EDCA/CA: Enhancement of IEEE 802.11e EDCA by Contention Adaption for Energy Efficiency

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***Abstract*—This paper presents a *Contention Adaptation (CA)* mechanism to improve the energy efficiency in IEEE 802.11e EDCA. By suspending some transmissions, the proposed EDCA/CA can reduce the number of collisions. Because unnecessary retransmissions are eliminated, the energy consumption is reduced. Extensive simulations have been performed to demonstrate the performance of the proposed EDCA/CA. The results show that EDCA/CA can reduce the energy consumption significantly. It reduces frame delay as well when traffic load is heavy. When traffic load is light, the proposed EDCA/CA will slightly increase the video delay, which in general is still acceptable. Furthermore, the proposed EDCA/CA is simple and easy to implement. It is fully compatible with the 802.11e EDCA. It is both effective and practical.**

***Index Terms*—IEEE 802.11e EDCA, energy efficiency, QoS, wireless LANs, multiple access protocol.**

I. INTRODUCTION

WIRELESS Local Area Networks (WLANs) provide economical and convenient wireless Internet access. With the rapid expansion of IEEE 802.11 WLANs, various products and services are growing tremendously. However, there are still many challenges for WLANs, especially for the emerging multimedia services. Among the key challenges are how to guarantee Quality of Service (QoS) and how to conserve energy. Comparing with traditional text-based data services, multimedia services usually exhaust much more energy and require more stringent QoS guarantees.

The medium access mechanism adopted in IEEE 802.11 is known as *Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA)*. The CSMA/CA is distributed and contention-based. Every 802.11 wireless station with frames to send must contend with other stations. The contention-based multiple access is inefficient when traffic load is heavy. The QoS will be hard to guarantee. Besides, it will exhaust energy very soon due to numerous retransmissions. The problems are even exaggerated for real-time services.

To improve QoS in IEEE 802.11 WLANs, the IEEE 802.11e [1] has defined *Hybrid Coordination Function (HCF)*, which comprises *HCF Controlled Channel Access (HCCA)* and *Enhanced Distributed Channel Access (EDCA)*. The EDCA aims to enhance the Distributed Coordination Function (DCF) defined in the original 802.11 Medium Access Control (MAC). Service streams are classified into different *Access Categories (ACs)* with different parameters. The EDCA could successfully prioritize different traffic. By setting proper parameters, higher-priority traffic will more likely win the channel access than lower-priority traffic. The EDCA is still distributed in nature. It is compatible with existing 802.11 standards. Based on the simulations we have conducted, we observe that EDCA can greatly reduce the transmission delay for *high-priority traffic* when comparing with DCF. However, high-priority traffic such as video or voice usually generates large amount of packets. Thus, traffic load is heavy. When traffic load is heavy, EDCA still suffers from intensive contentions. Due to frequent retransmissions, it increases energy consumption. This will exhaust battery power very soon. Although EDCA can reduce the transmission delay for high-priority traffic, energy consumption should be considered as well.

In our earlier paper [2], we proposed to incorporate *Contention Adaption (CA)* into EDCA to enhance it with *energy efficiency*. The proposed mechanism is called *EDCA/CA*. The basic idea is to monitor the *contention level*. When the contention level is higher than a threshold, the *contention adaption* mechanism is triggered to alleviate the contention. It dynamically defers the transmissions of some traffic. Therefore, the number of collisions in the system is reduced. However, the earlier proposed protocol cannot measure the contention level very precisely. Hence, the saving in energy is not that significant. In this paper, we present the new version of EDCA/CA, which is more accurate in the measurement of contention level. It can utilize channel efficiently and conserve more energy. Although some transmissions are deferred, the EDCA/CA[1] will not incur too much extra delay. Our simulations show that when the traffic load is heavy, the frame delay in EDCA/CA is even reduced. It can keep the original QoS differentiation and is fully complied with 802.11e EDCA. The proposed EDCA/CA is still distributed and does not need any help from Access Points (APs). In addition, it is simple and easy to implement.

The rest of this paper is organized as follows. Section II reviews the 802.11e EDCA. Section III presents the related work. Section IV discusses the proposed *EDCA/CA*. Simulation and numerical results are presented in Section V. Section VI summarizes the paper.

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[1]In the rest of the paper, we refer EDCA/CA to the new version of the protocol unless it is explicitly specified.

II. Overview of 802.11e EDCA

The IEEE 802.11 DCF is a distributed MAC protocol. A station needs to listen to the channel before it can transmit. If the channel is idle longer than *Distributed Inter-Frame Space (DIFS)*, the station can grasp the channel and initiate the transmission immediately. If the channel is busy, on the other hand, the station needs to wait until the channel becomes idle again longer than DIFS. It then starts *backoff process*. The station will randomly choose a number between 0 and the *Contention Window (CW)* as its initial backoff timer. The backoff timer elapses when the medium is idle. If the medium becomes busy anytime during the backoff process, the backoff timer is frozen until the channel is idle longer than DIFS again. The station can transmit only until the backoff timer expires. In DCF, all stations have equal opportunity in channel access.

The 802.11e EDCA [1] is similar to DCF. However, EDCA differentiates traffic into four *Access Categories (ACs)*. They are *AC_VO* (for voice traffic), *AC_VI* (for video traffic), *AC_BE* (for best-effort traffic), and *AC_BK* (for background traffic). *AC_VO* possesses the highest priority, while *AC_BK* is with the lowest priority. Each AC has its own queue and parameter set. The EDCA parameter set includes *minimum Contention Window size* (CW_{min}), *maximum Contention Window size* (CW_{max}), *Arbitration Inter-Frame Space (AIFS)*, and *Transmission Opportunity limit (TXOPlimit)*. CW_{min} and CW_{max} determine the CW size. CW is set as CW_{min} at the very beginning. A failed transmission will double CW until it equals CW_{max}. A successful transmission will reset CW to CW_{min}. Instead of DIFS, a station needs to defer for $AIFS$. Therefore, smaller CW_{min}, CW_{max}, and $AIFS$ will lead to a better chance of gaining the medium. That is, the priority is higher.

In EDCA, if a frame is transmitted successfully, successive frames in the same AC queue are allowed to be transmitted continuously within the time limit defined by $TXOPlimit$ without contention. This is called *Contention Free Burst (CFB)*. Comparing with DCF, in which only one transmission is permitted, the *CFB* in EDCA can improve medium utilization because contention is reduced.

III. Related Work

The IEEE 802.11e has drawn numerous research interests. Here we simply discuss few of them. The numerical results in [3] show that $AIFS$ can provide substantial discrimination among different *ACs*. The throughput of DCF and EDCA is compared in [4]. The paper concludes that *EDCA CFB* can produce better throughput. According to [5], data dropping rate is significantly reduced if *CFB* is adopted. This is because *CFB* could mitigate contention. The impacts of certain parameters such as frame size and mobility on the system throughput are discussed in [6]. Based on the simulation results, although the mobility of one station might affect the throughput in DCF, *CFB* would not degrade the performance of EDCA much. References [7] and [8] present analytical models of EDCA. They target on the saturation throughput analysis. An analytical model of EDCA in finite load conditions is presented in [9]. The paper concludes that the delay of high priority ACs can be minimized. However, the delay of lowest priority class is increased significantly. There are also some other papers discussing EDCA. Due to space limitation, we are unable to list all of them. Most of them focus on delay and throughput analysis. In addition to QoS differentiation, we consider energy conservation as well. To mitigate contention level by reducing unnecessary retransmissions, Call Admission Control (CAC) [10]–[12] can also be used. CAC aims to limit the number of sessions before they are admitted into the network. The proposed EDCA/CA, however, considers how to reduce unnecessary transmissions after sessions have been admitted. In addition, most CAC algorithms require AP to coordinate the process. In our proposed EDCA/CA, however, the protocol does not need any assistance from APs.

IV. Proposed EDCA/CA

As mentioned above, because EDCA is contention-based, stations would suffer from serious collisions when traffic load is heavy. This is especially crucial for multimedia traffic which normally generates a large amount of traffic. Meanwhile, energy which is critical for portable devices is wasted due to frequent retransmissions. Our objective is to design a method which can reduce the energy consumption without degrading the QoS in EDCA. In addition, the proposed technique must fully comply with current standards. It should be easy to implement as well. Same as that in EDCA, the proposed protocol should be still distributed in nature. It should not need any assistance from APs.

The basic idea of the proposed EDCA/CA is to pause some transmissions when traffic load is heavy. It will suspend some contentions to alleviate the system load. We call this as *Contention Adaption (CA)*. Contention adaption reduces the number of collisions, which in turn reduces the energy consumption because unnecessary retransmissions are eliminated. Intuitively, frame delay may be increased due to the delay of transmission. However, a frame will get more chance to be transmitted successfully when collisions are reduced. Therefore, it potentially will reduce the frame delay as well. Section V will quantify the delay and energy consumption.

In our earlier proposed EDCA/CA [2], it calculates the *queuing delay* of each traffic class continuously. It then regards the calculated value as a measurement of *contention level* to trigger the CA mechanism. Based on our profounder study, we found that *queuing delay* cannot predict the contention level very precisely. The reason will be discussed in Section V. Instead, *collision probability* can be easily measured and precisely reflect the contention level. Each station simply keeps tracking the number of channel accesses and records the number of collisions. The collision probability then can be derived as follows:

$$P_{collision} = \frac{N_{collision}}{N_{access}} \quad (1)$$

where N_{access} is the number of channel accesses, and $N_{collision}$ is the number of collisions among N_{access}. The station works in normal EDCA operation initially. After each channel access, the station updates the $P_{collision}$. Only previous n accesses are included for the calculation. Older accesses and collisions are discarded. If $P_{collision}$ is larger than a predefined threshold, $P^{begin}_{threshold}[AC]$, the transmission of the AC is temporarily suspended, where AC can be *AC_VO* or *AC_VI*. That is, *AC_VO* and *AC_VI* can have different thresholds. Frames then are accumulated in the queue. We call this as the start of the *CA phase* of the AC. On the other hand, the AC will go back to normal operation if $P_{collision}$ is less than $P^{end}_{threshold}[AC]$. This is called the stop of the *CA phase*. In order to make it stable, $P^{end}_{threshold}[AC]$ should be smaller than $P^{begin}_{threshold}[AC]$. During the CA phase, *AC_BE* and *AC_BK* are not allowed to transmit any frame. On the other hand, *AC_VO* or *AC_VI* can transmit frames only when the total number of bits accumulated in its queue is larger than $BITaccumulation[AC]$, where AC can be *AC_VO* or *AC_VI*. That is, *AC_VO* has its own $BITaccumulation$, so does the *AC_VI*. To take advantage of the *CFB*, $BITaccumulation[AC]$ should be related to $TXOPlimit$. Therefore, we define $BITaccumulation[AC]$ as follows:

$$BITaccumulation[AC] = \frac{TXOPlimit[AC] \times R_{transmission}}{C} \quad (2)$$

where $R_{transmission}$ is the transmission rate. C is a constant which is larger than or equal to 1. $TXOPlimit[AC] \times R_{transmission}$ is the maximum number of bits that can be transmitted in a $TXOPlimit$ duration. $BITaccumulation[AC]$ represents how many bits should be accumulated in the *AC* queue. After accumulating $BITaccumulation[AC]$ bits in the queue, the *AC* begins to contend the channel for frame transmissions. Because there might be still some frames arriving into the queue when the *AC* is contending for the channel, C should be set larger than or equal to 1. Otherwise, it may not be able to transmit all frames in the queue within one CFB. In CFB, multiple frames can be transmitted continuously without contention. In addition, the transmissions of *AC_BE* and *AC_BK* are suspended. Therefore, the number of collisions is reduced. Eventually, $P_{collision}$ will be less than $P^{end}_{threshold}[AC]$. The AC then goes back to normal EDCA operation.

V. Performance Evaluation

We have conducted extensive experiments by using *Network Simulator – version 2 (ns-2)*. In simulation, there was one *QoS Access Point (QAP)* which connected to several wireless *QoS Stations (QSTAs)*. QAP and QSTA are QoS-capable devices which are defined by 802.11e. QSTAs were the traffic sources. The wireless radio was 802.11b. The QAP also connected to a static station, which was the destination, by a 100 $Mbps$ Ethernet link. The destination station served as a sink which received the traffic generated from all of the QSTAs. Table I summarizes the parameters used in the simulation. The parameters were mainly obtained from 802.11 and 802.11e standards. The power consumed on transmit, receive, and idle modes were set to 1.65 W, 1.4 W, and 1.15 W, respectively [13].

Due to space limitation, we only present two sets of simulation results. In the first set of experiments, we aim to see the impact of $P^{begin}_{threshold}[AC]$. The objective of the second set is to see how does the parameter C affect the performance. In this paper, we emphasize on voice and video because they have more stringent QoS requirements. Besides, the CFB can only be used for voice and video traffic as that defined in 8021.11e. In simulation, we varied the number of QSTAs. Each QSTA generated one voice flow and one video flow. The data rates of voice and video were 64 $Kbps$ and 400 $Kbps$, respectively. The voice was modeled as on-off traffic. The video generated constant bit rate traffic.

TABLE I
System parameters

Parameter	Value	Parameter	Value
PHY	DSSS	bandwidth	11 Mbps
slot time	20 us	SIFS	10 us
TXOP[AC_VO]	3.264 ms	TXOP[AC_VI]	6.016 ms
TXOP[AC_BE]	0 ms	TXOP[AC_BK]	0 ms
CW_{min}[AC_VO]	7 slots	CW_{max}[AC_VO]	15 slots
CW_{min}[AC_VI]	15 slots	CW_{max}[AC_VI]	31 slots
CW_{min}[AC_BE]	31 slots	CW_{max}[AC_BE]	1023 slots
CW_{min}[AC_BK]	31 slots	CW_{max}[AC_BK]	1023 slots
AIFS[AC_VO]	50 us	AIFS[AC_VI]	50 us
AIFS[AC_BE]	70 us	AIFS[AC_BK]	150 us

The first set of simulation results are presented in Figs. 1–3. Because voice cannot tolerate high delay, we should set $P^{begin}_{threshold}[AC\_VO]$ higher than or equal to $P^{begin}_{threshold}[AC\_VI]$. Therefore, when system load is heavy, video traffic will suspend transmissions earlier than voice traffic. Fig. 1 illustrates the energy consumption of EDCA and the proposed EDCA/CA with different parameters. In the figure, $P^{begin}_{threshold}[AC\_VO]$ is set to 0.6. $P^{begin}_{threshold}[AC\_VI]$ varies from 0.4 to 0.6. In the simulation, C was set to 2. $P^{end}_{threshold}[AC]$, including *AC_VO* and *AC_VI*, was set to $P^{begin}_{threshold}[AC]-0.1$. Why C was set to 2 will be explained in the second set of experiments. Based on our simulation study, we found that the choice of $P^{end}_{threshold}[AC]$ is not that critical because it simply determines when the CA phase should stop. $P^{begin}_{threshold}[AC]$ and C are more important because they decide the trigger point of the CA phase, and how long an AC should be suspended. Based on our extensive simulations, we found $P^{begin}_{threshold}[AC] - 0.1$ is a reasonable choice for $P^{end}_{threshold}[AC]$.

Fig. 1 shows that when $P^{begin}_{threshold}[AC\_VI]$ decreases, the energy consumption is reduced. This is because smaller $P^{begin}_{threshold}[AC\_VI]$ implies that video will start CA phase earlier. The contention adaption reduces the number of collisions, which in turn reduces the energy consumption because unnecessary retransmissions are eliminated. Fig. 1 also shows that comparing with the original EDCA, the energy is always reduced when $P^{begin}_{threshold}[AC\_VI]$ equals to 0.5 and 0.4. When $P^{begin}_{threshold}[AC\_VI]$ is equal to 0.6, the energy is reduced only when the number of QSTAs is greater than 10. This is because when $P^{begin}_{threshold}[AC\_VI]$ is larger, the CA phase will start later. That is, when traffic load is light, there is almost no CA phase. Therefore, the QSTAs almost operate the original EDCA. Fig. 1 shows that, when $P^{begin}_{threshold}[AC\_VI]$ is equal to 0.4 and 0.5, the energy saved is proportional to the number of QSTAs. This is because when the load is heavy, EDCA will waste a lot of energy in retransmissions. The