The validity of IEEE 802.11 MAC modeling hypotheses

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Talk outline.

- DCF — the IEEE 802.11 CSMA/CA MAC.
- Mathematical modeling of 802.11 MAC.
- Implicit approximations made to make modeling practical.
- Directly testing these hypotheses with test-bed data.
- Summary, thoughts and conclusions.

The 802.11 DCF

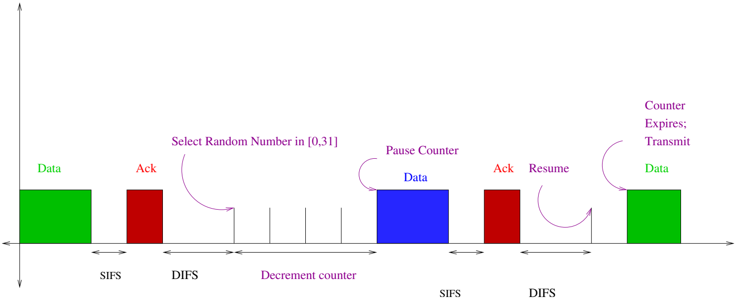


Figure: 802.11 MAC operation (not to scale)

The 802.11 MAC flow diagram

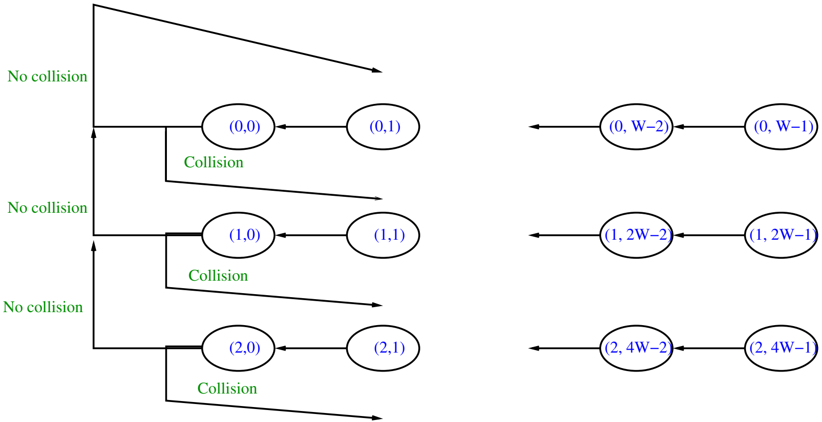


Figure: Saturated 802.11 MAC operation

Popular mathematical modeling approaches

- P-persistent:approximate the back-off distribution be a geometric with the same mean. E.g. work by Marco Conti and co-authors (F Cali, M Conti, E Gregori, P Aleph IEEE/ACM ToN 2000).
- Mean-field Markov models: seminal work by Bianchi (IEEE Comms L. 1998, IEEE JSAC 2000).

Bianchi's approach

Observation: each individual station's impact on overall network access is small.

Mean field approximation: assume a fixed probability of collision at each attempted transmission p, irrespective of the past.

Each station's back-off counter then a Markov chain.

Mean-field Markov Model's Chain

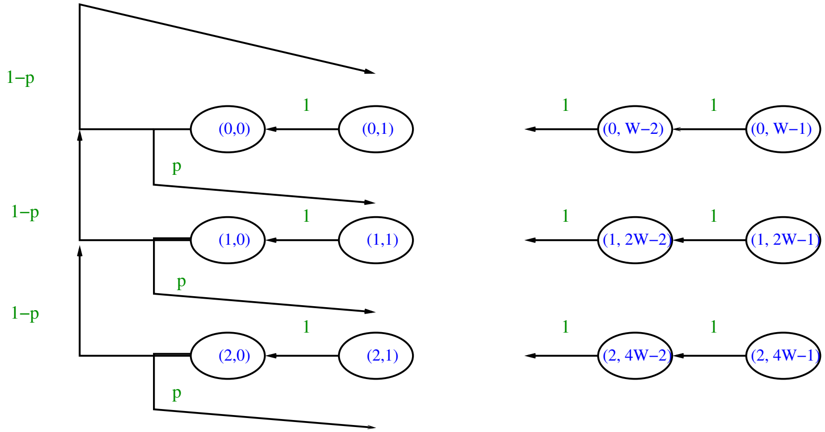


Figure: Individual's Markov Chain if p known

Mean-field Markov Overview

Stationary distribution gives the probability the station attempts transmission in a typical slot

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

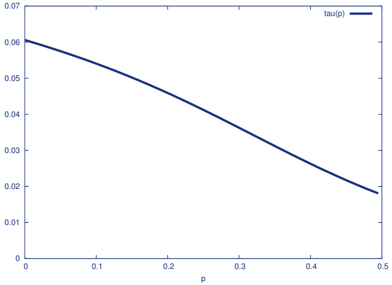


Figure: Attempt probability $\tau(p)$ vs p

The self-consistent equation

Network of N stations. Mean field decoupling idea: the impact of **every** station on the network access of the others is small, so that

$$1 - p = (1 - \tau(p))^{N-1}. \quad (1)$$

Solution of equation (1) determines the network's “real” p^*.

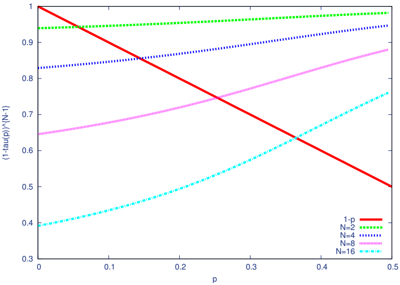


Figure: $1 - p$ and $(1 - \tau(p))^N$ for $N = 2, 4, 8 \,\&16$

Example developments

- Unsaturated 802.11, Small buffer: Ahn, Campbell, Veres and Sun, IEEE Trans. Mob. Comp., 2002; Ergen, Varaiya, ACM-Kluwer MONET, 2005; Malone, Duffy, Leith, IEEE/ACM Trans. Network., 2007.
- Unsaturated 802.11, Big buffer: Cantieni, Ni, Barakat and Turletti, Comp. Comm., 2005; Park, Han and Ahn, Telecomm. Sys., 2006; Duffy. and Ganesh, IEEE Comm. Lett., 2007.
- 802.11e, Saturated: Kong, Tsang, Bensaou and Gao, IEEE JSAC, 2004; Robinson and Randhawa, IEEE JSAC, 2004. Unsaturated: Zhai, Kwon and Fang, WCMC, 2004. Chen, Xhai, Tian and Fang, IEEE Trans. W. Commun., 2006.
- 802.11s, unsaturated: Duffy, Leith, Li and Malone, IEEE Comm. Lett., 2006.

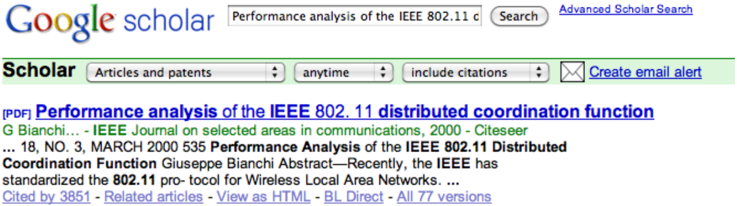
Standard approach to model verification

ASK: Do the model throughput and delay predictions match well with results from simulated system?

NOT: Make the approximations explicit hypotheses and check them directly.

Why do these models produce good predictions?
Is there a Therom we should know?

Why is this important?



Test bed

Figure: PC as AP, 1 PC and 9 PC-based Soekris Engineering net4801 as clients. All with Atheros AR5215 802.11b/g PCI cards. Modified MADWiFi wireless driver for fixed 11 Mbps transmissions and specified queue-size.

A first look at the data

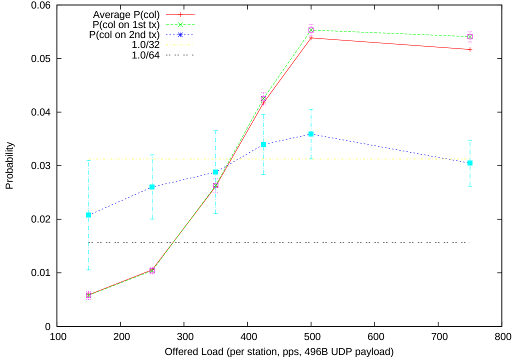


Figure: Collision probability at backoff stages versus load. 2 stations.

Also checked with simulations.

What are the hypotheses?

Common assumptions to all:

- $C_k = 1$ if k^{th} transmission results in collision.
- $C_k = 0$ if k^{th} transmission results in success.

Assumptions:

- (A1) $\{C_k\}$ is an independent sequence;
- (A2) $\{C_k\}$ are identically distributed with $P(C_k = 1) = p$.

Testing (A1): $\{C_k\}$ independent

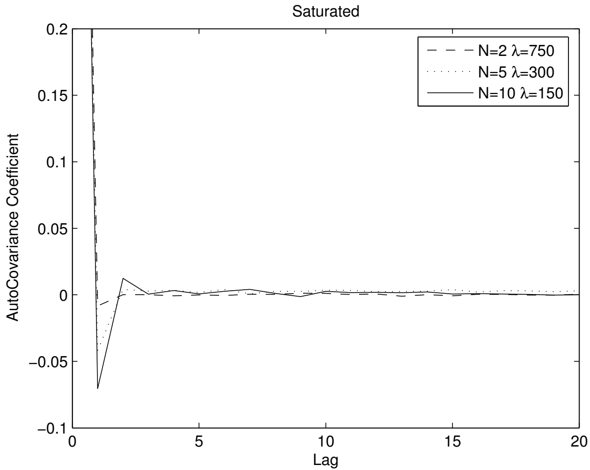


Figure: Saturated $C_1, \ldots, C_K$ normalized auto-covariances. Experimental data, $N = 2, 5, 10$, $K = 2500k, 1200k, 711k$.

Testing (A1): $\{C_k\}$ pairwise independent

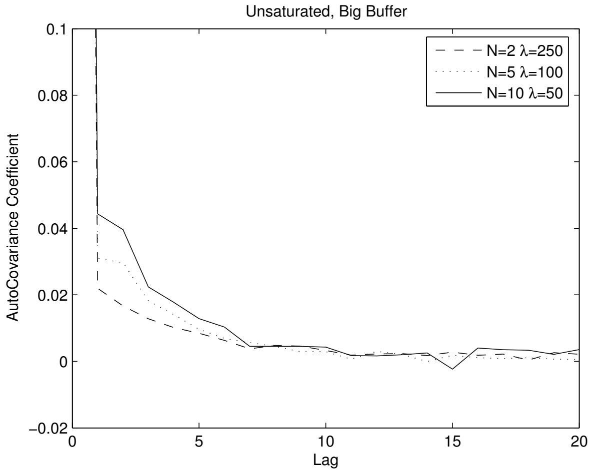


Figure: Unsaturated, big buffer $C_1, \ldots, C_K$ normalized auto-covariances. Experimental data, $N = 2, 5, 10$, $K = 1800k, 750k, 380k$.

Testing (A2): $\{C_k\}$ identically distributed

Record the backoff stage at which the attempt was made.
Probability p_i of collision given backoff stage i.
Assumption (A2): $p_i = p$ for all i.
MLE

$$\hat{p}_i = \frac{\#\text{collisions at back-off stage } i}{\#\text{transmissions at back-off stage } i}.$$

Hoeffding's inequality (1963):

$$P(|\hat{p}_i - p_i| > x) \le 2\exp\left(-2x(\#\text{transmissions at back-off stage } i)\right).$$

To have 95% confidence that $|\hat{p}_i - p_i| \le 0.01$ requires 185 attempted transmissions at backoff stage i .

Testing (A2): $\{C_k\}$ identically distributed

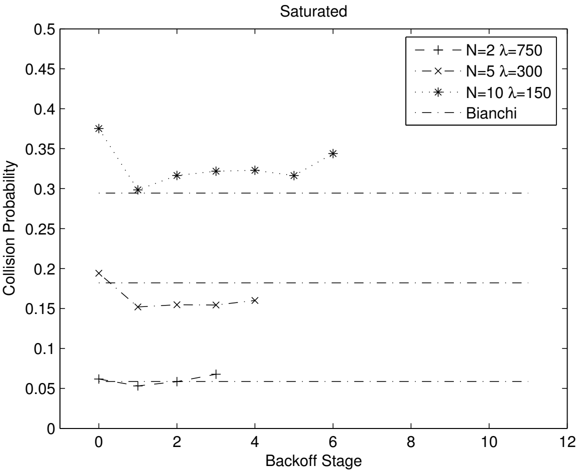


Figure: Saturated collision probabilities. Experimental data.

Testing (A2): $\{C_k\}$ identically distributed

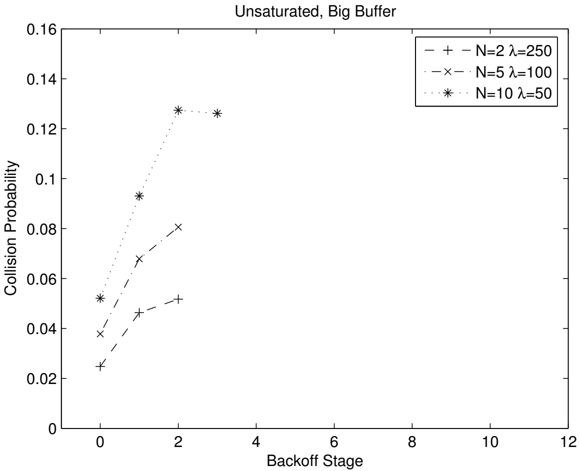


Figure: Unsaturated, big buffer collision probabilities. Experimental data.

What are the big-buffer hypotheses?

Big-buffer models:

- $Q_k = 1$ if packet waiting after k^{th} successful transmission.
- $Q_k = 0$ if no packet waiting after k^{th} successful transmission.

Assumptions:

- (A3) $\{Q_k\}$ is an independent sequence;
- (A4) $\{Q_k\}$ are identically distributed with $P(Q_k = 1) = q$.

Testing (A3): $\{Q_k\}$ pairwise independent

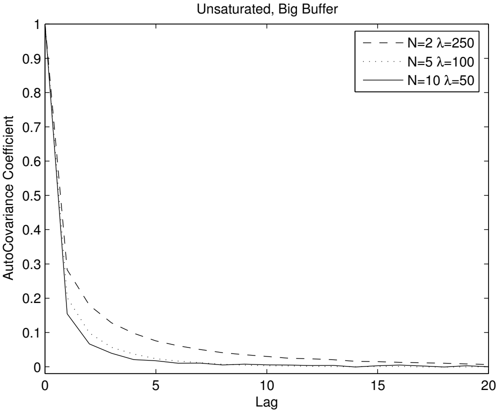


Figure: Unsaturated, big buffer queue-non-empty sequence normalized auto-covariances. Experimental data. $K = 1700k, 720k, 360k$.

Testing (A4): $\{Q_k\}$ identically distributed

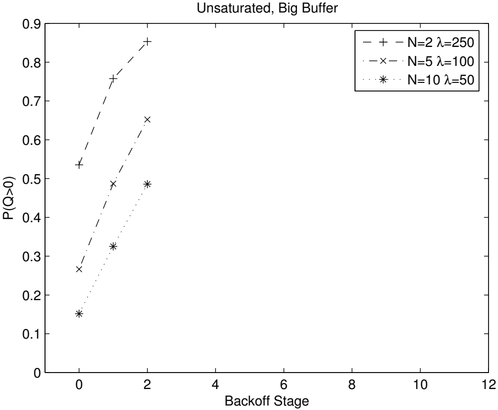


Figure: Unsaturated, big buffer queue-non-empty probabilities. Experimental data. (Note the large y-range!)

What about 802.11e?

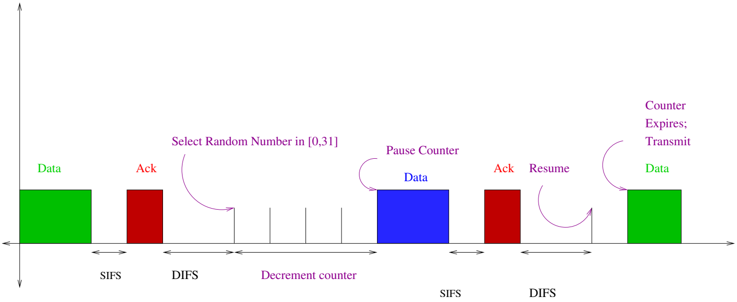


Figure: 802.11 MAC operation (not to scale)

What are the 802.11e hypotheses?

Models with different AIFS values:

- H_k is length of k^{th} period we spend in hold-states.

Assumptions:

- (A5) $\{H_k\}$ is an independent sequence;
- (A6) $\{H_k\}$ are identically distributed and if we know silence probability distribution can be determined from Markov chain.

Testing (A5): $\{H_k\}$ pairwise independent

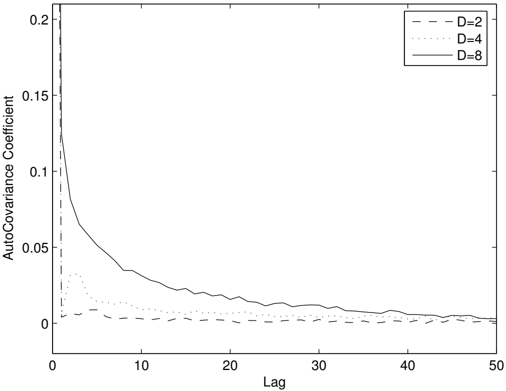


Figure: Hold state normalized auto-covariances. 5 class 1, 5 class 2 stations, $D = 2, 4 \& 8$. $K = 1700k, 1200k, 850k$. ns-2 data

Testing (A6): $\{H_k\}$ specific distribution

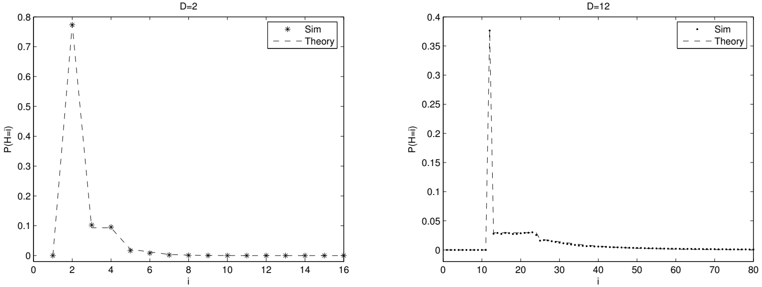


Figure: Hold state distributions, $D = 2, 12$. ns-2 data.

Kolmogorov-Smirnov test accepts fit for K of the order $10,000$; rejects it for K of the order $1,000,000$.

What are the 802.11s hypotheses?

Mesh model(s) assume:

- D_k is k^{th} inter-departure time.

Assumptions:

- (A7) $\{D_k\}$ is an independent sequence;
- (A8) $\{D_k\}$ are exponentially distributed.

Testing (A7): $\{D_k\}$ pairwise independent

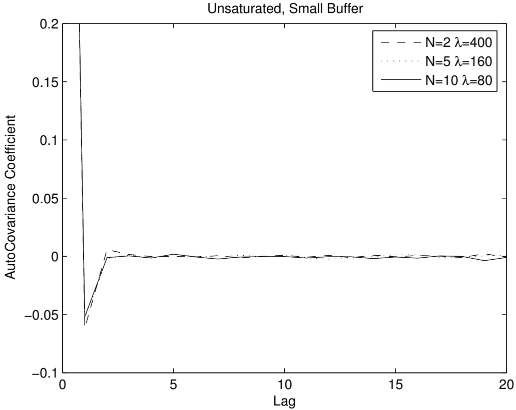


Figure: Inter-departure time normalized auto-covariances. Experimental data data

Testing (A8): $\{D_k\}$ exponentially distributed

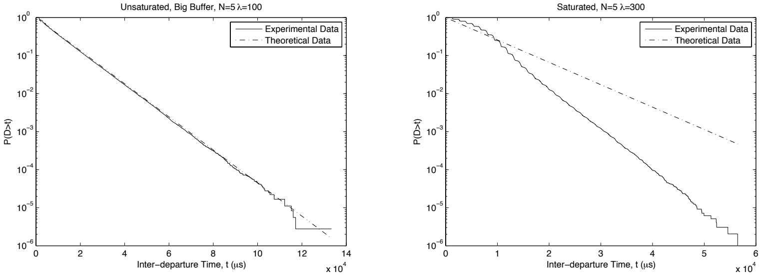


Figure: Inter-departure time distribution. 5 stations, small buffer. Low load, Big Biffer and Saturated. Experimental data

Summary

Assumption	Sat.	Small buf.	Big buf.
(A1) $\{C_k\}$ indep.	✓	✓	✓
(A2) $\{C_k\}$ i. dist.	✓	✓	×
(A3) $\{Q_k\}$ indep.	-	-	✓/×
(A4) $\{Q_k\}$ i. dist.	-	-	×
(A5) $\{H_k\}$ indep.	✓	-	-
(A6) $\{H_k\}$ dist.	✓	-	-
(A7) $\{D_k\}$ indep.	✓	✓	✓
(A8) $\{D_k\}$ exp. dist.	×	light load	light load

Table: $\{C_k\}$ collision sequence; $\{Q_k\}$ queue-occupied sequence; $\{H_k\}$ hold sequence; $\{D_k\}$ inter-departure time sequence.

What to do?

- Collision probability assumption pretty good.
  - Full Markov chain?
- Modeling variable queue more tractable.
  - Arrival process structure.
  - Can also build queue into Markov chain.
    R.P. Liu, G.J. Sutton, I.B. Collings, IEEE TWC, To Appear.
- 11e assumptions look OK, for moderate AIFS.
  - More specialized.
- When network is busy Poisson not that good.
  - Insensitive to distribution?

Impact of incorrect hypotheses?

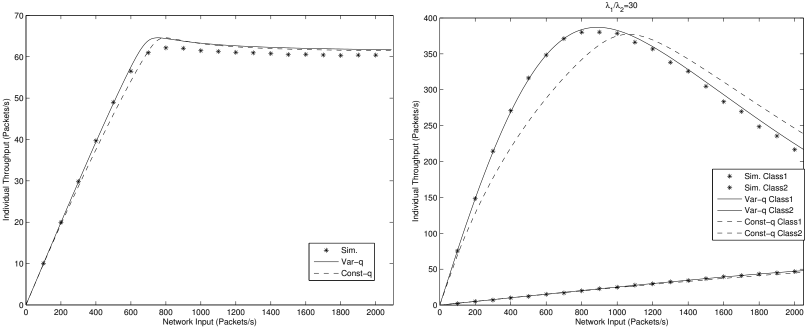


Figure: Theory & ns-2 data.

K.D. Huang & K.R. Duffy IEEE Comms Letters 2009.

Conclusions

- Some of our assumptions are good,
- Some are not so good,
- Our results are usually good, but not always.
- Possible to provide any analysis?
- Other assumptions: slottedness and channel.

Thanks! Questions?