On the Performance Characteristics of WLANs: Revisited

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Outline

- Introduction
- System Model and Experimental Set-Ups
- **Characteristics of IEEE 802.11 DCF Performance**
- TCP over WLAN Performance
- Conclusions
- Remarks

Introduction

- This paper focuses on WLAN performance in hot spots where degradation from **contention-based** multiple access is a major concern.
- One goal is to clarify **WLAN performance ambiguities** by studying inter-layer dependencies that stem from physical layer channel diversity.

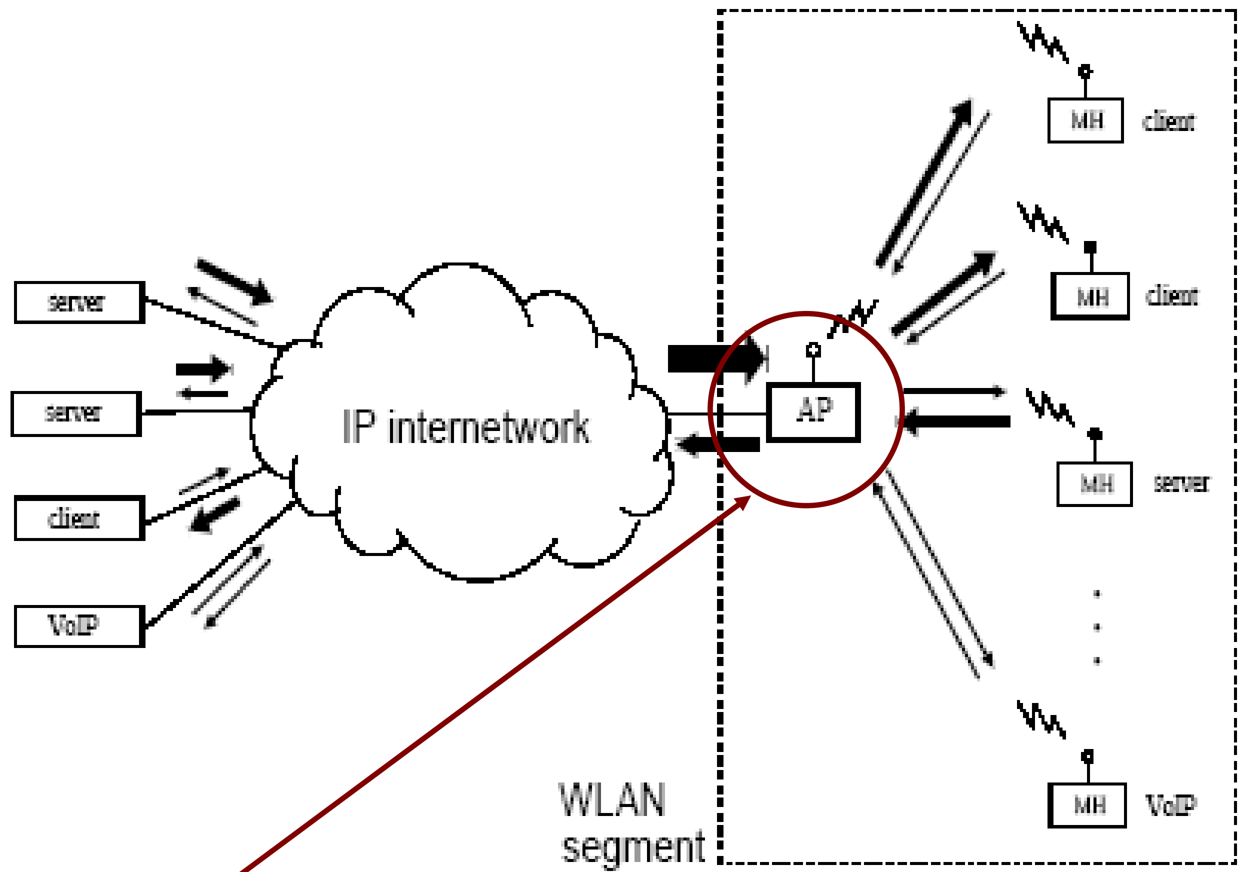
Contributions

- Demonstrate that contention-based DCF throughput degrades **gracefully** as offered load or number of wireless stations increases.
- Provide evidence of throughput degradation of IEEE802.11b WLANs due to **dynamic rate adaptation** which is unable to effectively distinguish **channel noise** from **collisions**.

Contributions

- Show that MAC layer **fairness** and **jitter** degrade significantly after a critical offered load level.
- Study the details of the **self-regulating** actions of DCF and TCP congestion control that benefit TCP over WLAN performance .
- Using a Markov chain model, the authors present mismatched circumstances where **buffer overflow** at the AP is a dominant factor in performance.

System Model



802.11 Infrastructure WLAN

ns-2 simulations

dumbbell topology with n wired servers and n wireless clients

DCF MAC Parameters

100 Mbps wireline
BER = 10^{-6}
Data rate = 11Mbps

slot time	20 μs
SIFS	10 μs
DIFS	50 μs
CWmin	31
CWmax	1023
physical preamble	144 bits
physical header	48 bits
ACK frame	112 bits
MAC header + CRC	224 bits

Table 1: IEEE 802.11 DCF MAC parameters

Experimental Set-Up 1

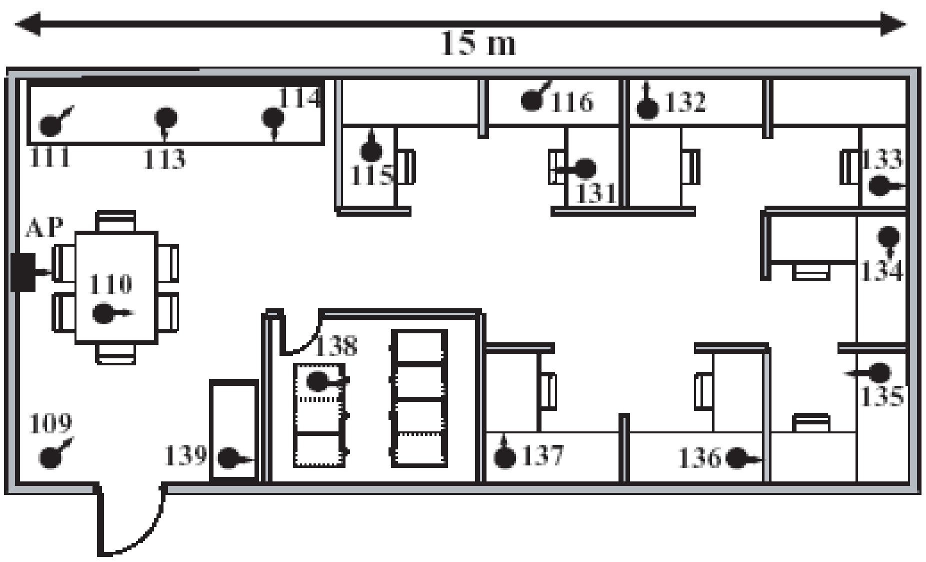


Figure 2: Basement indoor office environment showing locations of AP and wireless stations.

Purdue University

Experimental Set-Up 2

18 iPAQ pocket PCs running Linux v0.7.2

Enterasys RoamAbout R2 AP supporting 802.11b with RTS/CTS, data rate fixed at 11 Mbps and power control disabled.

Characteristics of IEEE 802.11 DCF Performance

DCF Throughput

Simulations

Wireless nodes symetrically placed on a circle of radius 10 meters with AP in the center.

Offered Load

CBR traffic for 2-100 wireless stations with small uniformly random inter-packet noise to break up synchronization.

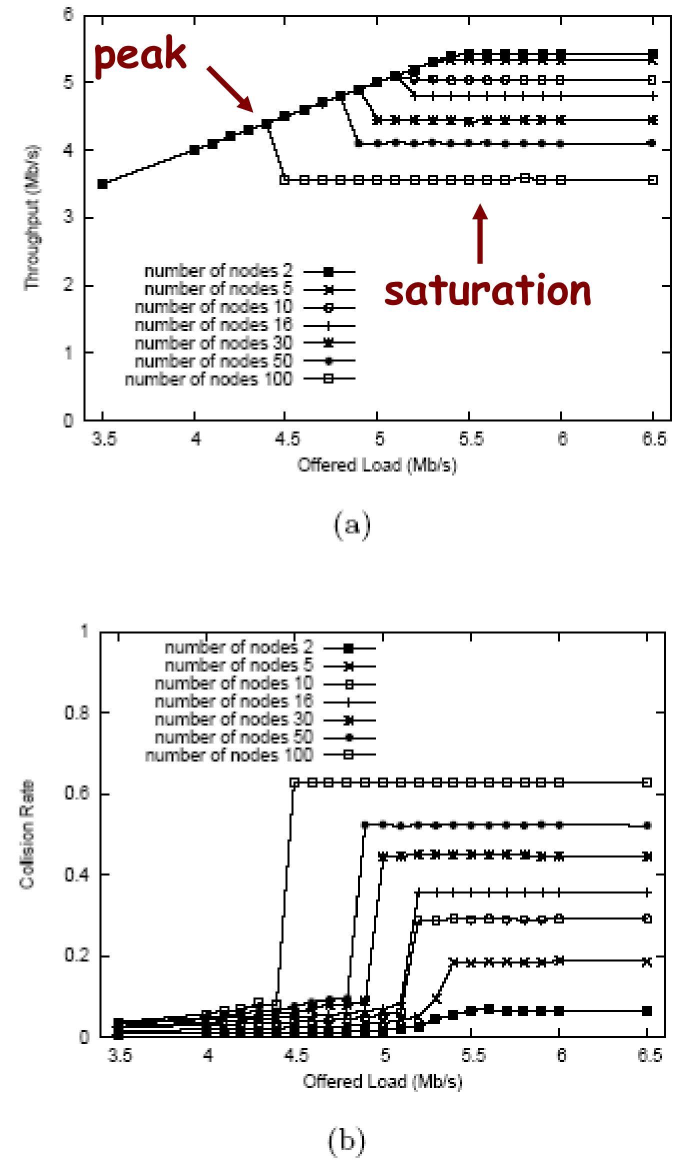


Figure 3: (a) Simulated IEEE 802.11 DCF throughput as a function of offered load for 2–100 wireless stations. (b) Corresponding DCF collision rate.

DCF
Peak and Saturation Throughput

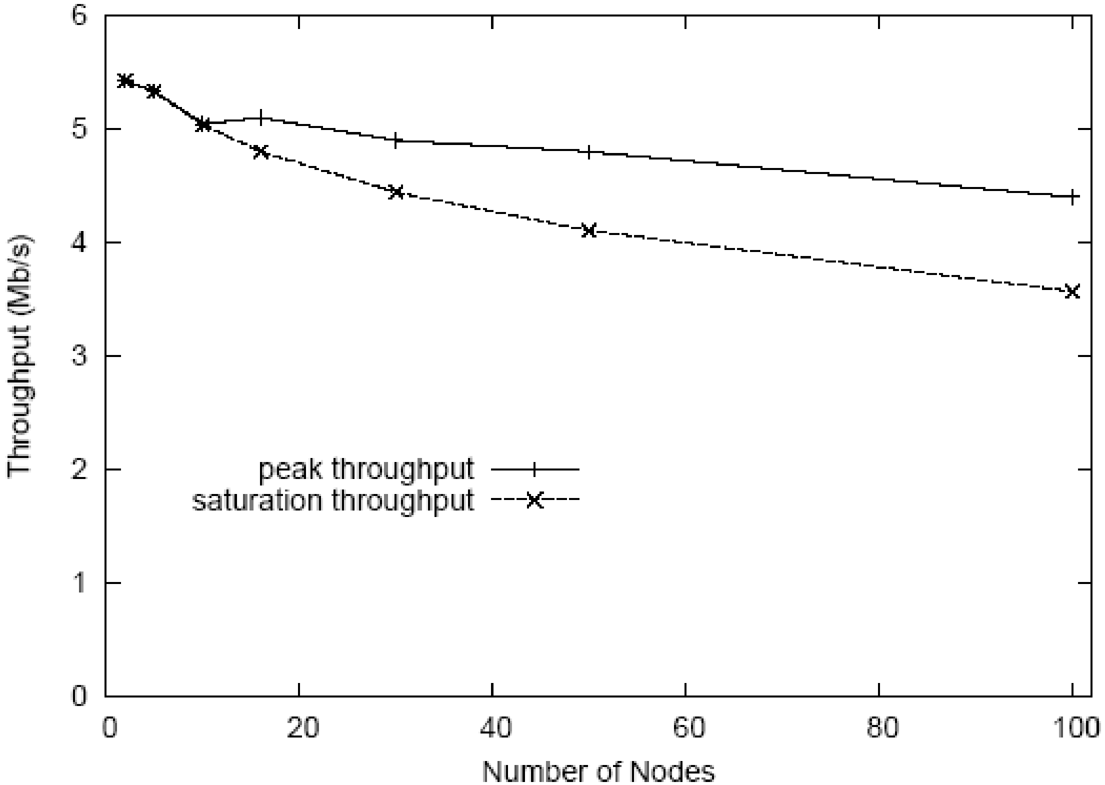


Figure 4: Decrease in DCF peak and saturation throughput as the number of nodes is increased.

Experimental DCF Throughput

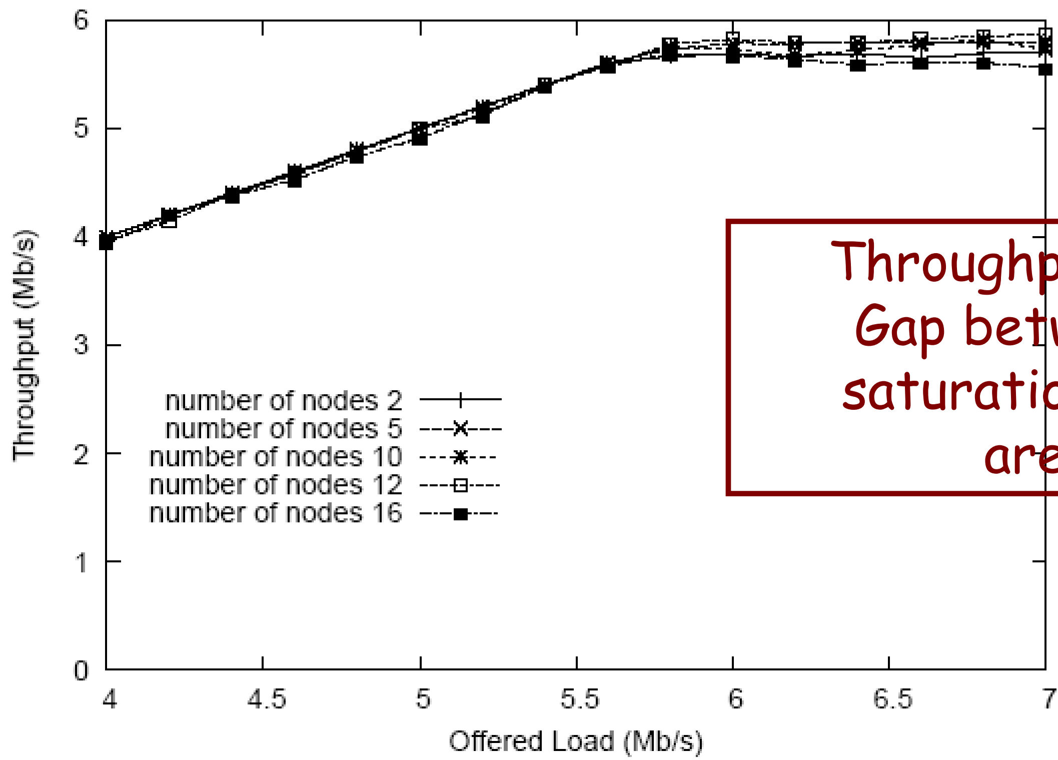
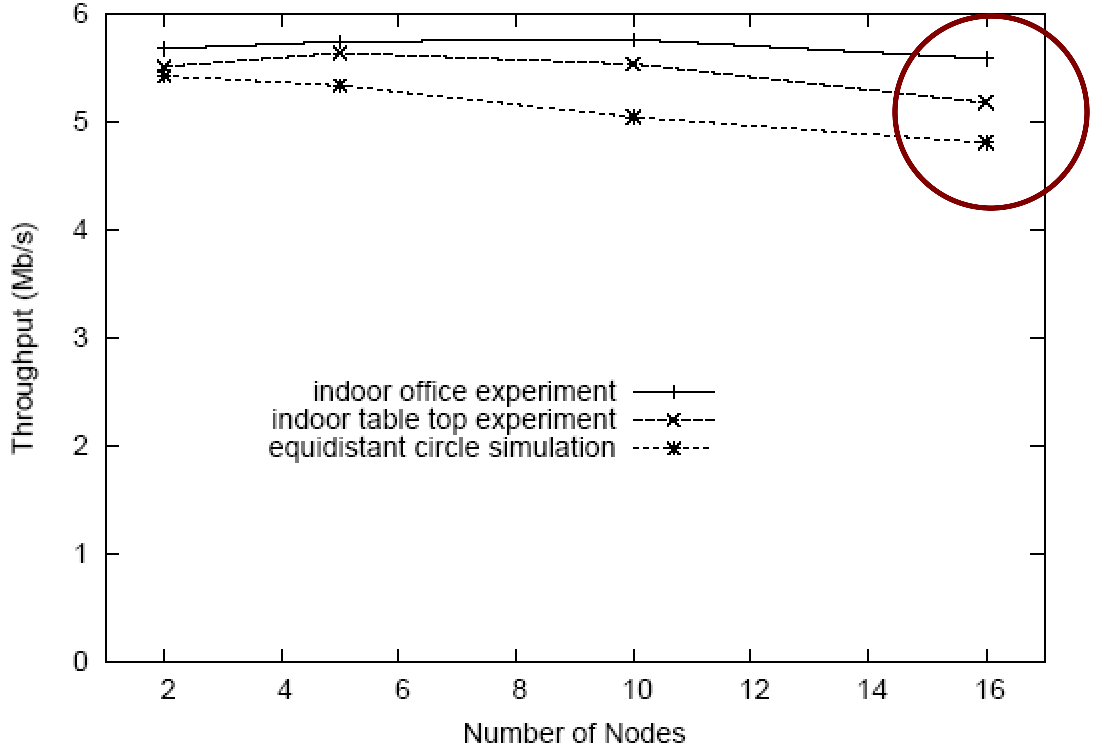


Figure 5: Empirical IEEE 802.11 DCF throughput as a function of offered load for 2, 5, 10, 12, 16 wireless stations in indoor office environment.

Throughputs are higher. Gap between peak and saturation throughputs are smaller.

Simulation vs Experiments



Difference due to physical layer diversity

Figure 6: Comparison of 802.11 DCF saturation throughput as a function of the number of wireless stations for indoor office experiment, indoor table top experiment, and equidistant circle simulation.

Physical Layer Channel Diversity

- Causes improvement in throughput for real experiments due to:
  - Simple capture effect
    - Successful decoding of dominant frame due to signal differential.
  - Exponential backoff of weaker station
    - This amplifies the access priority that the stronger station receives.

{ This bias is solely location dependent and related to variability of signal strength distribution in closed spaces.}

Dynamic Rate Adaptation

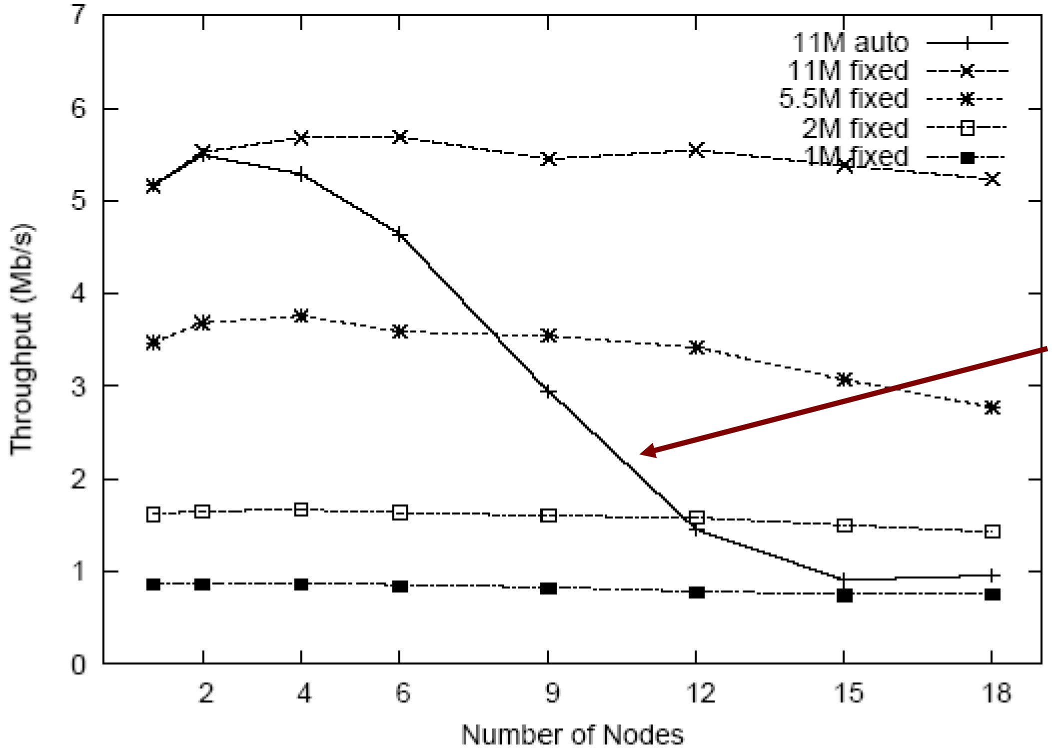


Figure 10: Empirical IEEE 802.11 DCF throughput as a function of the number of pocket PCs for auto rate and fixed data rates 11 Mbps, 5.5 Mbps, 2 Mbps and 1 Mbps in indoor table top environment.

Rate adaptation without RTS/CTS treats collisions as channel noise.

Single Client Locations

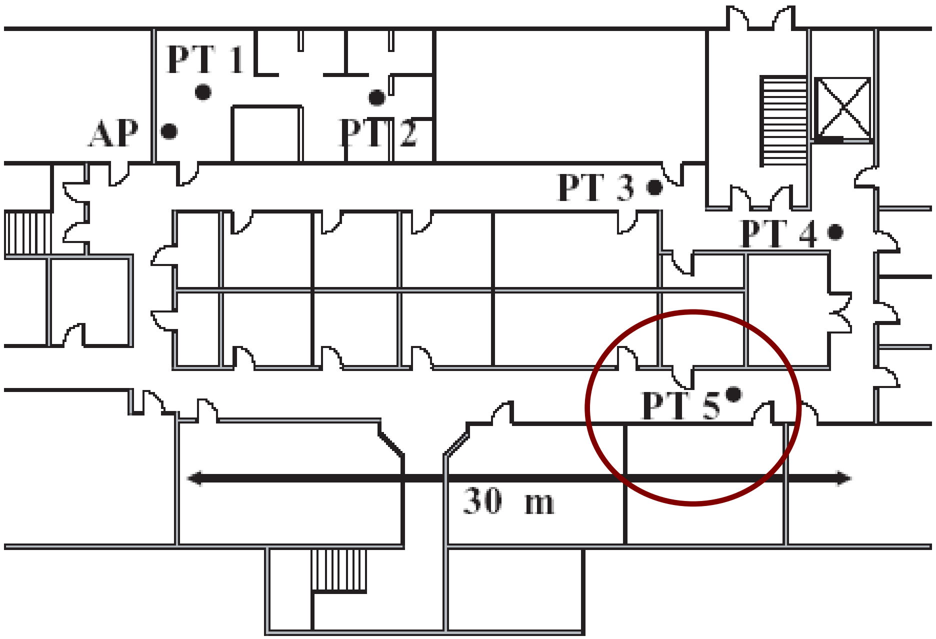
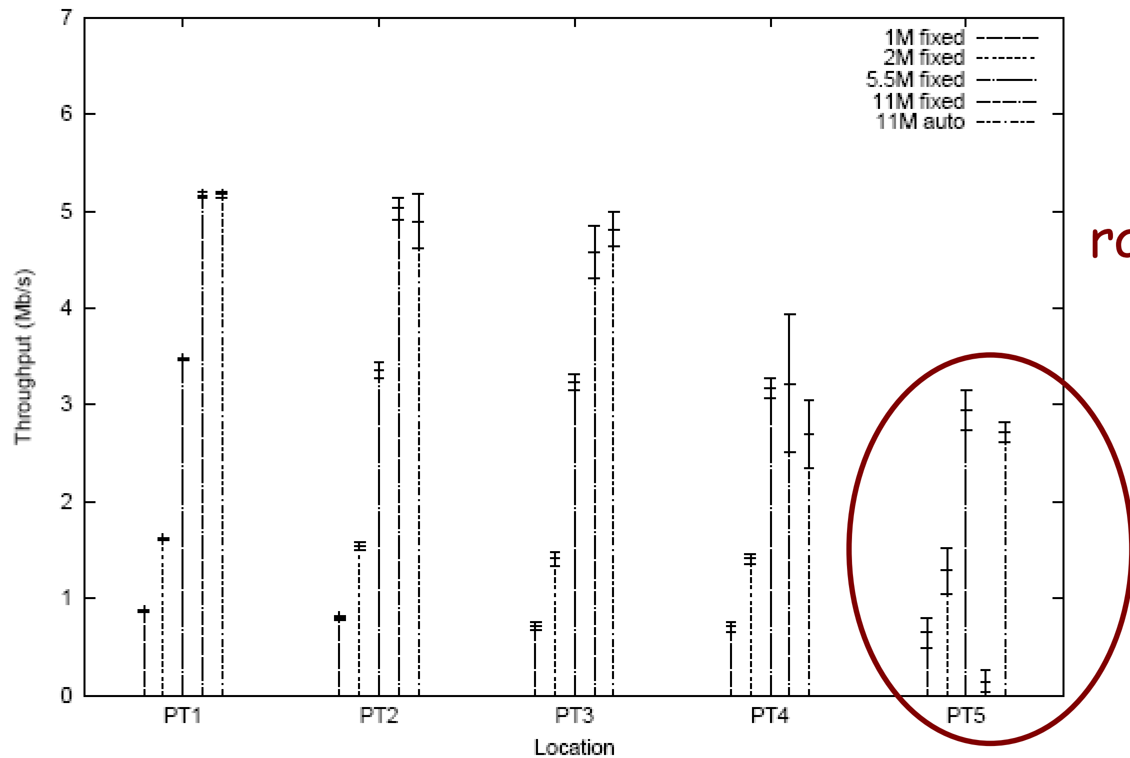


Figure 12: Basement corridor environment with single pocket PC positioned at locations PT1–PT5.

Rate Adaptation to Channel Noise



rate adaptation works here!

Figure 11: Empirical 802.11 DCF throughput of a single pocket PC at different locations along a rectangular corridor in the basement of the CS Building.

Experimental DCF Fairness

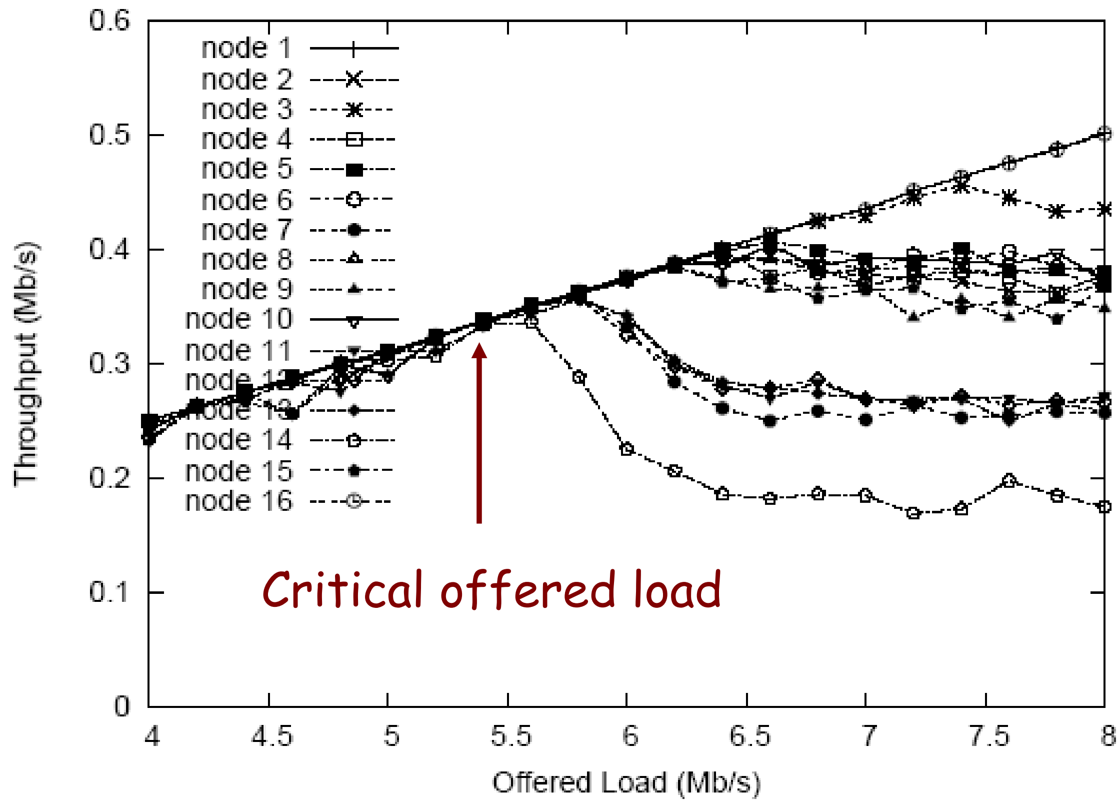


Figure 14: Empirical DCF fairness with respect to individual throughput share as a function of offered load for 16 iPAQs in indoor office environment.

Physical layer channel diversity amplifies unfairness

Simulated DCF Jitter

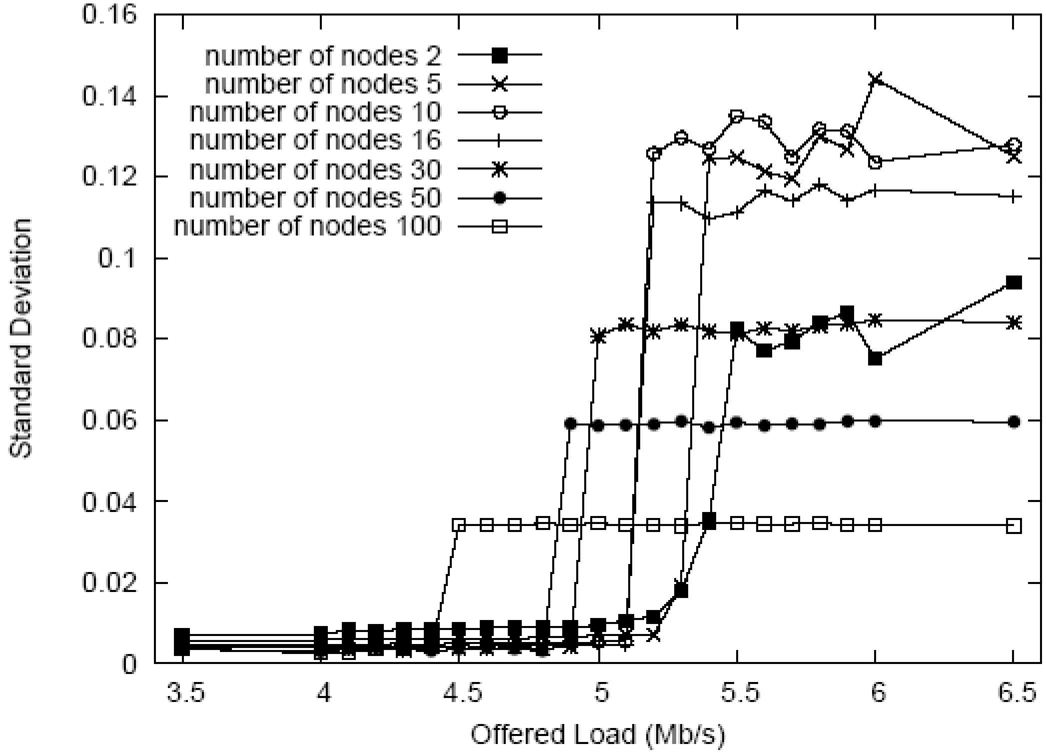


Figure 15: Simulated DCF jitter performance—captured as standard deviation of throughput—for the equidistant circle configuration.

Jitter exhibits a sudden jump!

TCP over WLAN Performance

TCP New Reno WLAN Simulations

Simulations

- Single point simulation model used.
- AP buffer size is 200 packets; 1500-byte TCP packets.
- TCP throughput is flat as multiple access contention increases.
- TCP collision rate also remains flat.

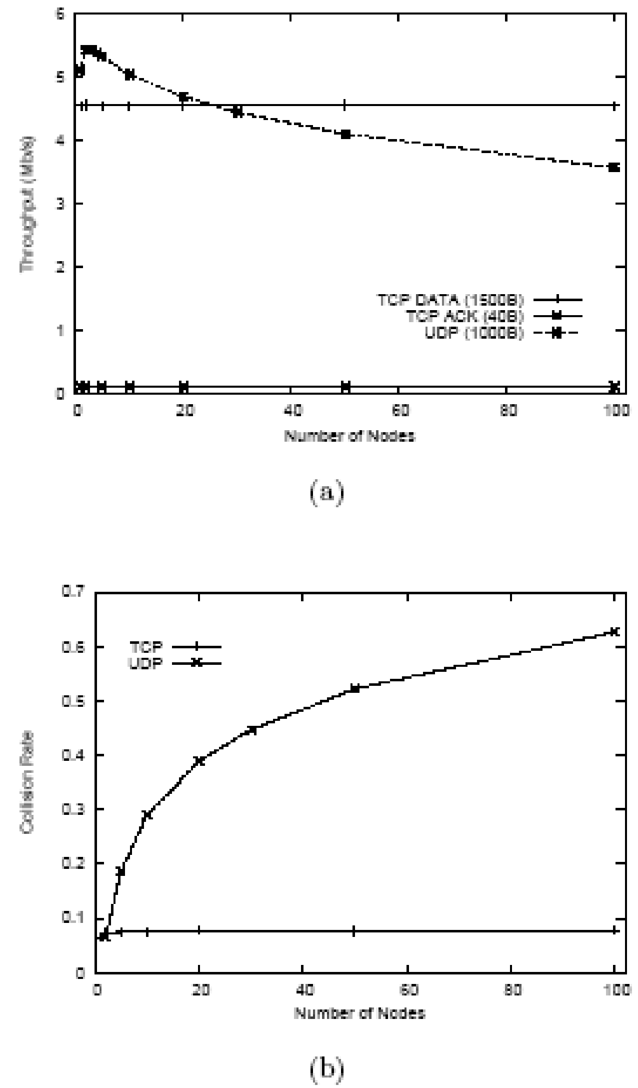


Figure 17: (a) TCP-over-WLAN throughput and ACK traffic as a function of the number of wireless stations; UDP throughput is shown for comparative purposes. (b) Corresponding collision rate.

TCP Reno WLAN Simulations

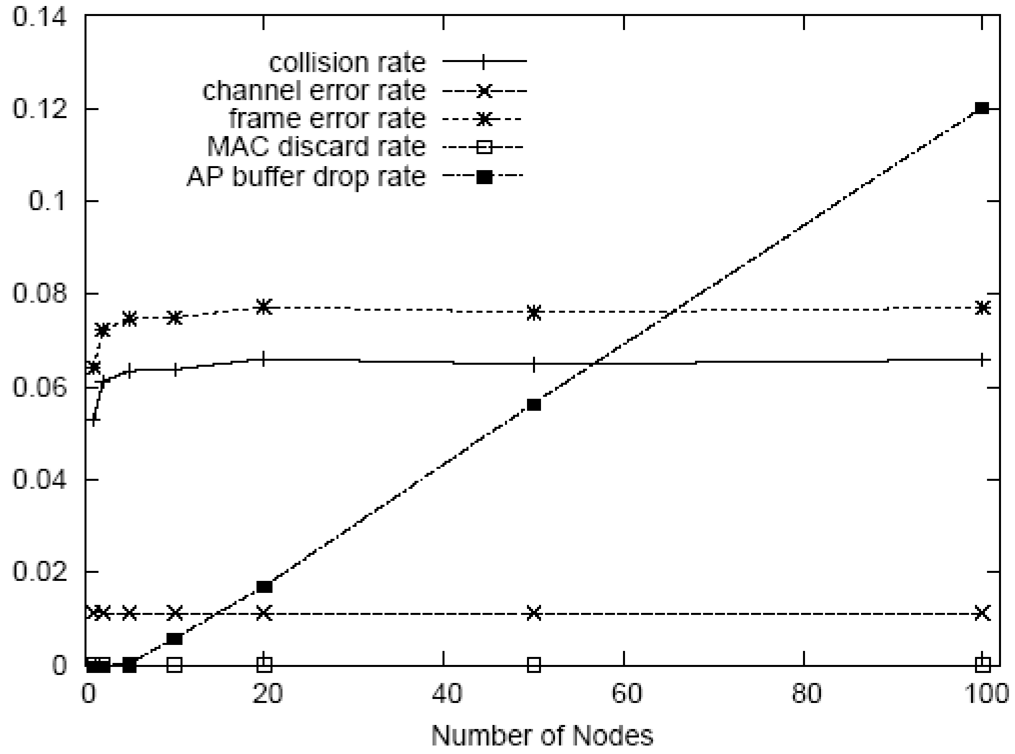


Figure 18: Frame error rate, collision rate, channel error rate, frame discard rate, and AP buffer drop rate as a function of the number of stations.

Bit error rate is only 10^{-6}

Markov Chain for TCP over WLAN

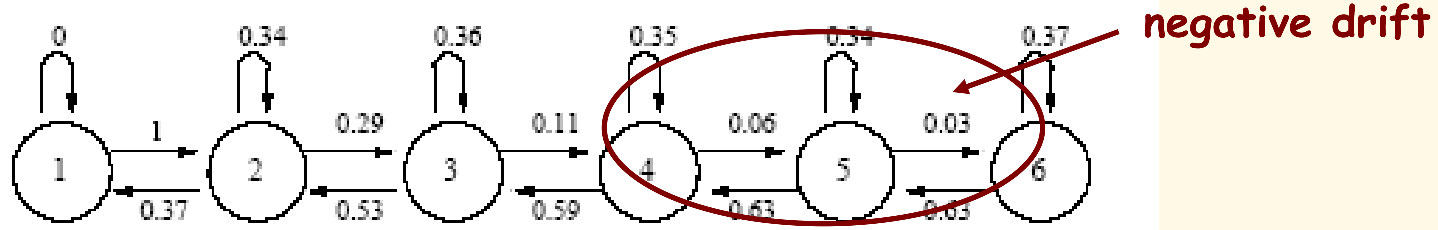


Figure 20: TCP-over-WLAN dynamics: inferred backlog Markov chain from simulation benchmark.

- Birth-death state given by number of backlogged wireless stations including the AP.
- Probabilities inferred from single point configuration simulation with 20 stations.

Simulated Counting State

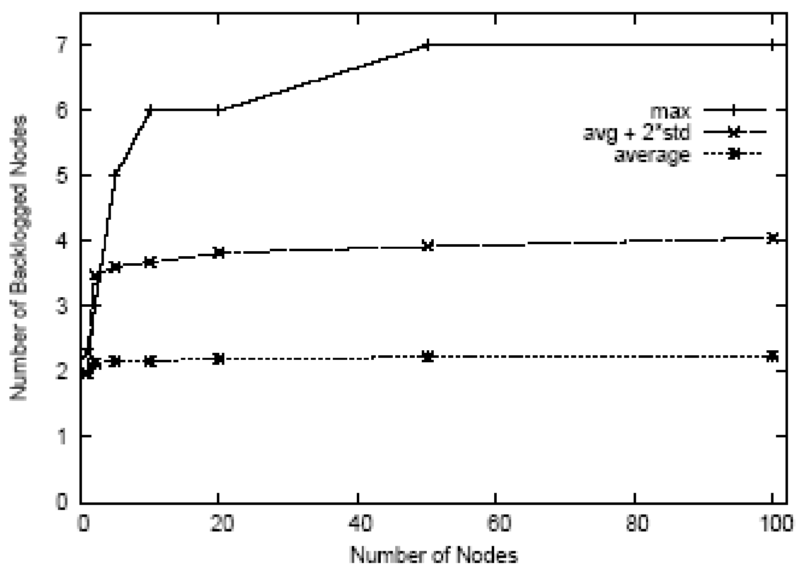


Figure 21: Average counting state in equilibrium for 2–100 wireless station simulation benchmark.

Experimental average counting state was 2.59

Operated under an effective contention level of 2-3 wireless stations

Dynamic Rate Adaptation with ONLY TCP flows

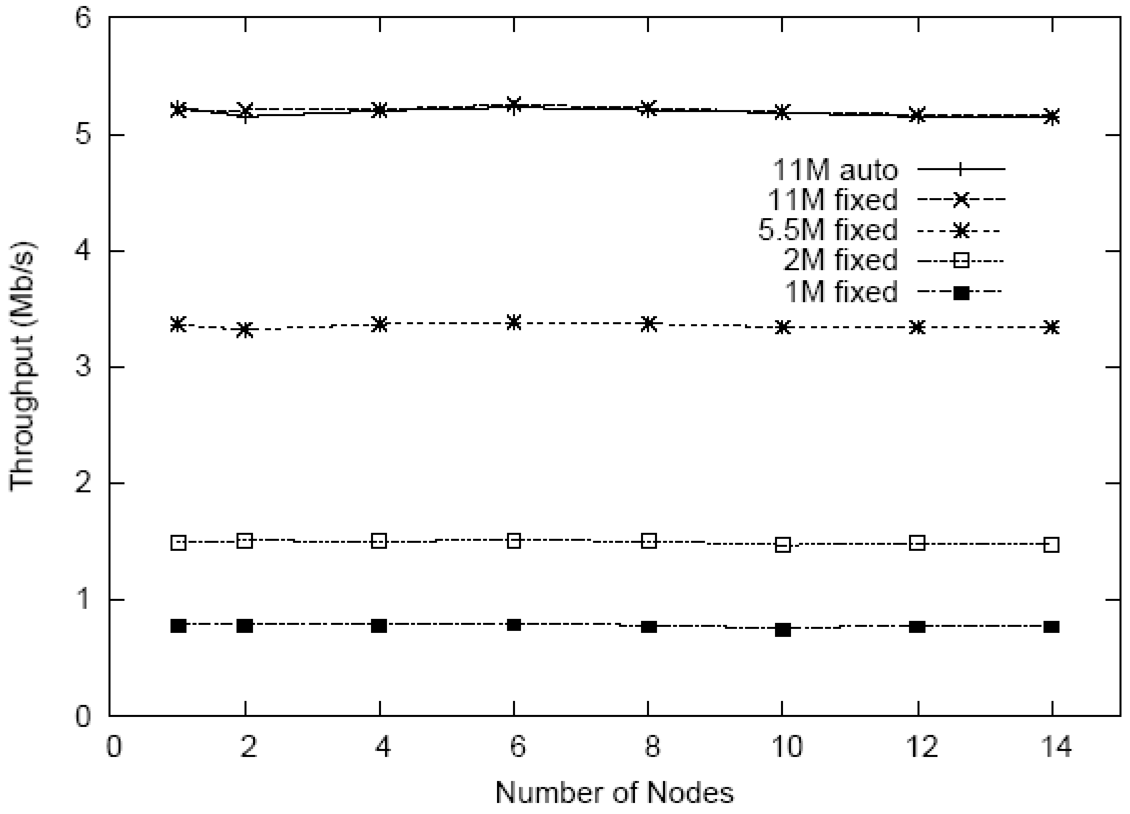


Figure 23: Empirical TCP throughput as a function of the number of pocket PCs for auto rate and fixed data rates 11 Mbps, 5.5 Mbps, 2 Mbps and 1 Mbps in indoor office environment.

Conclusions

- DCF throughput degrades **gracefully** as offered load or wireless access contention increases.
- MAC layer **fairness** and **jitter** degrade significantly after a critical offered load level.
- **Dynamic rate adaptation** causes throughput degradation of IEEE802.11 under moderate contention.

Conclusions

- TCP and DCF have a self-regulating effect that keeps collision rate flat as number of nodes increases when bit error rate is low.
- TCP can aid dynamic rate adaptation by reducing the occurrences of bursty collisions.

Remarks

- Authors did not simulate or measure TCP and UDP together!
- Authors stayed away from configurations with channel loss rates where rate adaptation would yield the performance anomaly.
- Hidden terminals not considered.

Questions?

Thank You!