Performance Evaluation of the Delayed-DCF Scheme in Wireless LANs

Qing Lin Zhao, Zhi Jie Ma, and Hong Ning Dai

***Abstract*—This paper evaluates the performance of a variant of IEEE 802.11 DCF (we call it the delayed-DCF scheme). In the delayed-DCF scheme, before transmitting a packet, each node first waits for a deterministic delay, and then enters the normal procedure of the legacy DCF. The delayed-DCF scheme adopts a mixed-type contention resolution method: the deterministic delay postpones the time that nodes contend for channel and its counter counts down without the influence of the channel status, while the legacy backoff time resolves collision when nodes contends for channel and its counter can be adaptively adjusted by the contention intensity of the channel. We find via simulation that there exists an optimal deterministic delay, which can minimize the mean and standard deviation of the MAC access delay while maximizing the system throughput. This good feature enables the delayed-DCF scheme to be very applicable to the delay-variance-sensitive applications such as voice over WLANs.**

***Index Terms*—Wireless LAN, delayed channel access, DCF, performance.**

I. INTRODUCTION

IEEE 802.11-based wirelesses LANs (WLANs) have been widely deployed. In the legacy IEEE 802.11 distributed coordination function (DCF) protocol [1], before transmitting a data packet, a node needs to wait for a DIFS interval, and then begins contending for channel. Upon winning the channel, the node starts sending the data packet and next prepares for receiving an ACK after a SIFS interval. In DCF, each node is limited to send at most one data packet upon each transmission opportunity. Since the DIFS, channel contention, SIFS, and ACK transmission will consume considerable time, the limitation of each node sending at most one packet each time badly degrades channel utilization. In the amendment of IEEE 802.11 DCF, the limitation is overcome by allowing nodes to transmit multiple packets each time. For example, IEEE 802.11e EDCA [2] introduces the transmit opportunity (TXOP) limit parameter, which defines the maximum duration in which a node can transmit multiple packets after obtaining a transmission opportunity. IEEE 802.11n [3] proposes an aggregation scheme, which aggregates multiple packets into a single large frame and then transmit the large frame for each transmission opportunity.

In IEEE 802.11e EDCA, different access categories (ACs) are also defined to provide service differentiation. An AC with a higher priority is equipped with a smaller contention window (CWs) and a larger TXOP limit, while an AC with a lower priority is equipped a larger CW and a smaller TXOP limit. Here, a smaller CW means a shorter contention time and hence can provide a lower-delay service required by real-time traffic, but it also implies that a few of packets can be backlogged and transmitted during a TXOP interval, failing in making full use of the TXOP facility. Therefore, the delayed channel access (DCA) scheme is proposed in [4]; the basic idea is to introduce a random delay before a node contends for channel so that more packets can be backlogged and transmitted during a TXOP interval, thereby improving channel utilization. Further enhancements on DCA include (i) adaptive DCA (ADCA) [5], which can dynamically adjust DCA parameters, so as to adapt to traffic characteristics, and (ii) selective DCA (SDCA) [6] which selectively and prudently applies DCA to TCP traffic, in order to avoid adverse effect on the TCP performance.

However, DCA, ADCA, and SDCA are far from being well studied. For example, DCA defines three triggering conditions while ADCA and SDCA define more to generate an random delay, but currently, no literatures theoretically investigate the quantities relationship between the triggering conditions and the generated random delay and explain how to set *an appropriate random delay* (or how to configure appropriate system parameter values used in triggering conditions). On the other hand, it is very vital to set the appropriate random delay in [4]-[6] for improving the system throughput while guaranteeing the delay requirements of real-time traffic.

To better understand DCA, ADCA, and SDCA, this paper investigates via simulation a simple but core problem: how a deterministic delay affects the system performance of the subsequent DCF procedure. More specifically, we want to study a simple variant of DCF and we call it the delayed-DCF scheme. In the delayed-DCF, before sending a packet, a node waits for a deterministic delay and then enters the normal DCF procedure. If the deterministic delay is equal to zero, the delayed-DCF becomes the legacy DCF. Note that there is a distinct difference between the deterministic delay and the backoff timer in the normal DCF procedure: the former is independent of the channel status, while the later is greatly affected by the channel status. The goal of this paper is to illustrate the impact of the non-zero deterministic delay on the collision probability, MAC delay mean, MAC delay variance, throughput, and total delay. This paper is very

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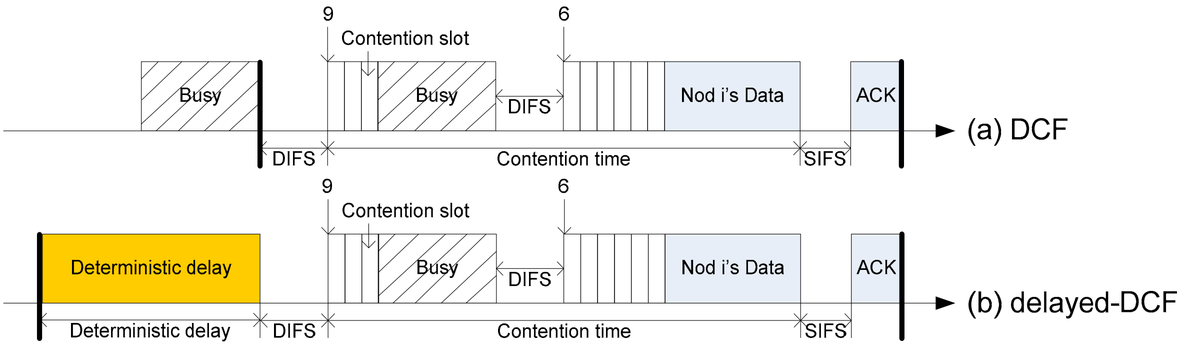

Fig. 1. Illustration of access modes in DCF and delayed-DCF

Helpful to deeply understand the DCA scheme and provide insights for establishing a theoretical performance model of DCA in future.

The rest of this paper is organized as follows. Section II overviews the basic DCA scheme. Section III outlines the DCF protocol and the delayed-DCF scheme. Section IV illustrates the impact of the deterministic delay on the system performance of DCF. Section V concludes this paper.

II. DELAYED CHANNEL ACCESS

The DCA scheme [4] intentionally introduces an additional delay before a node contends for channel. The purpose is to increase the aggregation size per transmission by waiting for the additional delay.

A longer waiting time is likely to result in a larger aggregation size, but it could also leave the channel unnecessarily idle even when the packet queue is non-empty. To minimize the unnecessarily idle time, DCA defines three events:

- The number of packets in the aggregation buffer ≥ apredefined threshold, σ.
- The waiting delay of the first packet in the aggregation buffer ≥ a predefined threshold, τ.
- The idling time since the last packet reached the aggregation buffer ≥ a predefined threshold, α.

In the above three events, the third event essentially defines a traffic burst of a flow, which is a sequence of packets where the inter-arrival time of two consecutive packets is within the time interval α. Also, the third event actually enables DCA to adapt to traffic load: with high traffic load, the burst duration can be longer and more packets are aggregated, achieving higher channel utilization; with low traffic load, the burst duration will be shorter but the unnecessarily idle time is reduced.

When any one of the three events is triggered, a node immediately assembles all packets backlogged in the aggregation buffer and forms an aggregation, then starts channel access and finally transmits this aggregation.

In DCA, the above three events jointly defines a random delay. The random delay solely relies on traffic characteristics and therefore is independent of channel status. After the random delay, a node starts contending for channel. Since the random delay postpones the time that nodes contend for channel, it necessarily affects the contention time and consequently the system performance. However, how to tune the random delay (or how to configure appropriate values of the three DCA parameters, σ, τ, α) is outstanding in current literatures. This paper is in the first step to toward this end.

III. DCF AND DELAYED-DCF

In this section, we first overview IEEE 802.11 DCF protocol, then present the delayed-DCF.

A. IEEE 802.11 DCF protocol

The IEEE 802.11 DCF [1] is based on carrier sense multiple access with collision avoidance (CSMA/CA). DCF has two channel access mechanisms: the mandatory basic access mechanism and the optional request to send/clear to send (RTS/CTS) access mechanism.

With the help of Fig. 1 (a), we now describe the main procedure used in the basic access mode.

Before transmitting a packet, a node must sense the channel for at least a DCF interframe space (DIFS). During the DIFS time, if the channel is sensed idle, the node may begin the transmission process; if the channel is sensed busy, the node will defer access and enter a contention period.

During the contention period, the node employs the BEB algorithm to resolve collisions. In the BEB algorithm, a node initially generates a random backoff time uniformly distributed in $[0, CW_{\min} - 1]$, where $CW_{\min}$ is a given minimum CW size. Thereafter, the backoff counter decreases by one for each idle time slot and is suspended for each busy slot. The suspended backoff counter resumes after the channel is sensed idle for a DIFS period. When the backoff counter reaches zero, the node starts transmitting the head of line (HOL) packet at the beginning of the next time slot. For example, in Fig. 1 (a), node i first chooses a backoff time equal to 9 and starts counting down. When the backoff counter reduces to 6, node i suspends the counter because the channel is sensed busy and resumes the counter later after the channel is sensed idle for a DIFS period.

For each successful transmission, the sender will receive an acknowledgement (ACK) frame after a short interframe space (SIFS). If the node does not receive the ACK within a certain time (i.e. ACK timeout), it assumes that the data packet was not successfully received at the destination node and doubles the CW and repeats the above procedure. Doubling of the CW stops after the maximum window size $CW_{\max}$ is reached. When a retransmission limit is reached, the sender discards the data packet. Note that according to the 802.11 DCF protocol, two consecutive data packet transmissions of a node is separated by at least a random time uniformly distributed in $[0, CW_{\min} - 1]$.

B. Delayed-DCF

Fig. 1 (b) illustrates the delayed-DCF. Like DCF, a node in delayed-DCF transmits at most one packet upon each transmission opportunity. However, unlike DCF, a node in delayed-DCF always waits for a deterministic delay (denoted by d in this paper) before entering the subsequent DCF procedure. A special case is that when the deterministic delay, d, is equal to 0, the delayed-DCF scheme becomes the legacy DCF protocol.

The delayed-DCF scheme actually adopts a mixed-type contention resolution method. One is the deterministic delay, which is independent of the channel status, and its counter is never suspended and will keep counting down once the counter is installed. The deterministic delay postpones the time that nodes contend for channel. Another is the backoff time, which is greatly affected by the channel status and therefore its counter will be suspended for a busy slot and resumed for subsequent idle slots. The backoff time increases as the contention becomes more intensive. The two types of delays objectively alleviate contention intensity.

TABLE I: DEFAULT PARAMETER SETTINGS USED IN THIS PAPER

CWmin/CWmax	32/1024	packet_time	500 bytes @Rdata
slot	20 µs	ACK	24 bytes @Rbasic + 14 bytes @ Rbasic
SIFS	10 µs	MacHeader	24 bytes @Rdata + 4 bytes @ Rdata
DIFS	50 µs	PhyHeader	24 bytes @Rbasic
Rdata	11 Mbps	RouteHeader	40 bytes @Rdata
Rbasic	1 Mbps	propagation_delay	0 µs

This paper concerns the impact of the deterministic delay d on the performance of the subsequent DCF procedure, which is never investigated before.

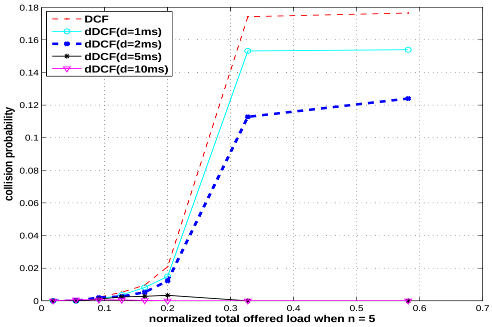

Fig. 2. The collision probability versus the normalized total offered load when $n = 5$.

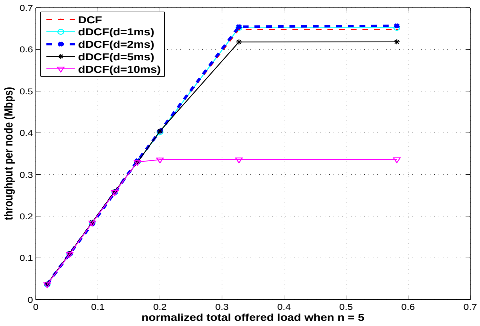

Fig. 3. The throughput per node versus the normalized total offered load when $n = 5$.

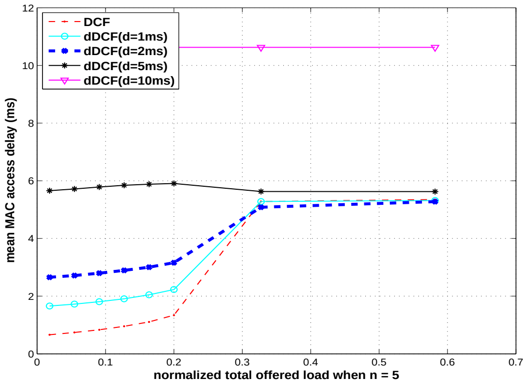

Fig. 4. The mean MAC access delay versus the normalized total offered load when $n = 5$.

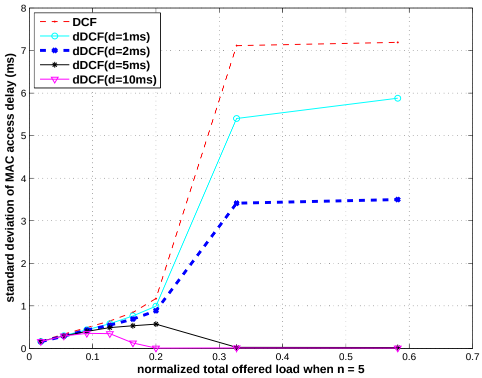

Fig. 5. The standard deviation of the MAC access delay versus the normalized total offered load when $n = 5$.

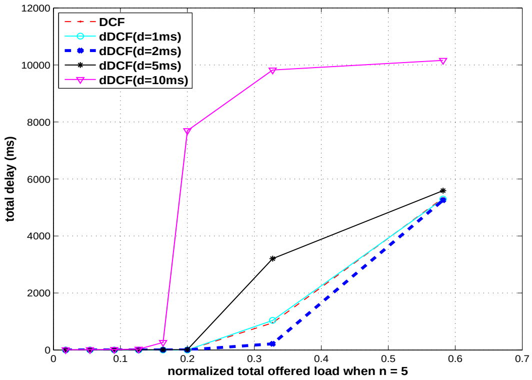

Fig. 6. The mean total delay versus the normalized total offered load when $n = 5$.

IV. PERFORMANCE

This section illustrates the performance of the delayed-DCF scheme, i.e., to show the impact of the deterministic delay d on the performance of the subsequent DCF.

We consider a one-hop star network with an AP and $n = 5$ nodes, where the AP only acts as the receiver of data packets from all nodes. We use the 802.11 simulator in ns2 version 2.28 [7] and the DumbAgent routing protocol in simulation. The default parameter values shown in TABLE I are set in accordance with 802.11b. The simulation time was for 100 seconds.

We assume Poisson arrivals and set d to 0 ms, 1 ms, 2 ms, 5 ms, and 10 ms. Note that $d = 0$ corresponds to the legacy DCF. These values of d fluctuate around 5 ms, the upper bound of the MAC access delay when there are 5 contending nodes in the legacy DCF. It has been proved in [8] that for a one-hop WLAN with n contending nodes, the mean MAC delay of a packet is $O(n)$, where the mean MAC delay is defined as the interval between when a packet becomes the head-of-line packet in the MAC buffer and when the packet is successfully received at the destination node. In simulation, we observes that the upper bound of the mean MAC delay is about n ms for n contending nodes.

Fig.2-Fig.6 respectively, show the collision probability, the mean and standard deviation of the MAC access delay, the mean total delay versus the normalized total offered load when $n = 5$. The abscissa of all graphs is the total offered load $\overline{\rho} \triangleq \frac{n\lambda L}{R_{data}}$, where R_{data} is the data rate. We summarize our observations as follows:

- As d increases, the collision probability decreases to zero, which is shown in . Consequently, the standard deviation of the MAC access delay reduces to zero as well, which is shown in . The root cause is explained in the next point.
- As d increases, the mean MAC access delay first increases when the traffic load is below a threshold (which is about 0.32 in our example), and then keeps at about $\max(n, d)$ ms when the traffic load is beyond the threshold. This is shown in . Our explanation for the constant MAC access delay is: when the traffic load approaches saturated and $d > n$, the MAC access delay is completely governed by the constant d (i.e., the deterministic delay) and therefore the subsequent random contention time is negligible. Necessarily, the the standard deviation of the MAC access delay is zero, as shown in .
- As d increases, the mean total delay in the delayed-DCF is apparently less than that in the legacy DCF for $d = 2$ ms, but remarkably larger than that in the legacy DCF for $d = 5$ ms and 10 ms. This is shown in .
- As d increases, the throughput per node in the delayed-DCF is slightly larger than that in the legacy DCF for $d = 1$ ms and 2 ms, but it remarkably reduces below that in the legacy DCF for $d = 5$ ms and 10 ms. This is shown in .

From the above observations, we can safely deduce that there exists an optimal deterministic delay (which is less than the upper bound of the corresponding MAC access delay and is equal to 2 ms in our example), minimizing the collision probability, the mean and standard deviation of the MAC access delay, as well as the mean total delay while maximizing the system throughput.

V. CONCLUSION

The DCA scheme is a variant of the legacy DCF protocol. In DCA, a node waits for a random delay before contending for channel (as in DCF) so that more packets can be backlogged and transmitted upon one transmission opportunity. This paper investigates a simple but core problem in DCA: how a deterministic delay affects the system performance of the subsequent DCF. We find via simulation that there exists an optimal deterministic delay, which can minimize the mean and standard deviation of the MAC access delay while maximizing the system throughput. This paper is very helpful for further modeling DCA and suitably designing its configurable system parameters.

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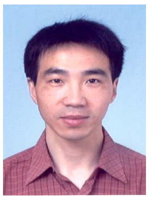

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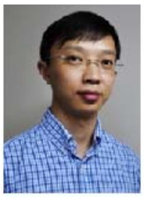

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