CHAPTER 1

INTRODUCTION

The wireless access network makes people enjoy the convenience of accessing the information freely, and supports the mobility for people acquiring the information in the moving regardless of where they are. Cellular network is the well-known wireless access network since 1960. However, the bandwidth of the cellular network is the bottleneck to provide specific services that need a great amount of bandwidth. Cellular network provides only voice transmissions in the early years, and now can provide simple multimedia data, such as images and icons. The transmissions of multimedia data such as video and bulk data should be further concerned because of the scarce bandwidth. Nowadays, the wireless local area network (WLAN) technologies have become mature and can provide much larger bandwidth than cellular network. In addition, the easy installation of the WLAN is also an attractive reason to use it.

The IEEE 802.11 wireless local area network (WLAN) can offer high data rates through IEEE 802.11a and IEEE 802.11b technologies [5], and the medium access control (MAC) protocol plays an important role in the service efficiency. The performance of the 802.11 MAC has been studied in [3][8][9][10].

Recently, many papers and the IEEE 802.11 task group E address several schemes [1][2][6][11][12][13] to enhance the IEEE 802.11 MAC protocol and to support service differentiation. These schemes include scaling the backoff contention window, assigning different interframe spaces (IFS), and assigning different frame sizes according to the traffic priorities. In [9], the conventional DCF with different combinations of minimum contention window (CWmin) and maximum contention window (CWmax) are simulated. The results show: (i) there is a tradeoff between the CWmin parameter and the number of the mobile stations (STAs) contending for the medium, and (ii) the CWmin parameter has a great influence on the performance. In [1], three schemes mentioned above are discussed and simulated through transmitting UDP and TCP flows. And, the authors recommend that the assigning different IFS scheme is the most suitable approach to provide service differentiation among the three schemes. The IEEE 802.11 DCF has been analyzed in [3] using the Markov model. In [10], by deriving an analytical model, the authors quantify the maximum protocol capacity, which referred to as a theoretical limit, by tuning the window size of the IEEE 802.11 backoff scheme.

In this thesis, we emphasize how to improve the performance of the 802.11 MAC protocol. We present a *Priority-Based Contention Control* (PCC) scheme to well manage the contention for the medium among the wireless stations (STAs) in the IEEE 802.11 wireless LAN. In the PCC scheme, each STA will listen to a *Priority Limit* (PL) sent by the access point (AP) or a STA to determine whether it is permitted to contend for the medium. That is, a STA is allowed to contend for the medium only when the STA has a traffic flow whose priority is larger than the PL value. Those STAs which are permitted the channel contention will also adjust their contention window (CW) sizes according to the values of the traffic priority and the PL. A high-priority traffic flow will get a high probability to win the contention. Moreover, a STA will dynamically adjust the CW size according to the colliding situation during the contention.

The PCC scheme has the following advantages: providing service differentiation among the traffic flows with different priorities and easing off the serious collisions in high traffic loads.

The remainder of this thesis is organized as follows. In Chapter 2, we introduce the related works and background, which includes the IEEE 802.11 access schemes and some service differentiation approaches. The PCC scheme is deeply introduced in Chapter 3. Chapter 4 presents the network configurations and simulation experiments, and finally Chapter 5 concludes the thesis.

CHAPTER 2

RELATED WORKS AND BACKGROUND

Several protocols for WLANs, such as IEEE 802.11 [5], HIPERLAN 1/2 [16], and Bluetooth [19], have established their standards to define the essential components and characteristics. All of them have their own protocol and objectives, thus incompatible occurs while portable and mobile devices roaming between different areas in which different protocol and appliances are equipped. IEEE 802.15 Wireless Personal Area Network (WPAN) is organized to deal with the issues of coexistence and interoperability between portable and mobile devices and other wired and wireless networking solutions. And, IEEE 802.15 WPAN Task Group 1 (TG1) specifies how the IP protocol can be used on top of Bluetooth. This is another solution for the devices to transparent roaming between heterogeneous networks.

In this thesis, we concentrate on the study of the IEEE 802.11 DCF access scheme. We show some related service differentiation schemes that are proposed in literature and corresponding advantages and disadvantages. Also, the IEEE 802.11 protocol is briefly described in the following.

2.1. IEEE 802.11 MAC Access Schemes

The MAC access schemes in the IEEE 802.11 standard have *Point Coordination Function* (PCF) for time bounded data transmitting and *Distributed Coordination Function* (DCF) for contention based data transmitting. Figure 1 depicts the IEEE 802.11 MAC architectures. DCF is the basic transmission scheme for IEEE 802.11 and is based on the carrier sense multiple access with collision avoidance (CSMA/CA) protocol. PCF is an alternative access scheme, which contains a point coordinator using a polling scheme to determine which STA has the right to transmit. Figure 2 shows the PCF channel access scheme. In PCF, the wireless medium is composed with a periodic interval called *SuperFrame*. The SuperFrame can further decomposed into two fold: Contention Free Period (CFP) and Contention Period (CP).

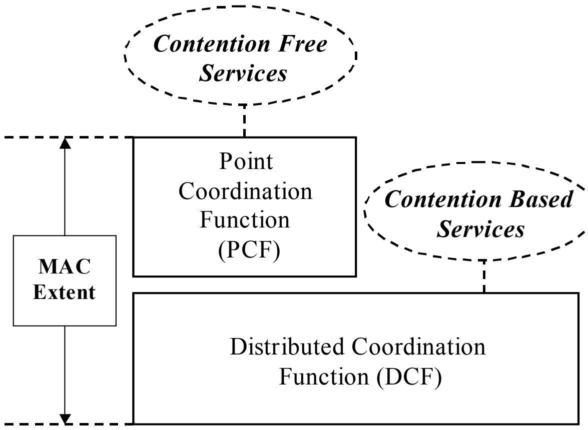


Figure 1. IEEE 802.11 MAC architecture

In the CFP, medium is dominated by access point (AP) using a polling scheme, which is not specified in the standard. STAs who have attempts to transmit in this period have to join the polling list maintained by AP, and AP uses a polling scheme to serve the STAs listed in the polling list. The beginning of the CFP always comes with a beacon frame being a *Delivery Traffic Indication Message* (DTIM) at the *Target Beacon Transmission Time* (TBTT), and the CFP repetition interval is defined the duration of the number of DTIM which is the TIM within beacon of setting DTIM count field of 0 every DTIM period. In the end of the CFP, AP would send a frame called CFP-end to announce the end of CFP to the STAs in the basic service set (BSS). Meanwhile, CF is starting and medium is accessed randomly as same as DCF. In DCF, the wireless medium is randomly accessed by STAs according to the rules of CSMA/CA.

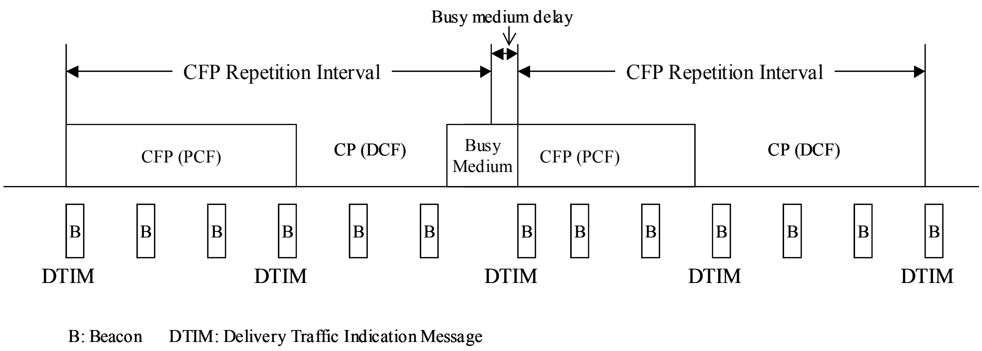


Figure 2. PCF channel access scheme

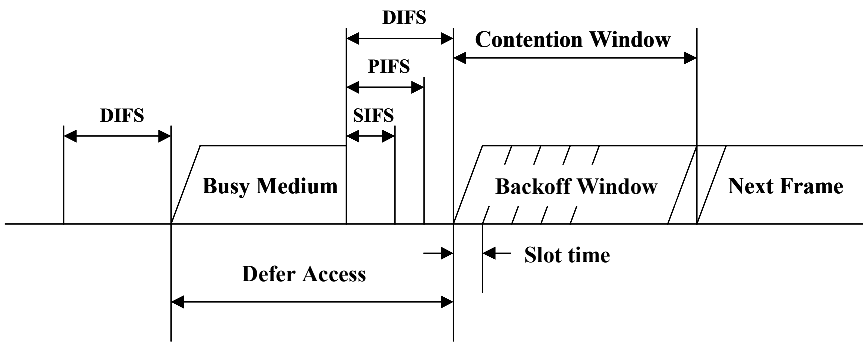


Figure 3. IEEE 802.11 channel access scheme

Figure 3 shows the channel access scheme of the IEEE 802.11.The IEEE 802.11 MAC protocol uses different IFSs to determine how long the idle time a STA has to wait before initialize a backoff procedure whenever a STA desires to transmit a frame or when a STA suffers a failed transmission. The backoff procedure adopted in the IEEE 802.11 standard is the well-known *Binary Exponential Backoff* scheme [5]. The IEEE 802.11 standard defines four types of IFS, which are Short IFS (SIFS), PCF IFS (PIFS), DCF IFS (DIFS), and Extended IFS (EIFS). And the time relevance among those IFS is SIFS < PIFS < DIFS < EIFS.

IEEE 802.11 standard has defined the backoff procedure [5]. The backoff procedure is invoked whenever a STA desires to transmit a frame or when a STA suffers a failed transmission. STA has to set its backoff window in a random basis before beginning the backoff. Equation 1 is used to calculate the backoff window. The backoff window is counted in the unit of the slot, and it can only be decrement if and only if the STA sense the medium idle for the duration of a slot time after the duration of DIFS time period or EIFS time period. If the medium is determined to be busy at any time during a backoff slot, then the backoff procedure is suspended. That is, the backoff window is not decrement for that slot. Transmission commences whenever the backoff window reaches zero.

$$Backoff\ Window = Random(\ ) \times Slot\_Time \tag{1}$$

Where *Random*( ) is a pseudo random integer uniformly distributed over the interval [0,CW-1], where CW is an integer within the range of values of the CWmin and CWmax.

2.2. Real-Time Communications

Real-time communications have become the main issues in the data communication networks, which is opposite to the telephony communication networks. Internet is the well-known data communication network, which provides the best-effort transmission for all kinds of traffic. This is therefore an enormous impact to transmit real-time traffic in the existing best-effort environment.

Universal Mobile Telecommunication System (UMTS) [4] defines the Third-Generation standards. The standards include four service classes for different characteristic of traffic in the communication network, which are Conversational class, which for time constraint traffic like voice; Streaming class, which for delay variance constraint like real-time video; Interactive class, which for round-trip time delay constraint like telnet and web browsing. The last one is Background class, which has no constraints.

Under the best-effort based transmission policy, to provide quality of service rather than best-effort service are indeed a crucial issue. Although the IEEE 802.11 standard provides PCF to support time-bounded traffic, however, it is not widely to be implemented in most of the WLAN cards due to its complexity. Also, despite the PCF provides CFP and CP for both time constraint traffic and best-effort traffic, it has been shown the inefficiency and causes the performance to be degraded in many literature.

2.3. Service Differentiation Schemes

Many literature and IEEE 802.11 Working Group E have proposed several schemes to provide service differentiation in the MAC and/or radio layer to enhance the conventional PCF and DCF [1][2][6]. We particularity emphasize the enhancement of the conventional DCF. The enhanced schemes include scaling the backoff contention window, assigning different interframe spaces (IFS), and assigning different frame sizes according to the traffic priorities. We give a brief survey in the following subsections.

2.3.1 Adaptive Backoff Contention Window Differentiation Approaches

In [9], the conventional DCF with different combinations of minimum contention window (CWmin) and maximum contention window (CWmax) are simulated. The results show: (i) there is a tradeoff between the CWmin parameter and the number of the STAs contending for the medium, and (ii) the CWmin parameter has a great influence on the performance. In [11], the modified backoff algorithm is proposed in ad hoc networks to support service differentiation. Three classes are used, which are Gold, Silver, and Bronze. Each of them is assigned a range of the contention window after a collision. The contention window is divided into three portions and controlled by two parameters, but the adjustment of the two parameters is not mentioned. This is not practical because those parameters dominate the performance of the wireless environment. T. Ozugur [12] presented the hierarchical backoff algorithm and the weighted-hierarchical backoff algorithm in ad hoc networks. Hierarchical backoff algorithm divides the backoff window into several branches according to the number of logical connections of the neighbor nodes. Hierarchical backoff algorithm has the drawback when there is large variation of the logical connections among the neighbor nodes, and causes some branches to be wasted. Weighted-hierarchical backoff algorithm is issued to address this drawback. Weighted-hierarchical backoff algorithm uses the logical connections within a node as the index, and uses this index and the indices of the neighbor nodes as the weight to calculate the desired portion of the backoff window. Weighted-hierarchical backoff algorithm causes some idle slots between stations with different logical connections. This is the drawback because the wireless medium is limited and scarce.

L. G. Martinez, B. Jafarian, and H. Aghvami [13] proposed a splitting algorithm in a wireless ATM environment, which is a popular research field being studied in the last years, and the MAC protocol is based on the Packet Reservation Multiple Access (PRMA) [14]. Multiple subsets are used to represent the set of different classes. In the beginning of the transmission, all users will be induced into subset 1. In case of collision, the users who are included in subset 1 with class level 1 (the highest) will retransmit in the next slot with probability p_1, and the others (includes all the remain users) are induced into subset 2 will retransmit with probability $1-p_1$ in the next slot. If the users in the subset 2 occur a collision again, they will be further divide into subset 3 and subset 4 with respective retransmit probability p_2 and $1-p_2$, and so on. Retransmission will continue until all the collisions are solved. However, the splitting algorithm will suffer serious collisions when there are lots of stations in a subset, especially when there are lots of stations in a class.

2.3.2 Differential Inter-Frame Spaces (D-IFS) Differentiation Approaches

As mentioned before, IFS is used to determine how long the idle time a STA has to wait before initialize a backoff procedure whenever a STA desires to transmit a frame or when a STA suffers a failed transmission. Therefore, the characteristic can be applied for the purpose of service differentiation. If a packet in a STA waits a shorter IFS time, then it has higher probability to be prior transmitted than other packets that wait a longer IFS time. Figure 4 shows the diagram of this approach where D-IFSi means the Inter-frame space of $class_i$ that has to wait before performing backoff procedure.

In order to efficiently differentiate service for distinct classes, the IFS distance between any two (consecutive) D-IFS as shown in Figure 5 is a considerable issue for designing and implementing the approach. A fixed and large IFS distance would suffer degradation of throughput whenever there are only low priority classes inside the serving area, and a small IFS distance would suffer the confusion of service differentiation. Thus, a more adaptive scheme should be involved to accommodate all cases.

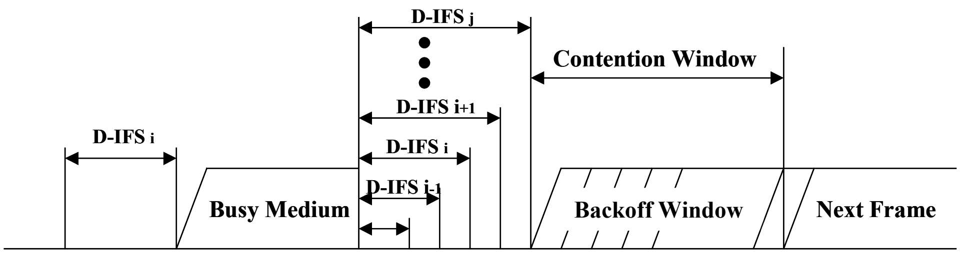


Figure 4. Differential IFS approach for service differentiation.

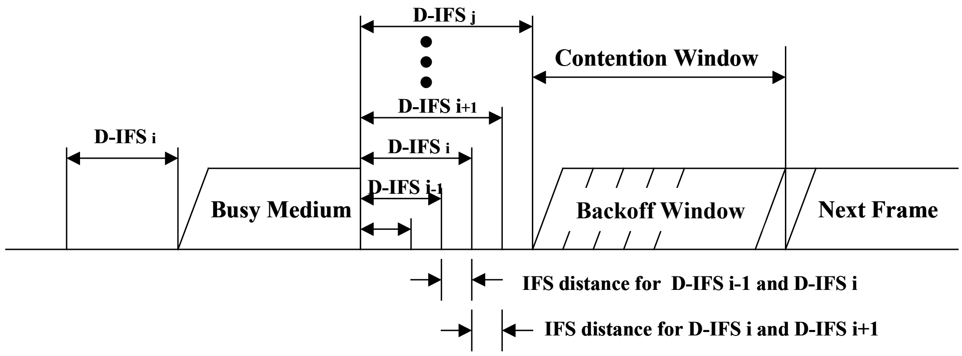


Figure 5. The IFS distance between two (consecutive) D-IFSs.

2.3.3 Differential Frame Size Differentiation Approaches

Under the CSMA/CA protocol in a shared medium, every STA has same probability to successfully contend for the medium when there are packets pending. Once a STA successfully transmit a frame with bulky payload, it would gather higher throughput as well. Hence, every frame can be considered owning a certain successful transmission probability equally likely with others. Thus, under the hypothesis, to distinct different level of service can be done if we assign different frame size to different priority. Therefore, in order to achieve service differentiation, we have to lengthen the frame size for high priority classes. For a given STA_j, the throughput T_j and the frame size L_j compare with the total throughput and frame size in a wireless environment with N STAs can be seen in Equation 2.

$$\frac{T_j}{\sum_{i=1}^{N} T_i} = \frac{L_j}{\sum_{i=1}^{N} L_i} \tag{2}$$

However, the status of the wireless medium is error prone, and time varying. It would suffer from higher violation probability for high priority frames due to theirs lengthily size. The *bit error rate* (BER) is proportional to the frame length and the *frame error rate* (FER) for a given STA_j is formularized in Equation 3.

$$FER_j = 1 - (1 - BER)^{L_j} \tag{3}$$

In fact, this is not practical because the high priority classes like voice and videoconference do not generate large frame at a time [4][7] and it is hard to guarantee the QoS profile of each class owing to the probabilistic medium access scheme.

CHAPTER 3

PRIORITY-BASED CONTENEION CONTROL SCHEME

To enhance the performance of the IEEE 802.11 WLAN, we present a Priority-Based Contention Control (PCC) scheme to well manage the contention for the medium among the STAs. PCC has capability to achieve service differentiation and to support real-time traffic transmission in the wireless environment. In the PCC scheme, each STA will listen to a *Priority Limit* (PL) sent by the access point (AP) or a STA to determine whether it is permitted to contend for the medium. That is, a STA is allowed to contend for the medium only when the STA has a traffic flow whose priority is larger than the PL. Those STAs which are permitted the channel contention will also adjust their contention window (CW) sizes according to the values of the traffic priority and the PL. A high-priority traffic flow will get a high probability to win the contention. Moreover, a STA will dynamically adjust the CW size according to the colliding situation during the contention. The PCC scheme can work with or without the centralized control of the AP, and are called PCC_AP and PCC_NAP, respectively. In the PCC_AP, AP has the global information about the amount of active flows in all STAs served by AP; therefore, AP can limit the number of contending flows by announcing an appropriate PL to the STAs. In the PCC_NAP, the responsibility for announcing the PL relies on the STA currently having frame transmissions on the channel.

During a frame exchange sequence, the PL is attached with each transmitted frame (RTS, CTS, MPDU, or ACK frame). We use the last 3 bits of the Duration field in the frame header to store the priority value from 0 to 7. That is, we modify the duration time into a new one, which is larger than and close to the original one and whose last 3 bits preserve the priority value. Since the redundant time duration is small, the system performance will not be affected largely. To avoid STAs misinterpret the PL sent by a STA without PCC support, each STA with PCC support will set the More Data field in each transmitted frame header. The STA with PCC support will ignore the PL containing in those frames whose More Data field is clear. The More Data field is usually used in the polling scheme and in the power saving mode. Its usage is described in section 3.1 in detail. Following, we describe the essential components in the PCC scheme.

3.1. Modified RTS / CTS / MPDU / ACK Frame Formats

Based on the proposal described above, we need to adjust the conventional IEEE 802.11 RTS / CTS / MPDU / ACK frame formats as shown in Figure 6 to meet our requirement. Beside, backward compatible is an important feature while supporting other advance service in the IEEE 802.11 WLAN. Basically, we do not want to create any new frame formats for the PCC scheme. Thus, the conventional IEEE 802.11 STAs would not be confused by the modified frame formats. Based on the reasons we have discussed above, and in order to make sure the *Priority Limit* (PL) to be seen obviously in the specific frame formats, we modify the Duration field in the RTS / CTS / MPDU / ACK frame formats to achieve the goal. Duration field is an important point for STAs who are not transmitting to set their *Network Allocation Vector* (NAV) for a period of time to stop sense the medium, and it is also sensitive for power saving capability. Therefore, the modification should be much careful for those points of views.

Octets:	2	2	6	6	4
	Frame Control	Duration	RA	TA	FCS

(a) RTS frame format

Octets:	2	2	6	4
	Frame Control	Duration	RA	FCS

(b) CTS / ACK frame format

Octets:	2	2	6	6	6	2	6	0-2312	4
	Frame Control	Duration/ ID	Address1	Address2	Address3	Sequence Control	Address4	Frame body	FCS

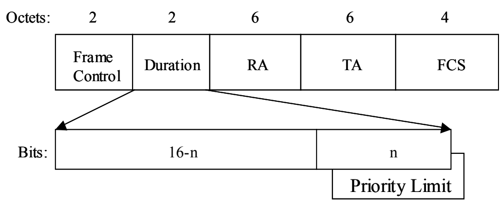
(C) MPDU frame format

Figure 6. Conventional IEEE 802.11 RTS / CTS / MPDU / ACK frame formats. RA is the address of the destination STA, and TA is the address of the STA transmitting the RTS frame (the RA field in the CTS frame is equal the TA field of the RTS frame).

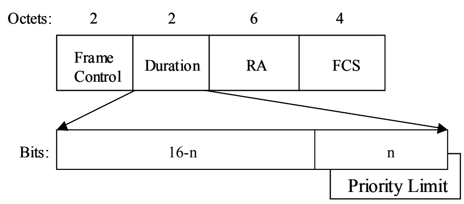
TABLE I
DURATION / ID FIELD ENCODING IN THE IEEE 802.11

Bit 15	Bit 14	Bit 13-0	Usage
0	0 - 32767		Duration
1	0	0	Fixed value within frames transmitted during the CFP
1	0	1-16383	Reserved
1	1	0	Reserved
1	1	1-2007	AID in PS-Poll frames
1	1	2008-16383	Reserved

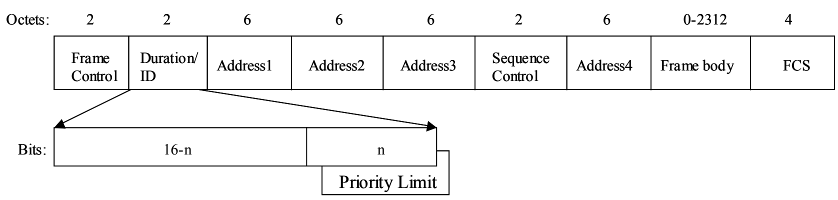
The size of the Duration field is two bytes, and its intentions and usages can be found in TABLE I. In the PCC scheme, the PL is valid in the transmitting frames in which the highest bit (Bit-15) of the Duration Field is zero. The Duration field is inserted value between 0 to 32767 to indicate the duration that other STAs have to wait for this period of time while transmitting, and our modification is to modify this duration value to a new one to show the PL. In our design, we use the last 3 bits for the PL as shown in Figure 7. Under the modification, the PL can be seen clearly and implicitly. And using the last 3 bits would have no effects on the other usages. In the other purpose of the Duration field, the highest bit (Bit-15) would be 1 rather than 0; this is an important point to distinguish the modified frames from the other frames in which the Duration field represents for other usages. Although we reserve 3 bits for the PL and it can represent up to 8 priority classes. However, the desired number of priority classes can be redefined to meet either the standard proposed traffic classes, or the new service classes in the future, e.g., an emergency class. In addition to support variety of classes, the PL has another useful feature described below. By adjusting the PL in the corresponding field will influence the total number of contending flows at the same time. Therefore, the PCC scheme can support soft QoS guarantee for time sensitive and limited time tolerance traffic, like voice and video by restricting the number of contending flows.



(a) RTS frame format



(b) CTS / ACK frame formats



(C) MPDU frame format

Figure 7. Modified RTS / CTS / MPDU / ACK frame formats with n bit of PL.

However, the above modification has a drawback when the adjusted Duration Field is different from the original one. The maximum overhead would be the time difference between the actual (original) timer and the timer adjusted to announce the PL, and the difference would between 0 to 7. The minimum difference is 0 if the actual timer is the same with the PL and the maximum is 7. For example, actual timer is XXX000, and PL is 111, thus the difference is 111(7), where the XXX means the remainder arbitrary bits in the Duration field. We suggest that the adjusted timer must be larger than the actual timer after modification. The reasons for the adjustment are to avoid the possible violation with the ACK frame, and it is fair for all nodes that are overhearing the transmitting frames in the transmission ranges of both the sender and the receiver. By this way, if the actual timer is XXX0111, and the PL is 000, the difference between the actual timer and adjusted timer is 1, rather than 7. The adjusted timer would be XXX1000 instead of XXX0000. The adjustment procedure is presented in Equation 4, where *L* means the last 3 bits (in our design) of the original value in the Duration field, *P* means the PL and *AND* means the Boolean expression. Note that both of them are represented in the binary representation.

$$\begin{cases} L \ \text{ AND } \ P & \text{if } L > P \\ (L \ \text{ AND } \ P) + 2^{\mathrm{n}} & \text{if } L < P \\ \text{No change} & \text{if } L = P \end{cases} \tag{4}$$

For the purpose of backward compatible, we modify the Duration Field in the specific frame formats. Upon this modification, conventional IEEE 802.11 STAs would not be influenced by the PCC aware STAs. However, the conventional IEEE 802.11 STAs may confuse the PCC aware STAs, because the Duration Field is set in their own way. To solve this problem, i.e. let the behavior of the conventional STAs do not influence the PCC aware STAs, we use one bit called More Data field in the

Frame Control subfield in the RTS / CTS / MPDU / ACK frame formats as shown in Figure 8. The usage of the More Date field and the reasons of using it are described below.

More Data field has three usages as defined in the IEEE 802.11 standard [5]. First, More Data field is set to 1 in data or management type frames transmitted by the AP to a STA in power-save mode to indicate that there are at least one MPDU (MAC protocol data unit) or MMPDU (MAC management protocol data unit) at the AP for that STA. Second, The More Data field is set to 1 in data type frames transmitted by a contention free (CF)-Pollable STA to the point coordinator in response to a CF-Poll to indicate that the STA has at least one buffered MPDU. Third, The More Data field is set to 1 in broadcast / multicast frames transmitted by the AP to indicate there are additional broadcast / multicast MPDUs or MMPDUs remain to be transmitted by the AP during this beacon interval.

The More Data field is suitable for the PCC aware STAs to compare the valid PL from the others, from the usage of the More Data field point of view, the More Data field is only used in the infrastructure networks, and it has no meaning in the ad hoc networks. In the first and third usages, the AP controls the value of the More Data field. Therefore, if the capability of the AP (whether PCC aware or not) were known by the STAs in the BSS, then the usage of More Data field would not be confused by all the STAs. This means all the frames sent by the PCC aware AP are valid. The verification of the capability of the AP can be accomplished under the association service. The second usage of the More Data field occurs when the PCF is deployed. However, in this thesis we do not consider the PCF access scheme, thus the usage would not happen. Note that the point coordinator controls the medium domination in the PCF. If the point coordinator were PCC aware station, then the non-PCC aware

STAs under the second usage would have no influence to the PCC aware STAs.

Once the transmitting frame sent by a STA with the More Data field set to 1, other STAs can certainly affirm that the PL is valid; otherwise, STAs would think this frame is sent by a conventional STA and would not interpret it.

Bits:	2	2	4	1	1	1	1	1	1	1	1
	Protocol Version	Type	Subtype	To DS	From DS	More Flag	Retry	Pwr Mgt	More Data	WEP	Order

Figure 8. Frame Control subfield of a control frame.

3.2. AP Behavior

In the PCC_AP, to adapt the inherent wireless characteristic (e.g., mobility) and to support QoS guarantee, AP must have the capability to record the information of the underlying transmitting flows and have the privilege to dominate the medium. On the other hand, the AP can perform the connection admission control (CAC) scheme, which is one of the most important aspects to influence the total quality of service and throughput (we leave it for future reading). In addition to the information of the recorded flows, AP must release an appropriate PL in the corresponding frames. The "appropriate PL" is another important issue that can influence the total throughput by controlling the maximum number of the contending flows. We give some discussion in section 3.4. In summary, AP plays a leading role in the PCC_AP.

3.3. STA Behavior

Every STA in the BSS has responsibility to aware the PL of the transmitted frames whenever there are packets pending for transmission. That is, STAs must realize the PL in the transmitted frames while they have attempts to transmit, and STA should record the PL in a field called PLF locally. After getting wise to both the PL of the transmitted frame (hereafter we call it GPL and the value stored in the PLF is called GPLL for convenience, note that the GPLL must agree with the GPL. This implies that GPLL has to be updated whenever a STA hear a PL inside the transmitted frames), and the priority of the traffic flows inside themselves (hereafter we call them LPLs for convenience), STAs compare GPL with LPLs to determine which flow has higher priority. If one of the LPLs is higher than GPL, then it means that traffic flow in the local queues has higher priority than the permitted PL, and the flow is admitted to contend for the medium in the next contention period, i.e. after this transmitting transmission. On the contrary, if no LPLs are higher than GPL, all of the packets in the queues must be suspended until the STA gets a lower GPL next time. This is because there might be lots of higher priority flows waiting for transmission. Note that in this circumstance, to avoid the misleading GPL suspends all STAs, we assume that each STA has a timer to expire the GPL. If a STA doesn't hear any new GPL after a period of time, it would set the current GPLL to be invalid, and then reset it to the lowest PL. This approach evitable the starving of channel when an error GPL occurs.

3.4. Contention Resolution Scheme

We devise a contention resolution scheme for both the PCC_AP and PCC_NAP. The contention resolution scheme proposed here is based on the differential contention window scheme. Its concept is the same as the IEEE 802.11 DCF to draw the backoff window size randomly over the interval [0, CW-1], and CW is an integer within the range of values betweenof the CWmin and CWmax. The contention resolution scheme of the PCC scheme has the following features (note that the priority classes defined here is that the higher the priority class of a flow is , the higher the priority it has):

i). Each class has a contention window and always different from other classes.

ii). Contention window adjustment is not only adjusted after packet collision, but also adjusted whenever the STA is admitted to contend for the medium.

iii). The higher priority classes retrieve smaller contention window than low priority classes.

iv). For each class, the contention window is dynamically varying according to the GPL and its priority.

Based on the above features, the generation of the contention window is described below.

(a) The relationship between the contention window of a priority class, and priorities of the traffic flows (LPLs) and GPL can be induced as

$$\begin{cases} CW_i \propto GPL. \\ CW_i \propto \dfrac{1}{LPL_i}. \end{cases} \tag{5}$$

Note that the relationship is from the contention window of a specific priority class point of view (CW_i).

(b) By means of the relationship listed in (a), we define an equation to calculate the contention window for each class under different GPL as

$$contention\ window = INT\left(N \times \frac{1}{(LPL - GPLL) + 1} \right), \tag{6}$$

where INT(X) is a ceiling function that generates a smallest integer greater than or equal to X. And N is a scaling factor and we discuss the affection of the value of N in the following.

N is a factor to scale the contention window. However, the higher the N is, the longer the possible waiting time is. On the contrary, the lower the N is, the larger the collision probability is. Hence, the value of N is a tradeoff between the channel throughput and the congestion level. In our design, N has a default value that coincides with the CWmin as defined in the IEEE 802.11 standard. However, we can assign a more suitable value to N by estimating the number of contending flows. In the PCC_AP, we utilize the amount of flows in the BSS to be the fundamental element of considering the scaling factor. AP can estimate this number from the recorded traffic flows and maps the number into N with constraint $S < N < T$. Then AP announces the value of N via the beacon frame or the management frames. This means that AP can change the value of N dynamically to accommodate the number of flows under its serving area. Note that if the amount of flows is large and those flows are uniformly distributed in different class, then the task of mitigates the possible serious collision can be done by attaching the suitable GPL within the transmitting frames. The calculation of contention window is aim to ease off the possible serious collision when there are lots of flows in a class. It is obvious that when there is an abundance of flows in a class and all of them contend for the medium simultaneously, the contention window for that class should be large enough to accommodate such the amount of flows. Therefore, the contention window should be extended (or be shrunk, if there are a few flows in the BSS) dynamically when the amount of flow changes drastically as time goes on. The most common places to see such circumstances are big downtown, restaurants, and airport lounges. The constraint of the range of the value of N gives a stable throughput and channel utilization, and as stated previously, the larger the value of N may cause longer waiting time and the smaller value of N may cause much collisions.

We show the diagram of the relationship between each permitted priority class and their contention window size in Figure 9. The contention windows size is calculated with Equation 6 and the term N is the scaling factor, M means the distance between the highest priority to the PL. For example, support that N is set to 32, and the priority value of each class is between 1 to 10. When PL is 5, the permitted priority classes are 5, 6, 7, 8, 9, and 10, and the contention window sizes for those priority classes are 32, 16, 11, 8, 7, and 6, respectively.

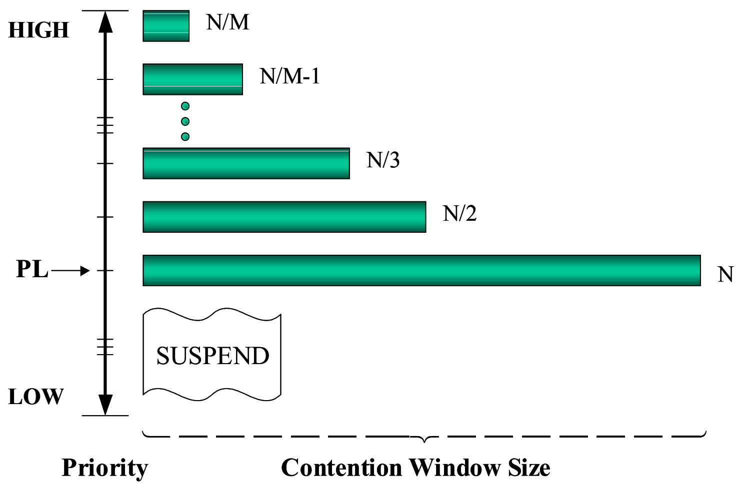


Figure 9. The priority classes and contention window sizes mapping diagram.

We store the PL in the Duration field and the scaling factor N is included in beacon frame or other management frames for the purpose of making no difference with the conventional RTS / CTS / MPDU / ACK frame formats. And the overhead of storing the PL in the Duration field is introduced. In fact, the overhead can be eliminated if the frame formats are designed different from the original frame formats. For example, a field called *Extension Field* (EF), which contains both the PL, and scaling factor information can be inserted in all the frame formats to meet our requirement. However, this modification suffers a serious problem that could not coexist with the conventional IEEE 802.11 devices. Figure 10 depicts the RTS frame format with EF, and EF can be further divided into two fold for PL and scaling factor.

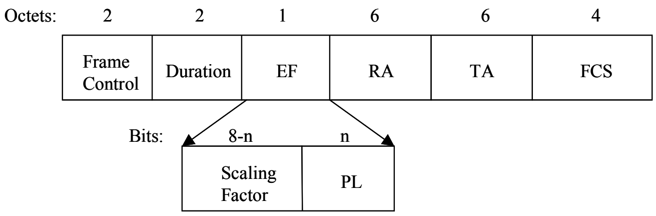


Figure 10. RTS frame format with 1 octet of extension field (EF).

Moreover, to support more conscientious time constraint flows (e.g., soft guarantee), new frame formats can be applied to restrict the specific contending STA. A new field called *Next Accessible Address* (NA) is inserted into the RTS frame format as illustrated in Figure 11. The NA field withdraws the flow of a STA from the BSS (note that the PL still works under this scenario), but the frame formats can only be supported under PCC_AP. More specifically, two important schemes must be used in order to apply the NA field. First, the CAC (Connection Admission Control) has to be deployed; therefore, AP can properly input the next accessible address of a STA who had admitted to transmit time constraint flow at the time. Second, scheduling algorithms have to be invoked. It is necessary for the scheduling algorithm to select the packets of a flow that had granted from the AP to transmit at the time.

Furthermore, the EF and NA fields can coexist in all frame formats (in the PCC_AP) to provide both service differentiation and guarantee of time constraint service.

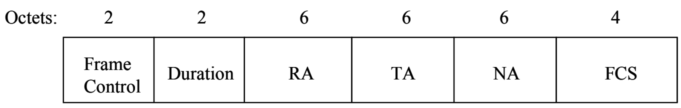


Figure 11. RTS frame format with next accessible address (NA).

3.5. Algorithms

Two algorithms for the contention resolution scheme in the PCC scheme for both the PCC_AP and the PCC_NAP are described below. These two algorithms are (i) basic access algorithm, which is used for the PCC aware STAs to calculate the contention window to contend for the medium, and (ii) collision resolution algorithm, which is used for the PCC aware STAs who are suffering a collision.

In either PCC_AP or PCC_NAP, each STA has to attach its GPLL with the transmission frames. The GPLL must coincide with the GPL, and therefore, the GPLL is relevant to the previous GPL the STA hears. Once a STA successfully contends for the medium, the GPLL of that STA would become the GPL for all the STAs under its cover area. Hence, the GPL is synchronous during every transmission period. In the PCC_AP, each transmission is between the AP and a STA, and the AP records all the flows of each STA under its serving area. Therefore, the AP always controls the GPL, and further, controls the desired amount of contending flows. We describe the basic access algorithm and collision resolution algorithm in the following.

3.5.1 Basic Access Algorithm

First, we discuss the process after a STA receives a GPL from the AP or a STA. Let LPL denote the priority of traffic flow being served in the STA. If LPL < GPL, then the STA is not permitted to contend for the medium. Otherwise, the STA will contend for the medium using the CW size calculated from Equation 6.

Next, we discuss how and when to issue the PL in an environment with and without the AP. In the PCC_AP, each traffic flow is between the STA and the AP. Once a STA wins the contention for the medium, the information (i.e. the number of the traffic flows and the traffic priorities) about the active flows in this STA is also sent to the AP using the piggyback. After a period of time, the AP can roughly conclude the information about how many active flows and their priority distributions under its serving area. Therefore, the AP can calculate a proper PL by this information.

During a frame exchange sequence, the AP uses the Duration field to announce the PL in the CTS and ACK frames for up-stream cases and in the RTS and MPDU frames for down-stream cases, respectively. The corresponding STA will send the same PL in its responding frames. Other STAs will also listen to the PL by tuning into the wireless channel. The PL can only be refreshed during different frame exchange sequences.

In the PCC_NAP, each STA has responsibility to calculate the PL. When a STA is willing to contend for the medium and also determines the channel idle, the STA will start a timer with the length equal to N/2 (in units of slot times), where N is the scaling factor which was discussed in section 3.4. The timeout happens when there is a continuous idle period with its length larger than the one of the timer. The timeout event indicates that there is no underlying traffic flow or there are some traffic flows with longer backoff time. In this case, the STA which is waiting for the GPL sets the GPLL value to the smallest one (i.e. set 1 in our experiments). Otherwise, the STA will detect a traffic flow being transmitted on the channel before timeout. In this case, the STA sets the GPLL value to the one indicated by the transmitted frames. After refreshing the GPLL value, the STA calculates the CW size according to Equation 6 and starts the channel contention. If the STA wins the contention, all of its transmitted frames will include the GPLL value. The destination STA also sends the same PL in its responding frames. It is notable that if the neighboring STAs, including the destination STA, have different GPLL before overhearing the transmitting frames, then after hearing the PL attached in the transmitting frames, they would refresh their GPLLs.

3.5.2 Collision Resolution Algorithm

Now, we discuss the situation when collisions occur. For a real-time traffic, we decrease the CW size by increasing the LPL to LPL+1 in Equation 6 when the first collision occurs. This action increases the probability for the real-time traffic to win the contention, because the CW size of the real-time traffic would be shrunk. Applying this scheme is useful in an environment which supports for multi-class traffic transmission when high priority traffic flows collide with low priority traffic flows. If more than one collision occurs, the CW size is incremental by increasing the GPLL by one for each collision until the GPLL is equal to the LPL. This action avoids a more serious collision occurs. If collisions still occur, we use the binary exponential backoff scheme as specified in the standard to recalculate the CW size. For a non-real-time traffic, the CW adjustment is the same as the real-time one with the case when more than one collision occurs. Hence, in the PCC_NAP, the GPLL value may gradually become larger if collisions occur, and resets to the lowest PL if the timeout event occurs.

The PCC scheme aims at per-flow basis, not per-STA basis. STAs could serve several flows to transmit in one class or multiple classes at the same time. To achieve the class-base fairness among different STAs, we adopt the mechanism that use one queue for one class within STAs and each class (queue) senses and contends the medium independently in logical. This mechanism achieves the fairness, and avoids the bias throughput among the contending STAs when a STA establishes more than one flow in a class to communicate with other STAs or hosts. For instance, a user is browsing the website for his stocks and at the next time he tries to browse news website or something else by opening other browser(s) to achieve his attempts. If we don’t consider the mechanism in such situation, the user would get higher bandwidth than other STAs who browsing only one website at the same time.

Wireless networks provide convenience and efficiency for people to access information remotely and freely. However, the lifetime of the wireless networks is depends on its limited power. Therefore, how to efficiently consume the limited power is another issue for wireless networks. The IEEE 802.11 standard [5] has defined the *Power Saving* mode (PS) and related rules, and other frame formats, such as PS-Poll, for both PCF and DCF. In PCC scheme, STAs have no effect under the conventional environment, i.e. STAs can follow the rules defined in the standard. Furthermore, STAs can extend the rules to make power saving capability more adaptive. By hearing the GPL within the transmitting frames, every STA can roughly measure the congestion level at the time. If the congestion level is measured extremely high by observing the GPL and channel polluted ratio is found awfully in its radio range, the STA could enter the *doze state* for a longer time than tradition ones even if there are flows pending for transmission (the flows have lower priorities than permitted priority) and even if they do not inform the AP (in the case that there are flows destine to the STA is still ongoing, then the STA would not be able to enter doze state). The announced GPL within the transmitting frames is the index about how many flows currently are permitted to transmit and this value would be more convinced in the PCC_AP in which the selection of the GPL is in an accumulative manner across different classes according to the number of flows recorded in the AP. Therefore, if a STA hears a GPL is much higher than its LPLs, there may be a certain amount of flows are waiting for transmission. Thus, the STA could take a longer sleeping time to avoid waiting for those flows with higher priorities.

3.6. Analysis

The IEEE 802.11 DCF has been analyzed in [3] using Markov model in which the collision probability, p, in any slot is independent of the history of each STA. A parameter τ in [3] can be inferred to as the access probability of each STA in any slot.

It is notable that the parameter τ is inferred from the regular contention window size as specified in the IEEE 802.11 standard. In [10], by deriving an analytical model, the authors quantify the maximum protocol capacity, which referred to as a theoretical limit, by tuning the window size of the IEEE 802.11 backoff procedure. The access probability in a slot for each STA can be considered as the well-known *p-persistent* protocol which is called *1-persistent* protocol in the Ethernet.

We infer the collision probability for the PCC scheme. The collision probability p in a slot is inferred by using the access priority τ_i of each priority class. The access priority τ_i can be sampled from $\frac{1}{E[B_s]}$.

B_s means the set of contention window sizes used by a packet when it suffers a collision before a successful transmission and $E[B_s]$ is the average value of the set Bs. In [10], the value of $E[B_s]$ is shown by using the average contention window size.

The collision probability p_c of the conventional DCF can be formalized in Equation 7 with the access probability τ.

$$p_c = 1 - (1-\tau)^{n-1} \tag{7}$$

On the other hand, the probability of a STA to success transmission which is denoted as p_s is formalized in Equation 8.

$$p_s = n\tau(1-\tau)^{n-1} \tag{8}$$

In the PCC scheme, each priority class has different contention window and different backoff window according to the GPL. Therefore, in order to analyze the PCC scheme, several notation and assumptions are draw out. First, the overall priority classes are within a range of $[PL_{\min}, ..., PL_{\max}]$, every flow must belong to a priority class. Second, the number of flows in each priority class is denoted as n_j, $j \in [PL_{\min},...,PL_{\max}]$, i.e. priority class with priority value i has n_i flows contending for the medium. Thus, the total number of flows in the BSS is notated as n and $n = n_{sum(PL_{\min},PL_{\max})}$, where $n_{sum(PL_{\min},PL_{\max})} = \sum_{m=PL_{\min}}^{PL_{\max}} n_m$. Third, in the PCC scheme, not every flow is permitted to transmit. The permitted priority class PL_{permit}, which is known as the GPL, is decided via accumulative summation of flows from high priority class to low priority class. This implies the number of contending flows can be decreased to a certain amount. Here, we use N_c to express the number of contending flows under the PCC scheme, and $N_c \le n$. It is notable that n may be much larger than N_c. Finally, the access probability of priority class with priority value i is denoted as τ_i.

Now, we use the preliminaries mentioned above to show the characteristics of the PCC scheme. As we know, the access probability of each priority class is different and there may be several priority classes contending for the medium at the same time. Therefore, the collision probability P_{p3c} (it is abbreviated from P_{pccc}) can be formulated as

$$P_{p3c} = \frac{1}{PL_{\max} - PL_{\min}} \sum_{PL_{permit}=PL_{\min}}^{PL_{\max}} \left[1 - \sum_{L=PL_{permit}}^{PL_{\max}} n_L \tau_L (1-\tau_L)^{n_L - 1} \prod_{i \neq L, i \in \{PL_{permit}, PL_{\max}\}} (1-\tau_i)^{n_i} - \prod_{j \in \{PL_{permit}, PL_{\max}\}} (1-\tau_j)^{n_j} \right]. \tag{9}$$

For a given GPL, the success transmission probability P_{pccs} is as following.

$$P_{pccs} = \sum_{L=PL_{permit}}^{PL_{\max}} n_L \tau_L (1-\tau_L)^{n_L - 1} \prod_{i \neq L, i \in \{PL_{permit}, PL_{\max}\}} (1-\tau_i)^{n_i} \tag{10}$$

If the access probabilities of each class are the same as δ, then the probability of a flow to transmit a packet successfully is as following.

$$\sum_{L=PL_{permit}}^{PL_{\max}} n_L \tau_L \left(1-\tau_L\right)^{n_L-1} \prod_{i\neq L, i\in\left\{PL_{permit}, PL_{\max}\right\}} \left(1-\tau_i\right)^{n_i}$$

$$= \sum_{L=PL_{permit}}^{PL_{\max}} n_L \delta\left(1-\delta\right)^{n_L-1} \prod_{i\neq L, i\in\left\{PL_{permit}, PL_{\max}\right\}} \left(1-\delta\right)^{n_i} = \sum_{L=PL_{permit}}^{PL_{\max}} n_L \delta\left(1-\delta\right)^{n_L-1} \left(1-\delta\right)^{n_{sum\left(PL_{permit}, PL_{\max}\right)}-n_L}$$

$$= n_{sum\left(PL_{permit}, PL_{\max}\right)} \delta\left(1-\delta\right)^{n_{sum\left(PL_{permit}, PL_{\max}\right)}-1} = N\delta\left(1-\delta\right)^{N_c-1} \qquad (11)$$

Of course, Equation 11 shows an obvious result when the access probabilities of each class are identical. And, the situation is that the contending flows are only up to N_c, rather than n (note that $N_c \ll n$).

However, in the PCC scheme, the access probabilities are distinct for different priority classes because of the contention resolution scheme. It can be seen that the access probability δ is the lowest permitted PL (equals to the GPL) in the PCC scheme. Therefore, the flows, which are associated with the PL larger than the permitted PL, would have smaller contention window and thus have larger access probability than the flows associated with PL identified with the GPL. Hence, Equation 11 shows the upper bound of the success access probability and it presents the identical access probability of all the permitted contending flows as in the conventional DCF. Although Equation 11 presents the upper bound of the successful access probability, the PCC scheme has the feature that is shown in Equation 12 and this feature makes the service differentiation easily to be come to. Note that P_{pccs_x} is the successful access probability of the priority class with priority x.

$$P_{pccs\_PL_{\max}} > P_{pccs\_PL_{\max}-1} > \ldots > P_{pccs\_PL_{permit}+1} > P_{pccs\_PL_{permit}} \qquad (12)$$

CHAPTER 4

SIMULATION EXPERIMENTS

We carefully setup the simulation environment with C programming language. In our simulation experiments, system configurations and parameters are listed in TABLE II. The wireless channel capacity is up to 10Mbps and the spreading spectrum technology is under *Direct Sequence Spread Spectrum* (DSSS). Other parameters related to DSSS are agreed with the standard recommended values. We assume the wireless channel is in the ideal condition without interference and propagation delay. Also, we assume a STA always has a pending frame to transmit and only initiates a flow at a time. The RTS and CTS handshake mechanism is used to compare the performance without using of them.

TABLE II
SYSTEM CONFIGURATION AND PARAMETERS

Parameter	Value
PHY	DSSS
CHANNEL BIT RATE	10 Mbps
SLOT TIME	20 us
CWmin	Adaptive
CWmax	Adaptive
SIFS	10 us
PIFS	30 us
DIFS	50 us
RTS LENGTH	20 octets
CTS LENGTH	14 octets
ACK LENGTH	14 octets
PAYLOAD LENGTH	Adaptive
RETRY LIMIT	16

4.1 Simulation Results for the Conventional IEEE 802.11 WLAN

Figure 12 shows the simulation results for the conventional IEEE 802.11 DCF with the amount of STAs from 10 to 200. Three scenarios are mainly simulated where the CWmin and CWmax are set to 8 and 256, 32 and 1024, 128 and 1024, respectively. And these scenarios are respectively referred to as DCF(8, 256), DCF(32,1024), and DCF(128,1024). The related literature about adjusting the CWmin and CWmax to assess the performance of the IEEE 802.11 DCF can be found in [5][9]. All of the experiments for the conventional IEEE 802.11 DCF are assumed to have the mean packet payload length of 1000 octets and under an ideal channel. The simulation experiments with RTS and CTS invoked in the transmission is referred to as DCF(8,256,R/C) opposite to DCF(8,256), for instance.

Figure 12(a) presents the throughput of the conventional DCF access scheme. We measure the aggregate throughput in ten megabits per second. The throughput degradation rapidly when there are plenty of STAs, especially in the case of DCF(8,256). Small contention window makes the STAs more aggressive to contend for the medium. In the case of few STAs in contention, small contention window reduces the possible backoff window size and long idle time. Thus, a better throughput is generated. On the contrary, however, in the case of lots of STAs in contention would easily collide with other. Hence, there is a tradeoff between the contention window size and the amount of contending STAs. The scenarios invoked with the RTS and CTS handshake mechanism reveal a stable throughput than the scenarios without invoking the mechanism.

Figure 12(b) shows the average delay of the three scenarios. The delay is measured from the time (in milliseconds) a packet starts to contend for the medium to the end of the completion of the transmission. It is notable that the delay is the time pass until a transmitting packet is successful transmitted. If a packet were dropped because it reaches the RETRY LIMIT as defined in the TABLE II, then the delay time would not be included into the calculation of the average delay.

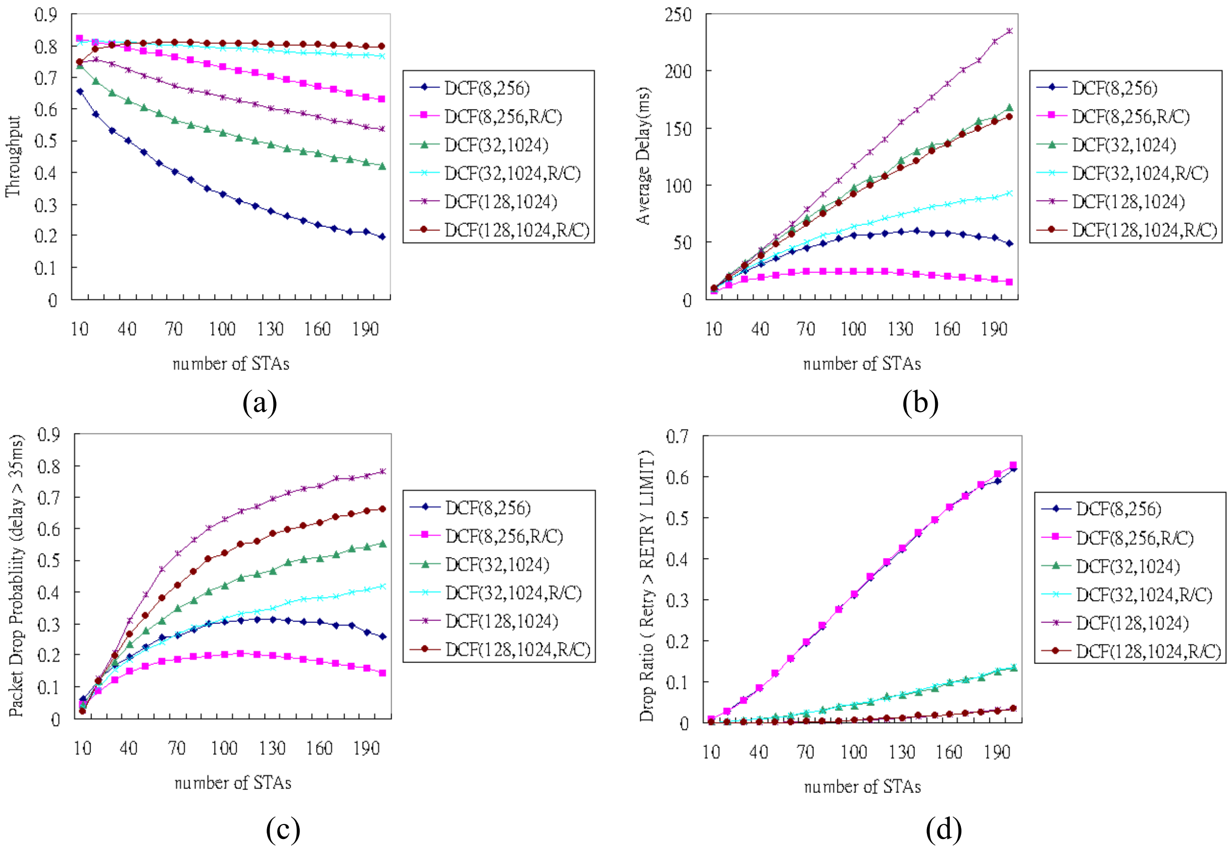


Figure 12. The (a) aggregate throughput, (b) average delay, (c) packet drop probability and (d) drop ratio of the conventional IEEE 802.11 DCF access schemes with different combination of the CWmin and CWmax.

Undoubtedly, the result curves are directly proportional to the number of STAs whatever under any scenarios. In both DCF(8,256) and DCF(8,256,R/C), the average delays increase until the amount of STAs up to 130 and 110, respectively. And goes out these points, the average delays smoothly decrease. The reasons may be the same as the LCFS (Last come first service) effect in the well-known binary exponential backoff scheme. Figures 12(c) and 12(d) show the packet drop probability and drop ratio of the conventional IEEE 802.11 DCF access scheme. The packet drop probability is the fraction of discarded packets caused by transmission errors or violating the delay bound (> 35ms). The drop ratio is the fraction of discarded packets caused by the retry times larger than RETRY LIMIT.

4.2 Simulation Results and Discussion

We use diversity of traffic transmission in simulating the PCC scheme. We use the last 3 bits of the Duration Field in the frame header to store the PL from 0 to 7, and reserve the PL values 0 and 7 for future design. For example, both of them could be used for the most urgent traffic such as fire and emergency calls. Four classes of traffic flows are used, which represent conversational class (voice), streaming class (videoconference), interactive class (WWW), and Background class (E-mail), respectively. The traffic models are referred to [4][7]. The priority settings are with voice (5) > videoconference (3) > WWW (2) > E-mail (1) and the packet payload length are 208 octets, 663 octets, 5120 octets and 9216 octets, respectively. The first two traffic classes are considered as high-priority traffic and the others are considered as low-priority traffic. Three channel access schemes are simulated. The first scheme is the conventional DCF. We do not specify any priority in this scheme and the values (CWmin, CWmax) are set to (8, 256) or (32, 1024), and we refer them as DCF(8, 256) and DCF(32, 1024). The second scheme is called Enhanced DCF (EDCF), which was proposed by the IEEE 802.11 task group E. In EDCF, the values (IFS, CWmin, CWmax) are differently set according to the traffic priority. For high-priority traffic and low-priority traffic, these values are set to (30us, 8, 256) and (50us, 32,1024), respectively. The third scheme is the proposed PCC scheme, which contains PCC_AP and PCC_NAP, and we set the scaling factor with a fix value to 32. The mapping of the priority class and traffic class is listed in TABLE III.

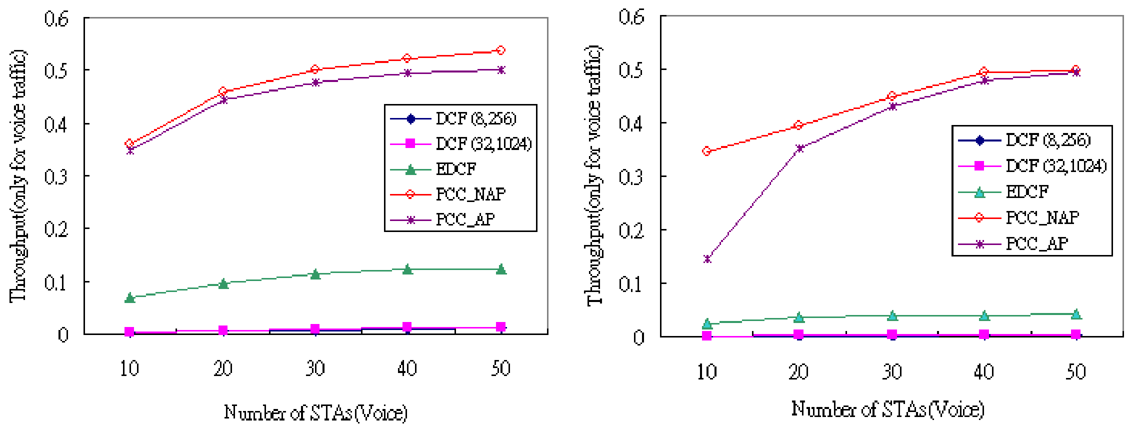
Figures 13-16 show the simulation results for the voice traffic. In these

TABLE III

PRIORITY CLASS TO TRAFFIC CLASS MAPPING

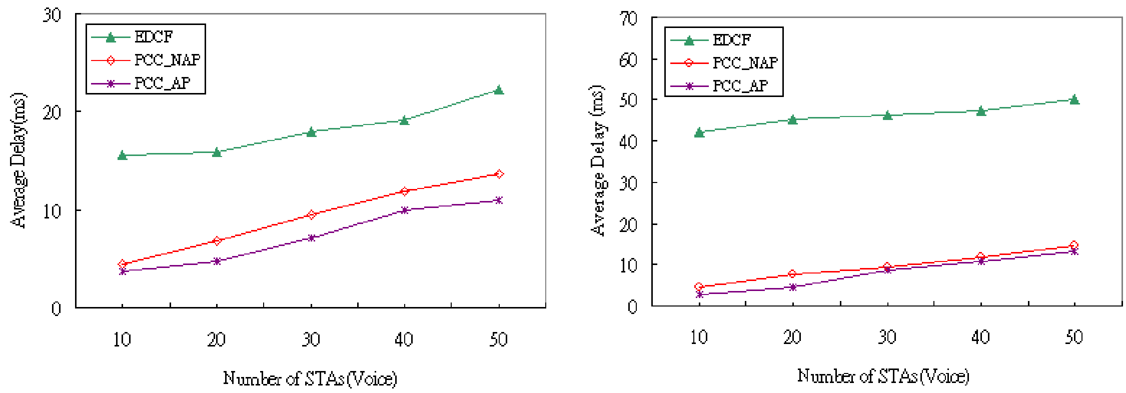
<table>
<tr><th></th><th>DCF</th><th>EDCF</th><th colspan="2">PCC</th></tr>
<tr><th>Priority Class (PC)</th><th>Traffic Class</th><th>Traffic Class</th><th>Traffic Class</th><th>Notes</th></tr>
<tr><td>7</td><td rowspan="8">NOT SPECIFIC</td><td rowspan="5">High (30us,8,256)</td><td>NOT SPECIFIC</td><td>-</td></tr>
<tr><td>6</td><td rowspan="2">Conversational</td><td>Retransmission priority for PC 5</td></tr>
<tr><td>5</td><td>-</td></tr>
<tr><td>4</td><td rowspan="2">Streaming</td><td>Retransmission priority for PC 3</td></tr>
<tr><td>3</td><td>-</td></tr>
<tr><td>2</td><td rowspan="3">Low (50us,32,1024)</td><td>Interactive</td><td>-</td></tr>
<tr><td>1</td><td>Background</td><td>-</td></tr>
<tr><td>0</td><td>NOT SPECIFIC</td><td>-</td></tr>
</table>

experiments, there are 50 STAs for each low priority traffic class as background traffic and each high priority traffic class has the same amount of STAs. Figure 13 shows the aggregate throughput for voice traffic. In both Figure 13(a) and 13(b), PCC_AP and PCC_NAP gain a stable throughput than other schemes. This is because the collision resolution scheme protects the voice traffic classes from contention with other traffic classes. Figure 14 shows the average delay. In Figure 14(a) and 14(b), the EDCF is up to 20 ms and 50 ms because the contention with videoconference traffic and the possible of contention with low priority traffic. DCF(8, 256) and DCF(32, 1024) are not shown in the Figure 14 because the delays are larger than 100 ms. For real-time traffic, the delay jitter is another index for judging the service quality. Figure 15 presents the simulation results for average delay jitter. PCC scheme reduces the delay jitters, especially in PCC_NAP. DCF is not shown as the same reason in Figure 14. In Figure 16, the packet drop probability is shown. The simulation results show that the performance of the experiments invoking the RTS and CTS handshake mechanism are much better than the experiments without using of them. And, the results in Figures 13-16 show that the PCC scheme achieves both low delay latency and low jitter for voice traffic and gains much higher performance than other schemes.



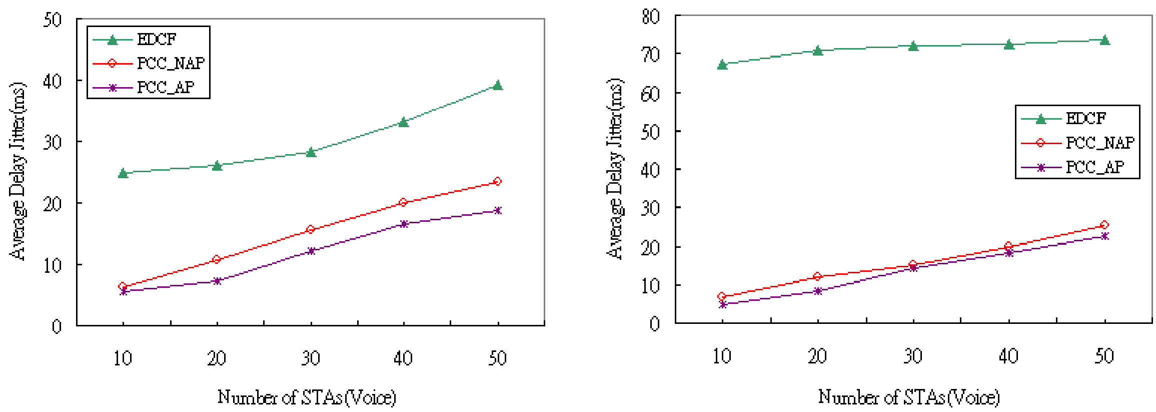
(a) (b)

Figure 13. Throughput for voice traffic: (a) with RTS/CTS, (b) without RTS/CTS.



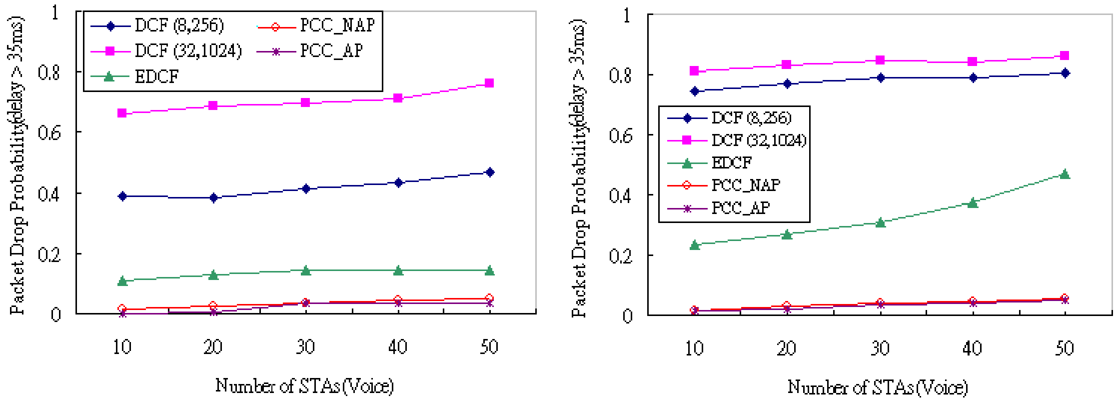
(a) (b)

Figure 14. Average delay for voice traffic: (a) with RTS/CTS, (b) without RTS/CTS.



(a) (b)

Figure 15. Average delay jitter for voice traffic: (a) with RTS/CTS, (b) without RTS/CTS.



(a) (b)

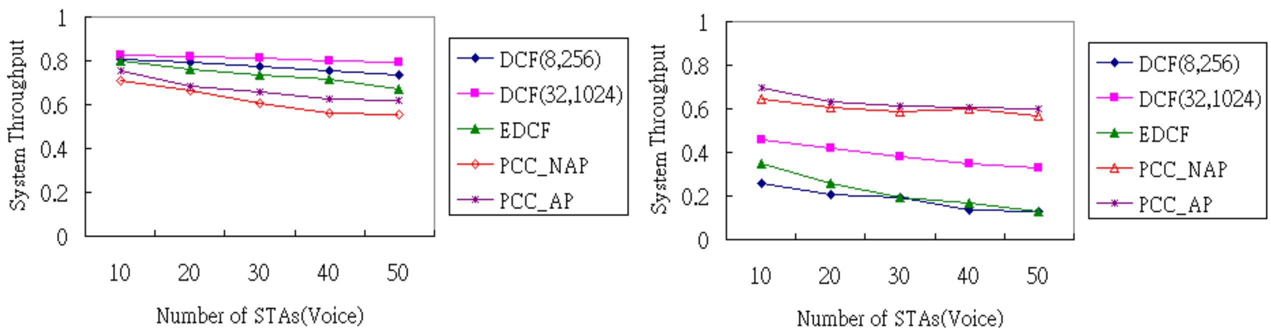
Figure 16. Packet drop probability for voice traffic: (a) with RTS/CTS, (b) without RTS/CTS.

By observing the results in Figures 13-16, the centralized PCC scheme PCC_AP seems less efficiency than distributed PCC scheme PCC_NAP. This is because the selection policy of the PL in the AP is not the optimized policy. We use the accumulative policy to determine the value of PL for convenience. In fact, we can calculate the PL according the importance of the flows recorded in the AP. For example, assigning different weight to different flows under the same accumulative policy and to determine the PL according to the summary of the weights of the flows located in a specific range. How to select an optimal policy is left for our future work.

Now we show the comparisons of the system performance of the simulated access schemes. Figures 17 and 18 show the throughput of the simulated access schemes. Note that the x-axis presents the number of voice STAs, and the value of 10 means there are 120 STAs in the serving area. In Figure 17(a), DCF(8,256), DCF(32,1024) and EDCF gain better throughput than PCC_AP and PCC_NAP. This is because the PCC scheme prevents the real-time traffic from collision with other traffic. The packet sizes of the real-time traffic are much smaller than non-real-time traffic; however, once a non-real-time traffic successfully wins the contention, than the throughput would be largely increased. In Figure 17(b) without RTS/CTS handshake mechanism, the same environment lead to worse results in DCF and EDCF because the large packets pollute the medium lengthy while suffering a collision.

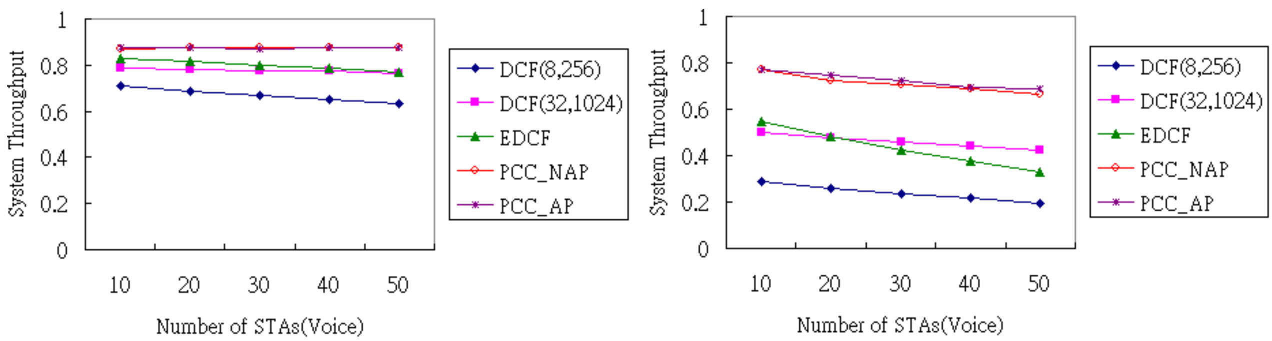
Therefore, we simulate other experiments in Figure 18 to compare the throughput of the access schemes with a mean packet size 1000 octets. Both Figure 18(a) and 18(b) present that the PCC scheme gains better throughput than other schemes. The results in Figure 18 show that the success transmission rate of the PCC scheme is much higher than other schemes and therefore the throughputs gathered by PCC scheme are much better no matter with or without invoking the RTS and CTS handshake mechanism.

By showing Figure 17 and 18, we can summarize that PCC scheme can ease off the serious collision under a heavy load condition and it gains much better performance than other schemes.



(a) (b)

Figure 17. The throughput of the simulated access schemes with different packet sizes: (a) with RTS/CTS, (b) without RTS/CTS.



(a) (b)

Figure 18. The throughput of the simulated access schemes with mean packet size 1000 octets: (a) with RTS/CTS, (b) without RTS/CTS.

We show two variations of the PCC scheme and measure the performance to compare with the PCC scheme simulated above. The first variation is aimed at the PCC_NAP scheme. In the PCC_NAP, once a STA collides with other STAs, it will adjust the contention window and GPLL value based on the status at that time (e.g., number of collisions, current GPLL). After the adjustment, the STA will contend for the medium with the frame that includes a new GPLL value (one larger than before). Thus, the permitted PL would be increased by at least one if the winning contender has collided before. The permitted PL is easy to step up if the contenders are too much. Therefore, the variation is to control the time to adjust the GPLL. We simulate the experiments that the adjusted times are after two collisions, three collisions, four collisions, and five collisions of a packet, and they are denoted as PCC_NAP(2), PCC_NAP(3), and so on.

Figures 19-21 show the results for the first variation. The results show that the variant PCC_NAP schemes do not get better performance than PCC_NAP, and the performance is much worst in PCC_NAP(5).

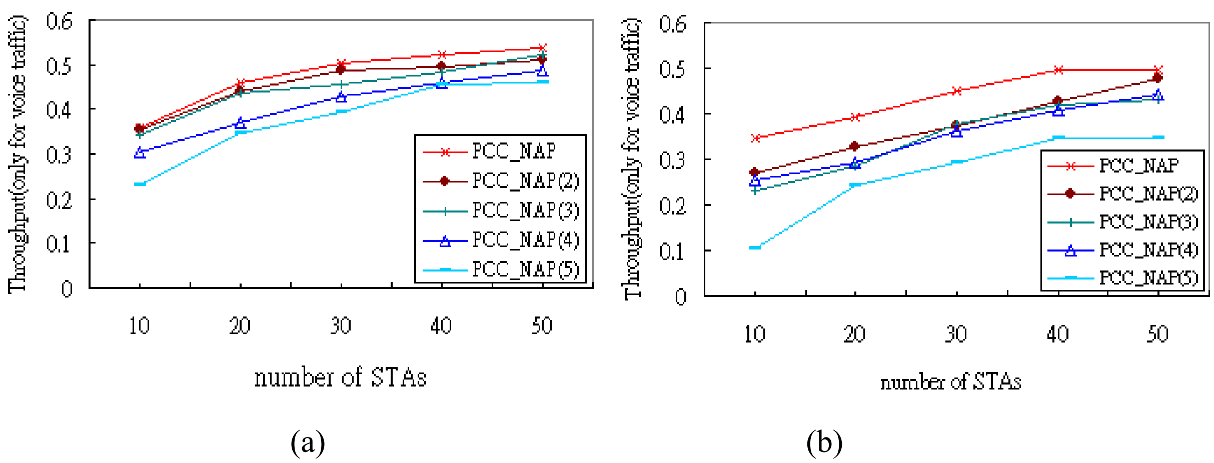
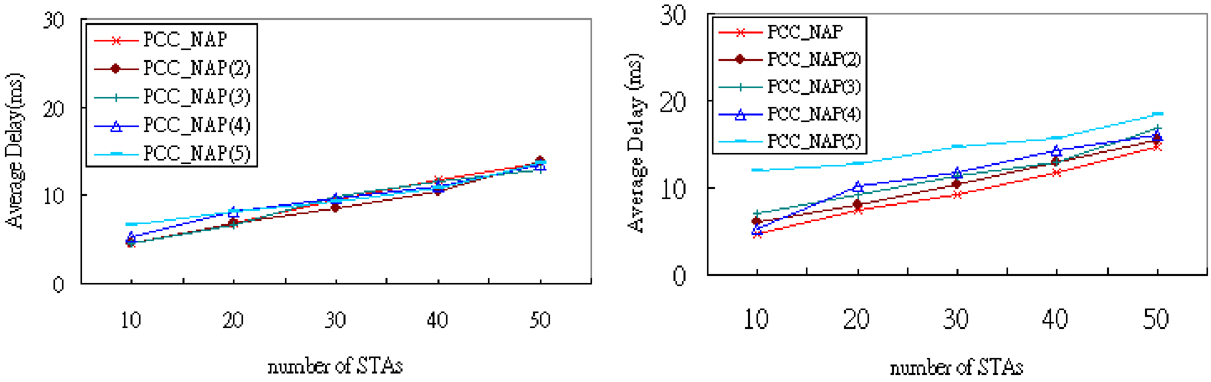
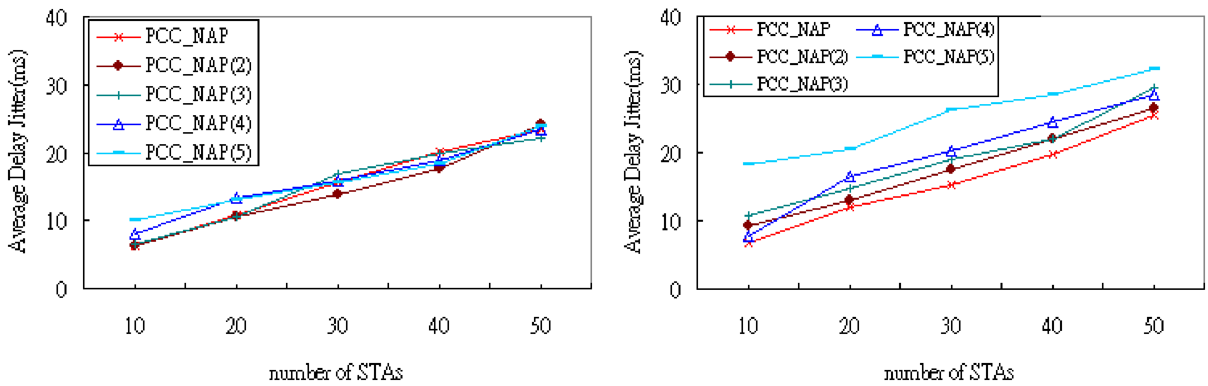


Figure 19. Throughput for voice traffic of the variant PCC_NAP schemes: (a) with RTS/CTS, (b) without RTS/CTS.



(a) (b)

Figure 20. Average delay for voice traffic of the variant PCC_NAP schemes: (a) with RTS/CTS, (b) without RTS/CTS.

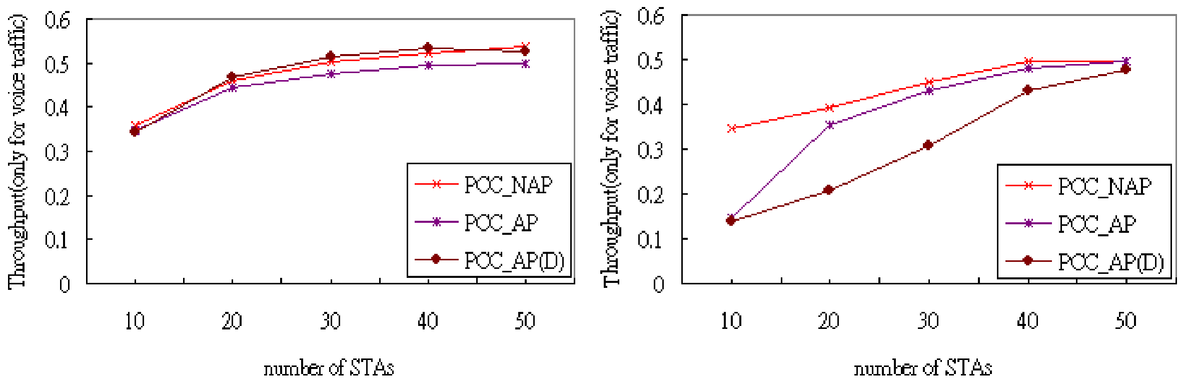


(a) (b)

Figure 21. Average delay jitter for voice traffic of the variant PCC_NAP schemes: (a) with RTS/CTS, (b) without RTS/CTS.

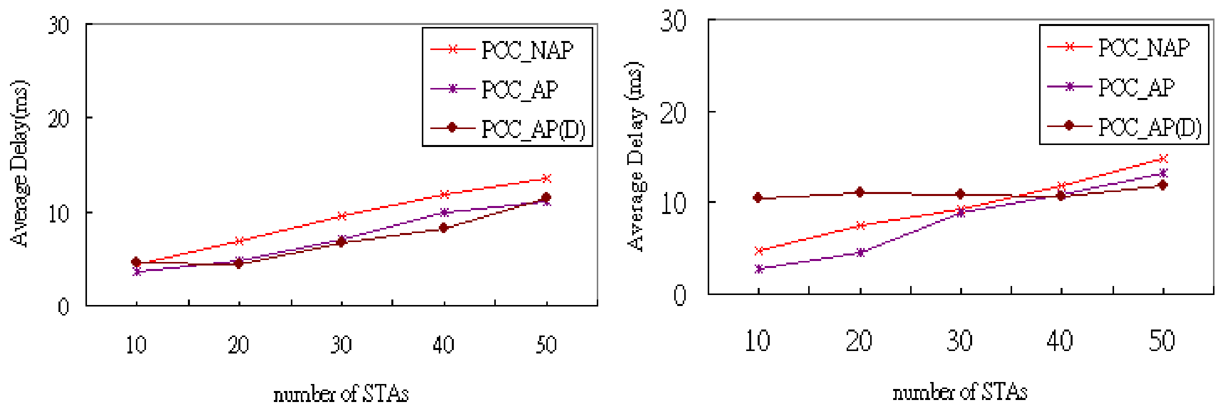
The second variation is aimed at the PCC_AP scheme. We use the Extension Field as depict in Figure 10 in the frame headers to indicate the scaling factor and PL. The scaling factor is counted in the unit of 4. This means that the scaling factor can up to $2^{2+5} = 128$. We restrict the scaling factor a lower bound to 4 and the amount of accessible flows to 32.

Figures 22-24 show the results of the variant PCC_AP scheme. Generally, we would think that the performance will better than original PCC_AP. However, the results get the opposite of what one wants. In the case of the amount of high priority flows are less than 32, the AP would point the PL to the low priority classes and extend the scaling factor. This causes the high priority classes suffer a more serious collision and lengthen the access time. In the case of the amount of high priority flows are larger than 32, especially when a class has more than 32 flows, the performance gradually become better and better. In fact, the affection is much obvious when a lot of flows in a class. We can find that the delay and delay jitter are reduced when there are lots of voice flows.



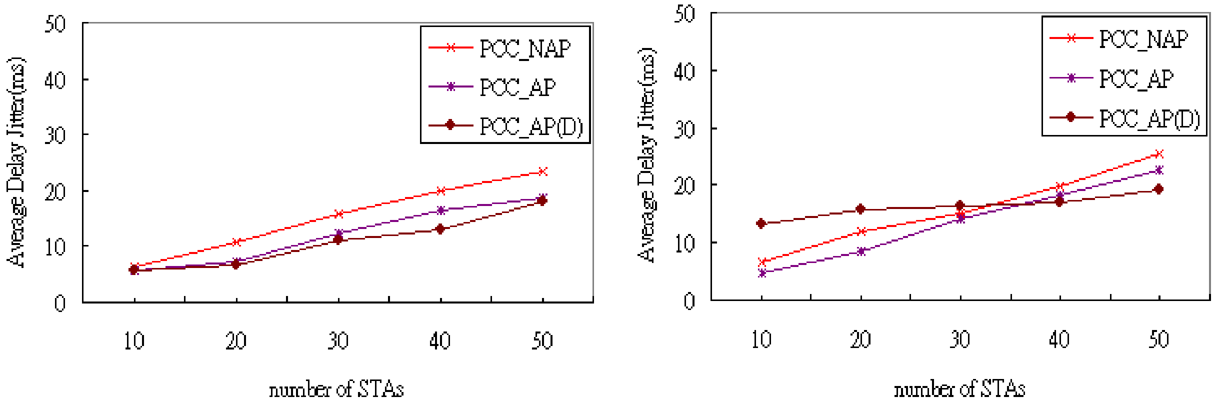
(a) (b)

Figure 22. Throughput for voice traffic of the variant PCC_AP schemes: (a) with RTS/CTS, (b) without RTS/CTS.



(a) (b)

Figure 23. Average delay for voice traffic of the variant PCC_AP schemes: (a) with RTS/CTS, (b) without RTS/CTS.



(a) (b)

Figure 24. Average delay jitter for voice traffic of the variant PCC_AP schemes: (a) with RTS/CTS, (b) without RTS/CTS.

CHAPTER 5

CONCLUSIONS AND FUTURE WORKS

In this thesis, we present a Priority-Based Contention Control (PCC) scheme to well manage the contention for the medium among the STAs. The PCC scheme can work with and without the AP, which are named PCC_AP and PCC_NAP, respectively. The PCC_AP is a centralized scheme while the PCC_NAP is a fully distributed scheme. Both the PCC_AP and PCC_NAP can be further considered to work within the IEEE 802.11.

We have fully described the PCC scheme in the previous chapters, and in the simulation experiments, the PCC scheme obtains much higher throughput and reduces the delay latency and delay jitter for real-time traffic than both the Enhance DCF and DCF access schemes with different combination of the minimum contention window and maximum contention window.

Under a heavy load traffic condition, the PCC scheme may influence the low priority traffic flows, even makes them suspend in the worst case. In fact, we concern about the service quality of the high priority traffic flows. Therefore, how to provide the quality of service for the real-time traffic is much important than other elastic traffic. And in fact, in an environment that lots of flows contend to each other, even we let the low priority traffic flows join the contention, the medium would become much worst. No contributions and advantages can be found in such situation. Thus, we do not grant the low priority traffic flows to contend for the medium if there are lots of flows contending for transmission.

In the future, we will research the relevant issues of providing the quality of service in the wireless environment. And we will further analyze and evaluate the PCC scheme to make the PCC scheme more efficient and adaptive to provide better performance.

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