Performance issues & improvement on 802.11 MAC

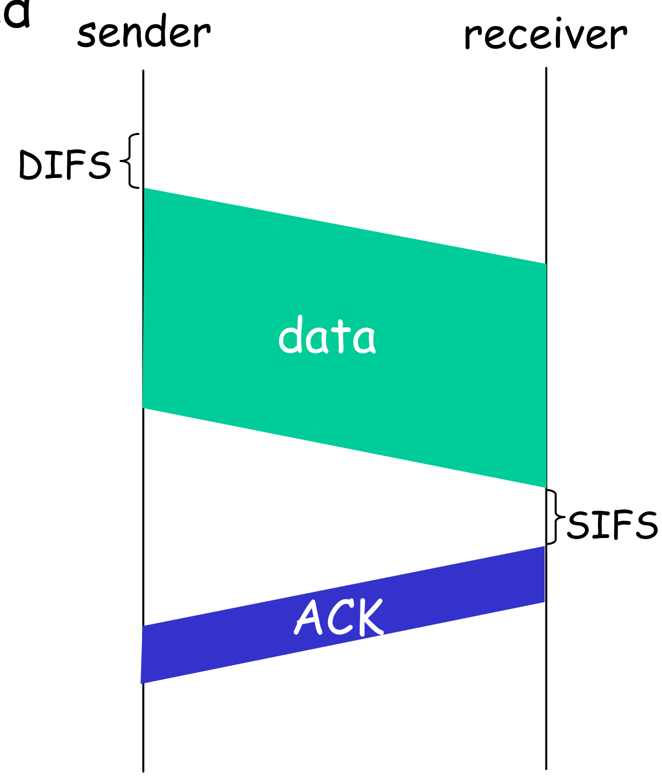
- review of 802.11 MAC
- performance issues
- improvements
  - idle sense
  - an overlay approach
  - more …

802.11 CSMA/CA

802.11 sender

1 if sense channel idle for **DIFS** (distributed inter-frame spacing) then
  - transmit entire frame (no CD)

2 if sense channel busy then
  - start random backoff time
  - timer counts down while channel idle
  - transmit when timer expires
  - if no ACK, increase random backoff interval, repeat 2



802.11 receiver

- if frame received OK

  return ACK after **SIFS** (short inter-frame spacing)

Discussion

- why collision avoidance instead of detection?
- why using ACK?
- why random backoff?
- why backoff after transmission failure?
- why exponential backoff?

Performance Anomaly of 802.11b

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Heterogeneous transmission rates

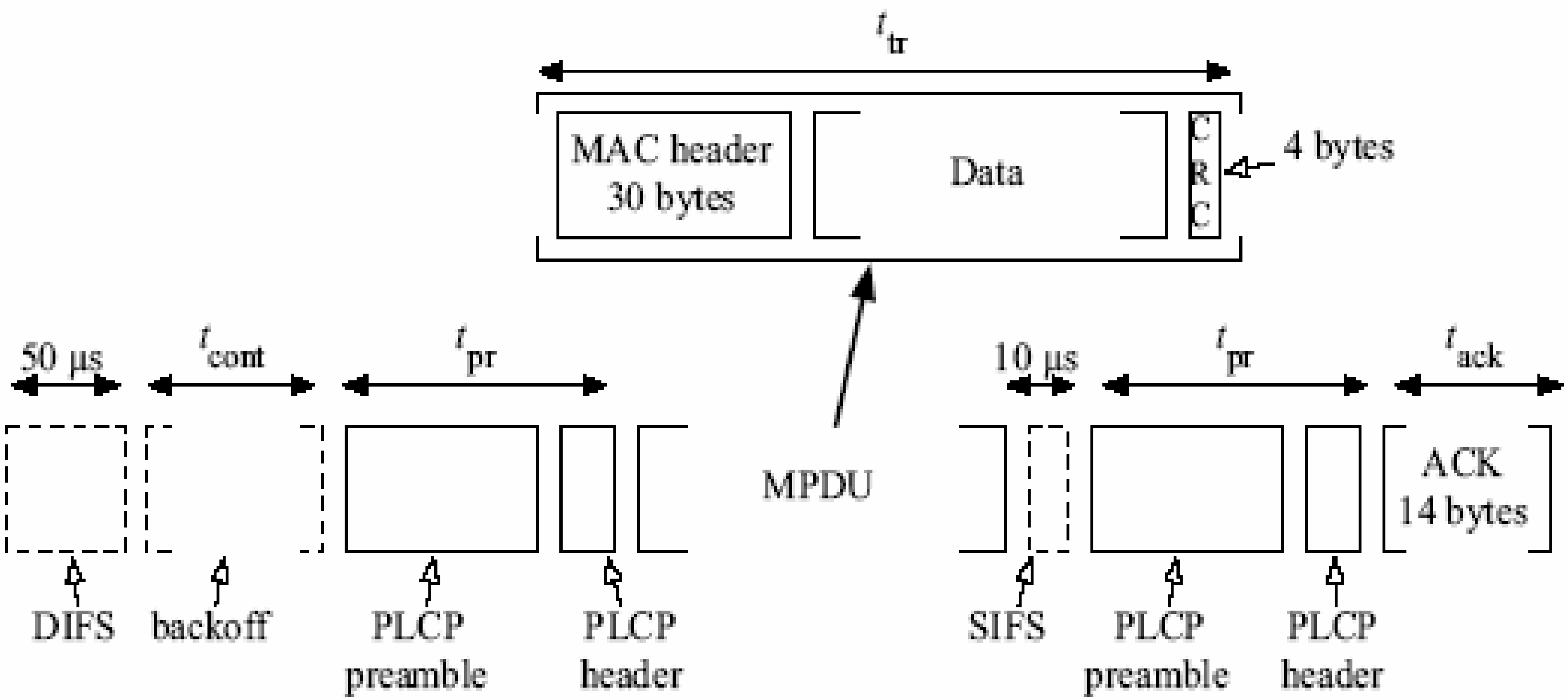
- rate adaptation
- 802.11b: 11, 5.5, 2, 1Mbps
- assumptions:

N hosts: N-1 fast, 1 slow

R : transmission rate of fast host (11Mbps)

r : transmission rate of slow host (5.5, 2 or 1 Mbps)

Transmission time of a frame in 802.11b



Transmission time

- Fast Host: $$T_f = t_{ov}^R + \frac{s_d}{R} + t_{cont}$$

  Slow Host: $$T_s = t_{ov}^r + \frac{s_d}{r} + t_{cont}$$

  T: overall transmission time, T_f: fast host, T_s: slow host

  t_{ov} : overhead time, t^R_{ov} : fast host, t^r_{ov}: slow host

  t_{cont} : contention time, s_d: frame size

$$t_{ov} = DIFS + t_{pr} + SIFS + t_{pr} + t_{ack}$$

Fast host

Equal probability of access for all hosts

U_f: channel utilization by a fast host

$$U_{\mathrm{f}} = \frac{T_{\mathrm{f}}}{(N-1)\,T_{\mathrm{f}} + T_{\mathrm{s}} + P_{\mathrm{c}}(N) \times t_{\mathrm{jam}} \times N}$$

$P_c(N)$: for a successful packet, probability of collision

$$P_{\mathrm{c}}(N) = 1 - (1 - 1/CW_{\mathrm{min}})^{N-1}$$

t_{jam} : average time spent in collisions

$$t_{\mathrm{jam}} = \frac{2}{N} T_{\mathrm{s}} + (1 - \frac{2}{N})\,T_{\mathrm{f}}$$

Fast host (cont'd)

X_f: throughput at the MAC layer of a fast host

$$X_{\rm f} = U_{\rm f} \times p_{\rm f}(N) \times R$$

where $p_{\rm f}(N) = \frac{s_{\rm d}}{R\, T_{\rm f}}$, proportion of useful throughput

$$U_{\rm f} = \frac{T_{\rm f}}{(N-1)\, T_{\rm f} + T_{\rm s} + P_{\rm c}(N) \times t_{\rm jam} \times N}$$

Slow host

U_s: channel utilization by slow host

$$U_s = \frac{T_s}{(N-1)\,T_f + T_s + P_c(N) \times t_{jam} \times N}$$

X_s: throughput at the MAC layer of slow host

$$X_s = U_s \times p_s(N) \times r$$

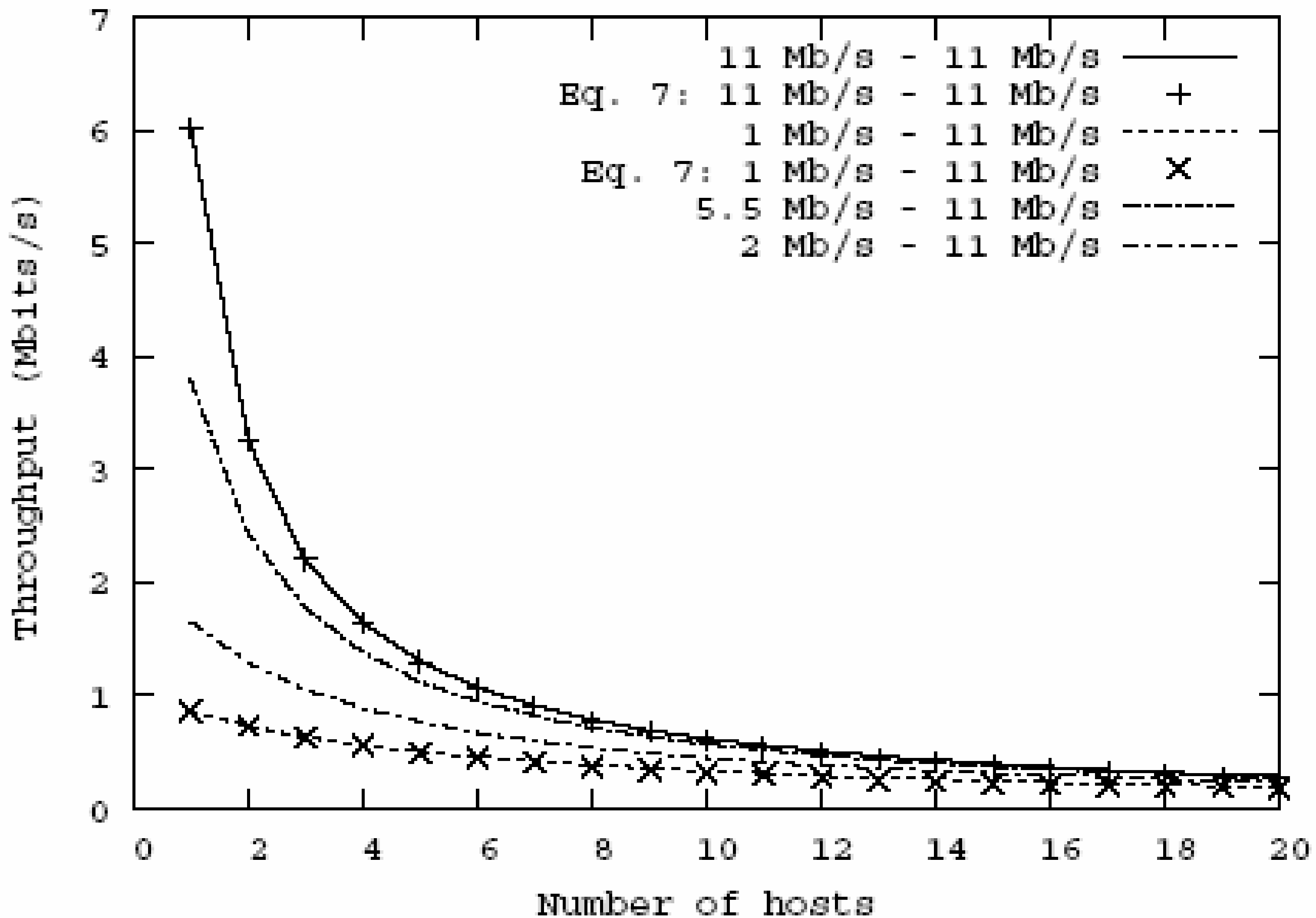
$$\text{where } p_s(N) = \frac{s_d}{r\,T_s}$$

Performance anomaly of 802.11b

- Fast hosts transmitting at a higher rate R obtain the same throughput as slow hosts transmitting at a lower rate r, i.e.,

$$X_s = X_f = X.$$

Simulation studies



Throughput experienced by a 802.11b host when all hosts except one transmit at 11Mb/s

Idle Sense: An Optimal Access Method for High Throughput and Fairness in Rate Diverse Wireless LANs

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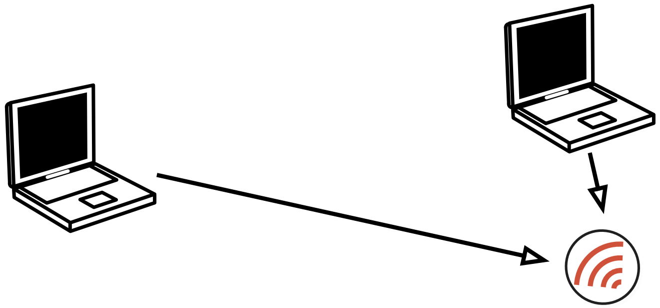
Known problems with DCF

- performance anomaly in rate diverse cells
  - slow host limits the throughput of faster hosts
- exponential backoff
  - good short term fairness for N=2, degrades for larger N
- contention control (not differentiate collision & frame error)
  - "bad day" effect
    - a host loses frames due to bad transmission conditions

      -> frequent exponential backoffs -> increased CW (even lower transmission probability)
  - physical capture effect

Physical layer capture effect



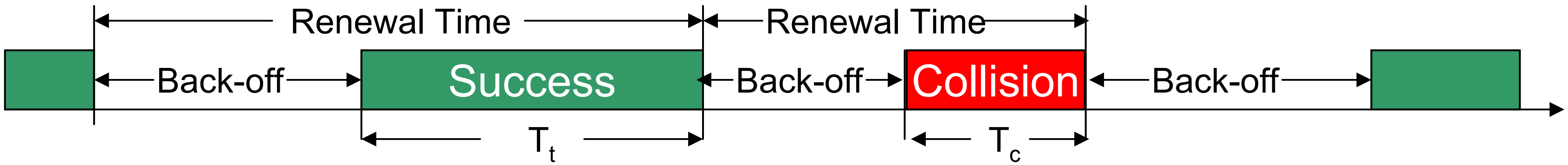
- The stronger signal in a collision may be successfully received
- It causes long term unfairness
  - Farther host has a greater average contention window

(Kochut *et al.*, ICNP'04)

Towards a better access method

- keep good aspects of DCF
  - no explicit information exchange
  - random backoff
- modifications
  - no exponential backoff
    - make hosts use similar values of CW $\Rightarrow$ fairness
  - adapt CW to varying traffic conditions
    - more hosts, bigger CW; less hosts, smaller CW
    - do not change CW upon frame loss
    - what is optimal CW?

Analysis of channel contention



- transmission attempt probability: β
- Prob. that there is no channel activity: $P_i = (1 - \beta)^N$
- Prob. that there is a successful transmission:

  $P_t = n\,\beta(1 - \beta)^{N-1}$
- Prob. that there is a collision: $P_c = 1 - P_t - P_i$
- network throughput:

$$\theta = \frac{P_t\, s_d}{P_i T_{slot} + P_t T_t + P_c T_c}$$

$$\Rightarrow Cost(\beta) = \left(\frac{T_c}{T_{slot}} P_c + P_i\right) / P_t$$

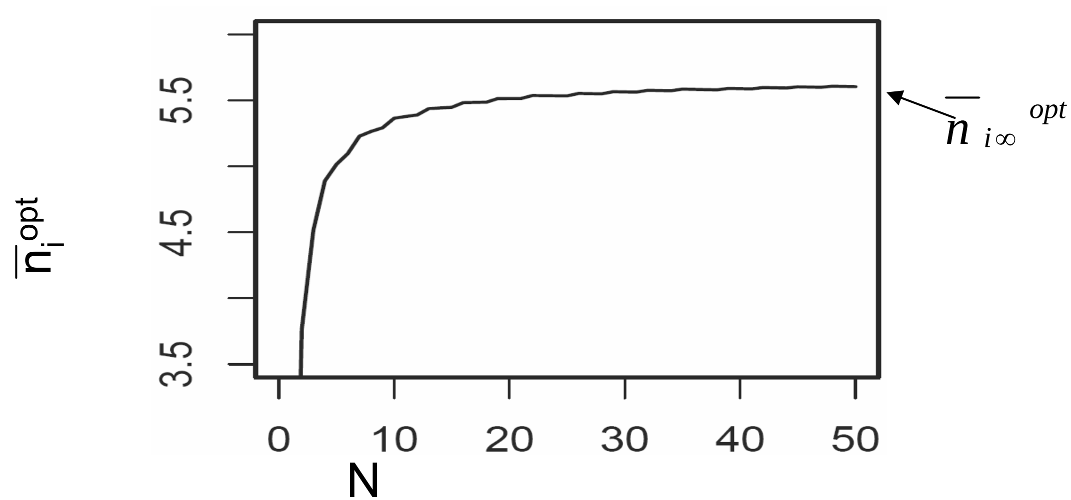
Insight

minimize $$Cost(\beta) = (\frac{T_c}{T_{slot}} P_c + P_i) / P_t$$

$$\frac{dCost}{d\beta} = 0$$

$$1 - N\beta^{opt} = (1 - T_{slot}/T_c)(1 - \beta^{opt})^N$$

Given T_c/T_{slot} (e.g. 68.17 for 802.11b), numerically solve β^{opt}



Expected number of consecutive idle slots: $$\overline{n}_i^{opt} = \frac{(1-\beta^{opt})^N}{1-(1-\beta^{opt})^N}$$

Insight

$$1 - N\beta^{opt} = (1 - T_c / T_{slot})(1 - \beta^{opt})^N$$

$N \to \infty$

$$\overline{n}_{i\infty}^{opt} = \frac{(1-\varsigma/N)^N}{1-(1-\varsigma/N)^N} = \frac{e^{-\varsigma}}{1-e^{-\varsigma}}$$

$\varsigma = N \beta^{opt}$ = 0.1622 for 802.11b

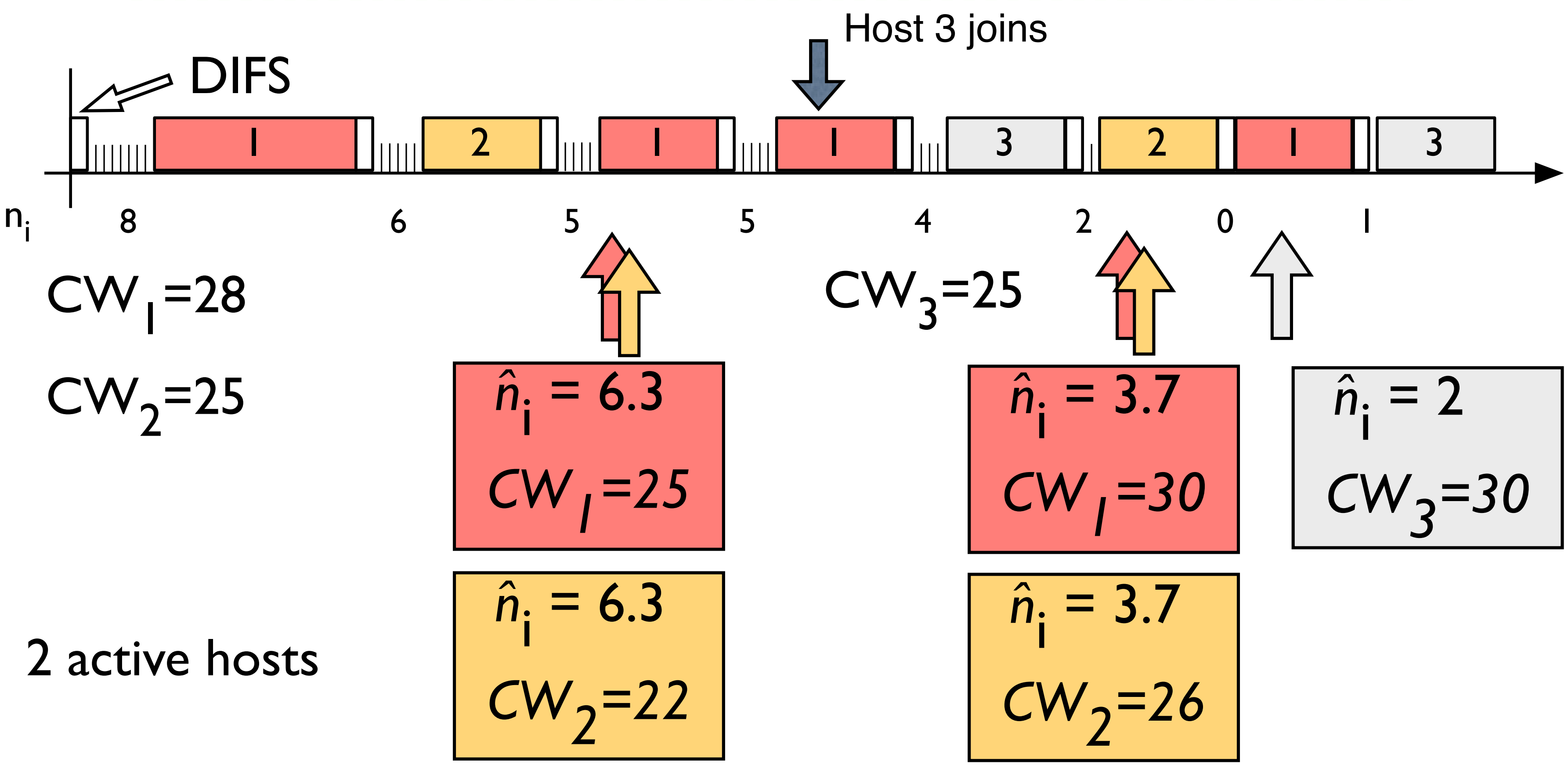
802.11b: $\overline{n}_{i\infty}^{opt}$ = 5.68

Idle Sense

- Hosts track $\overline{n}_i$ and make it converge to the target value
  - Each host estimates $\overline{n}_i$
  - Rises/Lowers CW when $\overline{n}_i$ too small/big compared to $\overline{n}_i^{target}$
  - Adjusting CW is done according to AIMD

$\Rightarrow$ all hosts converge to a similar value of CW

Example



(α= 1/1.2, ϵ=0.01, ntrans=3, $\overline{n}_i^{target}$ = 5.7)

Properties

- Contention control independent of frame loss detection
  - No "bad day" effect
  - Solves the physical layer capture effect
- Short term fair
- Fixes performance anomaly
  - Time fairness achieved by scaling CW according to the transmission rate
- Hidden terminal problem: use RTS/CTS
- No hardware modification required

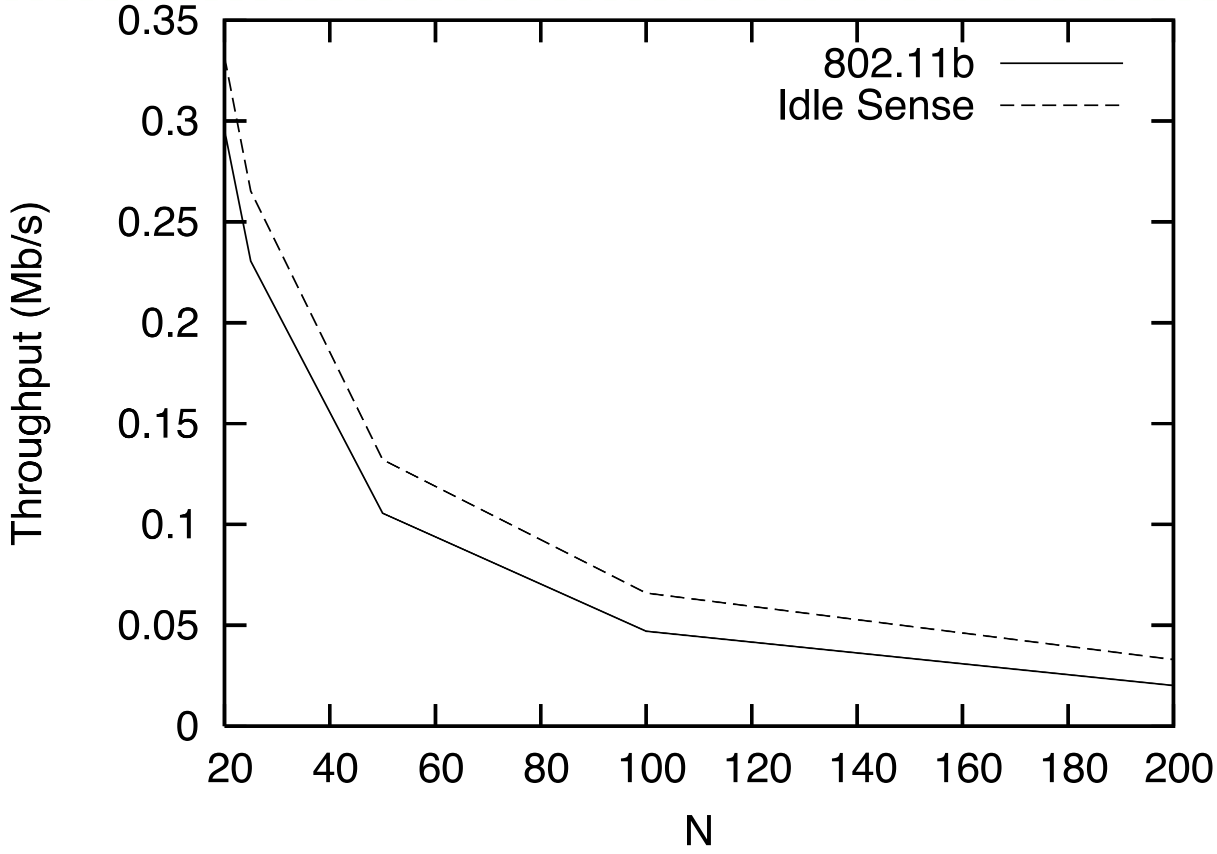
Properties: Channel adaptation

- With *Idle Sense*, the collision probability P_c is known and bounded (after convergence)
  - Frame loss probability $P_{err} \approx 1 - P_c - P_{ok}$
    - P_{ok} can be observed
- Provides a new means for setting the right transmission rate
  - Change rate when P_{err} exceeds a given threshold
  - May be combined with SNR measurements

Performance evaluation

- Throughput
- Fairness: Jain index
- Convergence speed
- Time fairness

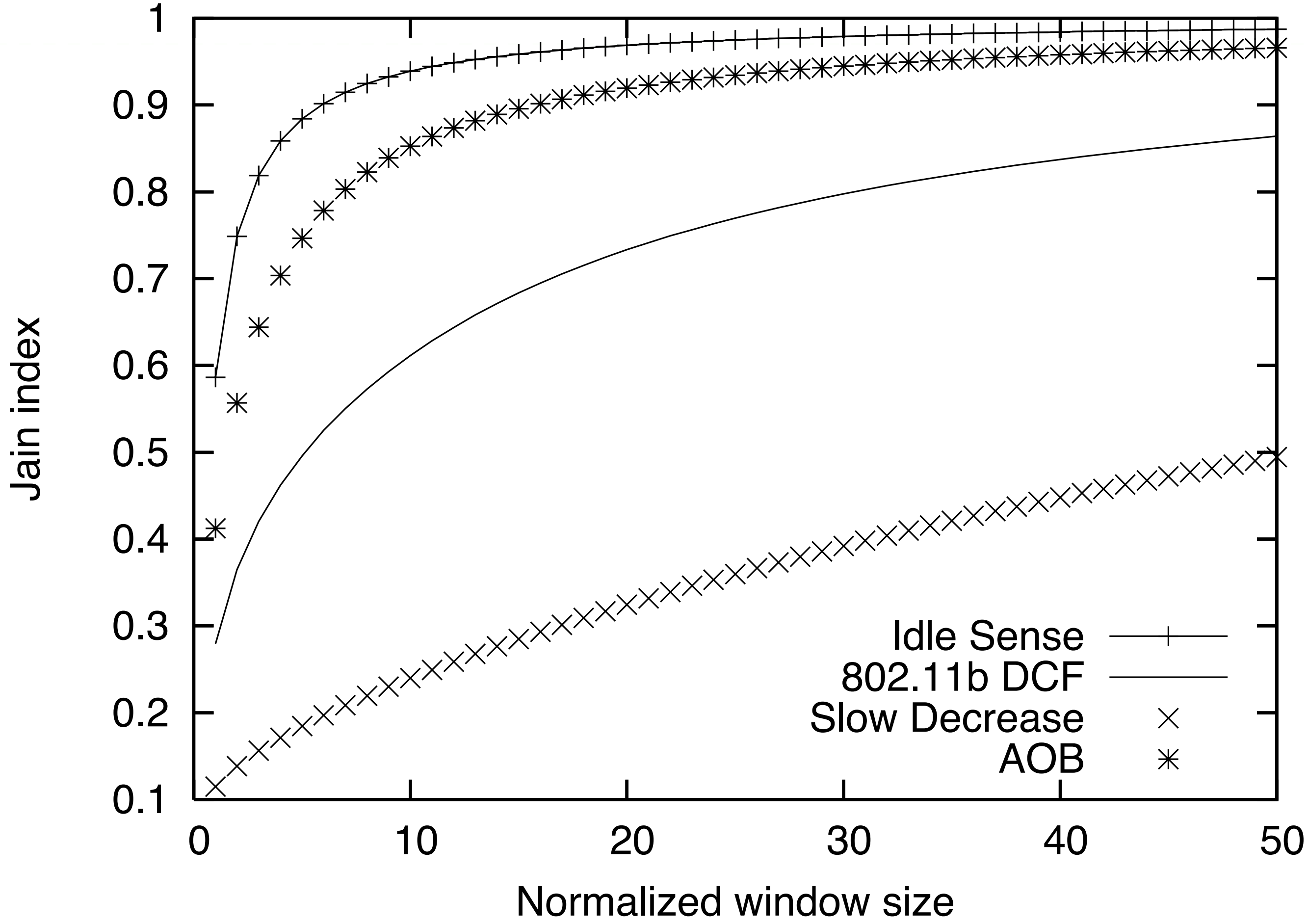
Throughput



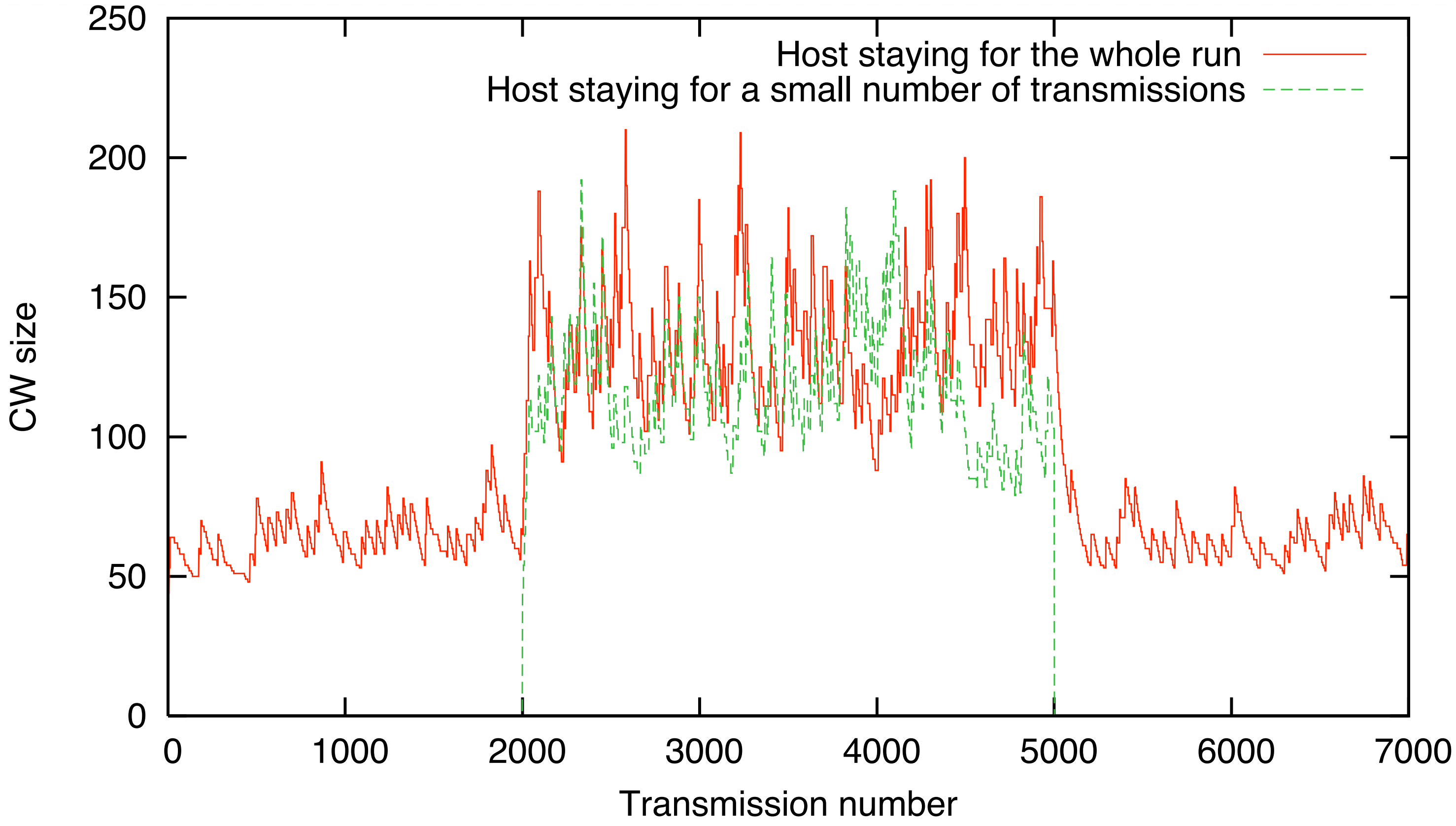
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
20
40
60
80
100
120
140
160
180
200
N
Throughput (Mb/s)
802.11b
Idle Sense

Fairness

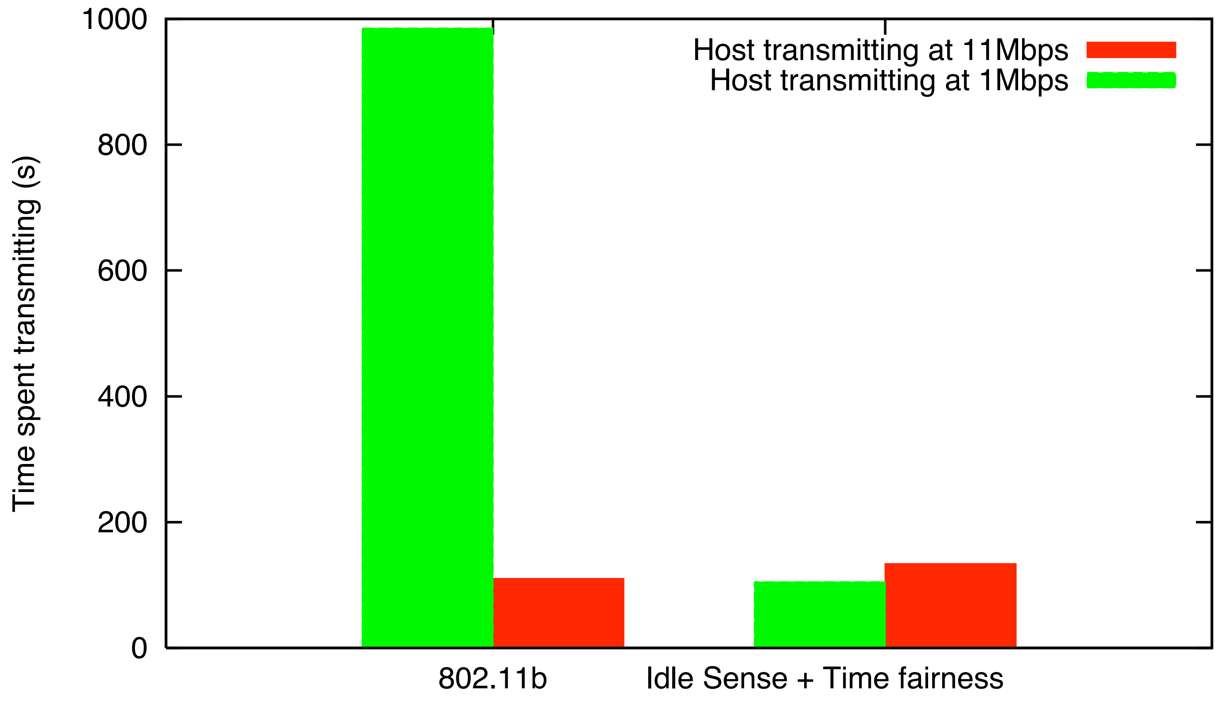
50 hosts



Convergence speed



Time fairness



Conclusions

- Performance gains
- Addresses many issues in wireless LANs
  - Main property: it uncouples frame loss and contention control
- Enables other improvements
  - eg. give more weight to the access point