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Comparison of pre-backoff and post-backoff procedures for IEEE 802.11 distributed coordination function

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Abstract: Accurate analytical modeling of IEEE 802.11 distributed coordination function (DCF) is very important to characterize IEEE 802.11 medium access control (MAC) layer performance. The two backoff procedures used in the IEEE 802.11 DCF, namely pre-backoff and post-backoff procedures, are commonly treated as the same in existing analytical DCF models for simplicity. This paper makes the first effort to point out the difference between these two backoff procedures. Through intuitive reasoning and simulation results, we show that the two backoff procedures yield un-negligible differences in the performance of average access delay, but give the same performance of throughput.

Keywords: IEEE 802.11, medium access control, distributed coordination function (DCF), network simulator NS-3

Classification: Wireless circuits and devices

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1 Introduction

The IEEE 802.11 Medium Access Control (MAC) uses the distributed coordination function (DCF) as a common mechanism to access the medium. This has triggered researches on the performance analysis and enhancement of DCF [2, 3, 4, 5, 6, 7, 8]. Most analytical models for IEEE 802.11 DCF are based on Markov chain model. A famous one proposed by G. Bianchi [2] used a two dimensional discrete Markov chain network to model the behavior of binary exponential backoff mechanism used in DCF under saturated conditions. Some studies [3] enhanced Binachi's model by considering imperfect channels, finite buffer, and limited retry. In addition, many latter studies [4, 5, 6, 7, 8] extended the Bianchi's model to operate in non-saturated conditions, so that the extended model become more realistic.

In practical network operations, the incoming traffic load is unsaturated in general. Therefore, in this paper we focus on unsaturated models. Existing unsaturated models [4, 5, 6, 7, 8] are different in mathematical descriptions and complexities. L.Y. Shyang et al. [4] introduced a new idle state accounting for the case of the station with empty queue. For simplicity, F. Daneshgaran et al. [5] also considered the unsaturated conditions by adding a new state in Rayleigh fading channel. However, as defined in the standard [1], a random backoff is performed immediately after the end of each transmission even if no additional transmissions are currently queued. This post-backoff procedure was neglected in [4, 5]. In addition, we call the backoff procedure without the separate backoff states as pre-backoff. G.R. Cantieni et al. [6] modeled the additional post-backoff states to study the non-saturated regime. N.T. Dao et al. [7] provided an improved treatment of the post-backoff. K. Ghaboosi et al. [8] took into account the backoff and post-backoff processes with the MAC sub-layer transmission queue status. However, none of the studies above considered the differences between pre-backoff and post-backoff processes.

In this paper, we explore the inherent discrepancy between pre-backoff and post-backoff procedures. We aim to shed light on the following two questions: Is the simplified pre-backoff suitable for analytical model? Does the neglected part of post-backoff affect the characteristic of DCF? The difference between the two backoff procedures is first explained by intuition and further quantified and validated by simulations.

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2 Backoff procedure in 802.11 DCF analytical models

Most analytical frameworks for 802.11 DCF are based on Markov chain models to describe the behavior of binary exponential backoff scheme. The backoff procedure is the same in both saturated and unsaturated cases. The only difference in the analytical models between the unsaturated case and the saturated case is the time when the backoff counter is idle due to the absence of a packet.

As defined in standard [1], after a successful transmission, a station must wait a distributed interframe space (DIFS) and perform backoff even if it has no queued data frame in its local buffer. This process is often known as "post-backoff", as this backoff is done after a transmission as described in Fig. 1 (a). This post-backoff ensures that two consecutive transmissions are separated by at least one backoff interval. Hence, the idle state representing the empty buffer is also slotted after a successful transmission in the analytical model [6, 7, 8].

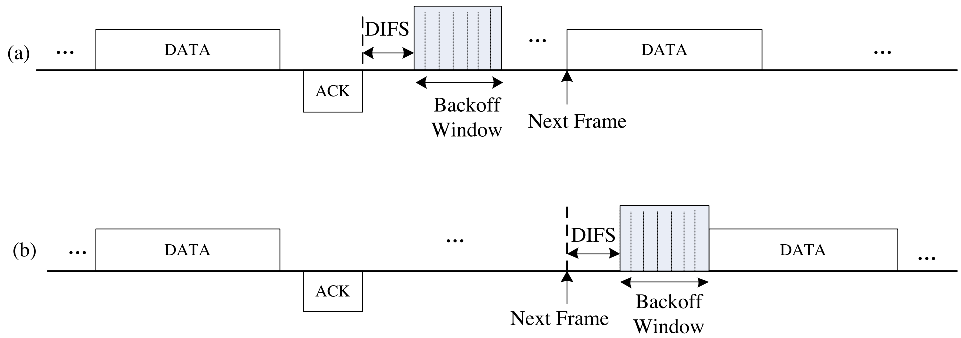

Fig. 1. Backoff procedure

However, for simplicity, the 802.11 post-backoff feature was not fully taken into account in some analytical models [2, 3, 4, 5] under the assumption that post-backoff has a negligible effect on the performance. After a successful transmission, the station enters an idle state with an empty buffer until a new packet arrives for transmission to invoke the backoff counter, as described in Fig. 1 (b).

The traffic interval is relatively long under the unsaturated condition. Correspondingly, the time to next transmission is long. Due to the relatively long interval of packet arrival, there is enough time for retry when collisions occur. Hence, successfully transmitted packets should be the same for both backoff procedures. However, if a new packet is generated after the post-backoff procedure, the packet may be transmitted immediately, but it is easy to collide with other nodes at the packet first time transmission as a result of longer delay. Therefore, the throughputs are the same but the access delays may be different under the unsaturated condition.

Let's make an example to illustrate the detailed difference between two backoff. There are two scenarios of homogeneous network, one using post-backoff procedure as described in Fig. 1 (a), and the other one using the

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pre-backoff as described in Fig. 1 (b). For simplicity, there are two nodes in each network and the packet arrival rate is 1 packet per second. The queue is empty after the packet successful transmission during the unit time. If two nodes generate the packet at the same time during a unit time, the collision will be happened at the first scenario but the collision probability at the second scenario is $\left({}^{1}\!/_{W_0}\right)^2$. W_0 is the contention window size. Notice that the collision in second scenario is much lower than in first scenario. Collision causes packet retransmission and results in the longer access delay. Hence, the pre-backoff has the better performance of access delay than post-backoff.

Since the request to transmit (RTS) and (clear to transmit) CTS mechanisms cannot effectively alleviate the collision, the performance by using pre-backoff and post-backoff of RTS/CTS mechanism should be the same with basic mechanism under the same situation. The analysis will be exemplified by simulation results presented subsequently.

3 Performance evaluation

To validate the discrepancy between pre-backoff and post-backoff, we conduct various simulations using the NS-3 simulator [9] for different network size and load.

Let us focus on the functionalities of the backoff procedure. There are only three fundamental working levels: application, MAC and PHY layers. Traffic is generated following a Poisson distribution for the packet inter-arrival times and arrival rates of all stations are the same. MAC and PHY employ the IEEE 802.11b infrastructure mode network. Table I gives the default parameters are given in as most analytical model using [2, 3, 4, 5, 6, 7, 8].

Table I. Parameter values for simulation

Parameter	Value
Physical modulation	DSSS
Channel frequency	2.4 GHz
Channel bit rate	1 Mbps
PHY header	24 bytes
MAC header	24 bytes
FCS size	4 bytes
ACK size	112 bits
Packet payload	1024 bytes
CWmin	31
CWmax	1023
Station short retry count	7
Station long retry count	4
Slot time	20 µs
SIFS	10 µs
DIFS	50 µs

Consider a network of all stations randomly deployed in a rectangular area and communicate with each other. The simulation time is set to be 10 seconds. All simulation results are obtained by averaging over 100 sample scenarios. By adjusting the network size and traffic load, we compare the throughout and access delay results of pre-backoff and post-backoff under

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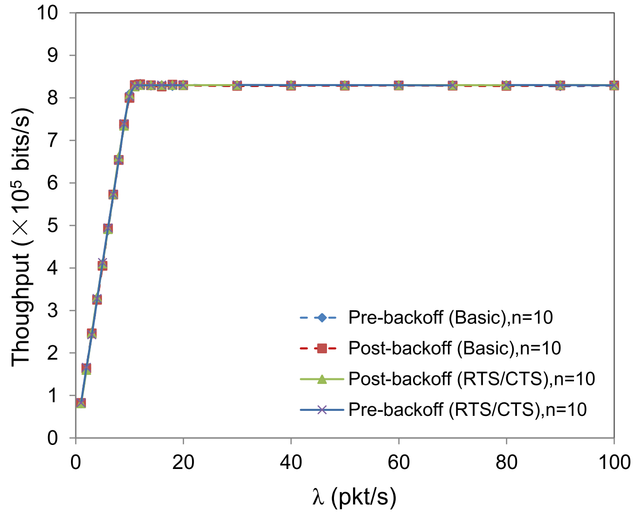
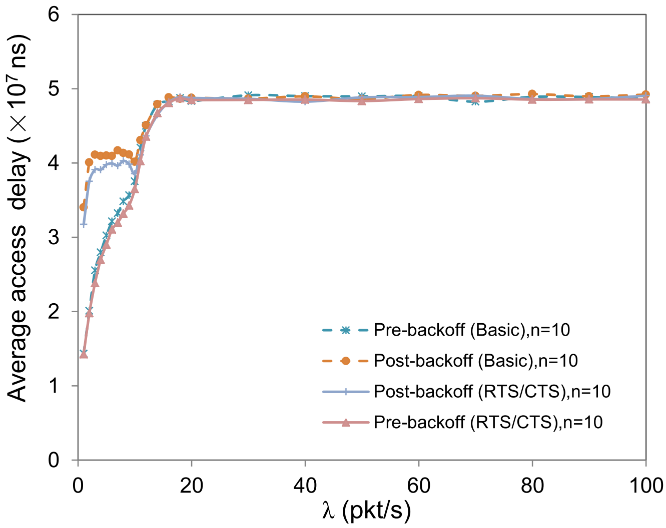
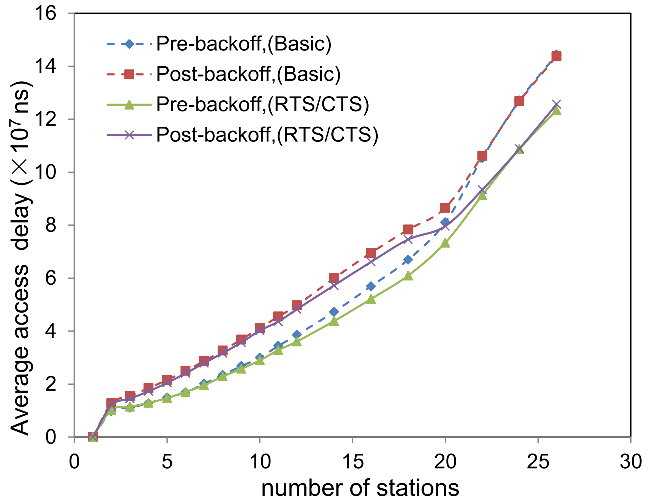


(a) Throughput vs. traffic load



(b) Average access delay vs. traffic load.



(c) Average access delay vs. number of stations (λ=5)

Fig. 2. The comparison of two backoff procedures

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basic access mechanism and RTS/CTS access mechanisms. The packet size in the RTS/CTS mechanism is the same as the basic access mechanism. We change the RTS/CTS threshold when evaluating its performance.

Fig. 2 (a) illustrates the throughput as a function of the packet rate λ, corresponding to basic access mechanism and RTS/CTS access mechanism. The scenario with 10 stations (n = 10) is considered. For this scenario, there is no obvious difference between pre-backoff and post-backoff, no matter which access mechanism is used and what the traffic load is.

Fig. 2 (b) shows the performance of average access delay as a function of the packet arrival rate λ, for 10 stations. Different access mechanism with pre-backoff and post-backoff are considered. We observe that pre-backoff and post-backoff give different performances when λ is relatively small, i.e., the situation of unsaturated condition. The access delay of pre-backoff increases with increasing packet arrival rate until it reaches the saturation zone. In contrast, the access delay of post-backoff is relatively smooth. The difference is larger at smaller λ with fixed number of stations under unsaturated condition. Meanwhile, in the unsaturation zone, the access delay of pre-backoff is less than the access delay of post-backoff under the same condition.

Fig. 2 (c) presents the average access delay as a function of the station number for $\lambda = 5$. The access delay of pre-backoff has a better performance than post-backoff when the stations number is less than 20. Beyond 20 stations, the performance of pre-backoff and post backoff begins to converge. The amount of difference among two procedures is approximately 9 *ms* which is close to the packet collision transmission time.

As we can see from Fig. 2, two backoff procedures give the same performance in the throughput and average access delay under saturated conditions. However, under unsaturated conditions, the difference of performances in average access delay by using two backoff procedures are obvious. The pre-backoff has lower access delay than the post-backoff under unsaturated condition. Meanwhile, the performance of backoff procedure is independent from access mechanisms.

4 Conclusion

In this paper, we have compared two different backoff procedures used in theoretical modeling of IEEE 802.11: post-backoff and pre-backoff mechanisms. Our analysis and simulation results have shown that the two backoff procedures give no difference in throughput and average access delay under saturated conditions. However, the difference in average access delay between the two procedures is obvious under unsaturated conditions. The differences of average access delay decrease with the increased of packet arrival rate. The post-backoff is the original backoff procedure described in IEEE 802.11. The pre-backoff procedure can be considered as a modified version of IEEE 802.11 DCF.

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