A Backoff Mechanism to Achieve Full Organization?

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Context/Goal

- Multi-hop ad hoc networks
- A single channel
- High traffic load (or bursty traffic)

- Decentralized MAC protocols
- Use a backoff mechanism to regulate the access to the channel

Metrics

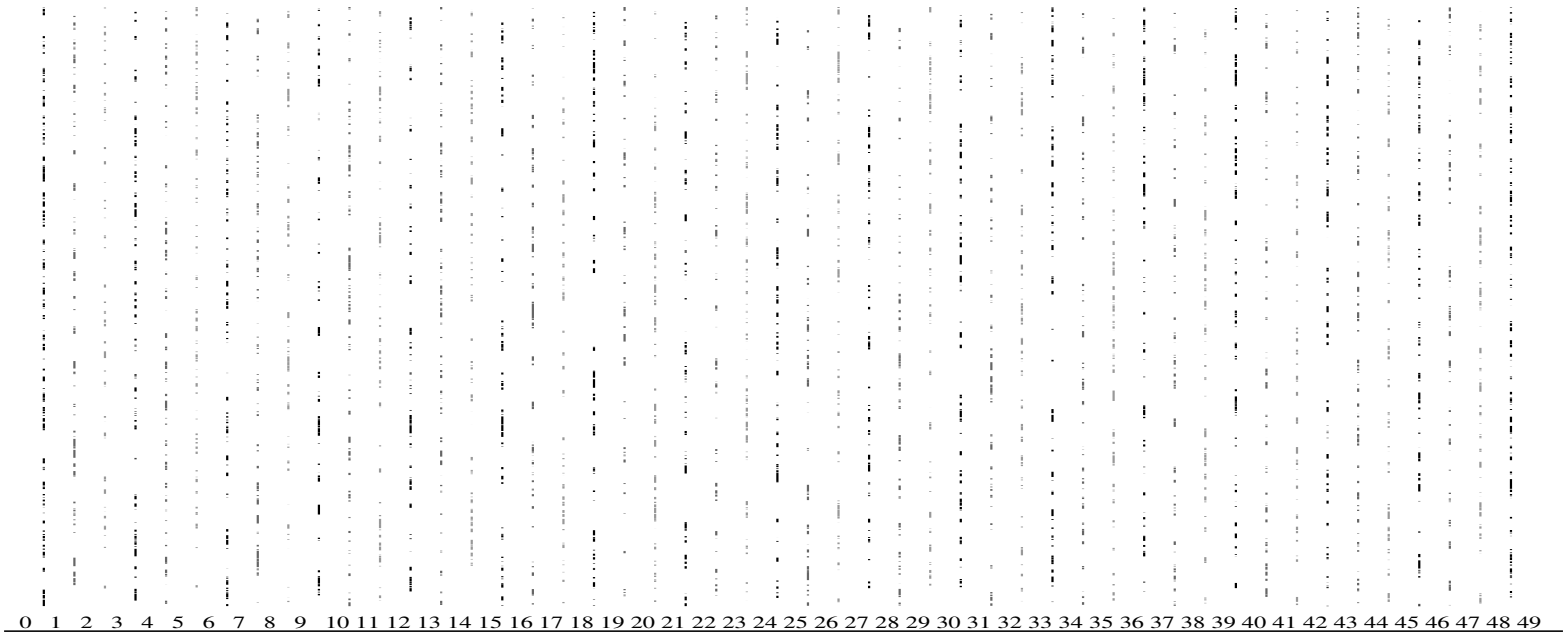
- Spatial reuse (σ): the fraction of network links that carry a successful transmission
- Jain's Fairness Index (FI):

$$\mathrm{FI} = \frac{(\sum_i x_i)^2}{n \sum_i x_i^2}$$

where x_i is the number of packets sent on link i and n is the number of links in the network

Claim

A backoff mechanism can be used to achieve the desired level of organization in a network



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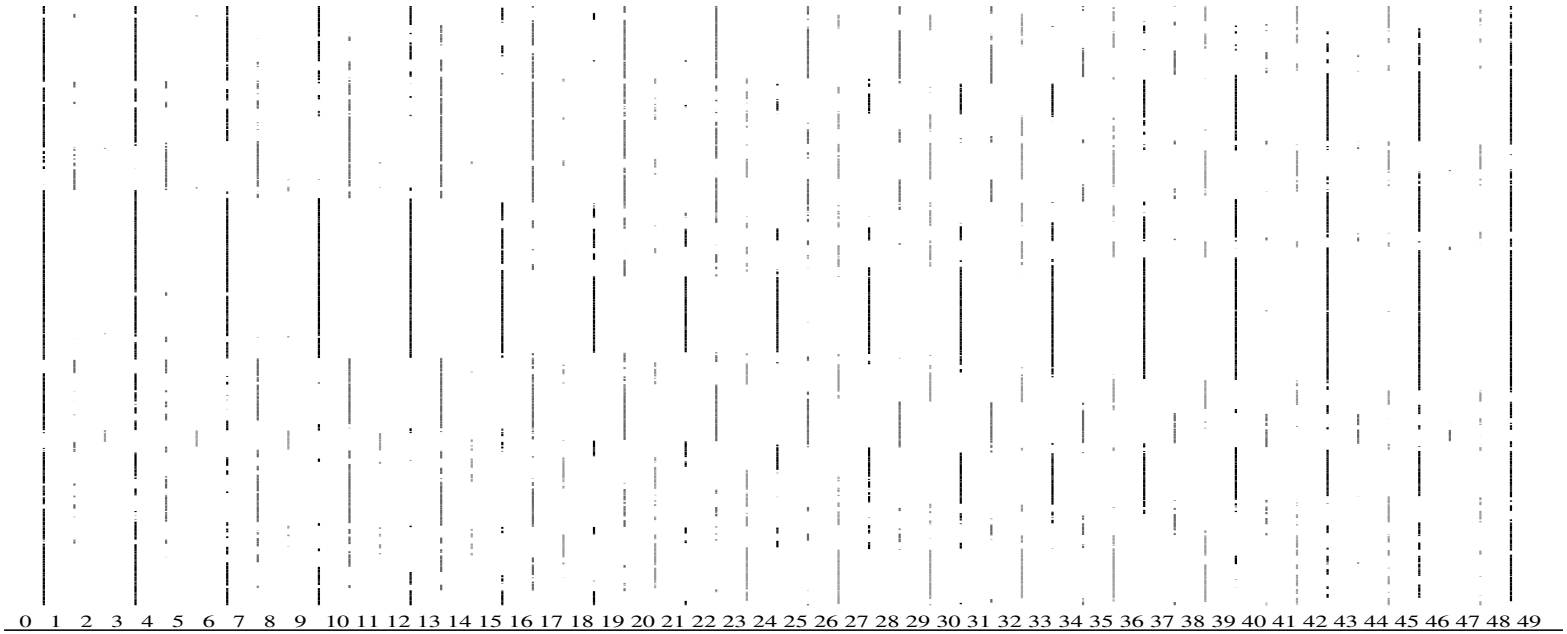

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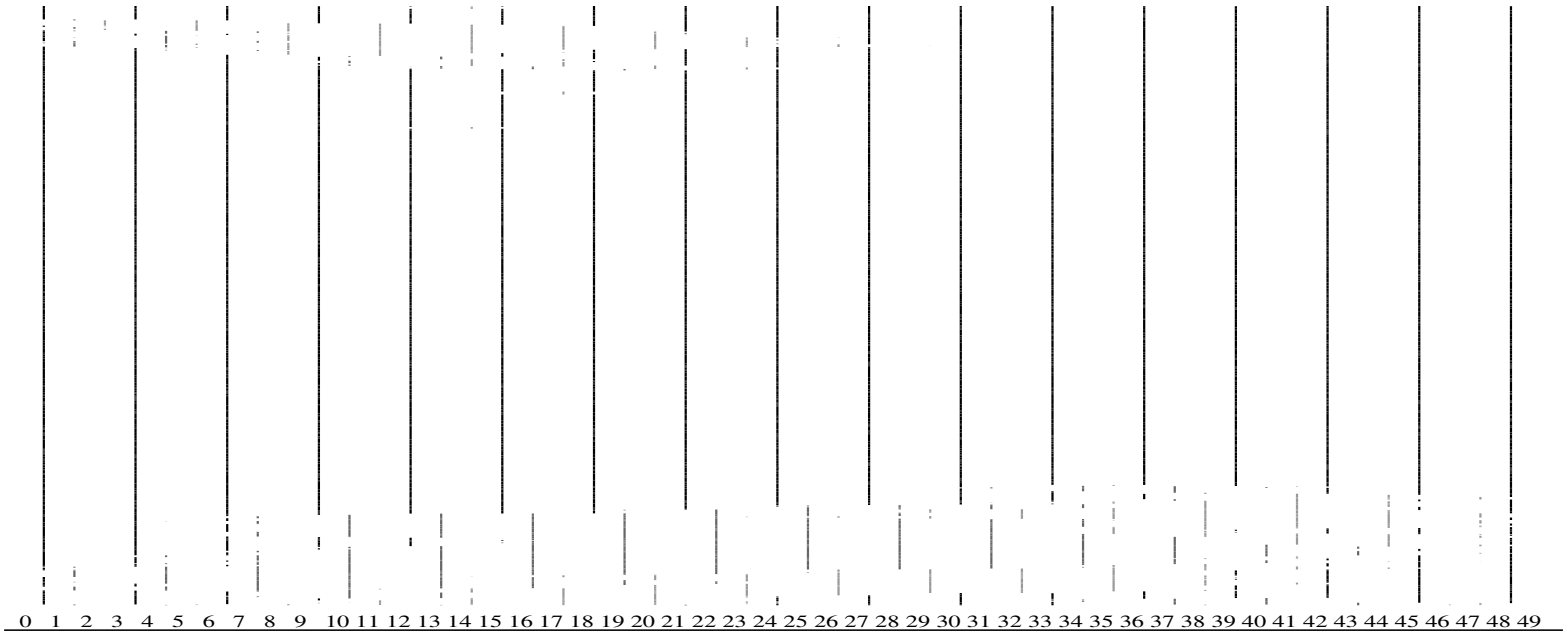


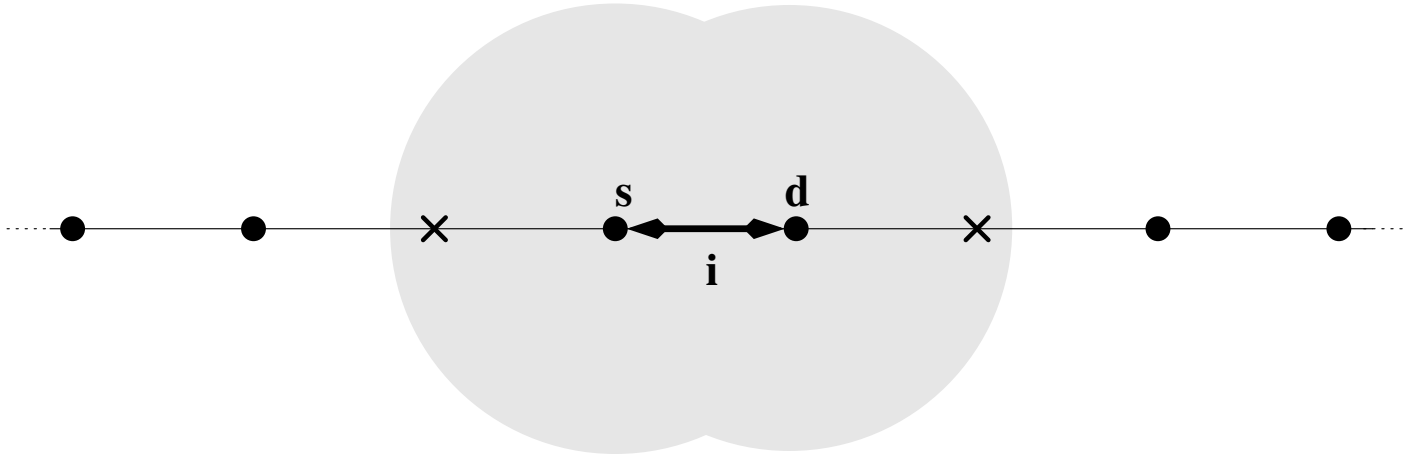
1 Introduction

2 In Theory
- Assumptions
- Packing analogy
- Spatial reuse
- Fairness

3 In Practice
- IEEE 802.11 MAC protocol
- Three unwanted situations
- Closing the gap

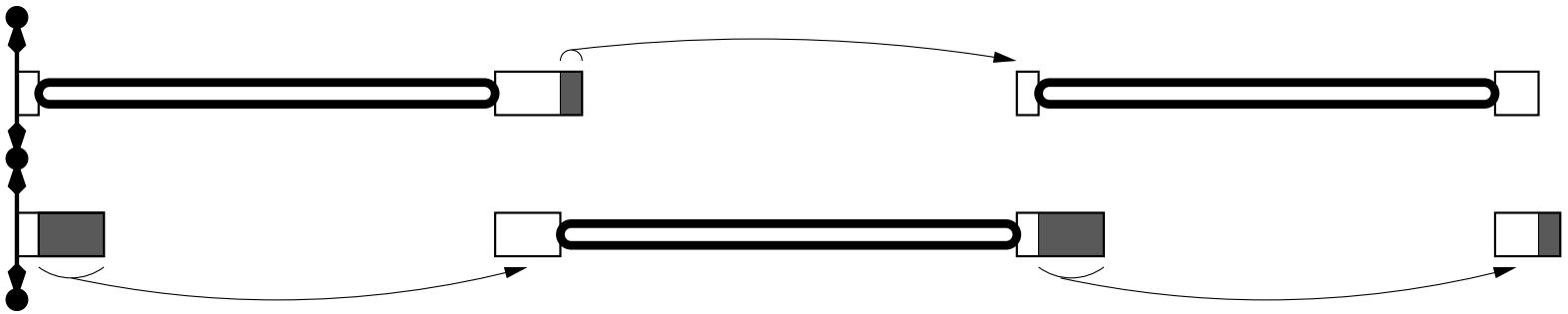
4 Conclusion

Assumptions



- exclusion domain
- bidirectional exchange
- saturated traffic conditions

MAC protocols under study

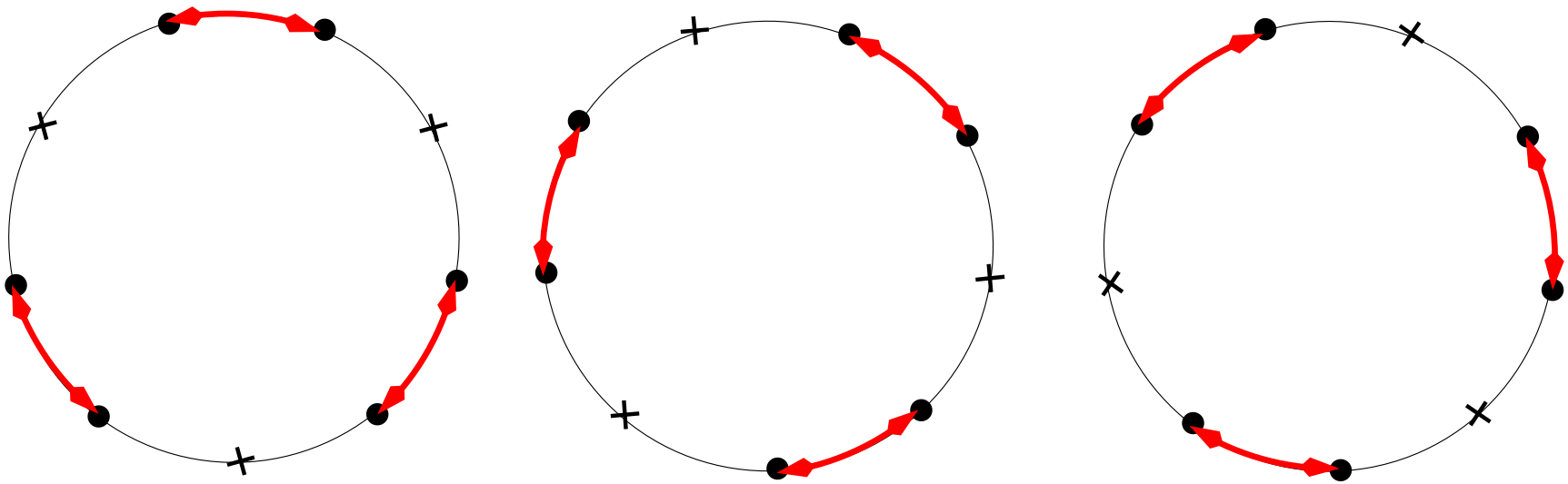


- Average exchange time: $1/\mu$
- Average backoff time: $1/\lambda$
- Continuous backoff distribution $\rightarrow$ no collision

Terminology

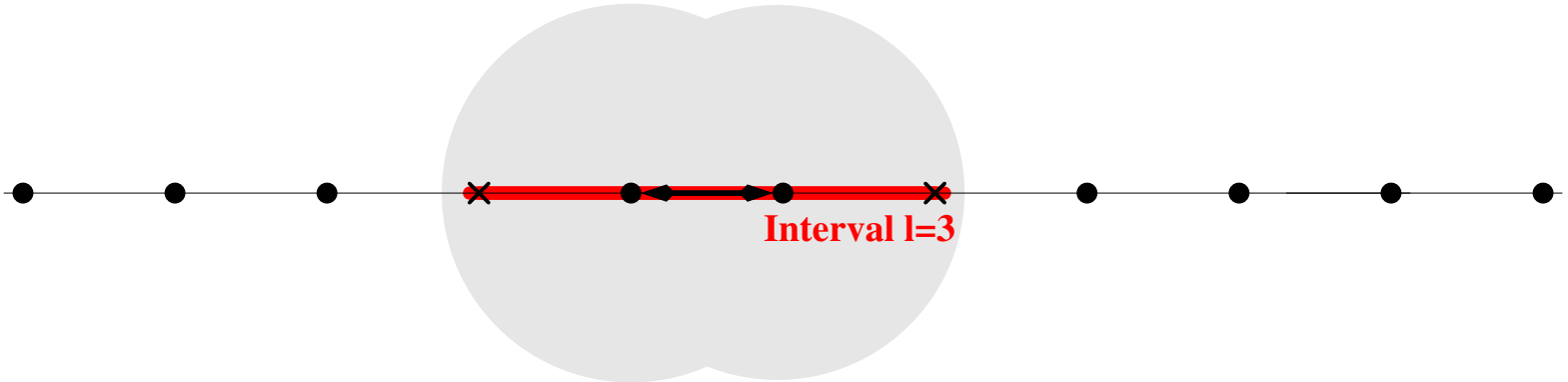
- transmission schedule (active and idle links)
- maximal spatial reuse

Terminology



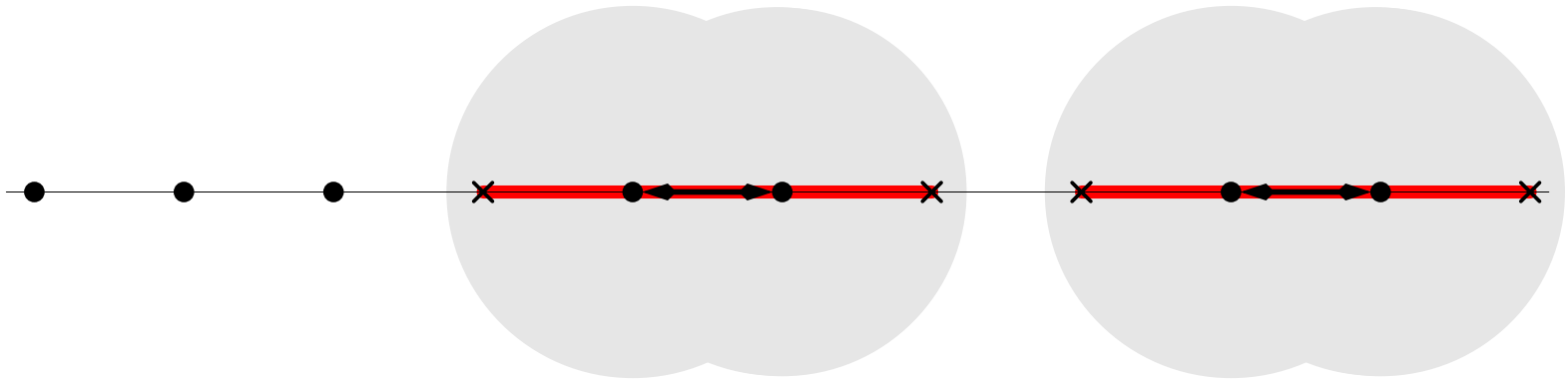
- transmission schedule (active and idle links)
- maximal spatial reuse

Packing analogy



- To each active link we associate an interval of length *l* on the line
- A transmission schedule is a set of non-overlapping intervals

Packing analogy



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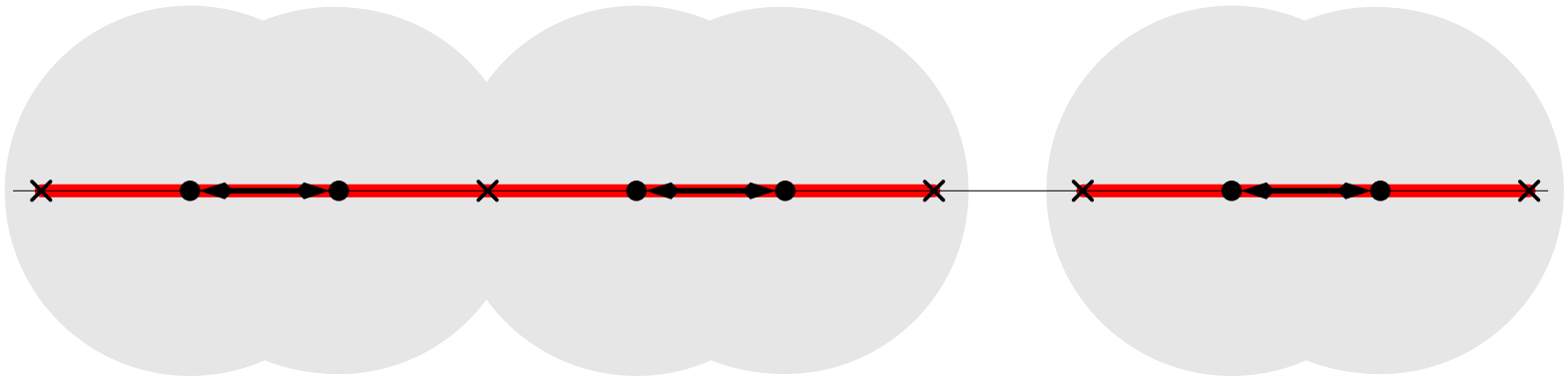

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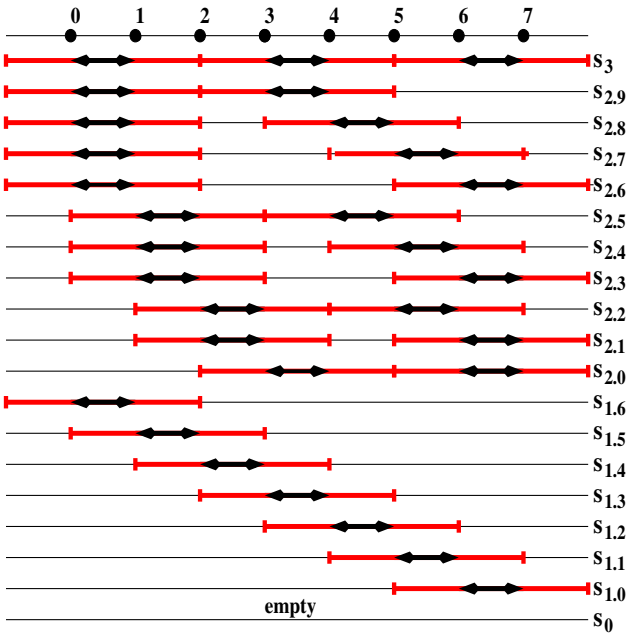
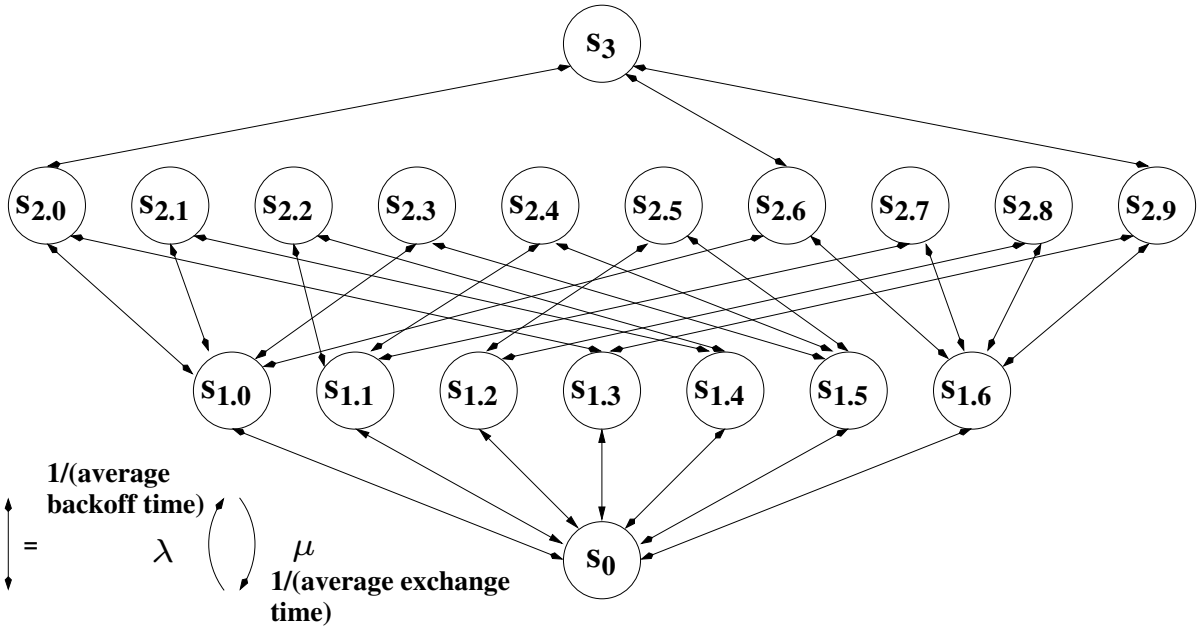
Markov chain representation





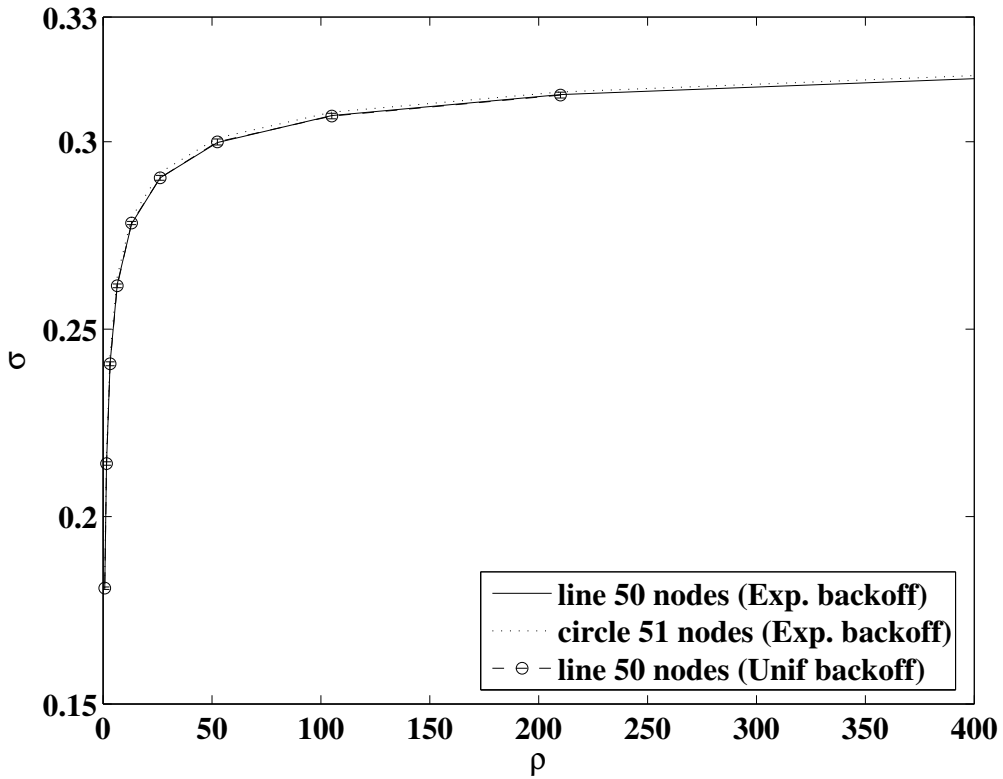
Markov chain equations

- The stationary probability of a *specific* transmission schedule with j active links is

$$\pi(j) = \frac{\rho^j}{\sum_k N(k)\rho^k}$$

  where $\rho = \frac{\lambda}{\mu}$ and $N(k)$ is the number of transmission schedules with k active links
- Organizing properties:
  - When $\rho > 1$, $\pi(j)$ increases with j
  - In the limit $\rho \to \infty$, only the transmission schedules with the highest number j of active links have a non-trivial probability
- True for all topologies and exchange time distributions
- In general, it is hard to find an exact form for $N(k)$

Spatial reuse



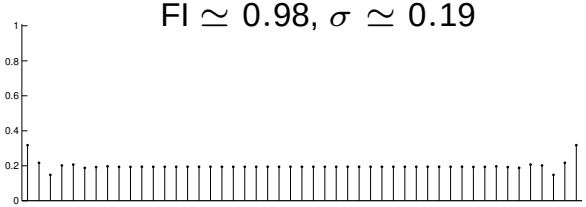
Infinite line network

$$\sigma \sim \frac{\rho y_1^{l-1}}{1 + l\rho y_1^{l-1}}$$

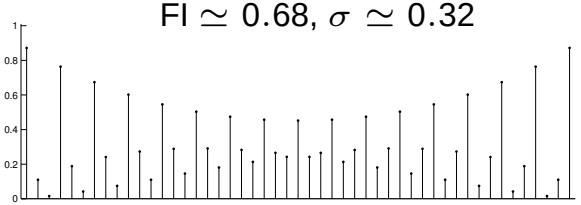
where y_1 is the real root of $1 - y - \rho y^l$ closest to the origin

Long-term fairness

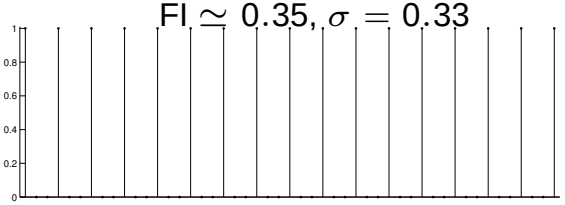
FI $\simeq 0.98$, $\sigma \simeq 0.19$



FI $\simeq 0.68$, $\sigma \simeq 0.32$



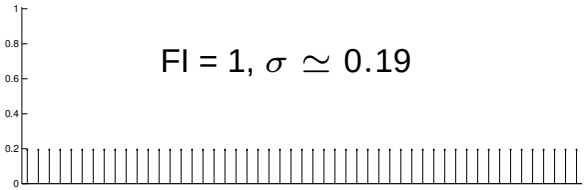
FI $\simeq 0.35$, $\sigma = 0.33$



Line topology 50 nodes

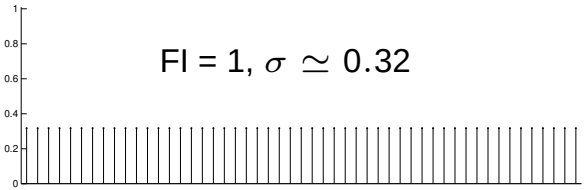
$\rho = 1$

FI = 1, $\sigma \simeq 0.19$



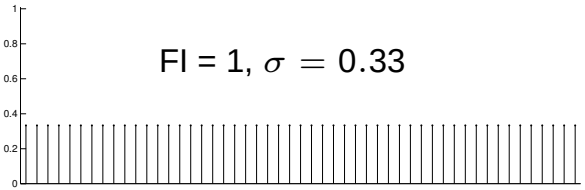
$\rho = 400$

FI = 1, $\sigma \simeq 0.32$



$\rho \longrightarrow \infty$

FI = 1, $\sigma = 0.33$



Circle topology 51 nodes

Long-term fairness: $\mathrm{FI} = \frac{\left(\sum_i p(i)\right)^2}{n \sum_i p(i)^2}$ where $p(i)$ is the probability that link i is active in the stationary regime

Short-term Fairness (current work)

- At large ρ it becomes hard to switch between schedules of maximal spatial reuse
- the short-term fairness suffers even in topologies that are long-term fair
- e.g.: $\rho = 400$ ($\mu = 1$)

FI(t)	long-term	t=10^4	t=10^3	t=10^2	t=10
Line (50 nodes)	0.68	0.64	0.63	0.50	0.38
Circle (51 nodes)	1	0.98	0.87	0.56	0.39

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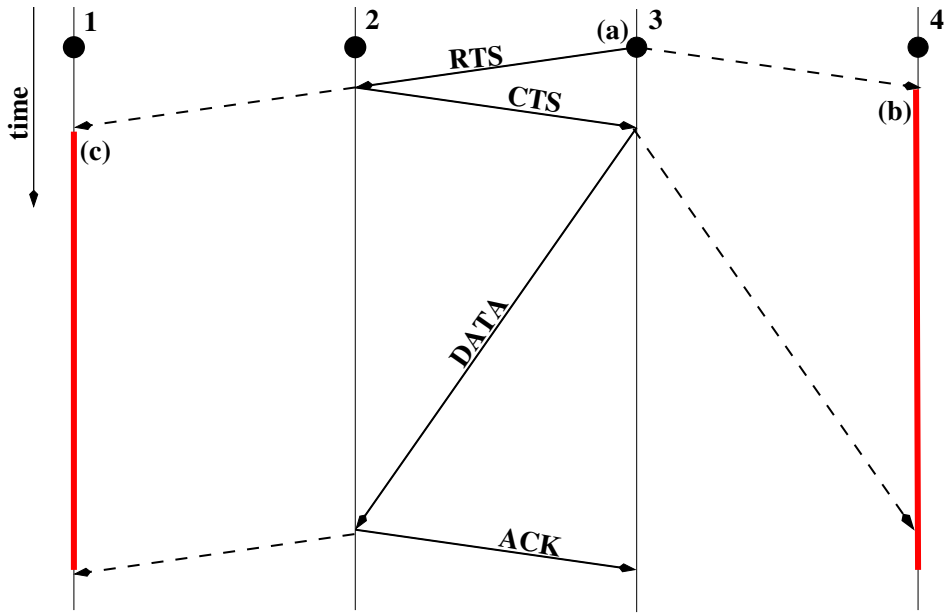
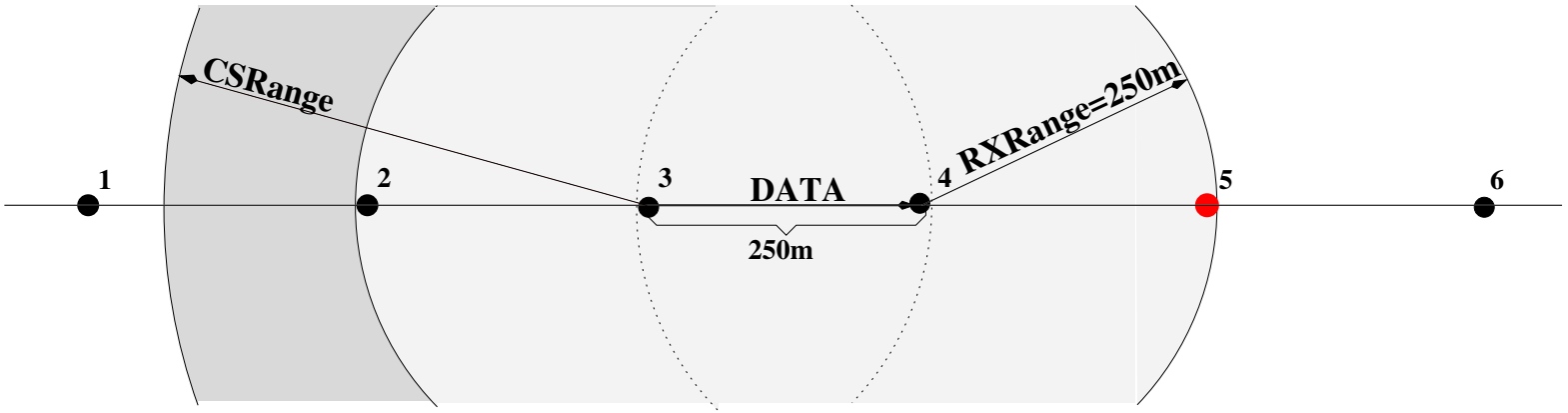
IEEE 802.11 MAC protocol

- Uses a uniform backoff distribution between 0 and $cw \cdot 20\mu s$ where cw is the contention window
- cw is doubled before a retransmission ($CW_{min} = 31, CW_{max} = 1023$)
- Physical carrier sensing
- Virtual carrier sensing: RTS-CTS handshake+NAV

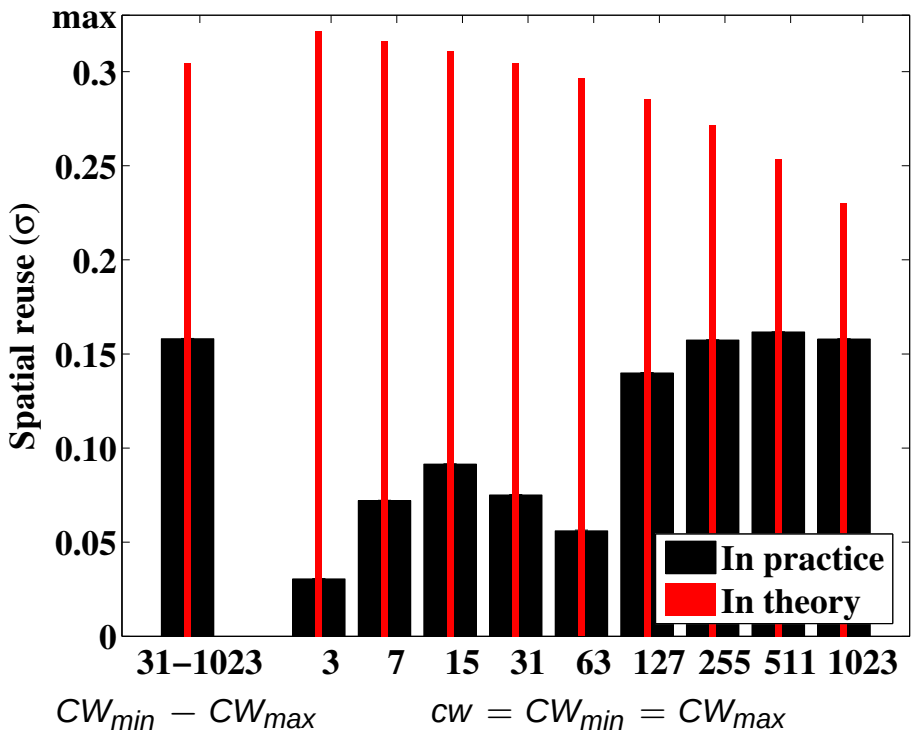


Physical layer



Ns-2 physical layer model (CSRange $\simeq$ RXRange)

What prevents 802.11 from operating at the limit determined by its physical layer?



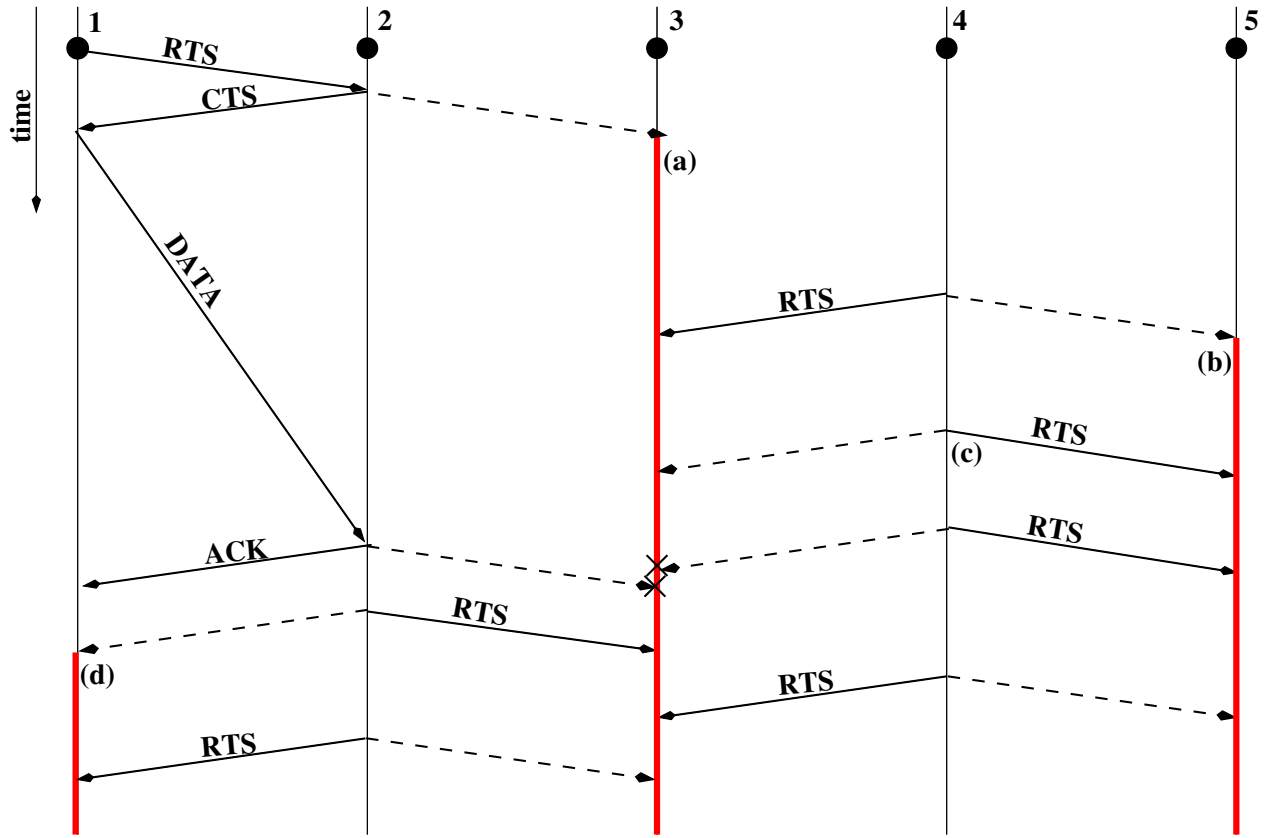
Simulation setup

- Line topology 50 nodes
- Saturated traffic conditions
- 1500 bytes DATA packets (μ is fixed)

Three unwanted situations

- The gagged node
- The jammed node
- The focused node

A gagged node is silenced by repeated RTS that are not followed by a DATA packet

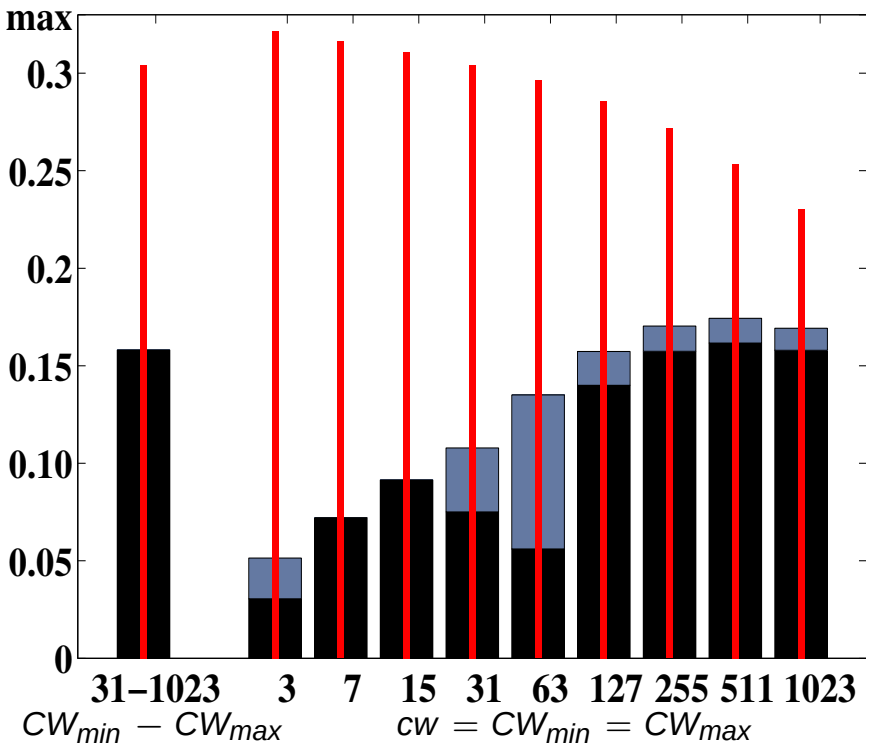


Spatial reuse of 802.11 without gagged nodes

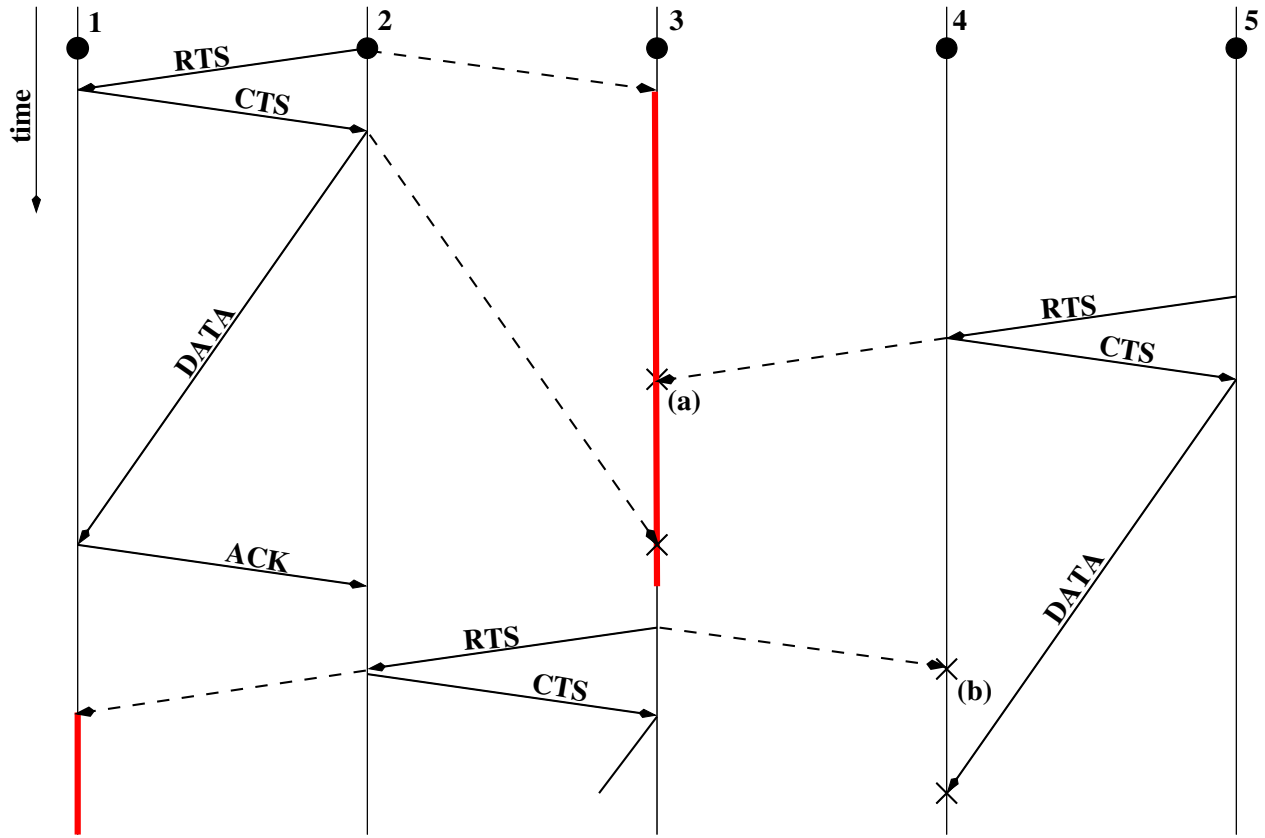
In practice (current ns-2 802.11)

Gagged node situation solved

In theory



A node is jammed by a DATA packet and cannot extract information in CTS packets sent concurrently



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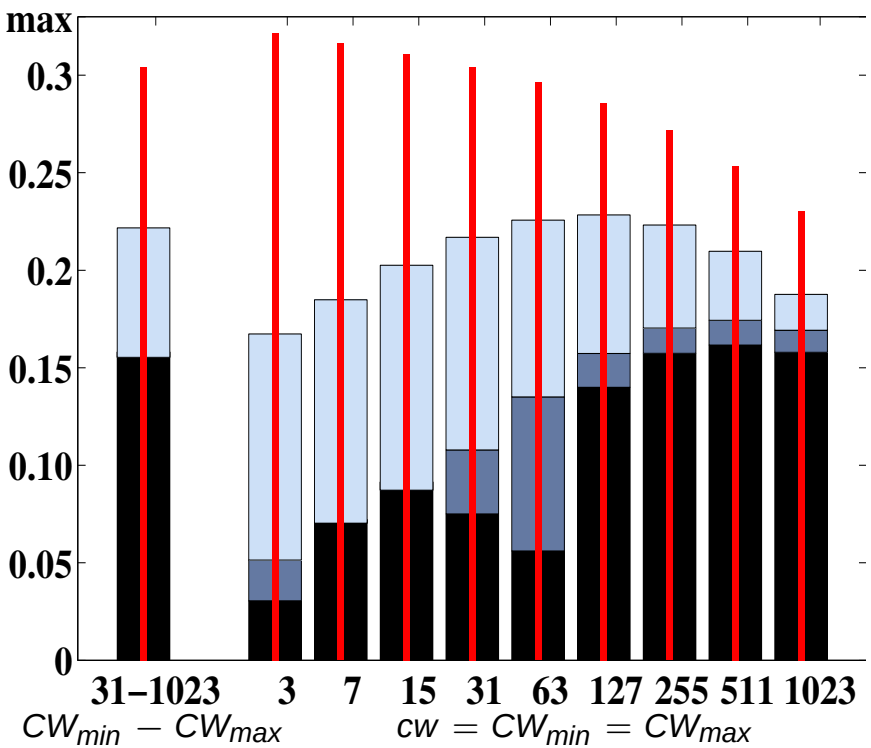
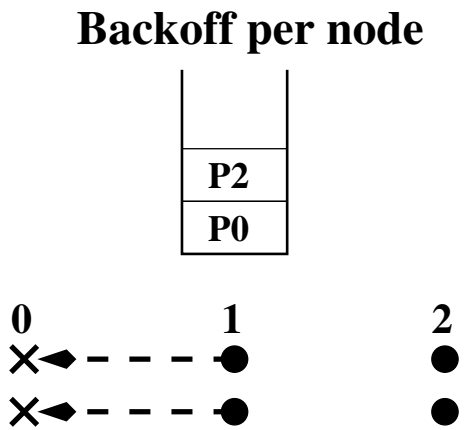
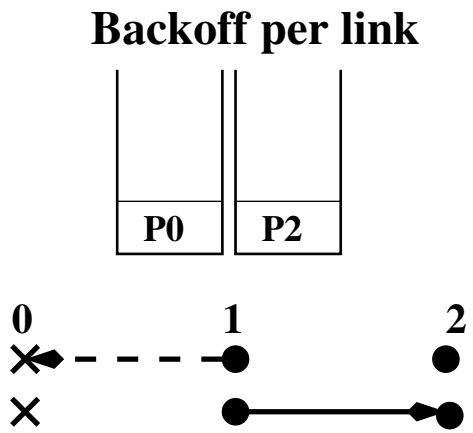


A node focuses its transmission attempts on a single of its neighbors that experiences high contention





Spatial reuse of 802.11 without focused nodes

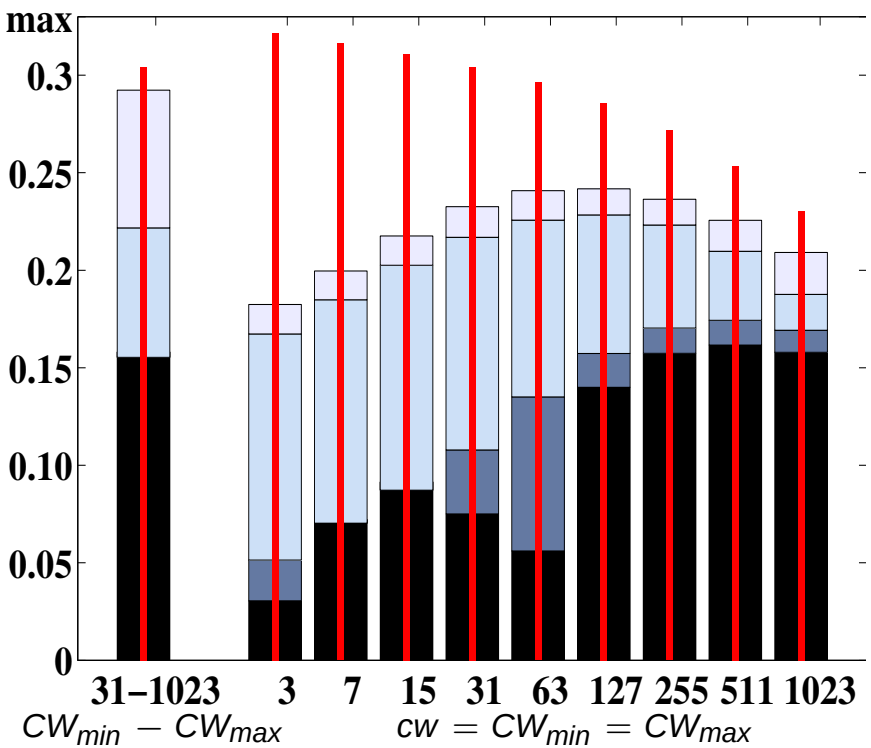
In practice (current ns-2 802.11)

Gagged node situation solved

Jammed node situation solved

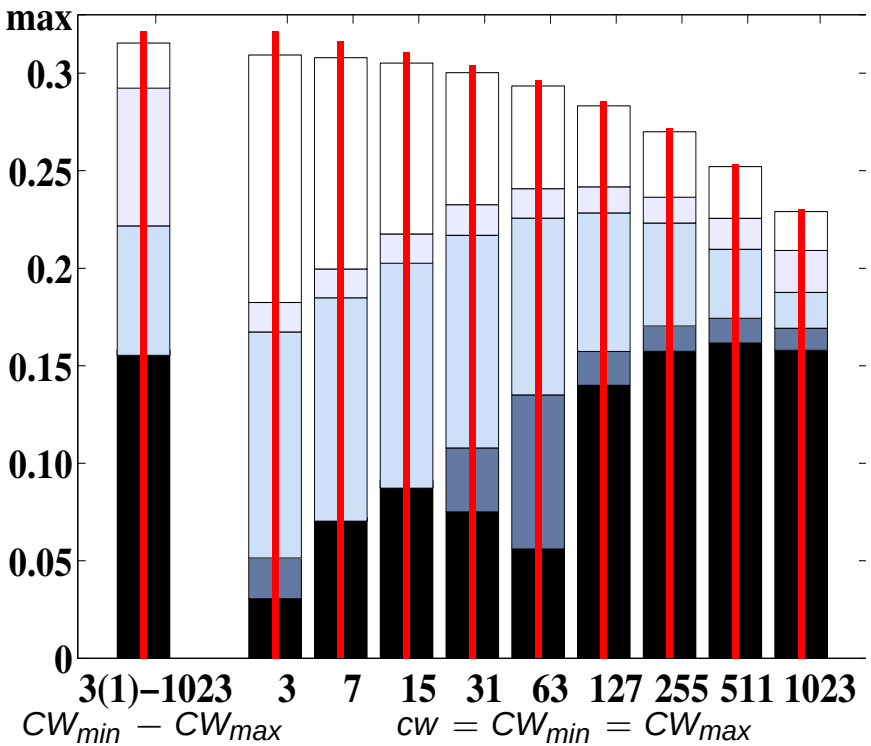
Focused node situation solved

In theory



Asymptotic reduction of the RTS-CTS overhead

- In practice (current ns-2 802.11)
- Gagged node situation solved
- Jammed node situation solved
- Focused node situation solved
- Reduction of the RTS-CTS overhead
- In theory



Conclusion

- A local backoff mechanism can be used to fully organize the transmissions in a network
- The level of organization depends on ρ the ratio between the average exchange time and the average backoff time
- One can choose the spatial-reuse/fairness trade-off by operating at the appropriate value of ρ
- In practice, the gagged, jammed, and focused node situations prevent the 802.11 protocol from operating the limits set by its physical layer