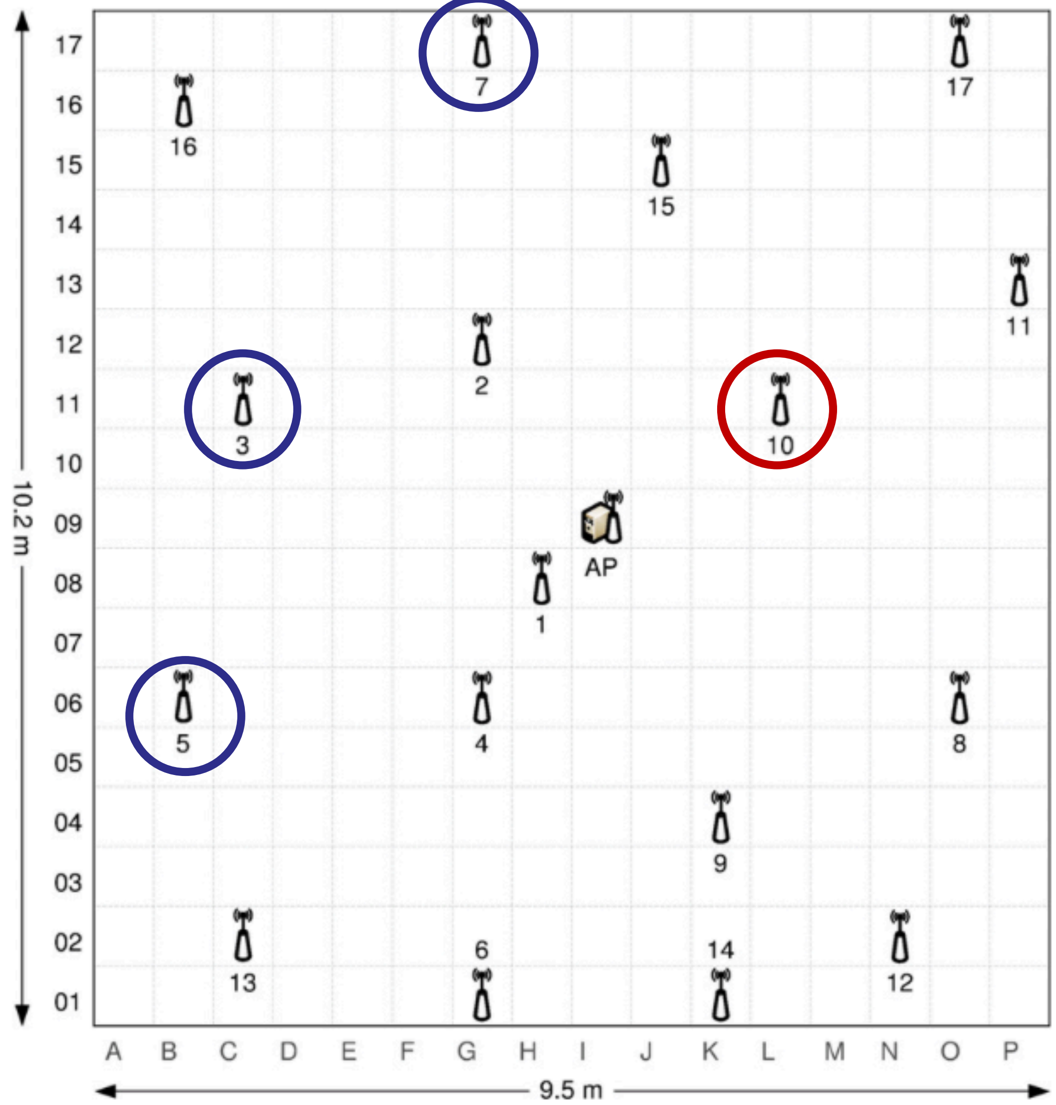


From theory to practice

Test-bed

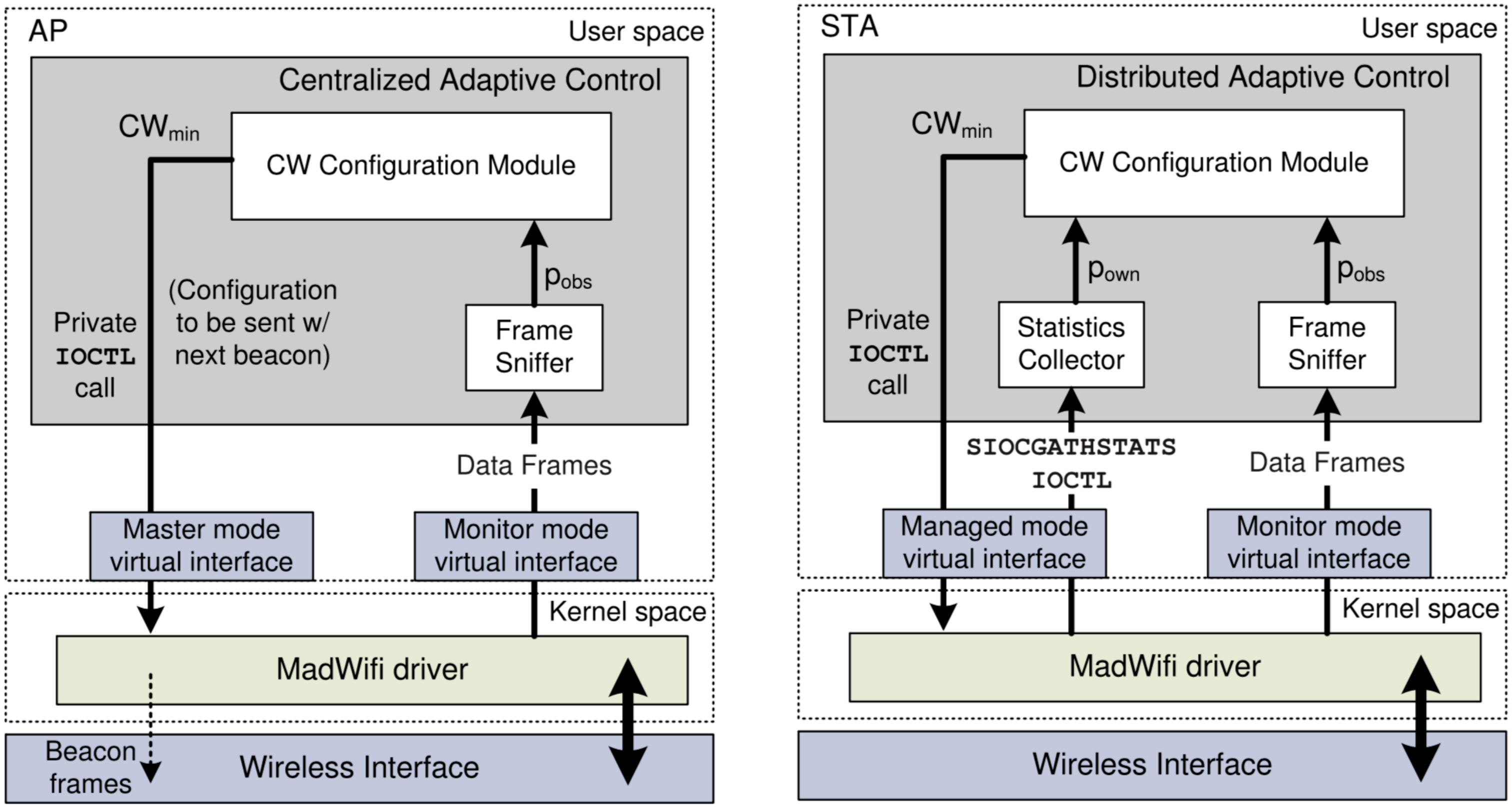
- Under raised floor
- 17 clients, 1 AP
- ≠ link qualities





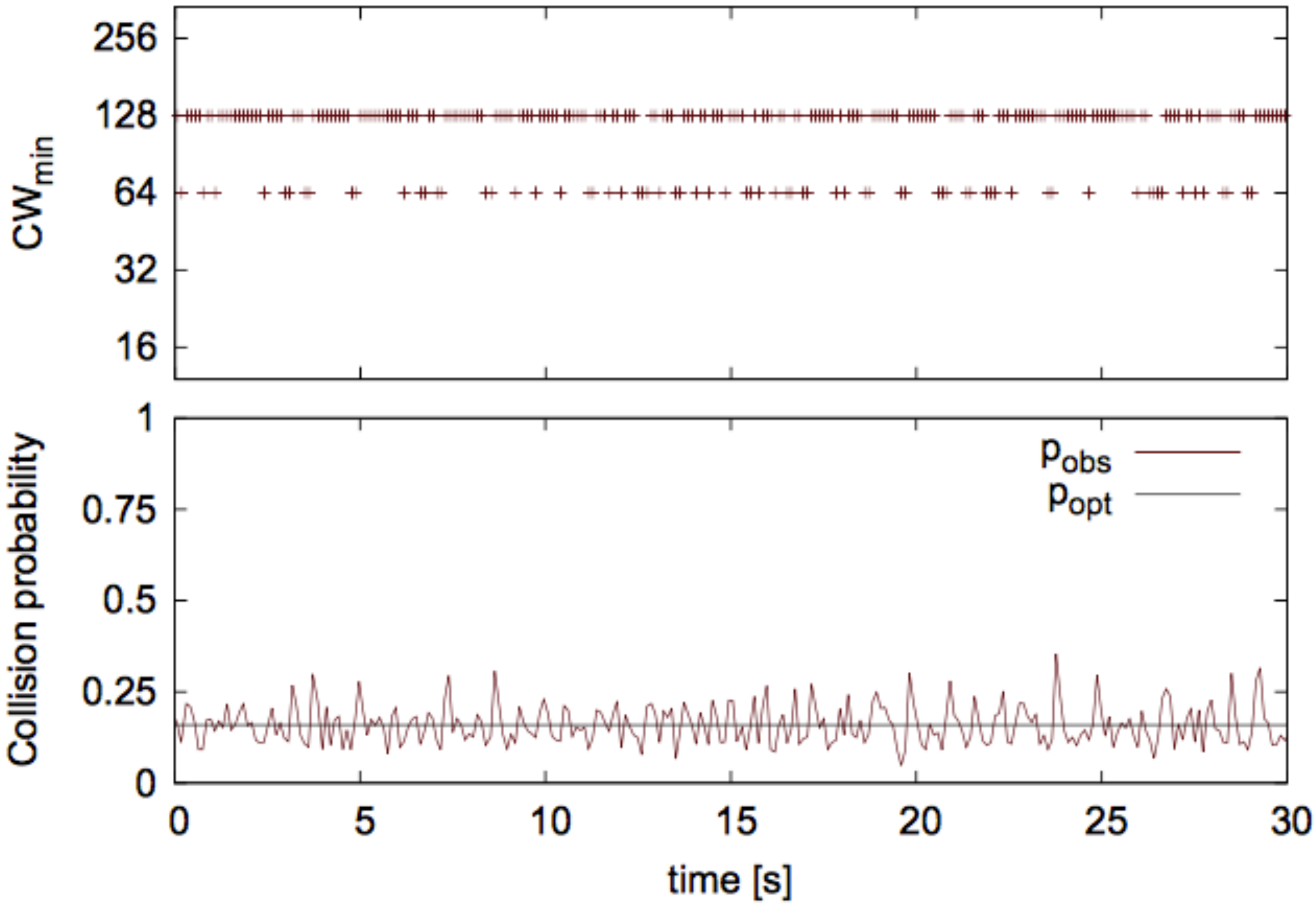
Devices

- Soekris net4826-48 devices
  - Atheros AR5414-based 802.11a/b/g card
  - Gentoo Linux OS (kernel 2.6.24), MadWifi v0.9.4

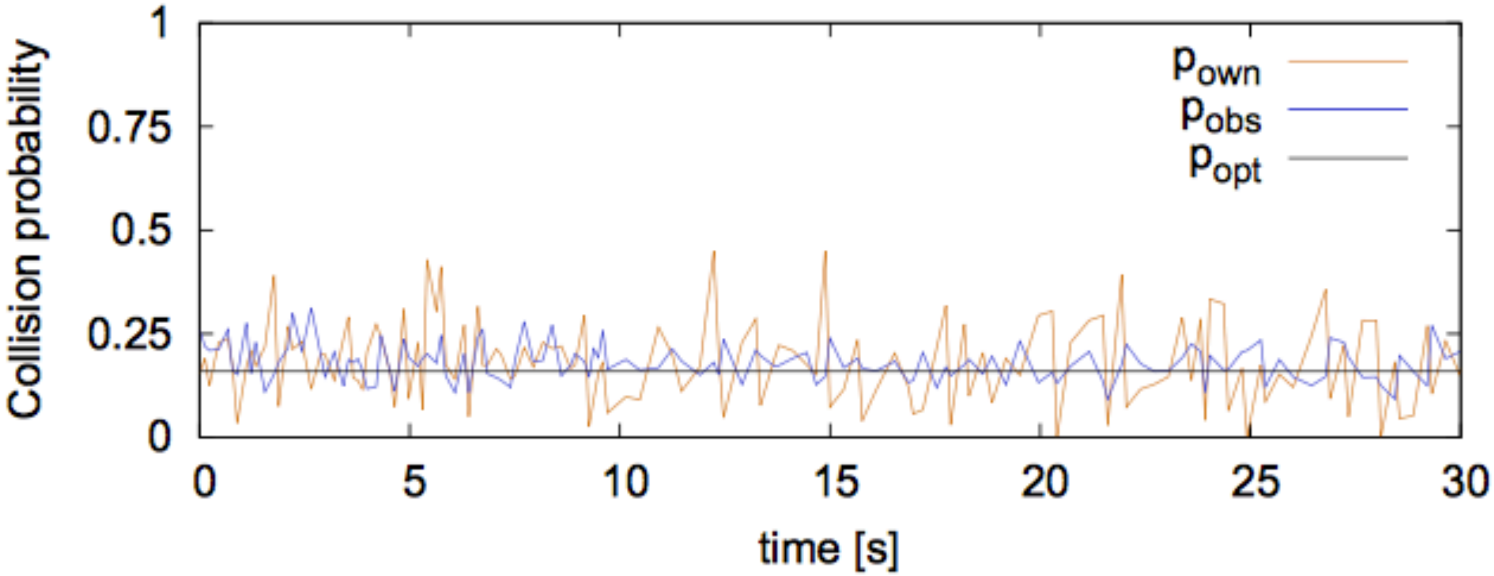


CAC: Validation – real-hw limitations

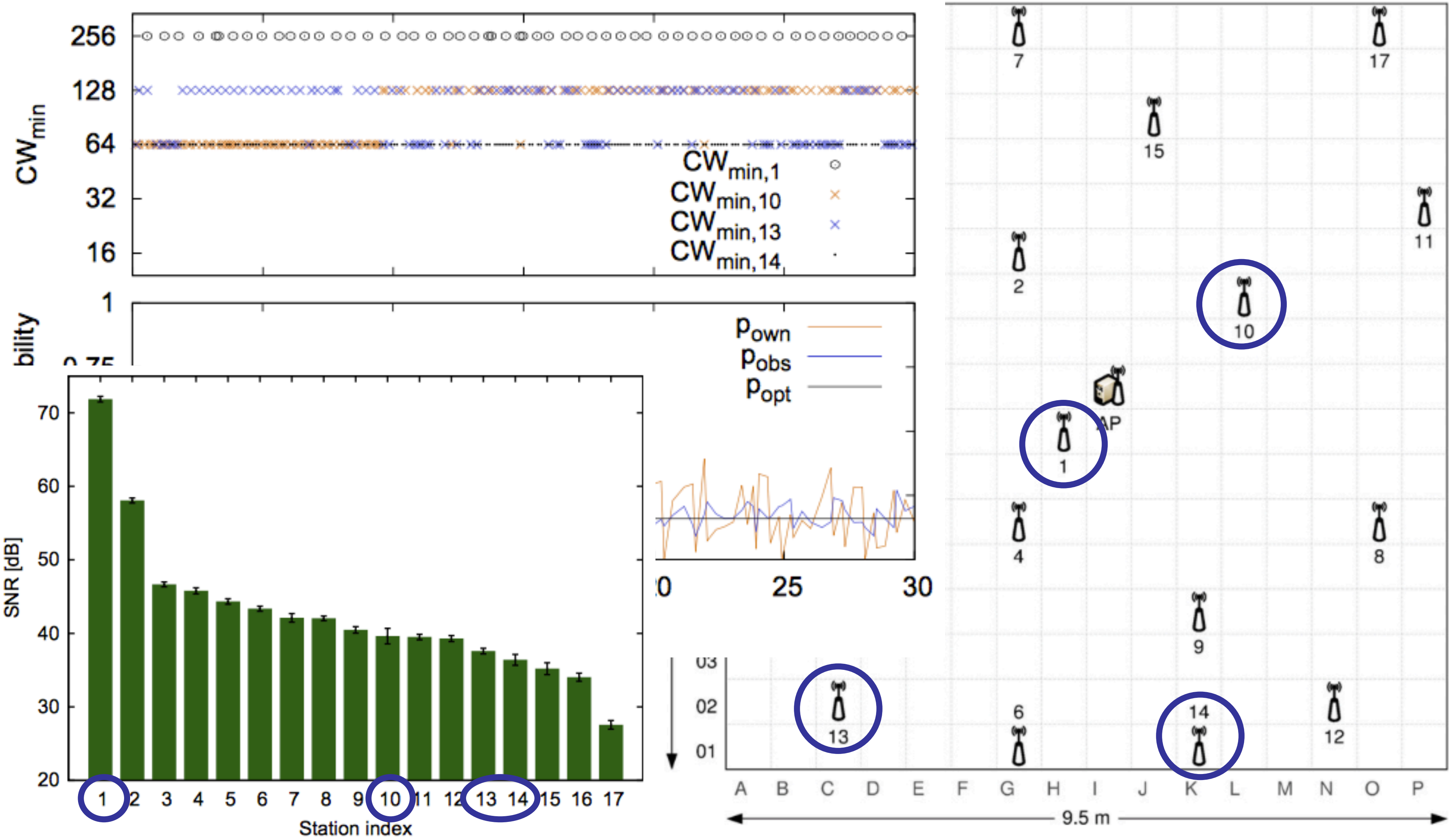
$$\mathtt{CW[t]} = \mathtt{pow}(2, \mathtt{rint}(\mathtt{log}_2(\mathtt{CW_{min}[t]}))).$$



DAC: Validation

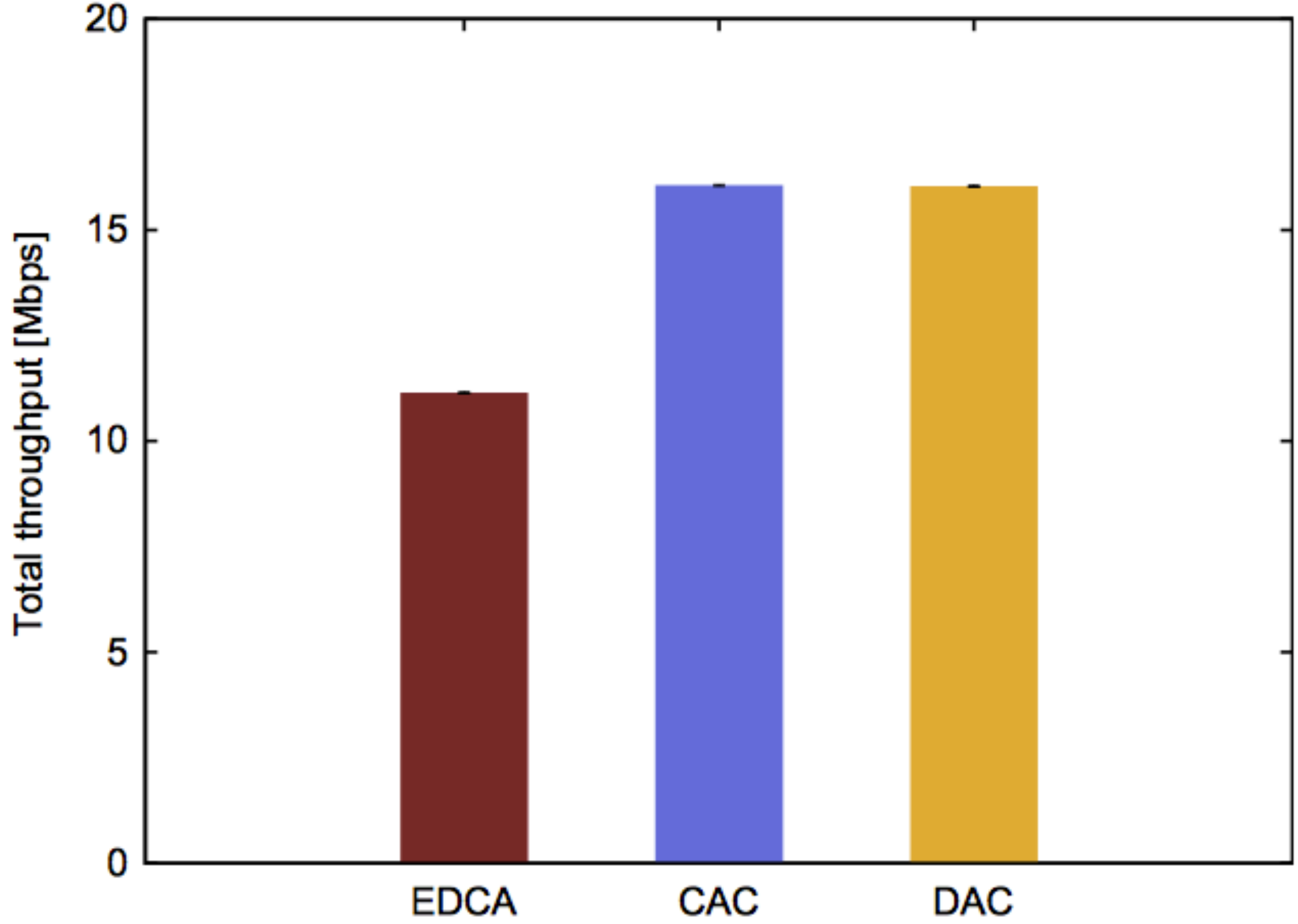


Test-bed

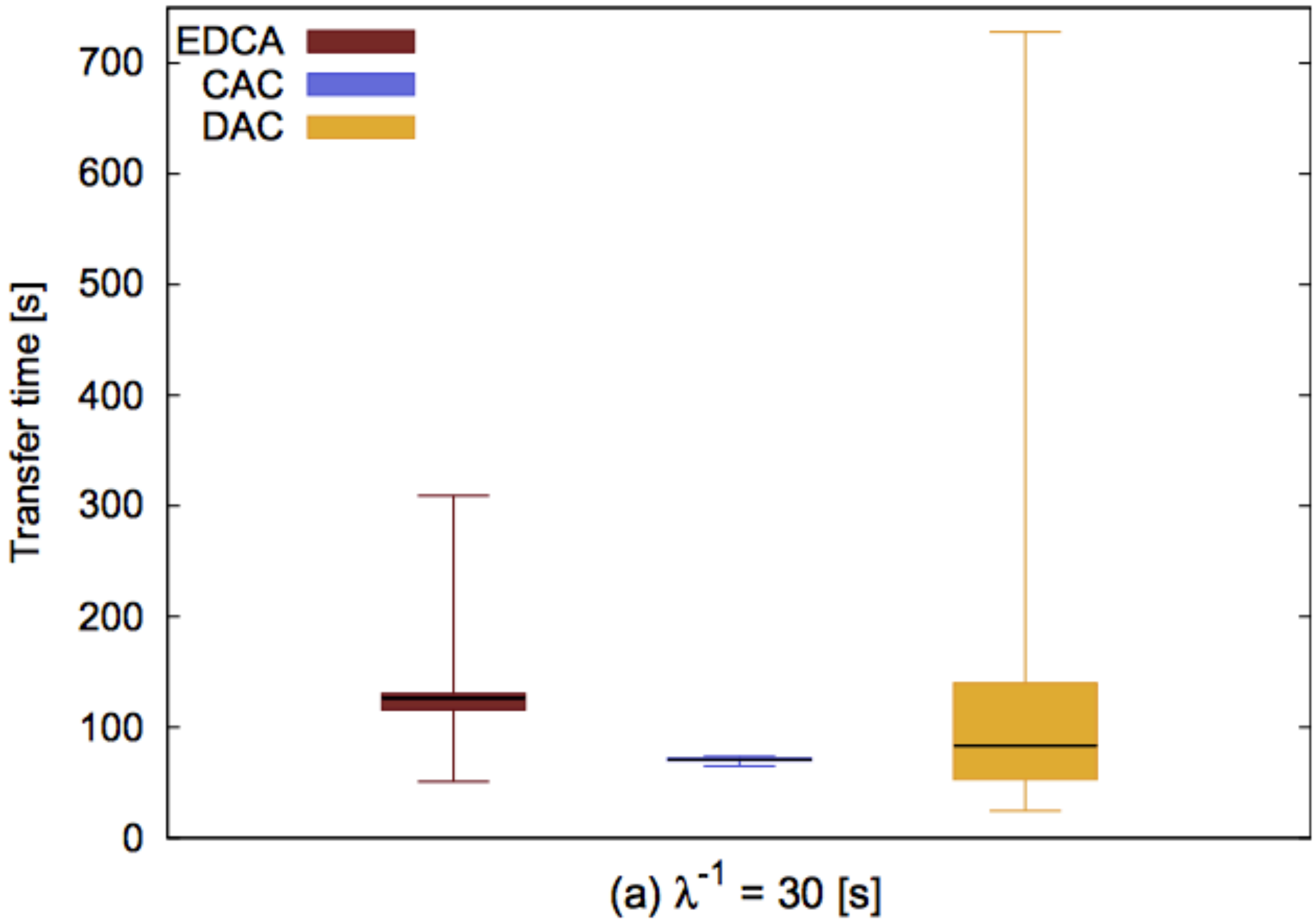


256
128
64
32
16
CWmin
CWmin,1
CWmin,10
CWmin,13
CWmin,14
1
pown
pobs
popt
25
30
70
60
50
40
30
20
SNR [dB]
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17
Station index
A B C D E F G H I J K L M N O P
9.5 m
AP

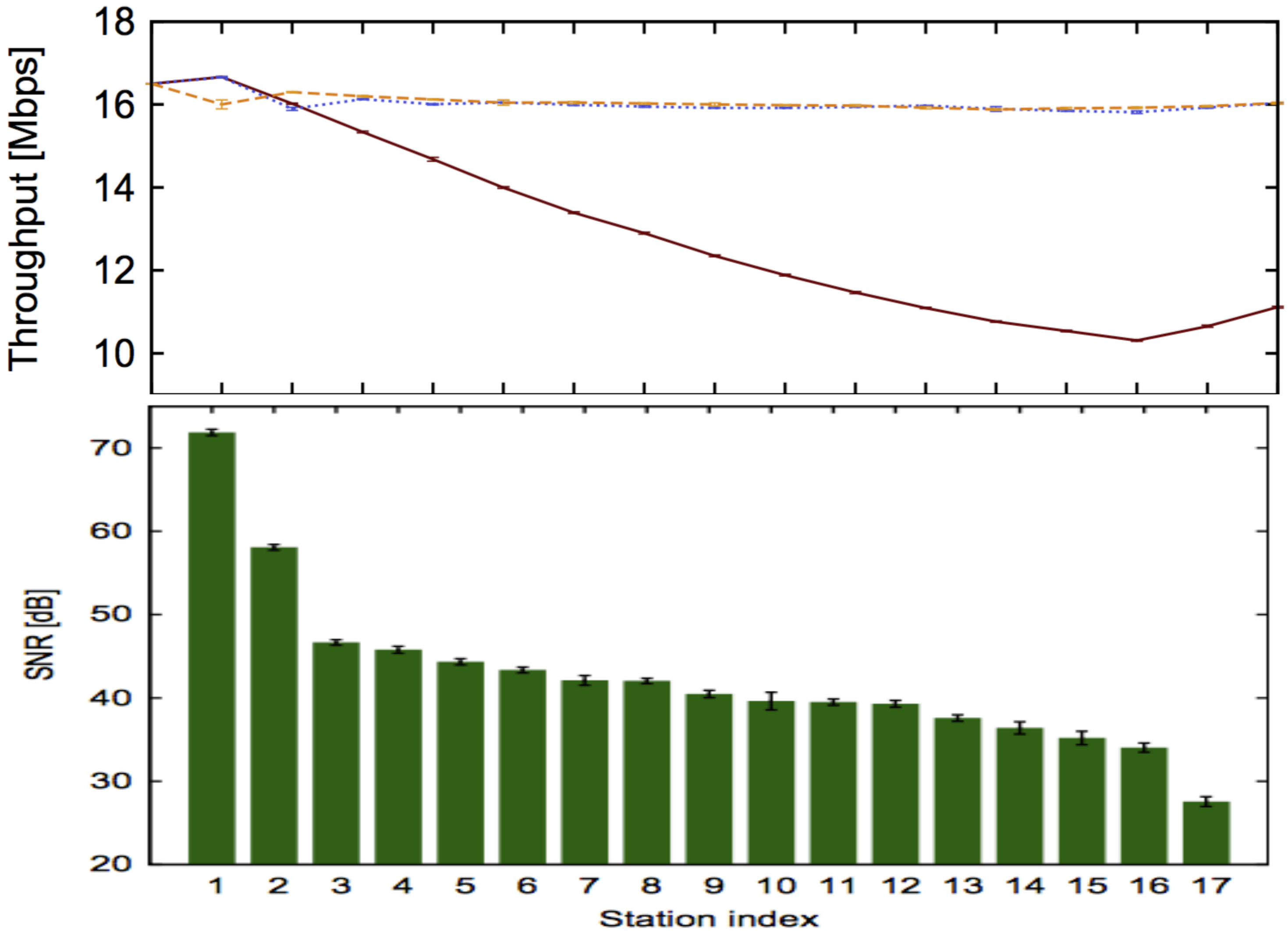
Total UDP throughput



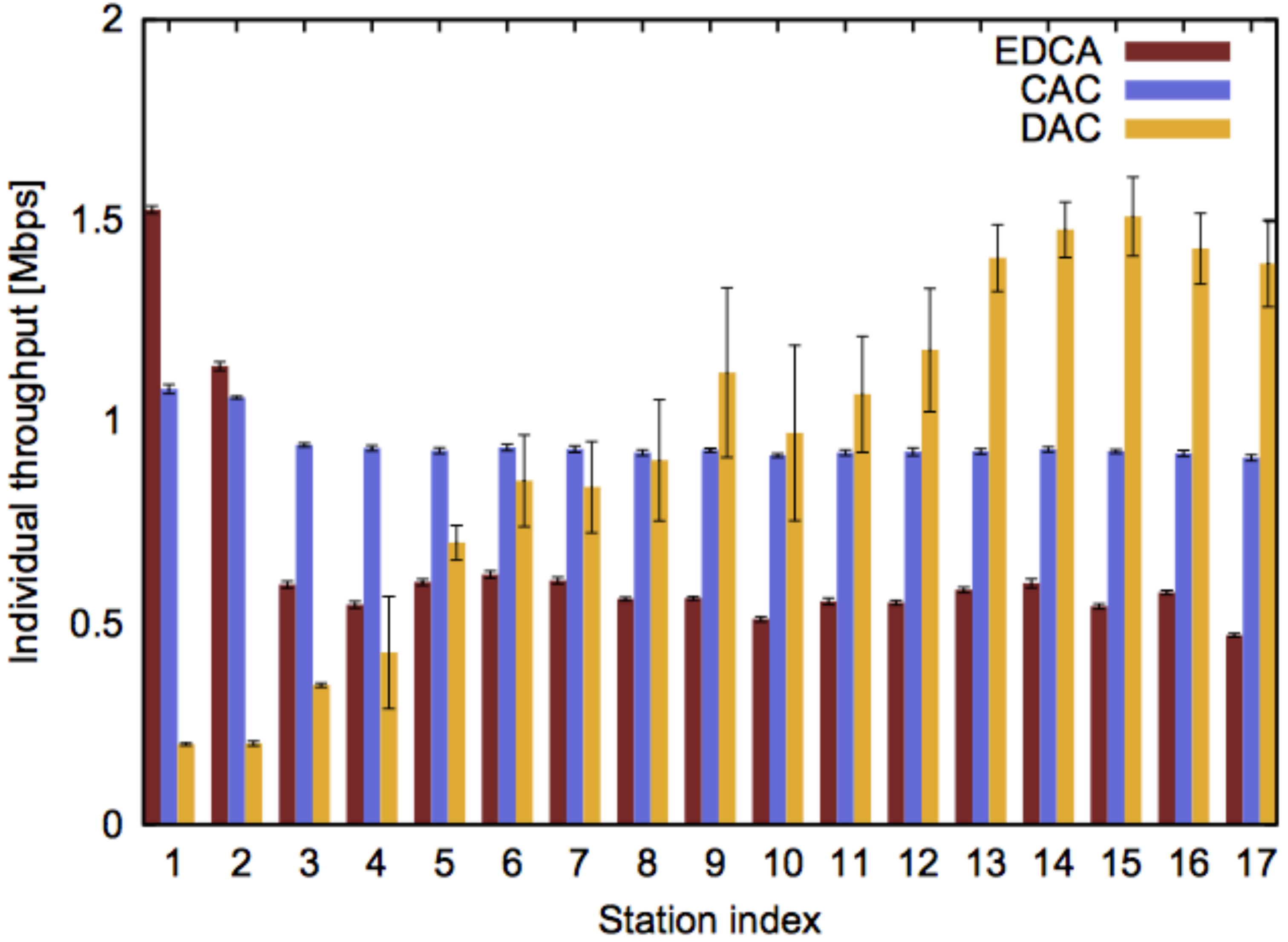
TCP transfers (10 MB) – non sat. cond.



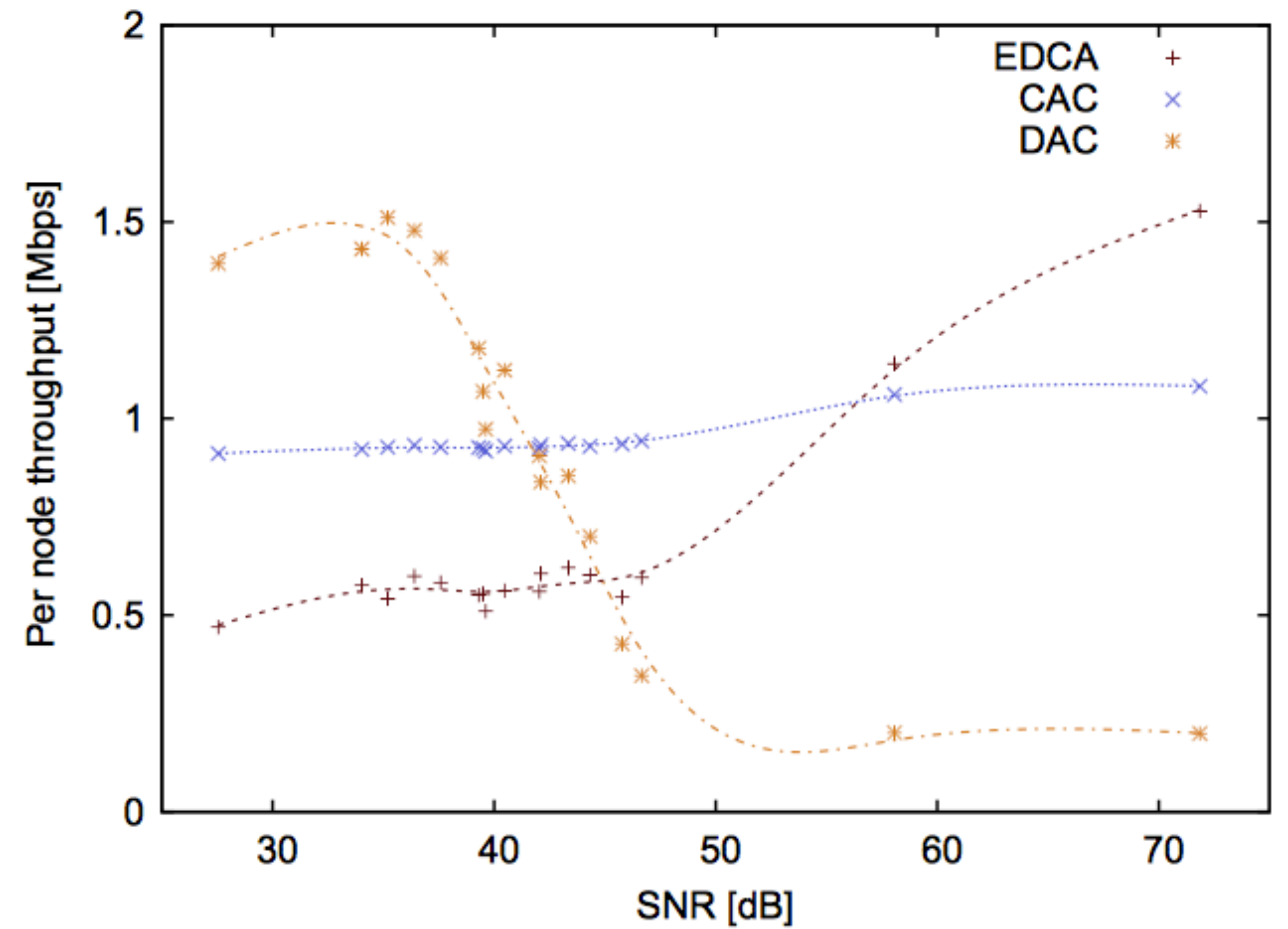
Throughput and Fairness vs. #stations



Per-station UDP throughput



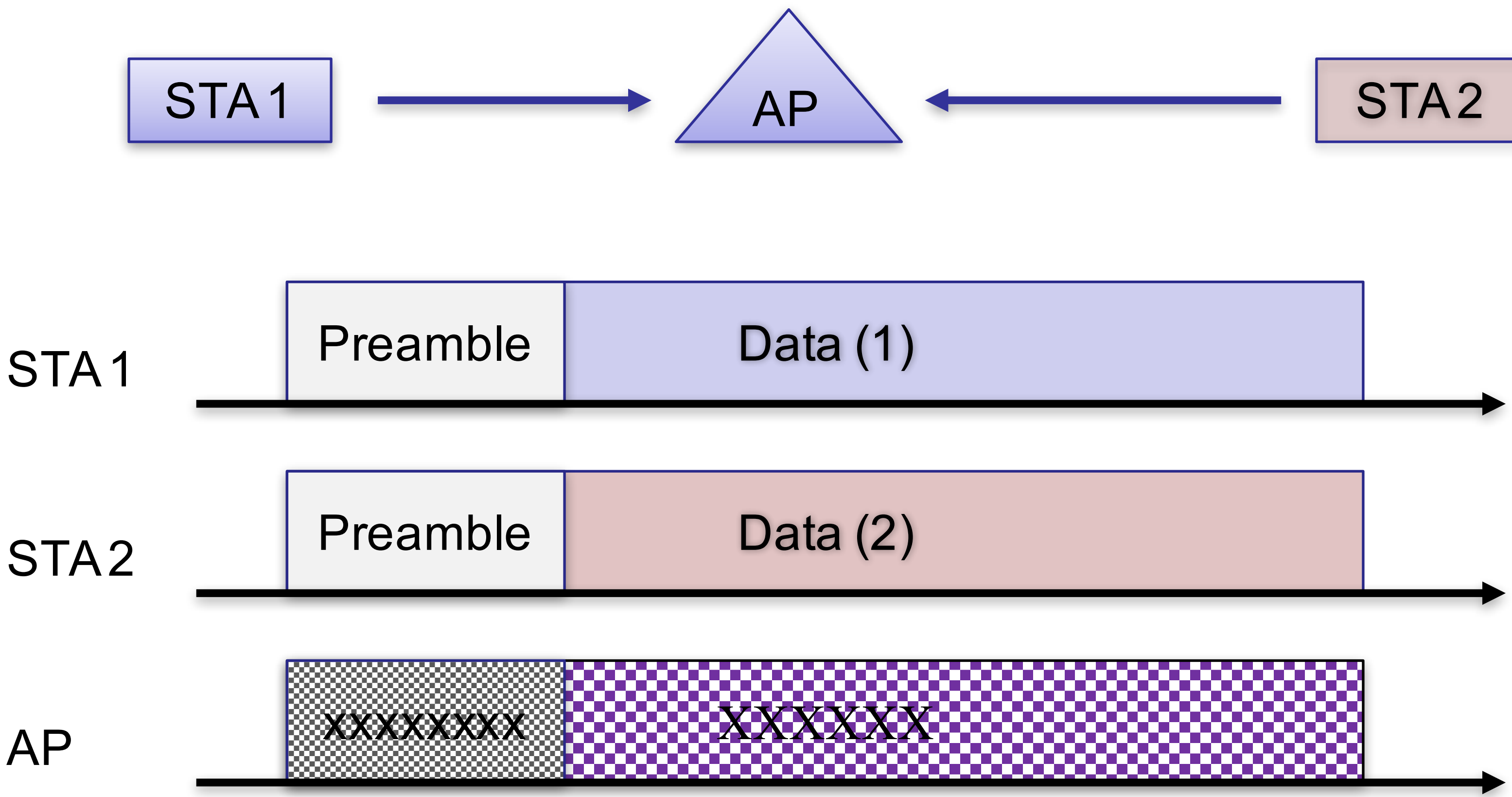
Throughput vs. SNR



Background, II

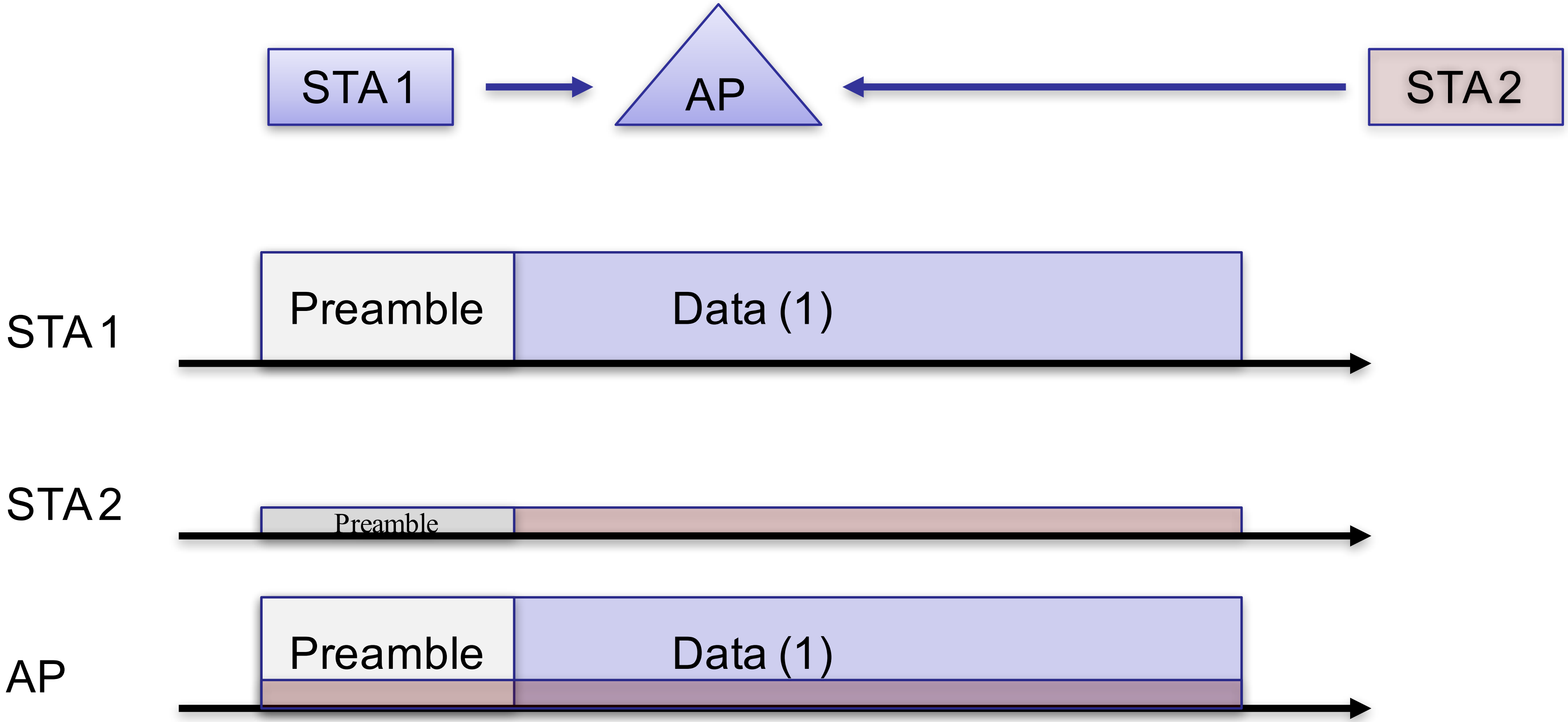
"Ideal" Collisions

- Assumption: in case of simultaneous transmissions, all frames are lost



Real World: Capture effect

- Real life: many times, a frame "survives" (i.e., "captures" the medium)



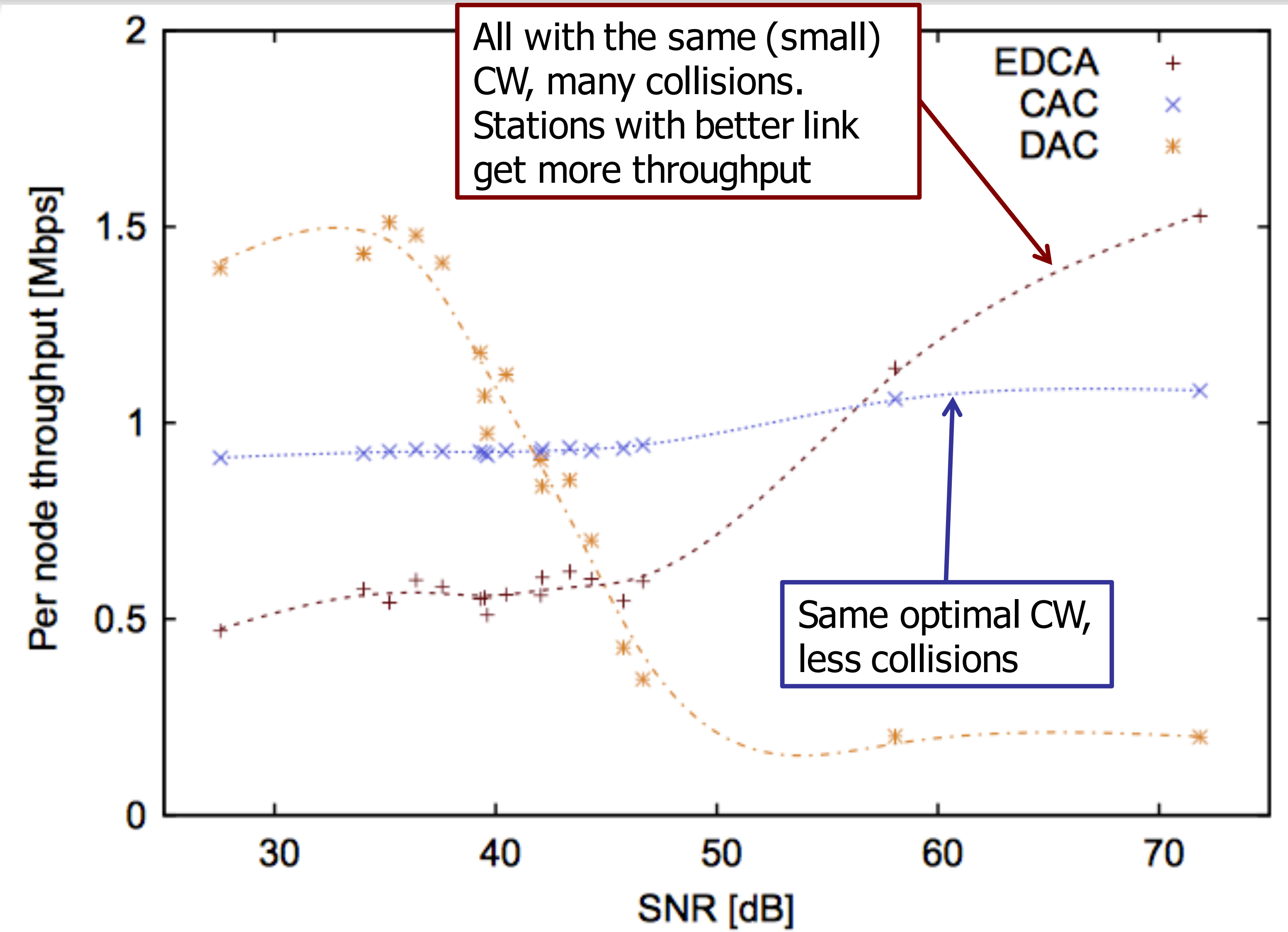
Capture effect: issues

- One station “sees” a failure
  - Lack of ACK
- The other station and the AP: success
  - Couldn’t detect the other one

- Consequences
  - Uneven distribution of resources
  - But improved throughput

Back to the results

Throughput vs. SNR



Capture effect: DAC

- Each station computes its own CW (increased if error increases)
- Error term 1: Optimal point of operation

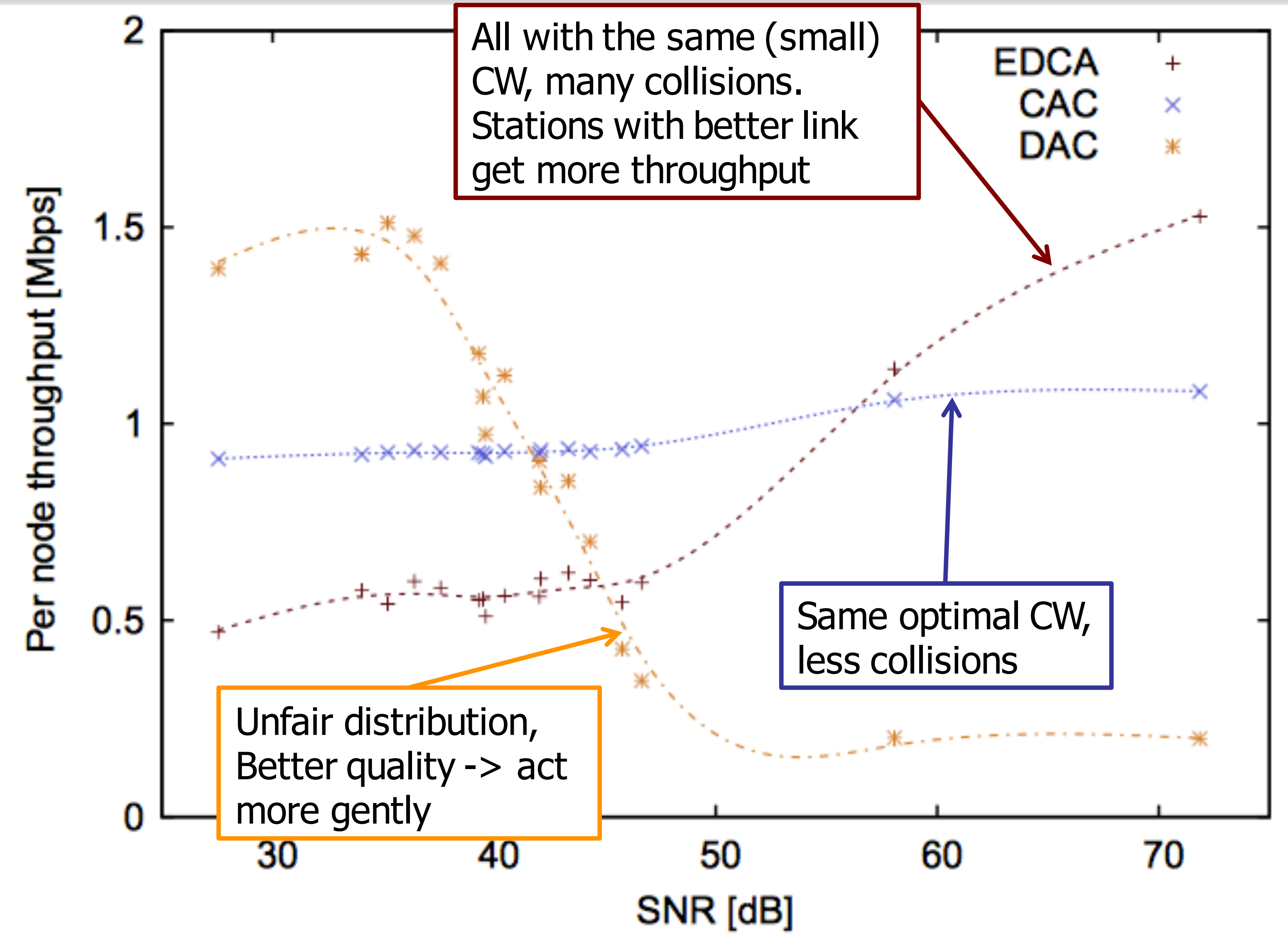
$$e_{\mathrm{opt}}(i) = \hat{p}(i) - p_{\mathrm{opt}}$$

- Error term 2: Fairness between stations

$$e_{\mathrm{fair}}(i) = \hat{p}(i) - p(i)$$

The higher the SNR, the smaller it gets

Throughput vs. SNR



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
    - Inherent to any scheme? (Without explicit communication between stations)
  - CAC works for sat. & non-sat conditions

References

- P. Serrano, P. Patras, A. Mannocci, V. Mancuso, A. Banchs, "Control Theoretic Optimization of 802.11 WLANs: Implementation and Experimental Evaluation," Elsevier Computer Networks, vol. 57, no. 1, January 2013.

- P. Patras, A. Banchs, P. Serrano, "A Control Theoretic Approach for Throughput Optimization in IEEE 802.11e EDCA WLANs," Springer Mobile Networks and Applications, vol. 14, December 2009

- P. Patras, A. Banchs, P. Serrano, A. Azcorra, "A Control Theoretic Approach to Distributed Optimal Configuration of 802.11 WLANs," Transactions on Mobile Computing, vol. 10, no. 6, June 2011

Many Thanks!

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