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A New ACK Policy To Mitigate the Effects of Coexisting IEEE 802.11/802.11e Devices

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***Abstract*— In IEEE 802.11 wireless networks, EDCA users' performance may be degraded because of the existence of legacy users and therefore would get a lower priority service. Such effects are mainly due to the fact that EDCA users are controlled by different contention parameters that are distributed in the beacon frames, but there is no control over legacy users as their contention parameters are PHY dependent, i.e. they have constant values. In this paper, we discuss different aspects of the legacy DCF and EDCA users coexistence. Also, we propose a simple distributed management scheme (called NZ-ACK) to mitigate the influence of legacy DCF on EDCA performance in networks consisting of both types of users without any modifications to legacy users. Finally, we use *Opnet* simulation to evaluate the performance of NZ-ACK. Results show that NZ-ACK outperforms 802.11 in terms of maintaining the priority of service and delay bounds of EDCA users while providing acceptable throughput for legacy users.**

I. INTRODUCTION

As an amendment to the IEEE 802.11, IEEE 802.11e-2005 was developed to provide quality of service (QoS) for real-time application while being backward compatible. Therefore, wireless networks are expected to have a combination of both EDCA (802.11e) and legacy DCF (802.11) users. Hence, the EDCA users' performance may be degraded because of the existence of legacy users, and therefore would get a lower priority service mainly due to the following fact: *EDCA users are controlled through different contention parameters (*$AIFS$*,* CW_{min}*,* CW_{max}*,* $TXOP$*) that are distributed in the beacon frames, but there is no control over legacy users because their contention parameters (*$DIFS$*,* CW_{min}*,* CW_{max}*) are PHY dependent, i.e. they have constant values.* For example, consider a simple scenario of a network with 802.11b PHY, EDCA users (all with voice access category, CW_{min} of 8, and $AIFS$ of 50μ seconds), and legacy DCF users (CW_{min} of 32, and $DIFS$ of 50μ seconds). Due to an increase in the number of EDCA users, the QAP (QoS access point) broadcasts new values of CW_{min} of 32. AIFS cannot be reduced since 50μ seconds is the smallest value allowed for non-QAP users, and DCF users' parameters are fixed. Hence, coexisting EDCA and DCF users would have the same priority to access the channel, and so the performance of EDCA users could be affected.

In this paper, we propose a scheme to mitigate the influence of coexisting legacy DCF on EDCA performance based on the following common behavior of EDCA and DCF: the duration included in each received frame is used to defer accessing the channel unless the user is the destination and is required to send back a response frame. Also, the duration of the last ACK frame in a transmission exchange is set to zero. Accordingly, all EDCA and DCF users contend for the channel directly after the last ACK frame. In our proposed mechanism, the QAP is allowed to set the duration of the last ACK frame to a non-zero value; hence we call these frames NZ-ACK frames, and we call the proposed mechanism NZ-ACK scheme. Upon receiving an NZ-ACK frame, an EDCA user would start to contend for the channel directly just as if a zero duration ACK frame is received. However, a legacy DCF user recognizes no difference between a normal ACK frame and a NZ-ACK frame. Hence, DCF users defer their access to the channel according to the nonzero duration value included in the received NZ-ACK frame. For an efficient performance, the QAP determines when to issue NZ-ACK frames, and the duration value of an issued NZ-ACK frame. We address these issues with the objective of mitigating the coexistence effects without starving the legacy DCF users, and utilizing bandwidth efficiently.

In addition to being simple and distributed, NZ-ACK scheme has the following features: 1) No modifications required to legacy DCF users, and backward compatibility. 2) No changes to the 802.11e standard frames' formats. 3) Minimal overhead to EDCA users as all processing is at the QAP. 4) Adaptively provide control over legacy stations, and reserve more resources for the EDCA users as necessary.

The rest of this paper is organized as follows. Section II provides background information about both DCF and EDCA. Section III gives an insight on the effects of coexisting DCF and EDCA devices, and presents general desirable features for any proposed solution. Related works are summerized in section IV. We discuss the details of our proposed mechanism in section V, and present its evaluation via *Opnet* simulation in section VI. Finally, conclusions are provided in section VII.

II. IEEE 802.11 BACKGROUND

A. Distributed Coordination Function (DCF)

The IEEE 802.11 standard [1], [2] defines DCF which is based on CSMA/CA. In basic operation, a station that has a packet to transmit will do so if the medium is sensed idle for a period of distributed interframe space (DIFS). Otherwise, the station goes into backoff following the Binary-Exponential-Backoff (BEB) procedure. The station chooses a number of time slots to wait before trying to transmit again. The number, or the backoff counter, is selected from the range $[0, CW]$,

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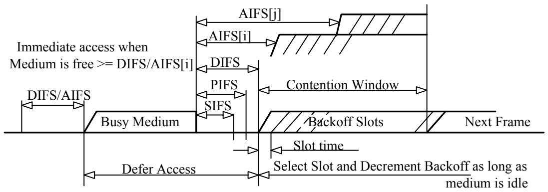


Fig. 1. Interframe Space Relations

where CW is called the contention window and is initially set to CW_{min}. The station decrements its backoff counter by one for every slot time the medium is sensed idle. When the backoff counter reaches zero, the station transmits its packet. Upon receiving a data frame, the destination responds by sending back an acknowledgment (ACK) frame after a short interframe space (SIFS) time. The packets transmitted carry the time needed to complete the transmission of a packet and its acknowledgement. This time is used by all other stations to defer their access to the medium and is called NAV, Network Allocation Vector. Collisions occur when two or more stations are transmitting at the same time, or when the ACK frame is not received after a timeout period. With every collision, the station doubles its CW unless it reaches a maximum limit CW_{max}, and selects a new backoff counter from the new range. The process is repeated until the packet is successfully transmitted or is dropped because a retry limit is reached.

B. Enhanced Distributed Channel Access (EDCA)

The IEEE 802.11e standard [3] defines EDCA that provides better service to real-time traffic. EDCA classifies data frames into four different access categories (ACs) according to the user priority (UP) provided by the above layers. Each AC constitutes an enhanced distributed channel access function (EDCAF) that works exactly the same as DCF. However, the contention parameters for each EDCAF could be different and are announced in the beacon frames. Each AC is categorized by different contention parameters including the arbitration interframe space (AIFS), CW_{min}, and CW_{max}. AIFS is the amount of time the medium should be sensed idle first. Moreover, EDCA introduces the transmission opportunity (TXOP) limit which indicates the maximum amount of time that the user should use when winning the right to transmit. An internal collision occurs when two or more EDCAFs win the contention at the same time and the same user. The AC with the higher priority is allowed to start transmitting data frames, and all others go into backoff as if an actual collision has occurred. In summary, an AC with a smaller AIFS value, smaller CW_{min}, and smaller CW_{max} has a higher priority to access the channel as explained in Fig. 1.

III. IEEE 802.11 DCF/EDCA COEXISTENCE

A. Problem Statement

Future wireless networks are expected to have a mix of both EDCA (802.11e) and legacy DCF (802.11) users. Hence, EDCA users' performance may be degraded because of the DCF users and therefore would get a lower priority service. We summarize the reasons for this degradation in the following. First, EDCA users are controlled through the use of different contention parameters ($AIFS$, CW_{min}, CW_{max}, $TXOP$) that are distributed via the beacon frames. On the other hand, there is no control over DCF users because their contention parameters ($DIFS$, CW_{min}, CW_{max}) are PHY dependent, i.e. they have constant values. Hence, when the total number of users increases, the CW values of EDCA users may be adjusted to reduce collision rates. As a result, DCF users would get a higher priority and hence may degrade the service provided to EDCA users. Also, the collision rate due to legacy users would affect the EDCA performance specially when there is a large number of contending DCF users. Second, the smallest AIFS value allowed for non-QAP EDCA users is equivalent to that used in DCF, i.e. DIFS. Since a smaller AIFS leads to a higher priority, DCF users probably will get a higher priority than some or all access categories of EDCA. Third, to grant EDCA users a higher priority, one may assign them smaller CW values than that of DCF users. However this leads to a higher collision rate as seen by EDCA users, and so the overall collision rate of the network. Fourth, the transmission time is controlled via the TXOP feature in order to provide QoS guarantees in EDCA. Such control is not applied by legacy users. Therefore, transmissions from DCF users may overlap with TBTT (Target Beacon Transmission Time), and may occupy most of the time when using lower physical rates.

B. Desirable Features

For the design of mitigating techniques, we argue that the following considerations are important for an effective performance and practical issues. First, there should be no changes to the legacy stations for compatibility issues. The new changes are to be implemented on the new 802.11e devices specially the QAPs. Second, legacy users should be controlled to provide EDCA users with a higher priority as expected, and to mitigate the degradation. The control over DCF stations should not waste bandwidth unnecessarily. For example, there is no need to prevent DCF users from using the medium if there is no EDCA traffic. Third, a new mechanism should not require complex computations or processing by the non-AP users, and should not alter the 802.11e/802.11 frames' formats. Fourth, because polling is not an attractive solution, new mechanisms should be working with the contention operation. Finally, the influence of any new technique should be the same (fair) for all DCF users.

IV. RELATED WORK

For an 802.11b network, [4] showed that AIFS is the best for delay performance, but would result in throughput starvation for legacy users. [4] concluded that to achieve fairness, both CW_{min} and $AIFS$ should be adapted with the mix of 802.11e and 802.11b priority users. In addition to these results, [5] demonstrated that the increase of collisions due to small CW values reduces the difference between EDCA and legacy DCF.

In [6], the authors suggest a scheme to improve the performance of the legacy users assuming they have multimedia traffic. A Hierarchical Token Bucket discipline between the IP layer and Layer 2 at the legacy users is used to classify, police, and schedule and shape the incoming traffic. The presented solution requires modifications to legacy users, and does not show how to solve the coexistence effects. In [7], a mechanism is used to prevent a legacy user from starting a data transmission if its transmission would overlap with the TBTT. The QAP broadcasts a factor that is used by legacy users to determine when such an overlap may occur. Accordingly, the time is divided into two periods: the first is used by all stations to contend for the channel, and then followed by the second period during which only EDCA users do contend for the channel. The proposed mechanism requires modifications to the legacy users, does not reduce the coexistence effects during the first period but may increase it because of the accumulation of the DCF users' contention, and may waste bandwidth unnecessarily during the second period when not used by any of the EDCA users.

ACKS [8] proposed that the QAP should skip sending back an ACK frame to a DCF user with some probability δ. Skipping ACK frames results in a waste of bandwidth for all users, regardless of the fact they are using DCF or EDCA. The time wasted is the total time needed to contend for the channel, and to transmit all data fragments, and corresponding ACK frames. Also, dropping a data frame that already has been successfully transmitted is not a good solution in a noisy wireless network. Finally, ACKS is proposed for a saturated network to achieve weighted throughput guarantees by fixing AIFS to DIFS and adapting the CW_{min} for all users. Consequently, as explained in [9], although the weighted throughput ratios are met, the QoS requirements of EDCA users would be affected when legacy users transmit at lowers rates since they do not deploy the TXOP limit feature.

V. NZ-ACK DETAILS

We propose a simple distributed management scheme, called NZ-ACK, to mitigate the influence of the legacy 802.11 DCF users on the 802.11e EDCA users in an infrastructure network by introducing a new policy of ACK frames. The design of NZ-ACK satisfies all features described in section III-B.

A. An Overview

Fig. 2 explains the basic principal of NZ-ACK scheme. As explained in $Part\ 1$ of Fig. 2, competing users would set their local NAV counters according to the duration value included in the header of the received frame. Following the EDCA or DCF rules, the NAV value of the last ACK frame, $ACK\ 1$ in the figure, in the current transmission exchange is set to zero. Accordingly, all EDCA and DCF users are allowed to start contending for the channel directly after the last ACK frame.

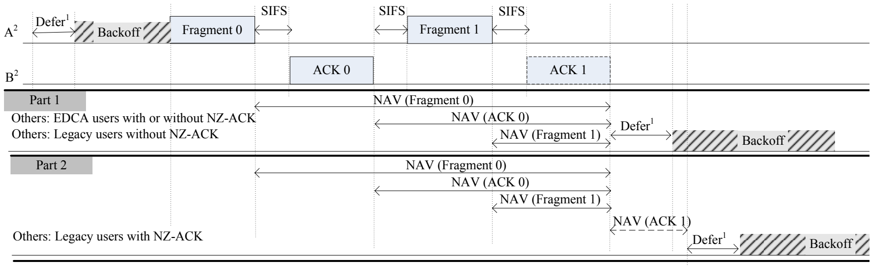
To mitigate the impact of the legacy DCF users on the EDCA users, we introduce a new type of ACK frames that are called Non Zero ACK (NZ-ACK) frames: the QAP sets the duration of a NZ-ACK frame to a nonzero value. A NZ-ACK frame is simply the last ACK frame of the ongoing transmission, $ACK\ 1$ in Fig. 2. NZ-ACK is designed so that a legacy DCF user does not recognize any difference between a normal ACK frame and a NZ-ACK frame. Then, as explained in Part 2 of Fig. 2, when $ACK\ 1$ is used as an NZ-ACK frame, the legacy DCF users update their NAV values using the duration of $ACK\ 1$. However, EDCA users would start directly their contention as shown in $Part\ 1$ of Fig. 2.

Consequently, NZ-ACK allows the QAP to increase the defer periods of the legacy stations in an adaptive way using the ACK frames that are common to all users. In addition, the QAP would be able to respond faster to different changes in users' behaviors because the ACK frame is a part of any data frame transmission; for example, a legacy user may adjust to a lower physical rate. Although there is an exception when direct link is used by EDCA users, legacy users always require receiving the ACK frames.

B. When to Issue NZ-ACK Frames

We propose to issue NZ-ACK frames only when there are active EDCA users with the probability ($\rho = \frac{n_{DCF}}{n_{DCF}+\hat{n}_{EDCA}}$), where n_{DCF} is the total number of legacy stations, and $\hat{n}_{EDCA}$ is the number of EDCA stations that have data frames. First, when n_{DCF} is much greater than $\hat{n}_{EDCA}$, there is a high probability of issuing NZ-ACK frames. In addition, when the number of active EDCA stations is constant, a small increase in the number of legacy users results in a faster increase of the probability. In general, the higher the number of DCF users in the network, the higher the need for NZ-ACK frames to protect EDCA users. Second, when the number of DCF users gets very small, the probability approaches 0. This is accepted since the effect of legacy users would be much smaller. Therefore, in such scenario we rely mostly on contention parameters so that DCF users will have a chance to compete with EDCA users without being starved. To summarize, we maintain the service priority of EDCA users while allowing DCF users to use the rest of bandwidth under different network conditions.

To find this probability, we use the concept of virtual EDCA queues. Before starting a QoS flow, an EDCA user should first send a request to the QAP with the QoS requirements of the flow including the average data rate, peak data rate, and nominal packet size. The QAP generates a virtual queue for the flow, and adds a virtual packet to the queue every $1/r$ seconds where r is the rate at which packets are generated. In order to maximize bandwidth utilization, we use the maximum possible interarrival time; r is set to the average rate for VBR and CBR sources. Moreover, a virtual packet is added to a virtual queue when a received frame indicates more data buffered at the user. Also, all queues are arranged according to the rate; i.e. the smaller the rate, the higher the priority. Finally, virtual packets are dropped in different cases: 1) The packet's waiting time becomes longer than some delay requirement. 2) The packet is the reason to issue the NZ-ACK frame (explained in the next section). 3) A data frame is received indicating no more data buffered. From the virtual queues, the QAP can estimate $\hat{n}_{EDCA}$ by the number of nonempty virtual queues.



1 Note: The figure does not provide actual values of Defer and Backoff, but only shows that they are required by every user.
2 Note: A and B can contend for the channel after current transmission just like the others (same rules apply depending on the deployment of NZ-ACK).

Fig. 2. An example of NZ-ACK operation with a transmission of two fragments

C. How Long is the Duration of an NZ-ACK frame

The QAP can determine the required utilization of EDCA users ($U_{EDCA} = \sum_{i=1}^{n_{EDCA}} \frac{r_i}{l_i} T_s$) and the legacy users utilization ($U_{DCF} = U - U_{EDCA}$), where U is channel utilization, n_{EDCA} is the number of EDCA users with QoS requirements, r_i is the data rate, l_i is the packet size, and T_s is the time to successfully transmit a packet ($T_s = AIFS + SIFS + T_{ACK} + T_{DATA}$) for every EDCA user i with QoS requirements.

Let u_c ($u_c = \frac{r_c}{l_c} T_s$) be the utilization of the virtual packet at the head of line of the first non-empty virtual queue; i.e. with lowest utilization. We find the value of the duration of current NZ-ACK frame by $d_c = u_c T$, where T is a predetermined period. The QAP maintains two parameters that are updated every T seconds: the time used by EDCA users with QoS requirements (t_{EDCA}), and the time used by legacy DCF users (t_{DCF}). Then we define the utilized time by $t_{used} = t_{EDCA} + t_{DCF}$, and the remaining time by $t_r = T - t_{used}$. The NZ-ACK frames is issued as long as ($\frac{t_{DCF} + t_r - d_c}{T} \geq U_{DCF}$) to assure that U_{DCF} would not be depleted.

D. Saturated Users

When users always have frames to transmit, delay requirements can not be guaranteed. Hence, we add the following changes. First, virtual queues are not used since they are not useful any more. Second, NZ-ACK frames are issued only as a response to a legacy user with the probability $\rho = \frac{n_{DCF}}{n_{DCF} + n_{EDCA}}$ with a duration of one time slot.

E. Implementation

All processing performed by NZ-ACK is implemented at the QAP. For the QAP to recognize the last fragment from a legacy user, the $morefragments(B10)$ bit of Frame Control field can be used since only one packet is allowed. On the other hand, the QAP can recognize last fragment or packet from EDCA users whenever the duration included is not enough (less than or equal to SIFS is used in our implementation) to start a new transmission from the same user.

EDCA users are required to distinguish between a regular ACK and a NZ-ACK. At the same time, a legacy DCF user must recognize no difference between both ACK and NZ-ACK frames (NZ-ACK must be seen as an ACK). To distinguish between ACK and NZ-ACK frames, we used the fact that all bits $B8$ to $B15$ except for $B12$ in the Frame Control field of control frames are always set to $'0'$. We selected $B10$ to be set to $'1'$ for NZ-ACK frames. Because no change is made to $Type$ and $Subtype$ fields of Frame Control field, legacy DCF users would still understand NZ-ACK frames as normal ACKs. Consequently, NZ-ACK scheme requires no changes to the legacy users' implementations. Finally, NZ-ACK does not add any overhead bits to the ACK frames, and does not require any extra messages other than those found in the IEEE 802.11e standard. The ADDTS requests, ADDTS responses, and DELTS frames are used to convey QoS requirements between the QAP and EDCA users.

VI. EVALUATION

We evaluate via simulation the performance of NZ-ACK and compare it to that of 802.11 using *Opnet* [10]. We consider an infrastructure network of users sharing a single wireless channel, a fully connected network (no hidden nodes), and no channel errors (collisions are the only source of errors). For performance analysis, we use the following metrics:

1) *Throughput:* the total data bits transmitted per time.
2) *Fairness Index (FI):* we used Jain Index [11] defined by $FI = \frac{(\sum_{i=1}^{n} S_i)^2}{n \sum_{i=1}^{n} S_i^2}$, where n is number of stations and S_i is the throughput of station i. The closer the value of FI to 1, the better the fairness provided.
3) *Delay:* the delay for each packet is measured from the moment that packet arrives at the MAC layer until its ACK response is received correctly.

A. Saturated Network

Each user always has data frames in a saturated network. We consider 802.11g PHY with a data rate/control rate of $54Mbps$/$24Mbps$, two different settings of CW_{min}/CW_{max} ($63/1023$, $63/511$) and compare scenarios with same settings, 50 EDCA users with voice access category and 50 legacy users, $DIFS$ for all users, and the PHY CW_{min}/CW_{max} of $16/1024$ which are used by legacy users. T is set to the beacon interval. The following summarizes our results.

NZ-ACK provides the best overall network performance (highest total throughput (about 6.67% and $7.99\%$of gain), lowest total delay (at least 7.82% and 9.65% lower)), highest EDCA throughput (about 17.2% and 19.4% of gain), and lowest EDCA delay (about 10.9% and 13.2% lower). This is because the legacy users have higher effects on EDCA users in

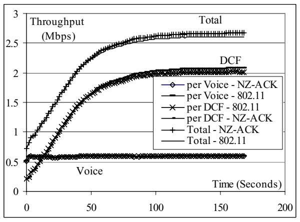


Fig. 3. Throughput

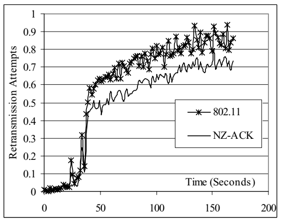


Fig. 4. Retransmission attempts

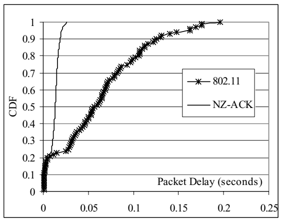


Fig. 5. Packet Delay, CDF

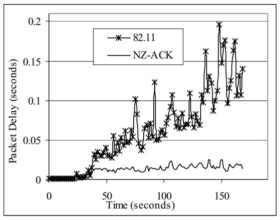


Fig. 6. Packet Delay

the 802.11 as seen by the higher DCF throughput (lowered by about 18% with NZ-ACK variants). Both NZ-ACK variants provide almost the same FI values for DCF users as that achieved by both 802.11 scenarios. Hence, the effect of NZ-ACK is the same for all DCF users. This is because NZ-ACK frames are sent by the QAP and thus are seen by all DCF users. Also, the retransmission attempts, and so the collision rates, in NZ-ACK are lower by at least 14% as it reduces the number of contending users when issuing nonzero duration NZ-ACK frames; only EDCA users are competing for the channel when DCF users are yielding.

B. Non-saturated Networks

We consider an 802.11b network with $11Mbps/1Mbps$ data rate/control rate, and CW_{min}/CW_{max} are $32/1024$ for legacy users. There are 18 voice EDCA users with CW_{min}/CW_{max} of $31/63$. Each voice source is modeled by an NO/OFF model with the ON and OFF periods are both exponential (0.352 seconds), and uses G.711 (silence) encoder with $64kbps$ coding rate and 160 bytes per packet. The simulation starts with one DCF user, and every 3 seconds another DCF user is added with no more than 50 DCF users added. Each legacy user generates traffic with an inter-arrival rate of exponential ($40ms$), and 1000 bytes per packet. DIFS of $50\mu s$ seconds is used by all users. Finally, the simulation is conducted for 170 seconds, and T is set to the beacon interval and delay used for dropping virtual packets is 0.1 seconds.

Fig. 3 shows a very small enhancement of the total throughput and throughput per DCF when using NZ-ACK after 40 seconds, i.e. when there are at least about 14 DCF users. In addition, Fig. 4 explains that NZ-ACK reduces the retransmission attempts, and thus number of collisions, with time as more legacy users are added to the network. This is because NZ-ACK reduces number of contending users during the periods where DCF users are deferred by the NZ-ACK frames. Fig. 6 shows that the delay is kept very small as long as the number of DCF users is less than 14 (at about 40 seconds). Then, the delay starts to increase and reach values up to 0.2 seconds. Also, the delay variation increases. However, NZ-ACK protects the voice traffic and keeps the delay and delay variation very small. Fig. 5 illustrates the CDF of packet delay; the probability of having a delay higher than a given value. While all delays are less than 0.026 seconds with NZ-ACK, there are chances of more than 0.2 that the delay is higher than 0.1 seconds for 802.11.

VII. CONCLUSIONS

In this paper, we discussed different aspects of the legacy DCF and EDCA coexistence and provided general desirable features for any mitigation solution. Based on those features, we proposed a simple distributed management scheme, called NZ-ACK, to mitigate the influence of legacy DCF on EDCA performance in networks consisting of both types of users. NZ-ACK controls legacy users by introducing a new ACK policy in which the QAP sets the duration of the last ACK in a transmission exchange to a nonzero value. While all processing of NZ-ACK is at the QAP, EDCA users are required only to distinguish the new ACK policy in order to ignore the duration included in a NZ-ACK frame and no modification is added to legacy users. Finally, we used *Opnet* to evaluate NZ-ACK, and results show that NZ-ACK outperforms 802.11 in terms of maintaining the priority of service and delay bounds of EDCA users while providing acceptable throughput for legacy users.

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