Performance Analysis of IEEE 802.11 CSMA/CA Medium Access Control Protocol

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Abstract IEEE 802.11 [1-2] is the new wireless network starndard which is going to be finished at the end of 1996. By use of two-dimension Markovian analysis, we derive the throughput and average delay of the MAC part of IEEE 802.11 to demostarte the efficiency of CA (collision avoidance) mechanism. Furthermore, we also focus on its performance with the existence of hidden terminals [9-10].

1. Introduction

With the rapid advance of mobile computing, high speed wireless local area networks (LAN) attract a lot of research interests in recent years. A new international standard IEEE 802.11 on wireless LAN has been established [1]. Its physical transmission is realized by either spread spectrum communication or non-directive infrared. The medium access control of IEEE 802.11 is using carrier sense multiple access with collision avoidance (CSMA/CA) as the fundamental access [2,7,8]. Continuing from the study of [9,10], we shall analyze IEEE 802.11 CSMA/CA performance with/without hidden terminals in this paper.

2. System Configuration

- **Packet Transmission Mechanism**

Following CSMA/CA, when a node has a packet to transmit, it has to wait until channel idle for a period of time called IFS (inter frame space, explained later). After channel idle for IFS, it uses a random number generator to set a random backoff time. In the coming slots, the user decreases its backoff time by one if it finds channel idle. In case channel is found busy, the backoff time counting should be frozen till channel being idle for IFS again. In addition, a user transmits an acknowledgment after receiving without error. The whole transmission mechanism is shown in Figure 1.

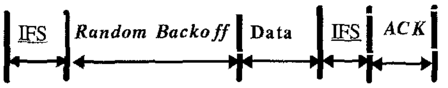

Figure 1 802.11 transmission mechanism

- **Introduction of IFS**

IFS is a new idea introduced in IEEE 802.11 MAC. The usage of IFS is something like the guard band in FDM system. At the current slot a user finds channel idle, its random backoff is still forbidden to be immediately performed until it has assured channel idle for a period of time called inter frame space (IFS). Recognized from its name, it is the "space" between "frames". Here frames are contention windows (users performing backoff), acknowledgments and data packets. In IEEE 802.11 we have three types of IFS which are SIFS (short IFS), PIFS (PCF IFS) and DIFS (DCF IFS) where PCF is point coordination function and DCF is distributed coordination function [1-2]. Different types of IFS have different lengths (DIFS=PIFS+1; PIFS=SIFS+1 with unit slot). Also different lengths of IFS represent different priority levels: a shorter IFS represents a higher priority. In IEEE 802.11, a user has to wait for DIFS before performing backoff while wait for SIFS before transmitting ACK. In addition, PIFS is used in contention free traffic hence will not be considered in this paper.

- **Backoff Time Set**

In IEEE 802.11, random backoff time follows as:

$$\begin{aligned}&Random\_Backoff\_Time\\&=INT(CW*Random())*Slot\ time;\end{aligned}$$

Where INT means integer function, CW (contention window) is an integer between CW_{min} and CW_{max} and Random() is a Pseudo(0,1) random number generator. For the value of CW, if the current packet has its first transmission, CW is set to be CW_{min}. In addition, after each collision to this packet, CA mechanism doubles CW until it reaches CW_{max}. Suggested values of CW in IEEE 802.11 Draft standard [1] are: CW_{min}=31, CW_{max}=255.

- **Contention window size**

In our analysis we set $CW_{max}=2*CW_{min}$, it means that a node does not change its CW length after the second collision. Therefore a node only doubles its CW after the first collision and keeps CW same even the current packet suffers more collisions. With those mentioned above, we define three user types, that are idle, unbacklog and back-

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define three user types, that are idle, unbacklog and backlog: an idle user is a user with no packet to transmit; an unbacklog user is a user with a new packet to transmit; a backlog user is an user with a retransmitted packet. In addition we assume no buffer case. Now let N be the number of all users, N_{idle} be the number of idle users, $N_{unbacklog}$ be the number of unbacklog users and $N_{backlog}$ be the number of backlog users therefore we have a finite-state Markov chain with state $S \equiv (N_{idle}, N_{unbacklog})$.

- **Hidden probability**

In CSMA family protocols, carrier sense capability is surely a key factor of system performance. In case carrier sense is not perfect, a node may not hear another node even they are in the same cell so called hidden terminal problems [9-10]. In this paper, we consider hidden terminal problem and have our assumptions as :

> *Define P_h to be the probability that one station could not hear another station. In addition, if a station is able/unable to hear another station, this situation does not change until the end of the current contention period. Also perfect packet transmission is assumed.*

- **Packet length**

In IEEE 802.11, packet length varies from 0 to 2312 octets. Here we only consider fixed packet length.

- **Gated system**

All arrivals after the beginning of the current contention period will not be served until the next contention period.

3. Analysis

Since the random backoff time in CSMA/CA is not a memories function, a two-dimensional Markov chair is needed for correct analysis. The details can be found in [4].

- **System throughput analysis**

In our 2-D finite state Markov chain, it is clear that we have only one class hence it is an ergodic system. Therefore we could calculate out stationary probabilities $\pi(S)$. Also we could calculate the average holding time $\overline{H}(S)$ and successful transmission probability $P_{suc}(S)$. Define Pkt_Time to be the length of a packet hence we could have a throughput formula as:

$$Throughput = \frac{\sum_{all\ state\ S} \pi(S) \cdot P_{suc}(S) \cdot Pkt\_Time}{\sum_{all\ state\ S} \pi(S) \cdot \overline{H}(S)}$$

Therefore we finish the throughput analysis.

- **Average delay analysis**

Little formula is adopted for average delay analysis. However, under no buffer assumption, some of the arrivals are blocked out hence we need to be careful when using Little formula.

Let the arrival to each user is λ (some of them may be blocked out), the total arrival entering the system (λ_{sys}) is the average idle user number ($\overline{N}_0$) plus λ.

$$\lambda_{sys} = \overline{N}_{idle} \cdot \lambda$$

And we know the average active user in the system $\overline{N}_{active}$ is:

$$\overline{N}_{active} = N - \overline{N}_{idle}$$

Now we could apply Little formula

$$\overline{N}_{active} = \lambda_{sys} \cdot T$$

$$D = T - Pkt\_Time - SIFS - Ack$$

where T is the average system time and D is the average delay time. Hence we finish the average delay analysis.

4. Numerical Results

Now we introduce system parameters as,

Pkt_Time	Ack_Time	SIFS	DIFS
20	2	1	3

unit: slot

In these results, we focus on two main topics. The first one is the efficiency of CA (collision avoidance) and the effect of hidden terminal problem.

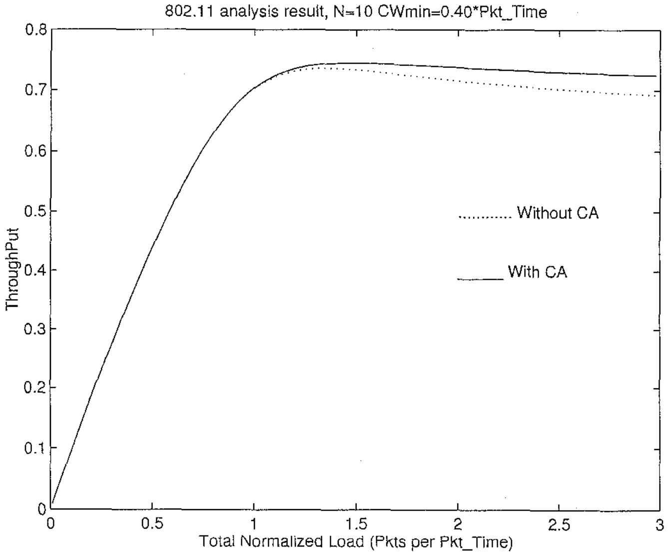
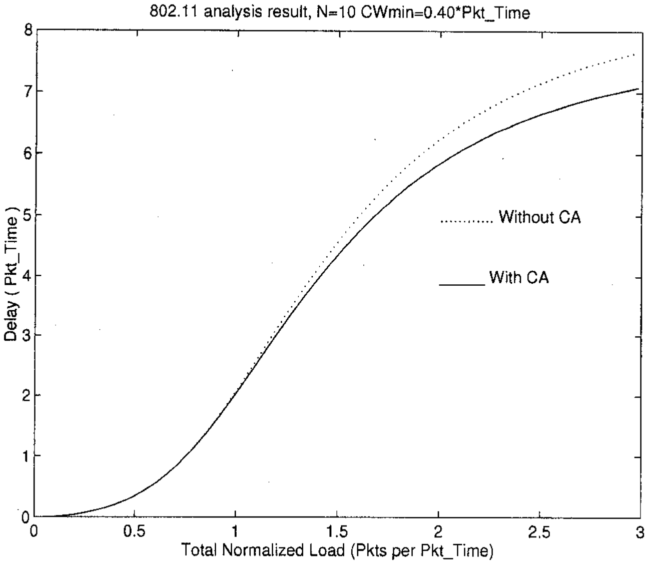


Figure 2



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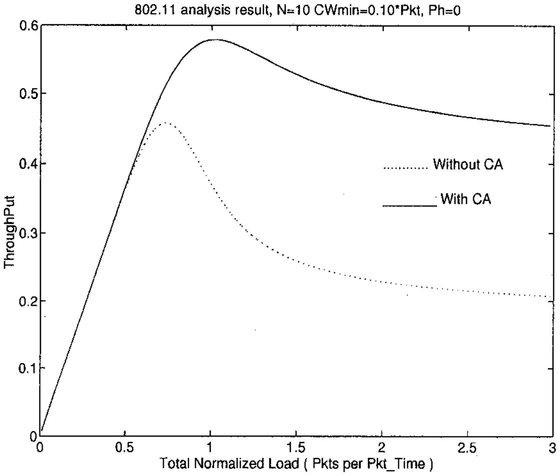

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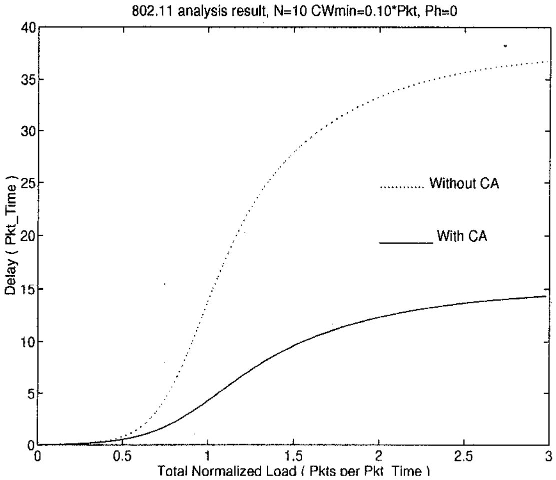

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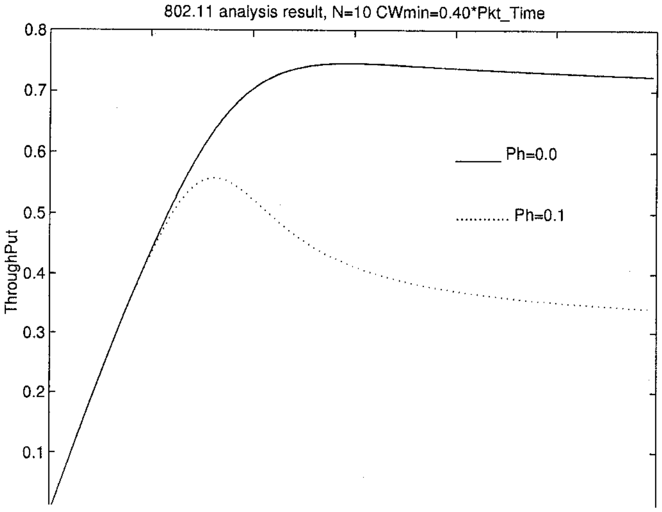

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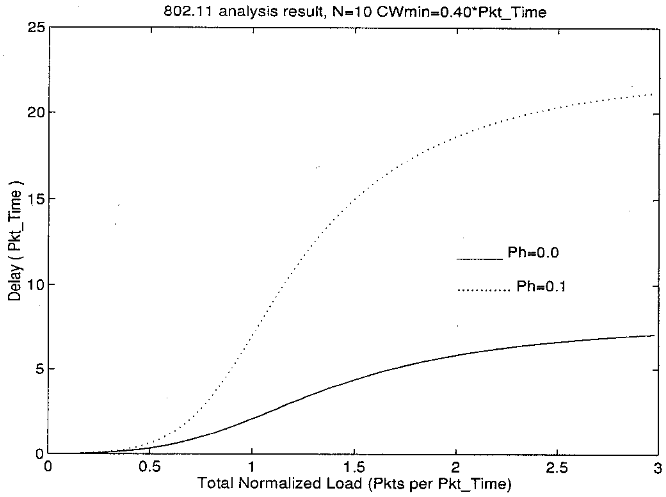

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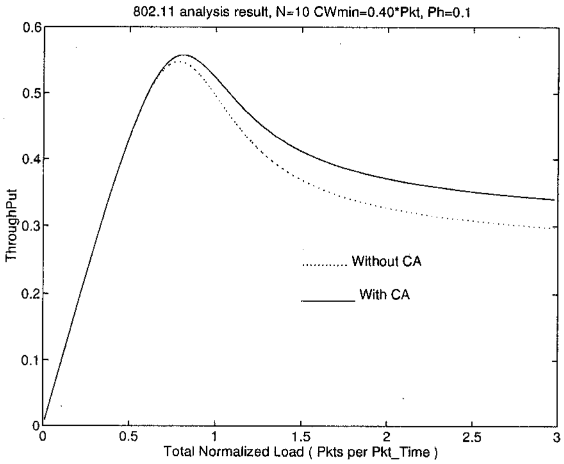

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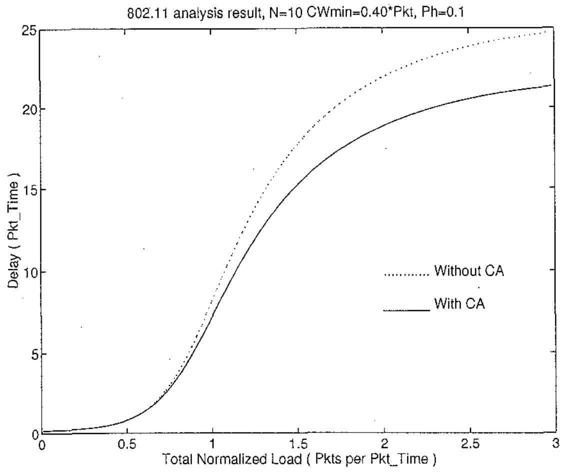

Figure 9

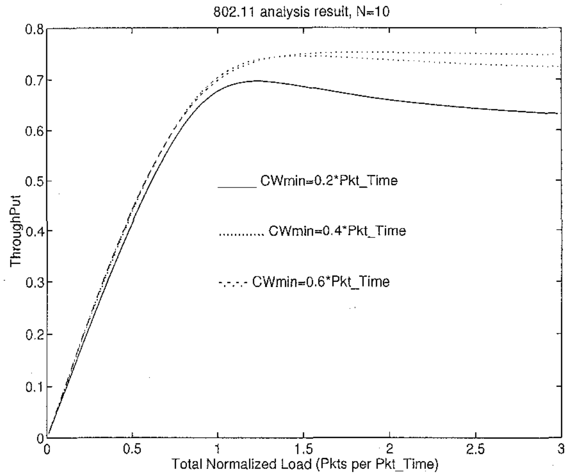

Figure 10

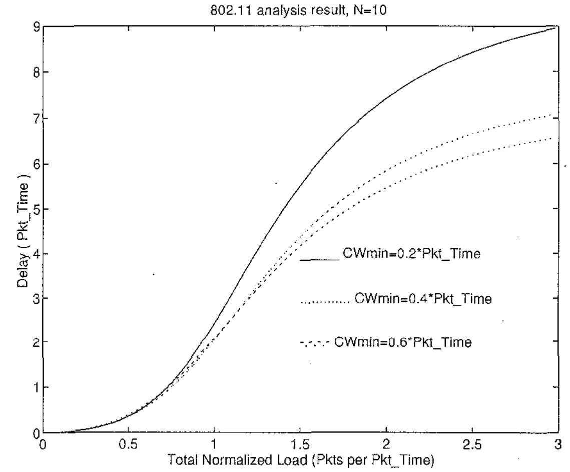

Figure 11

5. Results Discussions

In Figure 2 and Figure 3, we show the performance of CA versus no-CA. It could be figured out that adding CA mechanism does not show much differences. On the other hand, in Figure 4 and Figure 5 we found that CA mechanism has an outstanding performance in reducing collision probability. Hence we know that CA mechanism is efficient especially in high contention (low CW value) environment.

In Figure 6 and Figure 7, we show the performance with the existence of hidden terminals. It could be shown that the peak value of throughput decreases about 30% when hidden probability is 0.1. However, still we check the hidden terminal problems of CA versus no CA in Figure 8 and Figure 9. From those results, in hidden terminal environment we do not see much improvement of using CA mechanism.

In Figure 10 and Figure 11, we try to find an optimum value of CW_{min}. It is for sure that increasing CW_{min} could reduce the collision probability. On the other hand, it increase system overhead simultaneously. Therefore CW_{min} is a tradeoff between collision probability and system overhead.

6. Conclusions

CSMA is the most familiar and ubiquitous local area network MAC standard. IEEE 802.11 uses its modification-CSMA/CA as the MAC standard. In this paper, we found that CSMA/CA seems outstanding in collision avoidance, especially in high contention environment.

However, to be a wireless network standard, CSMA/CA is expected to provide a better solution for resolving some imperfect channel properties unique to wireless environment. In this paper, we consider common effects caused by channel fading. Unfortunately, CSMA/CA seems could do nothing to this unwanted effect. Although that, we are not surprised by this weakness of CSMA/CA. It is known that even adding CA mechanism, CSMA/CA still relies much on a precise carrier sense ability. This introduces one direction in the research of access protocols. Although IEEE 802.11 has PCF (point coordination function) to solve this problem, it is shown that its performance must suffer much from channel fading in DCF (distributed coordination function). In addition, the length of CW_{min} is also an important parameter. We found that it is a tradeoff between system overhead and collision probability. Therefore optimization of CW length is a great challenge in the future. In a data network, traffic is very bursty, hence if CW length could be dynamic adjusted, performance is believed to be improved much than a fixed CW value.

A local area network usually operates on a single channel, hence one of the primary network design challenge is to find an efficient way to share communication links. How to solve those problems under this protocol is still needed to be worked out.

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