An Optimized Retransmission Scheme with QoS Support for Wireless LAN

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ABSTRACT

Keywords: *IEEE 802.11, WLAN, MAC, CSMA/CA, DCF, PCF, EDCF, backoff, contention window, retransmission, QoS, real-time*

The Medium Access Control (MAC) protocol of the IEEE 802.11 standard is based on Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA). The basic retransmission mechanism, binary exponential backoff, may cause large packet delay and packet delay jitter that are not suitable for real-time traffic. In this thesis, we will first investigate some MAC enhancement mechanisms discussed in the IEEE 802.11 task group E, which was formed for enhancing the current 802.11 MAC protocol to support for applications with Quality of Service (QoS) requirements. Then, we will propose a jamming-based retransmission mechanism that is compatible with the 802.11 standard and could reduce the packet delay for real-time traffic. Besides, this mechanism performs stably when the traffic load is heavy. The optimal setting of our proposed mechanism is discussed analytically. We perform simulated experiments by comparing our proposed retransmission mechanism with the other two mechanisms discussed in the 802.11 task group E. We show that the jamming-based retransmission mechanism can reduce the packet delay and the packet dropping rate.

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CHAPTER 1
INTRODUCTION

As the mobile devices and Internet services become popular, the trend on providing wireless data services has emerged. The great improvement in channel modulation techniques makes the bandwidth of wireless medium large. It becomes feasible for real-time multimedia data to be transmitted via the wireless medium.

1.1 The Wireless Local Area Networks (WLANs)

The IEEE 802.11 *Wireless Local Area Network (WLAN)* [14] is an international standard that specifies the *Medium Access Control (MAC)* sub-layer and *Physical (PHY)* layer. The IEEE 802.11b using the 2.45GHz ISM band is able to provide up to 11Mbps data rate and the 802.11a operating on the 5GHz radio frequency with the *orthogonal frequency-division multiplexing (OFDM)* modulation scheme is able to offer up to 54 Mbps data rate as well [2]. Therefore, the WLAN with high speed and low cost access to the Internet is a promising platform to provide real-time services.

The basic building block of an IEEE 802.11 WLAN is called *basic service set (BSS)*, which is a set of *wireless stations (STAs)* controlled by a coordination function. The 802.11

WLAN can be configured as an Ad-hoc network, that is an independent BSS, or an infrastructure network, which is composed of an access point and the associated STAs.

In the 802.11 WLAN, the channel access for the STAs in a BSS is under the control of two types of coordination functions: *Distributed Coordination Function (DCF)* and *Point Coordination Function (PCF)*. The fundamental access method is DCF, which is based on the *Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA)* technique. The CSMA/CA is a contention-based multiple access technique that requires each STA to sense the medium to be idle for a period of time before sending a frame out. The period of time is called *inter-frame space (IFS)* whose length is related to the frame priority. The levels of frame priorities are classified as *Short IFS (SIFS)*, *PCF IFS (PIFS)*, *DCF IFS (DIFS)* and *Extended IFS (EIFS)*, which correspond to, for example, ACK frames, PCF control frames, data frames, and retransmission frames, respectively. More details about the frame priority could be referred to [1].

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1.2 Collision Resolution Scheme in WLAN

In the DCF, the *backoff procedure* is used for collision avoidance and collision resolution. A STA should wait for a backoff time, which is a random time interval, before its frame transmission. The backoff procedure starts when a STA attempts to transmit but detects the busy state of the medium. The STA will calculate a random backoff time, which is in unit of slot-time, according to the *Contention Window (CW)*. The CW specifies the range of possible backoff time. When a collision occurs during the frame transmission, the CW is doubled and is bounded by a maximal value, *CWmax*. This is so called binary exponential backoff in the DCF. The STA will decrease its backoff time counter by one if the medium is sensed idle for a slot-time and freeze the backoff time counter once the medium is busy. When the backoff time is decreased to zero, the STA transmits its frame immediately. The generation of random backoff time can be described as below:

$$BackoffTime = RandomInteger(0, \min(CWmin \times 2^{retries}, CWmax)) \times SlotTime\,. \qquad (1)$$

where *RandomInteger(Minimum, Maximum)* function generates a random integer in the range from *Minimum* to *Maximum* uniformly.

With the binary exponential backoff, the backoff time may increase tremendously for each retransmission. It causes a large packet delay. Moreover, the changes of CW values make the packet delay jitter large especially after a successful retransmission, since the increasing CW is immediately reset to the minimal value, CWmin. Hence, the binary exponential backoff is not suitable for the transmission of real-time traffic.

1.3 MAC Enhancement for QoS Requirements

To enhance the current IEEE 802.11 MAC protocol to support for applications with *Quality of Service (QoS)* requirements, the IEEE 802.11 task group E is formed. Many proposals addressing the DCF enhancement were discussed in the task group E [7]. However, those proposals leave the same retransmission problem unsolved for real-time traffic. In this thesis, we propose an efficient and adaptive retransmission mechanism to resolve the contention between real-time traffics by using jamming noises. The jamming noise could also separate the contention of real-time traffic from non-real-time traffic. Besides, we analyze the generation of jamming noises in detail.

1.4 Thesis Organization

The remainder of this thesis is organized as follows. Chapter 2 gives a survey on related researches about 802.11 MAC enhancements for real-time traffic. Chapter 3 describes our proposed jamming-based retransmission mechanism and discusses the optimal parameter setting of our proposed mechanism. In Chapter 4, we show the performance of our mechanism through simulation results. Our conclusions and future works are presented in Chapter 5.

CHAPTER 2
BACKGROUNDS AND RELATED WORKS

The provision of the QoS guarantees has become an important issue nowadays [3]. Some polling-based mechanisms were proposed to serve real-time traffic [4][5]. In [4], a variation of early deadline first (EDF) scheduling for real-time traffic and a variation of round-robin scheduling for non-real-time traffic are used. In [5], real-time traffic and non-real-time traffic are served by the PCF and the DCF, respectively. The differentiation services are provided in the DCF by using a "rollback" backoff mechanism. Four different traffic classes: conversation, streaming, interactive and background proposed by UMTS [6] are used. However, the implementation complexity of polling functions may be high.

In this chapter, we first introduce the IEEE 802.11 MAC protocol as our research background. Then, we investigate three DCF enhancement mechanisms: VDCF, pDCF and TCMA, which were discussed enthusiastically in the IEEE 802.11 task group E.

2.1 The IEEE 802.11 MAC Protocol

In an IEEE 802.11 WLAN, a BSS is a set of wireless stations (STAs) controlled by a single coordination function. The coordination function is a set of rules for STAs to share the radio resource inside a BSS properly. Many BSSs may also interconnect to each other by wireless air interface or wire-line. The architectural component used to interconnect BSSs is called *distribution system (DS)*. The entry point to DS is called *Access Point (AP)*. It works as a wireless bridge. The interconnected BSSs conceptually form an *extended service sets (ESS)*. Figure 2-1 depicts the constitution of IEEE 802.11 components.

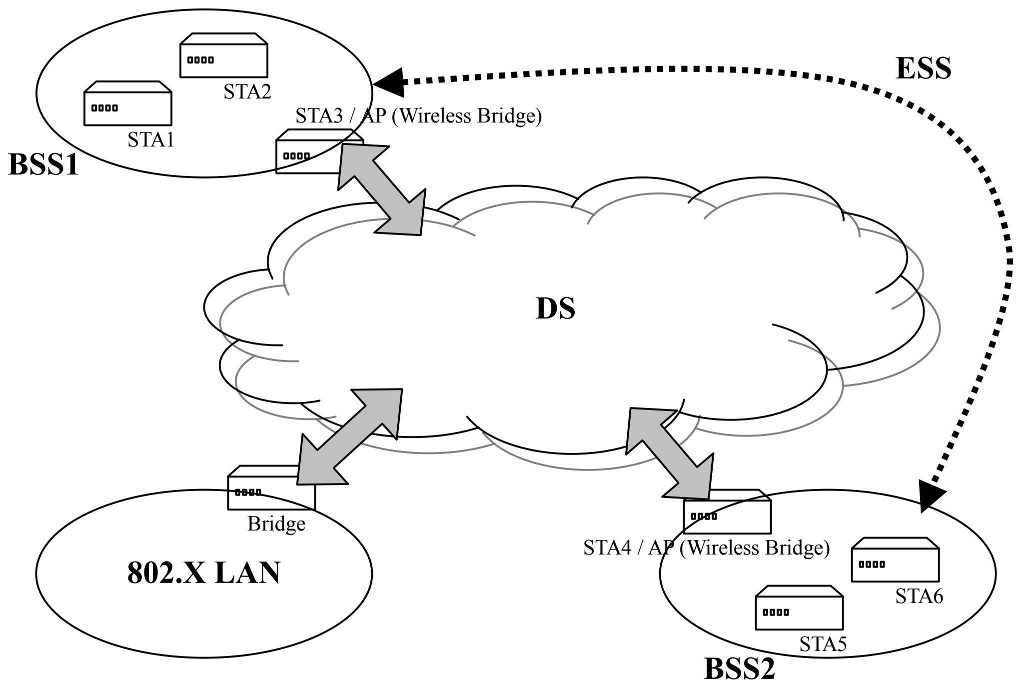

Figure 2-1 The Constitution of IEEE 802.11 Components

The architecture of IEEE 802.11 MAC sub-layer is constituted by two coordination functions: DCF and PCF. Figure 2-2 illustrates the relationship between these two functions. The fundamental access method is DCF, which was known as carrier sense multiple access with collision avoidance (CSMA/CA) technology. It is a contention-based technology, mainly based on the medium status sensed by STAs, which is busy or idle. Based on the medium status, two schemes are used for medium contention and collision resolution; they are backoff procedure and IFS deferring. Figure 2-3 shows the relationship between IFSs.

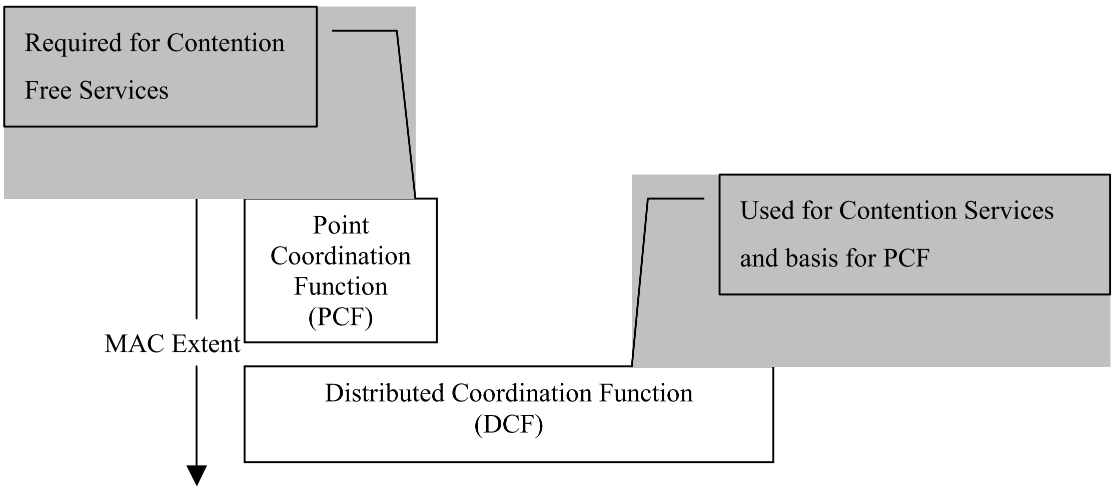

Figure 2-2 The IEEE 802.11 MAC architecture

The backoff procedure will starts under two situations. A station detects collisions, and a station attempts to transmit when channel is busy. STAs will calculate a random backoff time in unit of slot-time according to its Contention

Window (CW). The CW is an upper bound of backoff time. Every retransmission will cause the CW double but it's bounded by a maximum parameter *CWmax*. It is so called binary exponential backoff in the CSMA/CA. The STAs discount their backoff counter if the medium is sensed to be idle and freeze when medium is busy. Once the backoff counter is decreased to zero, the STA is able to transmit it frame.

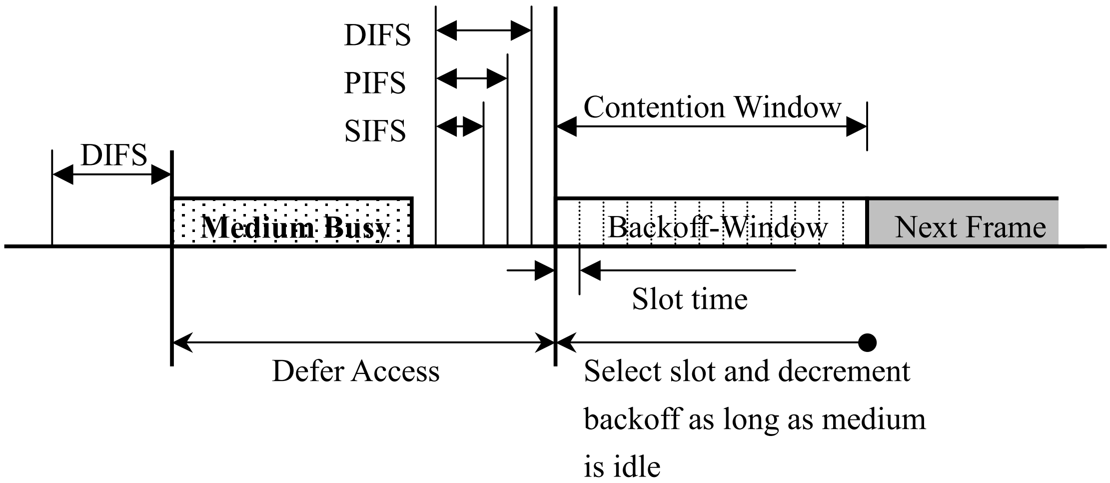

Figure 2-3 The IFS relationship of IEEE 802.11 MAC

The STAs calculate random backoff time according to (2). The RandomInteger(Minimum, Maximum) function generates a random integer in the range from Minimum to Maximum uniformly.

$$BackoffTime = RandomInteger(0, \min(CWmin \times 2^{retries}, CWmax)) \times SlotTime \quad (2)$$

Further, we could realize the contention procedure by Figure 2-4. Stations B, C and D with pending frames should defer their frame transmissions for Station A. After

Station A finishes its frame transmission, the medium becomes idle and all STAs start to contend for the medium. There are two stages of the channel contention, one is IFS deferring, and the other is backoff procedure. In this example, the STAs are waiting for their data frames transmission in DCF period, so they will all defer for a DIFS time long. After IFS deferring, STAs begin to decrease their backoff time counters. The STA with shortest backoff time survives on this stage and is able to transmit its frame. It is STA C in this example. Other STAs freeze their backoff time countdown and defer their transmissions to next transmission opportunity. The concept of medium contention mechanism in CSMA/CA is similar to the Ethernet MAC protocol, which is carrier sense multiple access with collision detection (CSMA/CD). However, the CSMA/CA prevents collision in advance.

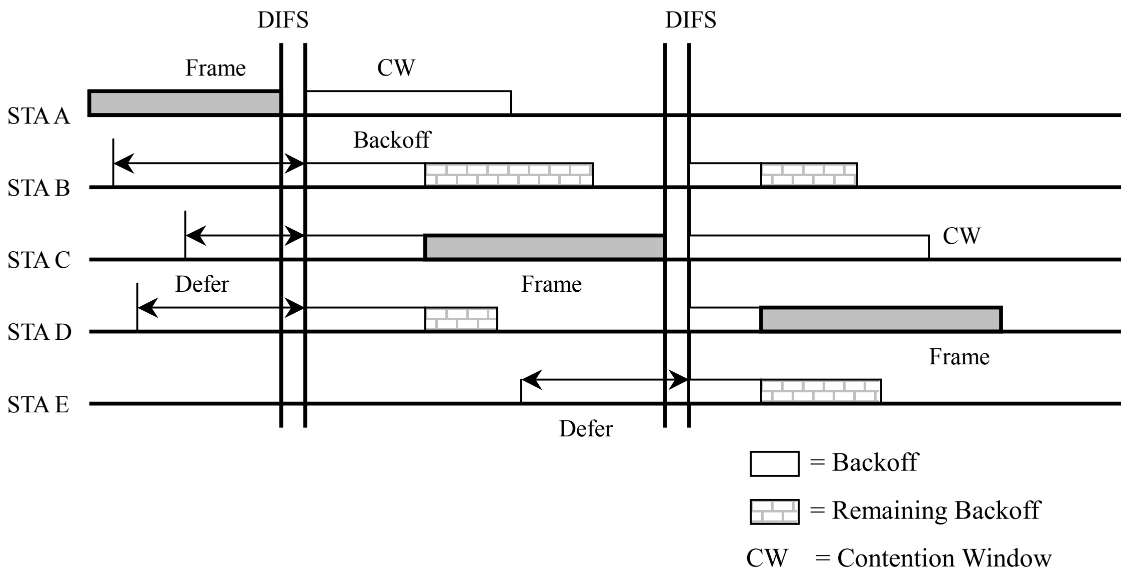

Figure 2-4 The contention period in IEEE 802.11

Because the carrier sense is not easy to carry out in the air interface, the 802.11 introduce a virtual carrier sense scheme. It makes use of a field in some 802.11 MAC frames to carry the evaluated value of transmission duration of the following frame transmission. The evaluated value is named *virtual network allocation vector (NAV)*. STAs could estimate the channel condition by this value without actually sensing the wireless signal, so it is a conceptually 'virtual' carrier sense scheme.

The PCF based on CSMA/CA is a mechanism for centralized access control. In the PCF, all the channel access within a BSS should be scheduled by a *point coordinator (PC)*. It is usually implemented as an access point, too. The PC is able to start and terminate a *contention free period (CFP)*. The CFP begins with a *Beacon* frame, which contains a *Delivery Traffic Indication Message (DTIM)* element. The Beacon frame also contains a contention free (CF) parameter set element that indicated the CFP duration, so the STAs within the same BSS could set their NAV value and restrict their transmission till the CFP end. By CF parameter set element and NAV, the contention-free access scheme could be applied in the contention-based CSMA/CA. In the contention free period, the PC polls certain STAs for frame transmission by its own scheduling scheme. The *contention period (CP)* and CFP will alternate. Figure 2-5 shows the situation of CFP/CP alternation. By Figure 2-5, we could also realize that a CFP might be delay to start due to the medium busy. Mostly, the former transmission in CP might be on going so the PC should not start CFP until the transmission is completed.

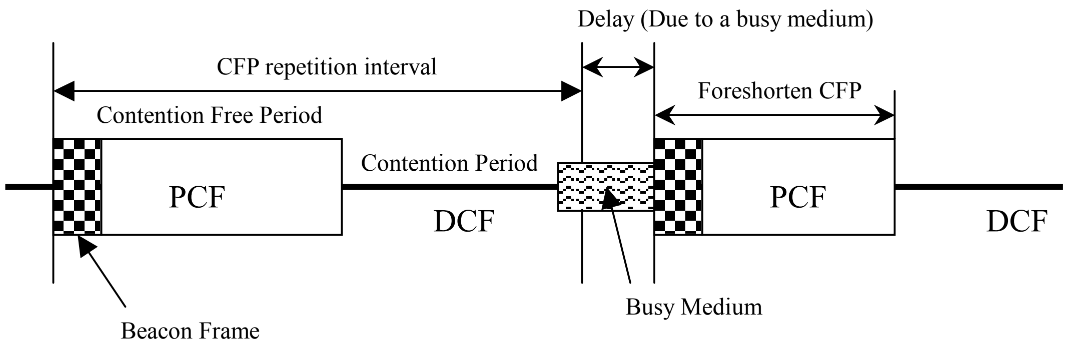

Figure 2-5 The CFP/CP alternation

Although the PCF might be useful for real-time multimedia traffic to provide QoS guarantee, the implementation of PCF is not popular due to its complexity. Furthermore, the IEEE 802.11 standard did not specify the polling scheme well, so the interoperability is still unknown.

2.2 MAC Enhancements in IEEE 802.11 Task Group E

Many proposals addressing the DCF enhancement were discussed in the IEEE 802.11 task group E. [8] summarized the features of these enhancements based on six functions: basic contention and collision resolution approach, class differentiation, packet differentiation, averting packet aging, scheduling of competing traffic streams, and adaptation to traffic intensity. It also indicates the issue about the coexistence between these features. In [9], a review of these proposals for DCF enhancements is given. We will investigate three DCF enhancement schemes in this thesis: namely *Virtualized Distributed Coordination Function (VDCF*), *Probabilistic Distributed Coordination Function (pDCF)* and *Tiered Contention Multiple Access (TCMA)*.

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2.2.1 Virtualized Distributed Coordination Function (VDCF)

The Virtualized DCF (VDCF) mechanism [10][11] with the low implementation cost was discussed enthusiastically. The idea of VDCF is to adjust the size of CW and IFS according to the traffic priority. These different IFSs are called *Alternative Inter-Frame Space (AIFS)*. The basic access method is similar to DCF as shown in Figure 2-6. The real-time traffic with smaller IFS and CW settings has better opportunity to access the channel. Each flow has its own backoff time counter inside a STA. Conceptually, there is a parallel queue in the VDCF for each traffic catalog and contentions between these queues will happen first inside the STA. Figure 2-7 depicts the conceptual parallel queue and the internal contention. If a collision is occurred inside the station, the highest priority frame will start its frame transmission while the lower one will be rolled back into the contention queue and wait for next transmission opportunity.

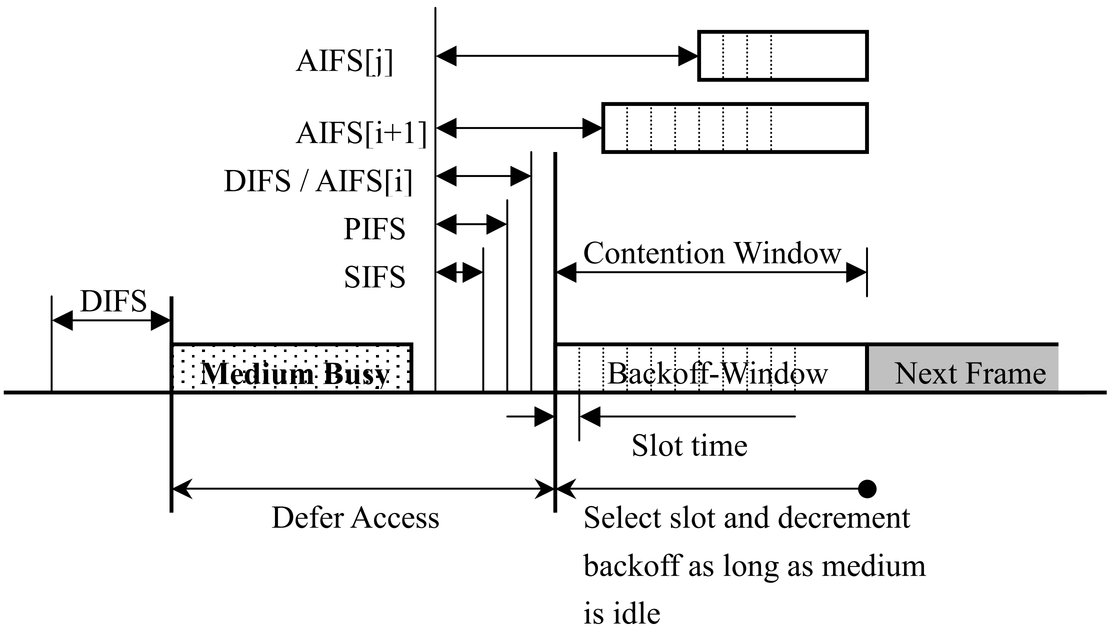

Figure 2-6 The access method in VDCF

However, the retransmission mechanism is still the binary exponential backoff. It will causes large packet delays for real-time traffic. The situation would be worse when the channel condition is bad or the traffic load becomes heavy. It is not suitable for real-time traffic with time-bounded requirements.

The default setting of the AIFS and contention windows for each traffic catalog is indicated in the QoS Parameter Set element (Figure 2-8) contained in Beacon frames and *Probe Responses* frames transmitted by the *Enhance Access Point (EAP)*. An EAP is defined as an AP with MAC enhancement functions. According to the revising of the IEEE 802.11e draft in Mar 2001, the VDCF and TCMA proposals has been combined so there is also a *CWPFactor* field in the QoS Parameter Set element for TCMA retransmission control. We will describe TCMA in section 2.2.3.

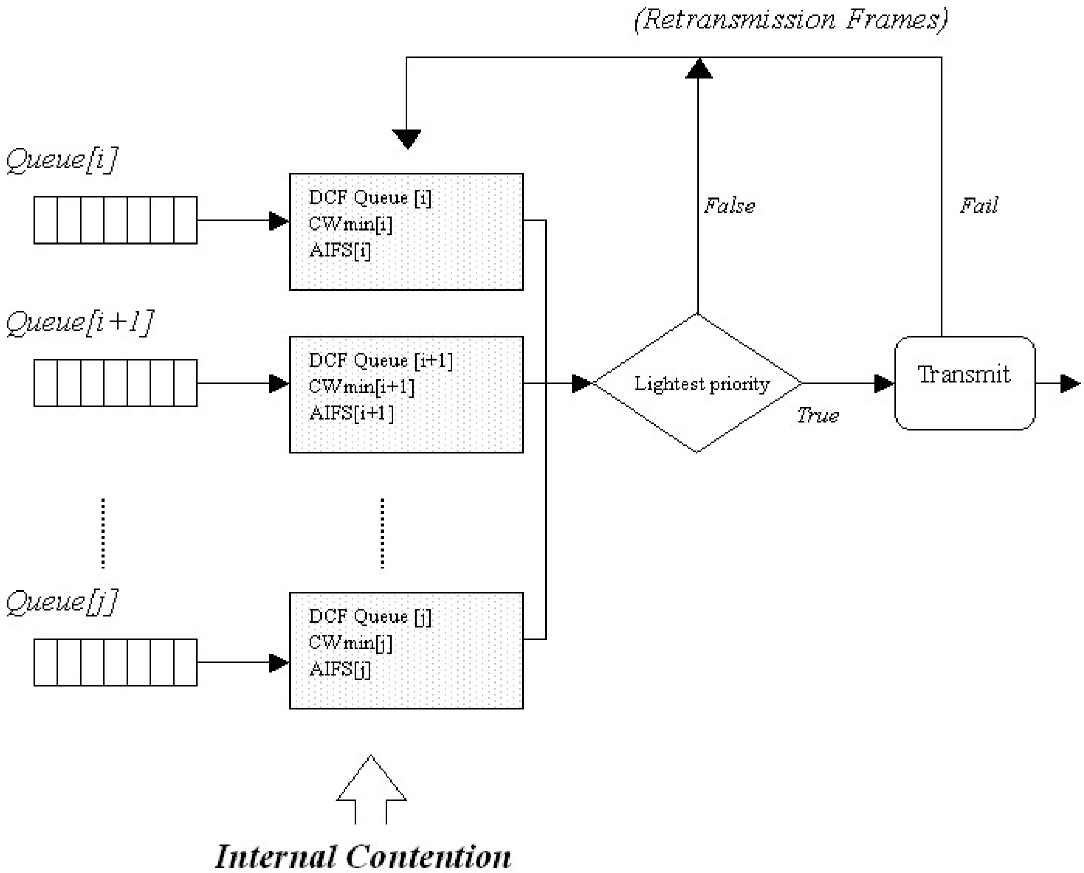

Figure 2-7 The conceptual parallel queue inside the VDCF

Element ID	Length	TXOP Limit	CWmin[i] values	AIFS[i] values	CWPFactor[i] values
			CWmin[0] ... CWmin[7]	AIFS[0]…AIFS[7]	CWPFactor[0]…CWPFactor[7]
(12)	(18)	(2 octets)	(8 octets)	(8 octets)	(8 octets)

Figure 2-8 The QoS Parameter Sets element in VDCF

2.2.2 Probabilistic Distributed Coordination Function (pDCF)

Instead of adjusting IFSs and contention windows to differentiate the QoS levels, the pDCF uses a probability-based mechanism to generate the backoff time and schedule frames. The pDCF medium access scheme could be controlled by just one probabilistic parameter set, Traffic Category Permission Probabilities (TCPP), that are the probabilities for each TC to persist in trying to access the medium per idle slot. The stations first calculate a station-based *Permission Probability (PP)*. PP is the summation from TCPP[0] to TCPP[7]. Then, ESTAs repeat to generate a random number, X, ranging from zero to one. The determination of backoff time in the pDCFis mainly depend on the random number, X and the PP. The backoff time is determined once the random number X is smaller than PP; otherwise the backoff time counter would be increased by one. Conceptually, pDCF is similar to p-persistent CSMA mechanism with a dynamic ‘p’ value equals to PP. The backoff time, denoted by t, could be considered as that the former t-1 slots were failed to persist in accessing the channel until the t^{th} slot.

Contrasting to the individual backoff counter for each TC in VDCF, the pDCF uses a share backoff counter. The pDCF schedules its TC internally. The scheduling method is to separate [0, PP] into several sections proportional to TCPPs and then calculate the range where the random number is located in. The frame of TC_k will be selected when the random number located in the section [$TCPP_{k-1}$, $TCPP_k$]. The local selection criterion could be described as follows:

$$\sum_{i=0}^{k-1} TCPP_i < X < \sum_{i=0}^{k} TCPP_i \quad (3)$$

Figure 2-9 depicts the concept of scheduling scheme in pDCF. In this example, the $TCPP_k$ is scheduled in the next transmission opportunity. The range [0,PP] would be separated into seven sections according to

$$T(n) = \sum_{i=0}^{n} (TCPPi) \text{ , } n=0,1,2\ldots 7 \quad (4)$$

The access point with pDCF function is called *Enhance Access Point (EAP)*. The EAP could dynamically upgrade the TCPPs, so the pDCF claims to be adaptive with traffic load. In pDCF, the relative QoS parameter set element is named *Enhanced Channel Access (ECA)* parameter sets element. Figure 2-10 shows the ECA parameter set element. As we could see that the whole pDCF could be controlled only by TCPP values.

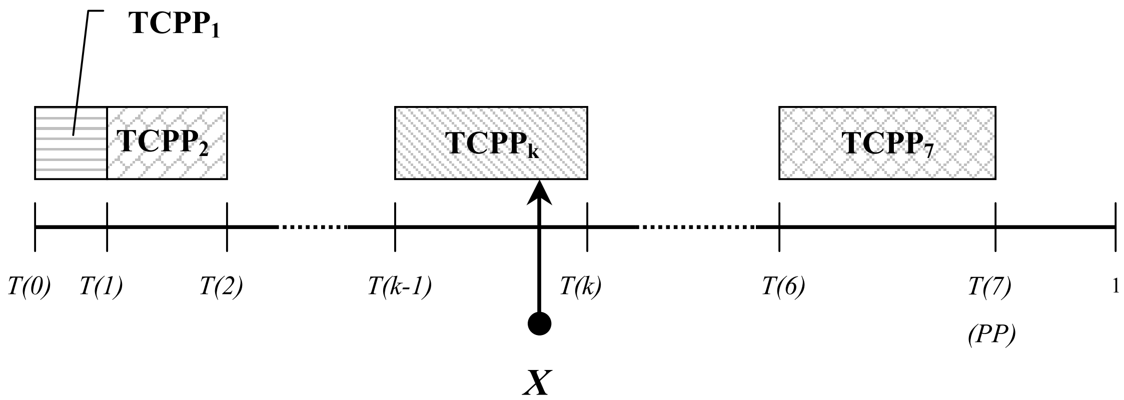

Figure 2-9 The scheduling scheme of pDCF

Element ID	Length	TCPP[TC] values
		TCPP[0]…TCPP[7]
(12)	(18)	(8 octets)

Figure 2-10 The ECA parameter set element of pDCF

2.2.3 Tiered Contention Multiple Access (TCMA)

The other scheme, named Tiered Contention Multiple Access (TCMA) [12][13], uses a smaller CW for each retransmission. The TCMA scheme maps eight traffic categories into four *Urgency Classes (UC)* according to the IEEE 802.1d Annex H.2 [20]. Each UC has its own backoff time setting. A packet in each class of packet queue will age, and if its age exceeds the threshold of the class, the UC of the packet will be dynamically updated to reflect their "transmission urgency". Figure 2-11 depicts the traffic categories mapping and reclassification process of TCMA.

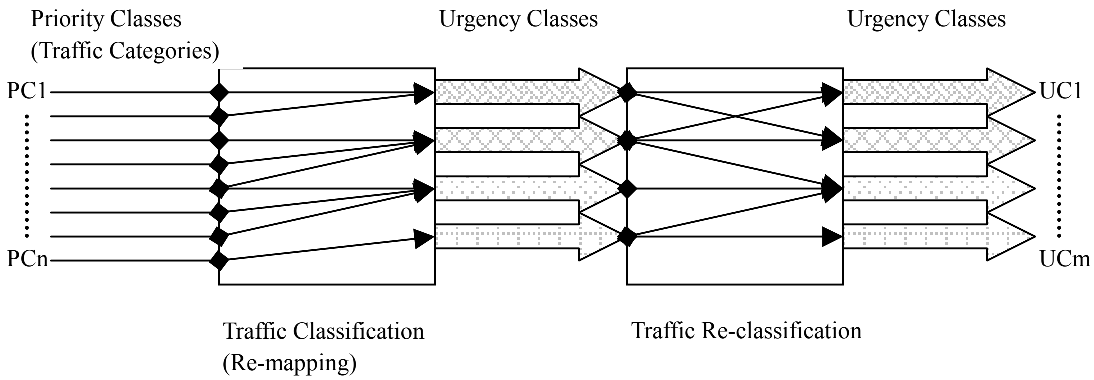

Figure 2-11 The classification and aging scheme in TCMA

The TCMA decreases the CW for each retransmission according to a scaling parameter, *CWPFactor*. The value of CWPFactor depends on the traffic priority. The relationship between the current CW and the new CW could be described as:

$$CW_{new} = \lceil (CW_{current} + 1) \times (CWPFactor / 16) \rceil - 1 \quad (5)$$

The diminished CW is used for reducing the overhead of backoff time. Nevertheless, this scheme incurs more packet drops due to enormous collisions in heavy traffic load as shown in our simulation results.

CHAPTER 3
THE PROPOSED MECHANISM

Large retransmissions are required when STAs are contenting channel by binary exponential backoff. The frame retransmissions will be a critical problem for time-bounded and jitter-sensitive real-time traffic. If the channel condition is bad too, the retransmission problem becomes more serious.

3.1 The Jamming-Based Retransmission Mechanism

In this thesis, we propose an efficient retransmission mechanism, named *jamming-based retransmission mechanism*, which can limit the packet delay and the packet delay jitter for real-time traffic. By jamming noise, the non-real-time traffic would block its the backoff time countdown because the channel is always sensed to be busy. It prevents non-real-time traffic from contending channel with real-time traffic. Besides, the jamming-based retransmission mechanism performs stable when traffic load is heavy because we had analyzed the optimal jamming time generation algorithm.

We propose that the retransmission of a real-time frame should start a jamming procedure instead of a backoff procedure to contend the channel. In the jamming contention phase, a STA with real-time retransmission frame will calculate a random jamming time and continuously send the jamming noise for the period of time after the channel is idle for a DIFS period. A STA starts frame retransmission if the channel remains idle after sending its own jamming noise. The STA with the longest jamming time will survive on the jamming contention phase. At least one STA survives on the jamming contention phase and the retransmission will be successful if there is only one survival.

A STA with the support of the jamming function is called *enhanced STA (ESTA)* throughout. The algorithm of jamming-based retransmission mechanism could be described as follow:

(i) An ESTA calculates a random jamming time. The length of jamming time is a random number in unit of slot-time.

(ii) The ESTA continuously sends jamming noise for the period of jamming time.

(iii) The ESTA senses the channel status. If the channel is idle, the ESTA send its retransmission frame, else, the ESTA waits for next transmission opportunity.

(iv) If collision is occurred, the ESTA schedules its retransmission frame to next transmission opportunity. The frame exceeds the retry limit or exceeds the delay time boundary will be dropped.

The algorithm for the random jamming time generation is according to a truncated geometric distribution:

$$P_J(f) = \begin{cases} p_J^{f-1} \cdot (1 - p_J), & 1 \le f < JW \\ p_J^{JW-1}, & f = JW \end{cases} \tag{6}$$

where

$P_J(f)$: *The probability function of a jamming time which is f slot-times long*
p_J : *Truncated geometric distribution probability parameter between* 0 *and* 1
JW : *Jamming Window*

The *Jamming Window* is defined as the boundary of a random jamming time. The probability distribution is more skewed with a smaller p_J and it is most possible for an ESTA to survive on a jamming contention period with a short jamming time. Figure 3-1 is an example of the probability distribution when *pj* is 0.6 and JW is 15. According to the probability distribution, large amount of ESTAs will get the shorter jamming time. Only a few ESTAs get the longer jamming time. So it is conceptually that few ESTAs contend channel with each other regardless the total number of ESTAs involving in the jamming contention phase. It is the reason that our mechanism performs stable.

The setting of *JW* is mainly dependent on the number of ESTAs simultaneously involve in the jamming procedures. Because the $P_J(JW)$ would be small enough to be neglected when JW is large, we can bound the JW value by the criterion:

$$JW = \min\left\{ jw \mid p_J^{jw-1} \le \frac{1}{N} \right\}, \tag{7}$$

where *N* denotes the number of ESTAs and *jw* is a set of jamming window values which satisfy the equation $p_J^{jw-1} \le \frac{1}{N}$. The simple criterion in (7) can be used to decide the proper *JW* value, where a large *JW* value is used to reduce the collisions for a large *N* value. For example, the *JW* value is 4, 7, 11 and 22 when p_J value is 0.2, 0.4, 0.6 and 0.8, respectively while *N*=100. The Table I below shows the each recommended *JW* value correspondingly mapping to different p_J value.

TABLE I

RECOMMENDED *JW* VALUES WHILE N=100

p_J	*JW*	p_J	*JW*	p_J	*JW*
0.05	3	0.40	7	0.75	18
0.10	4	0.45	7	0.80	22
0.15	4	0.50	8	0.85	30
0.20	4	0.55	9	0.90	45
0.25	5	0.60	11	0.95	91
0.30	5	0.65	12		
0.35	6	0.70	14		

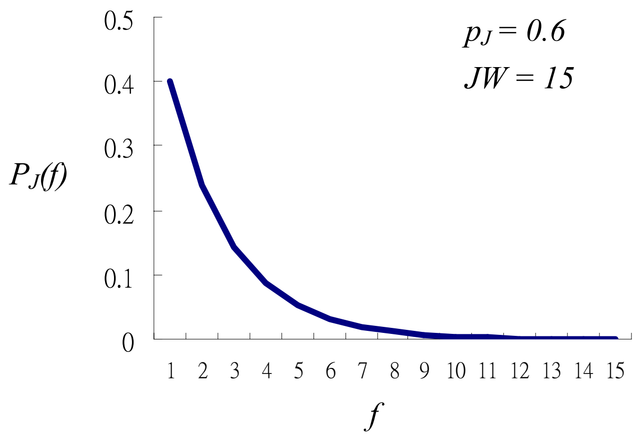

Figure 3-1 An example of the probability distribution of jamming time.

Figure 3-2 illustrates the jamming contention phase. There are four ESTAs, which are ESTA1, ESTA2, ESTA3 and ESTA4, sending the jamming noise at the same time. A legacy STA or an ESTA with non-real-time retransmission frames is involved in its backoff procedure. ESTA1 with the longest jamming time survives on the jamming contention phases and starts its frame retransmission. Other stations will wait for the next transmission opportunity. The legacy STA freezes its backoff time counter because the channel is always sensed busy. The collision occurs only when more than one ESTA has the same longest jamming time period. It is most likely to have a successful retransmission in each transmission opportunity with our proper control of jamming time.

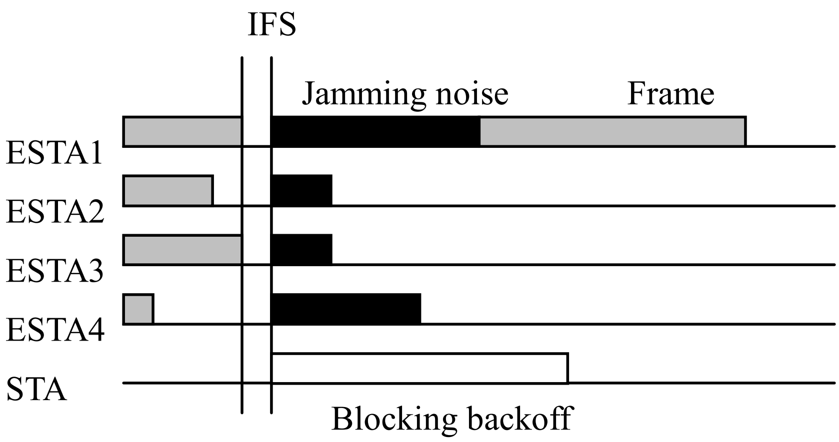

Figure 3-2   Jamming-based channel contention.

3.2 Parameters Optimization

We analyze the jamming retransmission cost to decide the proper p_J value. Assume that a data frame is with the size of *framesize* octets in average. Let

RetryLimit denote the maximum number of retransmission attempts. The probability of *i* ESTAs generating the longest jamming time of *f* slots could be calculated as follow:

$$P_J(N,f,i) = \binom{N}{i} P_J(f)^i \left(\sum_{j=1}^{f-1} P_J(j)\right)\left(\sum_{j=1}^{f-1} P_J(j)\right)\cdots\cdots\left(\sum_{j=1}^{f-1} P_J(j)\right)$$

This formula expresses that there are *i* stations among all *N* stations having the longest jamming time of *f* slots, and each of other *N-i* stations gets shorter jamming time than *f*. Its range is from *1* to *f-1*. The probability function could be given as below:

$$P_J(N,f,i) = \binom{N}{i} P_J(f)^i \left(\sum_{j=1}^{f-1} P_J(j)\right)^{N-i} \tag{8}$$

We let $JAM_{success}$ denote of the jamming time overhead when a station successfully transmits a data frame after a jamming contention phase, and $JAM_{failure}$ stands for the jamming time overhead if collision is occurred after jamming. $R_{success}$ and $R_{failure}$ are the retransmission costs while the retransmission is successful and unsuccessful, respectively. The followings are the representation of each parameter in equations:

$JAM_{success}$: *average jamming time when jamming is successful*
$JAM_{failure}$: *average jamming time when jamming is unsuccessful*
$R_{success}$: *a successful retransmission cost*
$R_{failure}$: *an unsuccessful retransmission cost*
$T_{framesize}$: *time to tramsmit a data frame*

A successful jamming means that only one station has the longest jamming time in a jamming contention phase and an unsuccessful jamming means that at least two stations get the same longest jamming time in a jamming contention phase. The jamming time overhead for a successful jamming and an unsuccessful jamming could be described as below:

$$JAM_{success} = \sum_{f=1}^{JW} P_J(N, f, 1) \cdot f$$

$$JAM_{failure} = \sum_{f=1}^{JW} \sum_{i=2}^{N} P_J(N, f, i) \cdot f$$

The time to transmit a data frame could be shown as below:

$$T_{framesize} = FrameSize / Bandwidth$$

The average retransmission costs for a successful jamming and an unsuccessful jamming could be described as follows:

$$\begin{aligned} R_{success} &= JAM_{success} \\ R_{failure} &= JAM_{failure} + T_{framesize} \end{aligned} \tag{9}$$

Therefore, we can come up with the average retransmission cost, R_{avg} as shown:

$$R_{avg} = \sum_{i=0}^{RetryLimit} \{ \left(i \cdot R_{failure} + R_{success} \right) \cdot \left(1 - \sum_{f=1}^{JW} P_J(N, f, 1) \right)^i \cdot \sum_{f=1}^{JW} P_J(N, f, 1) \} \tag{10}$$

We can determine the optimal p_J value with the minimum retransmission cost by given the size of a data frame and the number of ESTAs. For example, the optimal p_J value is 0.35, 0.45, and 0.5 when data *framesize* is 200, 300, and 400 octets, respectively as N is 100.

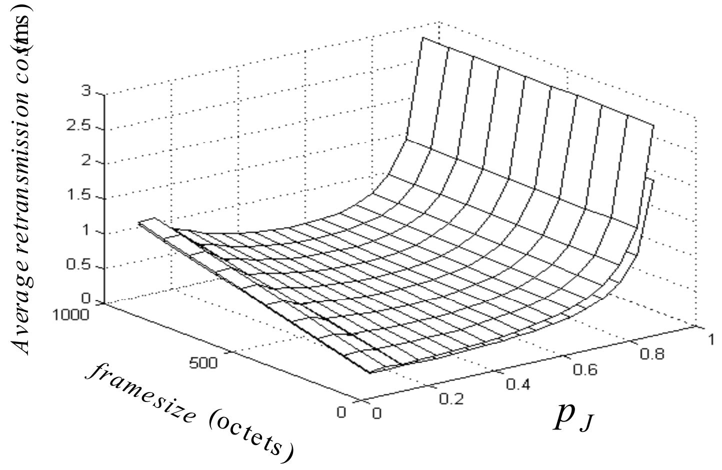

Figure 3-3 Average retransmission cost

TABLE II

RECOMMENDED p_J VALUES WHILE N=100

framesize	p_J	*framesize*	p_J
100	0.2	600	0.55
200	0.35	700	0.55
300	0.45	800	0.6
400	0.5	900	0.6
500	0.5	1000	0.6

Figure 3-3 shows the numerical result of average retransmission cost as *RetryLimit* is 5. The upper curved surface is with $N = 1000$ and the lower one is with $N = 100$. It can be seen that the retransmission cost is insensitive to N. Table II collects the optimal p_J values with the minimum retransmission cost, given the size of a data frame. Therefore, we first decide the p_J value from the size of the data frame, and then decide the *JW* value.

3.3 The Frame Format and State Diagram

The QoS parameter set element contained in the beacon frame is shown in Figure 3-4. We should take care of two system parameters: system capacity and frame size. These two parameters are denoted by the symbols: *N* and *framesize* mentioned in section 3.2, respectively. The parameters could be either fixed settings in the beginning or dynamically updates in order to reflect the traffic categories and traffic load by the jamming-functions-enable point coordinator. By minimizing the retransmission cost in (10), each ESTA could calculate the optimal p_J and *JW* value distributedly by using its local information or the QoS parameter pair, (*framesize, N*), from point coordinator.

Element ID	**Length**	**System Capacity**	**Framesize**	**Reserved Parameter**
		N[0] ... N[7]	FrameSize[0]…FrameSize[7]	Reserved[0]…Reserved[7]
(12)	(18)	(8 octets)	(8 octets)	(8 octets)

Figure 3-4 The required parameters of QoS parameter sets element for Jamming-base retransmission scheme.

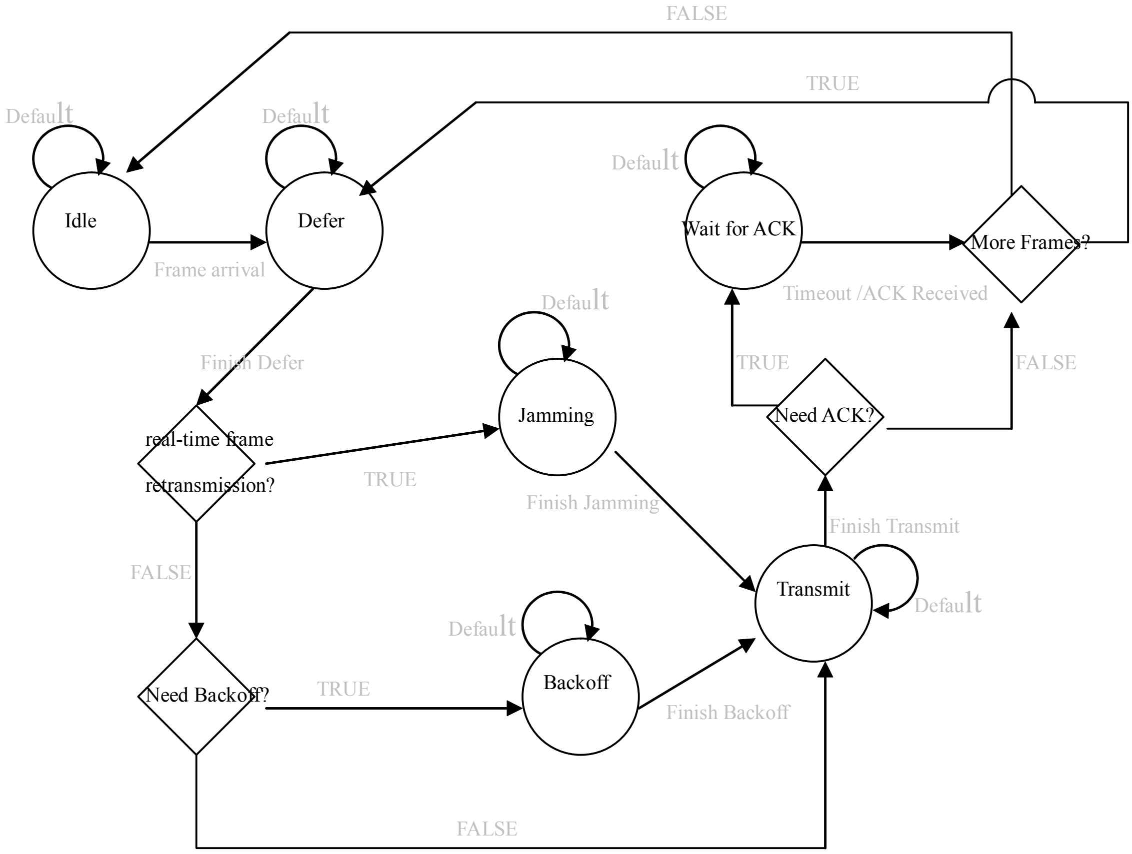

Figure 3-5   The State diagram for Jamming-Based retransmission scheme.

Figure 3-5 is the state diagram of the jamming-based retransmission scheme. Initially, the system is in the *Idle* state. Once the frame is arrived, the system transfers its current state to the *Defer* state to defer its transmission for a property inter-frame space. After IFS deferring, the real-time retransmission frames will start its jamming procedure. If no such a frame, the system would run the typical backoff procedure. In the *Jamming* state, the jamming noise is sent continuously after the local jamming period of time is calculated. If the station gets the longest jamming period of time, it could survive the *Jamming* state and enter the *Transmit* state, otherwise it should back to the *Defer* state and wait for the next transmission opportunity. Some traffic categories require an ACK frame to guarantee the reliable transmission will enter the *Wait-for-ACK* state after frame transmission. Whether the frame is successfully received or not, it should back to either *Defer* state or *Idle* state according to the frame waiting queue. An unsuccessfully transmission may cause a retransmission in the next transmission opportunity.

CHAPTER 4
SIMULATION RESULTS

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4.1 Performance Evaluation

We do performance evaluation by simulation. First, we assume that there is always a pending data frame to be transmitted in each STA. Then, we use the traffic models in [15] and run the evaluations again. The channel capacity is 10 Mbps and the channel condition is assumed to be error-free. The real-time data offered load is defined as the number of active real-time traffic flows. Seventy non-real-time traffic flows act as the background traffic. Each ESTA can deal with one traffic flow at the same time, and the flows always attempt to access the channel in each transmission opportunity. The *framesize* is 160 octets for real-time traffic and 512 octets for non-real-time traffic. Here, we compare our proposed jamming-based retransmission scheme with other two schemes: VDCF and TCMA. All of them use the same access method except for the retransmission mechanism. The (CWmin, DIFS) values are (15, 40us) and (31, 50us) for real-time traffic and non-real-time traffic, respectively. The CWPFactor is 8 in the TCMA. p_J is 0.35 and *JW* is 9 in the jamming retransmission mechanism. Comparisons between these three schemes are from the aspects of mean

MAC delay (in millisecond), packet dropping rate, average packet delay jitter and channel utilization when real-time traffic flows increase. The mean MAC delay is the time period from the start contending for the channel to the end of successful transmission. The average packet delay jitter is defined as the average difference between previous and current successful frames delay. The channel utilization stands for the rate of successful data transmission time. Table III collects the settings for our simulations.

In Figure 4-1 (a)(b), the Jamming has a lower MAC delay than other two schemes and the MAC delay is less sensitive to the traffic loads. Notice that the TCMA has a little more delay when the real-time traffic offered load is low because the packets do not exceed the retry limit. With the increasing offered load, the packet dropping rate becomes huge and packet delay time increases because collisions are aggregated with a smaller CW. TCMA quickly drops the packets for lower delay. It is not a good way to reduce the packet delay because the enormous dropping frame may cause the upper-layer of the network to retransmit these packets for reliability and it may aggravate the congestion situation in the MAC layer. Even though no retransmission in the upper layer, it is still difficult to matching the boundary of dropping rate for real-time traffic. This experiment reveals the ability of the jamming retransmission to limit the packet delay. The stable performance is attributed to the feature for our jamming algorithm: a large probability to survive a station in each transmission opportunity no matter how many stations is involved in the contention.

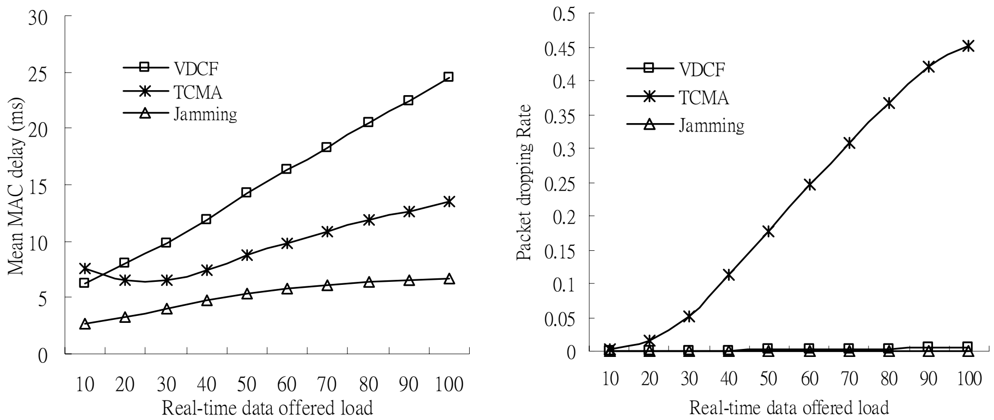

Figure 4-1. (a) (b)

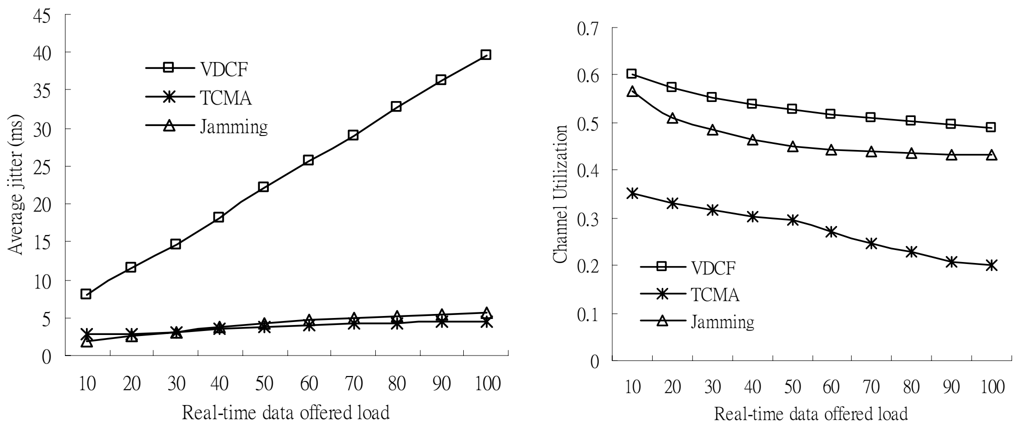

Figure 4-1. (c) (d)

Figure 4-1 Comparison between different retransmission mechanisms.
(a) Mean MAC delay. (b) Packet dropping rate.
(c) Average jitter. (d) Channel utilization.

. Figure 4-1 (d) shows the jamming retransmission mechanism improves 36.48% channel utilization than TCMA, but 12.25% less than VDCF. The reason is that VDCF gives more chance to non-real-time traffic and Jamming wastes a little jamming time. The outcome reflected in the average packet delay jitter of real-time traffic is shown in Figure 4-1 (c). VDCF is from 3.08 to 6.09 times the average packet delay jitter of jamming retransmission mechanism.

4.2 Simulation Results

Furthermore, we design a wireless LAN simulator. The physical parameters are followed the IEEE 802.11b DSSS mode standard. Referred to [15], which discussed lots of traffic characterization and simulation analysis, we use voice traffic as the real-time traffic that is modeled by a two state Markov chain as shown in Figure 4-2. The traffic of two different flows is assumed to be independent. A transition between the 'Talking' and 'Silent' states can happen at anytime with the transition probability Pt,s (Ps, t) from the 'Talking' to 'Silent' (from 'Silent' to 'Talking'). For a given average time duration Tt (Ts) at 'Talking' ('Silent') state Pts (Pst) is exponential distributed with mean 1/Tt (1/Ts). Here we assume Tt=1000 and Ts = 1350 (millisecond). The data rate is 64Kbps and frame duration is 20 millisecond. The non-real-time traffic is generated by an ON/OFF source with ON state duration to be 3.3 sec and OFF state duration to be 22.8 sec. The ON and OFF periods are distributed according to Weibull distribution. The *framesize* is bimodal distributed from 256 to 512 bytes. The simulation result is shown in Fig 4-3. The result is matched with our previous observation.

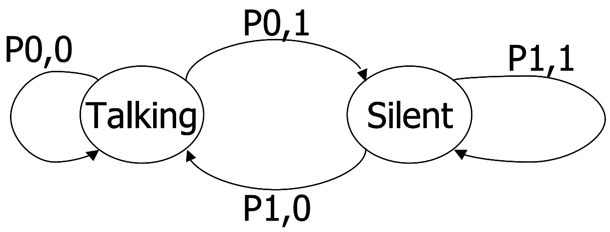

Figure 4-2 Voice traffic model by a two-state Markov chain.

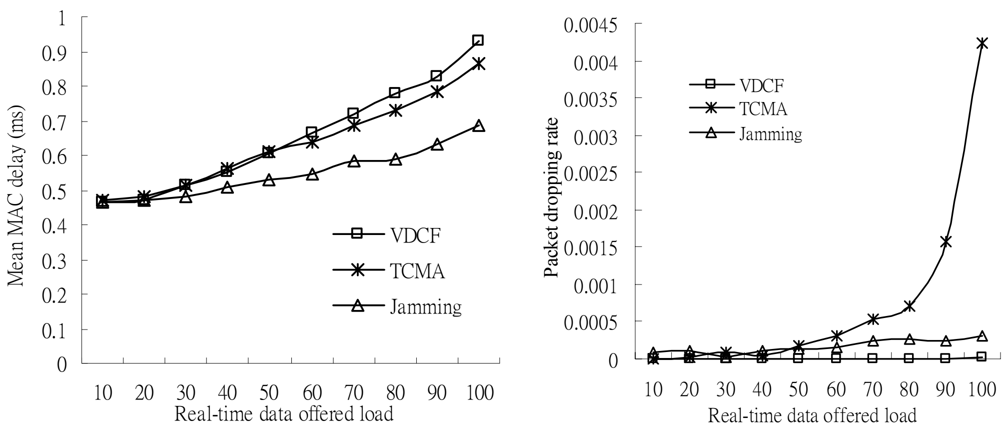

Figure 4-3 (a) (b)

Figure 4-3 Comparison between different retransmission mechanisms with the traffic model of two-state Markov chain.
(a) Mean MAC delay. (b) Packet dropping rate.

TABLE III

SIMULATION PARAMETERS

Name		***Value***	***Unit***
Channel Capacity		10	Mbps
Slot-time		20	μs
Real-time	Data frame size	160	Octets
	Frame inter-arrival time	20	ms
	Traffic offered load	Variable	Flows
	Mean Talking-State duration	1	sec
	Mean Silent-State duration	1.35	sec
	CWmin	15	
	DIFS	40	μs
	Pj	0.35	
	JW	8	
	CWPFactor	8	
Non-real-time	Data Frame Size	256/512	Octets
	Traffic offered load	70	Flows
	Mean ON-State duration	3.3	sec
	Mean OFF-State duration	22.8	sec
	CWmin	31	
	DIFS	50	μs

CHAPTER 5
CONCLUSIONS AND FUTURE WORKS

In this thesis, we proposed a jamming-based retransmission mechanism, which can meet QoS requirements for real-time traffic in the contention period. The jamming noise keep the non-real-time traffic from contention with real-time traffic so that the real-time data frame could be rapidly retransmitted without the effects of large delay and variant jitter which may be caused by the binary exponential backoff specified in the IEEE 802.11 MAC protocol. The random jamming time generation algorithm is according to a truncated geometric distribution. With the jamming noise and truncated geometric distributed random jamming time, our proposed mechanism could achieve a stable performance regardless of the traffic loads

We have used an analytical method to determine the proper length of a jamming noise, which is mainly dependent on the size of data frame being transmitted. Base on the retransmission cost function, we can dynamically update the optimal parameters in our jamming noise generation algorithm.

The stations with the jamming function are compatible with legacy stations. The proposed retransmission mechanism can be combined with other internal packet scheduling schemes to achieve better performance. In the future, we will study the differentiation of jamming retransmissions according to the traffic priorities. The call admission control will be involved too.

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