國立交通大學

資訊科學與工程研究所

碩 士 論 文

IEEE 802.11(e)動態串流指派
與頻寬保證設計

Traffic Stream Assignment and Bandwidth Guarantee
over IEEE 802.11(e)

研 究 生：徐明琬

指導教授：王協源

中 華 民 國 九 十 五 年 六 月

IEEE 802.11(e)動態串流指派與頻寬保證設計
Traffic Stream Assignment and Bandwidth Guarantee over IEEE 802.11(e)

研 究 生：徐明琬　　Student：Ming-Wan Hsu

指導教授：王協源　　Advisor：Shie-Yuan Wang

國 立 交 通 大 學
資 訊 科 學 與 工 程 研 究 所
碩 士 論 文

A Thesis

Submitted to Institute of Computer Science and Engineering

College of Computer Science

National Chiao Tung University

in partial Fulfillment of the Requirements

for the Degree of

Master

in

Computer Science

June 2006

Hsinchu, Taiwan, Republic of China

中華民國九十五年六月

摘要

近年來，IEEE 802.11 標準已成爲最普遍的無線技術，但其本身並不適合多媒體應用，無法具備提供服務品質 (QoS) 支援與頻寬保證的能力。 於是，IEEE 另開發出 802.11e 標準來修正傳統 802.11 標準的種種缺點。在 IEEE 802.11e 內，定義了一個 poll-based 的 HCF 頻道控制管理 (HCCA)。在 HCCA 中，允入控制 (Admission Control) 單元需根據資料流的需求與目前頻道狀態，來決定是否允許資料流加入排程。

開始發展 802.11e 標準後，許多研究者提出了他們的方法來保證多媒體資料的處理量，提升 802.11e 的能力。對於 802.11e 的允入控制與排程上，不少新的觀念看法被提出。但是，只取決於無線存取點本身的資訊，來做出允入或拒絕的決定，並不足以爲整個無線系統增進 QoS 保證。在一個公開場所，需要有充足的無線存取點來提供完整的訊號覆蓋和頻寬。以最強的信號爲依據選擇存取點，可能導致無效率的頻道運用與 QoS 支援。

本文主要集中在討論 802.11e 的 HCCA 部分，提出動態串流指派系統，來提升 802.11e 無線網路的實用性，有效率的使用頻道，增進其表現。系統並考慮各條資料流的用戶優先權，根據優先權，調度排程者決定承認或拒絕請求。模擬結果顯示，比起原本的 802.11e 無線網路，我們的系統可支持更多 QoS 要求，因而增加系統的總處理量。此外，關於存取點間交換訊息與處理資料流造成的時間損耗，模擬實驗數據顯示，其值微小、不會大幅影響資料流表現。

Abstract

The IEEE 802.11 standard, which is the most popular technology in recent years, does not satisfy the needs of multimedia applications and cannot provide the guarantees for quality of service (QoS). As a result, IEEE 802.11e was developed to enhance the shortcomings of the traditional IEEE 802.11 standard. For the poll-based HCF Controlled Channel Access (HCCA) defined in 802.11e, an admission-control algorithm is needed to make decisions on whether or not to admit a traffic stream (TS) based on the stream's requirements, the utilization of currently-used channel.

In accordance with the current version of the IEEE 802.11e standard, many researchers have proposed their schemes to guarantee the throughputs of multimedia applications and to refine the policies of 802.11e. Some of them give a new perspective on the admission control and the scheduler of 802.11e. However, making decisions, which depends on the information of an access point itself, is not enough for the QoS guarantee for an entire wireless network. For example, in an open space a network operator is eager to deploy sufficient access points to provide users with adequate network coverage and bandwidth. In such a case, all users associate with the access point with the strongest signal may cause the unbalanced channel utilization and poor QoS support. As such, we proposed a new scheme to remedy this problem.

In this paper, a dynamic-assignment scheme, based on the HCCA parts of 802.11e, is proposed for enhancing the performance and channel utilization of a practical 802.11e-based wireless network. This scheme also considers the user priority of each traffic stream. Depending on the priorities of traffic streams and the messages from other access points, the scheduler makes a decision to admit, deny, or re-transmit the request from a mobile station. The simulation results show that our scheme can support more QoS demands of applications and thus increase the total throughputs of the whole network. Besides, the overheads of exchanging necessary control messages are also estimated via simulations. The results show that the overheads generated by our scheme are not significant.

.

誌　　　謝

首先，感謝恩師王協源教授在這兩年內對我的指導與照顧，在專業領域上，經過這兩年的扎實訓練，著實獲益良多；而在立身處世方面，老師亦教予我許多。

再來，感謝口試委員沈文和教授、陳志成教授以及黃寶儀教授特地撥冗前來交通大學，聽取我們的論文報告並加以指導，在他們的建議下，修正不足之處，讓這篇論文得以更加完善。

感謝網路與系統實驗室的每一個成員，與你們的相處與相互協助，讓我了解到團體合作的方法與溝通技巧，也充實了我的兩年研究所生活、帶給我快樂。

最後，感謝父母對我的栽培，姊姊對我的照顧，有了他們無比的耐心包容我、陪伴我，我才能順利的完成學業。

Table of Contents

List of Figures

List of Tables

1. Introduction

1.1 Motivation

Wireless Local Area Networks (WLANs) have become necessary for many enterprise and public networks and are widely available today. The most common WLAN technology today is the one standardized by the IEEE 802.11 working group [1]. Nowadays more and more applications are used over such wireless networks. As such, the Quality of service (QoS) and multimedia supports become more and more important to wireless networks. In the future, Internet service providers shall offer their customers a variety of applications, such as video-on-demand, audio-on-demand, voice-over-IP and high-speed Internet access, etc. However, the IEEE 802.11 standard was not originally developed for those applications. As a result, there have been many efforts to make it suitable for multimedia applications. These enhancements have been organized and specified in the IEEE 802.11e standard [2].

To support QoS in the MAC layer of the popular 802.11 WLAN standard, the IEEE 802.1le standard adds some new features. However, these features do not provide the final solution to satisfy the needs of multimedia applications. Instead, it is possible for researchers and vendors to enhance the QoS ability of the existed standard by using these features. In this paper, a dynamic-assignment scheme is proposed for enhancing the performance and channel utilization of an 802.11e wireless network.

1.2 Problem Description

Direct communications between an 802.11 wireless network interface card (NIC) and an access point occur over a common channel frequency. In an 802.11 network, each access point (AP) operates on a fixed channel frequency that is assigned in advance. And a wireless NIC which wants to connect to this network has to tune its transceiver to the frequency, on which the sensed signal strength is the strongest. This can be done by the channel scanning process defined in the IEEE 802.11 standard.

After determining the most usable channel, the access point to which this NIC wants to associate is determined as well because access points, the transmission coverage of which overlaps, should set their operational channel frequencies properly to minimize the signal interference. Otherwise, a mobile node's roaming between access points will not work well, and performance will degrade because of interference between access points.

For a WLAN, the service provider shall deploy enough access points to provide adequate signal coverage and system bandwidth for users. In such a situation, a user may have multiple access points to select. The rule of choosing the AP which has the strongest signal may result in inefficient channel utilization. Due to this observation, this paper discusses the dynamic methods of assigning traffic streams to adaptable access points.

The proposed schemes were mainly based on the contention-free mechanism of the 802.11e. To implement the contention-free policy in a MAC layer, the admission control unit of an access point admits bandwidth to mobile nodes which query for QoS applications. And thus the admitted traffic streams will be polled periodically. For practical situation, such as many students in a videoconference, these students both require a guaranteed bandwidth of wireless medium. If the students gather at a corner of the room, most of them may access to the same access point regardless of other idle APs nearby. In this case, the QoS demands of users do not meet not because of the starving resources but because of the unkown of system state.

Figure 1 shows the topology of overlapping basic service sets (BSS), but omit the wired backbone network behind these three access points. It can be observed that most mobile stations will associate with AP3 and may ask AP3 for their QoS requirements According to IEEE 802.11e reference scheduler, unaffordable contention-free requests will be denied by AP3, and these unaffordable traffic streams will become contention traffic which uses the CSMA/CA method to access wireless medium

As illustrated in Section 2.4, the IEEE 802.11e standard states the possibility to consider user priorities (UP) while scheduling traffic streams in contention-free admission control. This may be implemented by examining the UP field in TSPEC to decide whether to admit, retain, or drop a stream. If a higher UP stream needs to be serviced, a scheduler of AP might drop lower UP streams. In general, the higher user priority it specifies the more time-critical data it transmits. For example, the priority of voice over IP (VoIP) data is higher than the priority of video on demand (VOD) data.

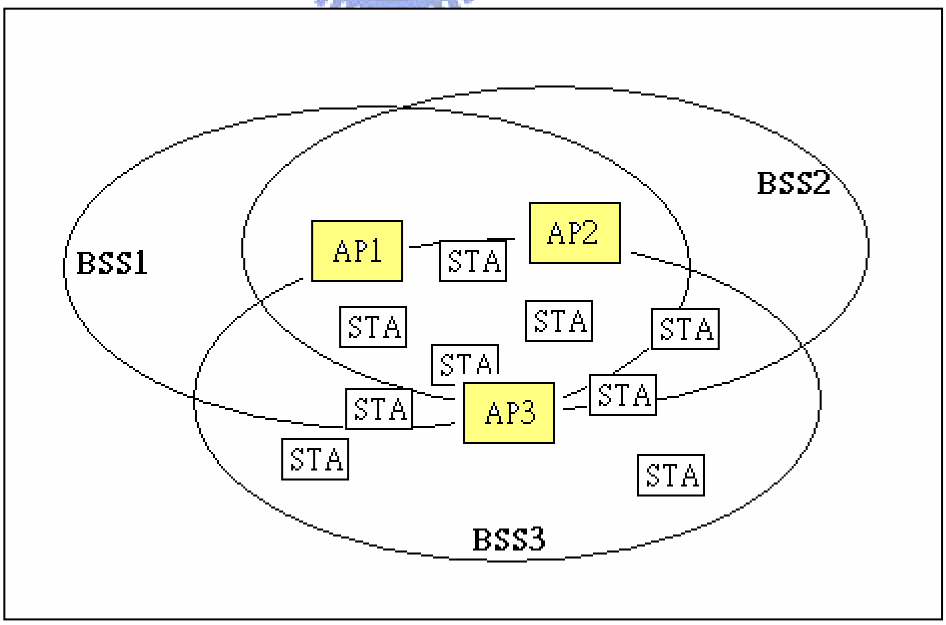

Figure 1. The practical topology of overlapping BSS

1.3 Related Work

Over the past few years, numerous studies have been proposed on the problem of guaranteeing QoS for multimedia applications in a wireless network. Lots of researchers focus on the development and improvement on the IEEE 802.11e standard. Some of them only concentrate on the contention-based channel access mechanism of 802.11e from simply evaluate its performance [3]-[6] to enhance its functionality [7]-[9]. Others may study the behavior of the controlled channel procedures or improve the capability of the scheduler and admission unit in an IEEE 802.11e AP.

IEEE 802.11e standard [2] includes an example scheduling algorithm, referred to as the Simple Scheduler. This scheduler provides a reference for researchers to develop more complicated implementation in the future. Qiang Ni [10] investigated the performance of the simple scheduler, and showed that HCCA can guarantee the delay requirement for constant bit rate (CBR) traffic. However, the delays of variable bit rate (VBR) video flows are completely uncontrolled. By identifying the weaknesses of the simple scheduler mentioned in IEEE 802.11e, several algorithms for schedulers have been proposed to improve the attained performance [11]-[14].

The scheduling algorithm proposed in [11] provides improved flexibility by allowing access points to poll each mobile station with variable intervals, assigning variable length transmission opportunities. In [12], the FHCF scheme is proposed to be fair for both CBR and VBR flows. It tunes the time allocation to mobile stations based on queue length estimations. In [13], the author proposes a Feedback Based Dynamic Scheduler (FBDS) to allocate the first-hop bandwidth in an 802.11e network using the HCF controlled channel access. Thus the proposed FBDS algorithm succeeds in guaranteeing delay bounds required by multimedia applications. The scheme in [14] takes channel conditions into consideration to make scheduling decisions and shows significant performance improvements compared to earlier schemes that could not take channel conditions into account.

The scheduling algorithms mentioned above focus on the QoS guarantee for per traffic stream in a controlled-based manner. Some traffic management schemes for the admission control aims at achieving high link utilization which is also the main considering issue of this paper. On the other hand, an admission control is important for the 802.11e network to support QoS adequately. The 802.11e standard has included an admission control policy to cooperate with the simple scheduler. However, the policy is not good enough to support QoS services, because it assumes that all traffic streams are transmitting at CBR, and implemented based on the minimum physical rate. The minimum physical rates are often considerably slower than the mobile stations' actual physical rates, and thus it may cause the inefficiency of the reference policy. [15] proposes a physical rate based admission control scheme (PRBAC) which enhances the reference policy by taking account of both the wireless channel characteristics and the stations' mobility. Boris Makarevitch [16] considers scheduling algorithms and described an efficient measurement-based admission control for the 802.11e controlled channel access.

The admission control policy illustrated above only makes decisions using channel utilization or other knowledge sensed by the policy. For the purpose of enhancing the network performance, the dynamic assignment is proposed in this paper to handle QoS requests depending on the information from the entire network. Access points will exchange messages to inform others their current bandwidth loads. Through the cooperation of all access points, an unsatisfied traffic stream can be moved from the current associated access point to a suitable one which has enough bandwidth for the TS. In addition to adapt the requirement of time-critical services, the user priority is also considered by the dynamic assignment.

1.4 Organization

The rest of this paper is organized as follows. A brief overview of the 802.11 standard and the 802.11e standard is described in Chapter 2. In Chapter 3, a new dynamic assignment scheme is proposed to improve the channel utilization and fit the QoS requirements of applications. A scheme which considers the locations of APs and the mobility of clients is also introduced. In Chapter 4, the performances of the proposed schemes was evaluated and proved by simulations. In Chapter 5, complicated cases were simulated with the dynamic assignment. The results of dynamic assignment were compared with those of the simple scheduler in IEEE 802.11e. The simulation parameters, including the realistic traffic models, are also mentioned in this chapter. In Chapter 6, we discuss the further improvements which can be done in the future. Finally, in Chapter 7 the conclusion of this paper is drawn.

2. Background

This section mainly describes an overview of IEEE 802.11e MAC. At first, the parameters and functionality of current IEEE 802.11 MAC are briefly introduced. Then compared with the legacy IEEE 802.11, the difference and the quality of service (QoS) enhancements of IEEE 802.11e are presented as the following.

2.1 Legacy IEEE 802.11 MAC

Coordination function is the logical function that determines when a station operating within a basic service set (BSS) is permitted to transmit and may be able to receive protocol data units (PDUs) via the wireless medium (WM). The coordination function of IEEE 802.11 may have one point coordination function (PCF), which provides contention-free frame transfer, and will have one distributed coordination function (DCF), which provides contention frame transfer based on CSMA/CA. The MAC architecture can be described as shown in Figure 2 as providing the PCF through the services of the DCF.

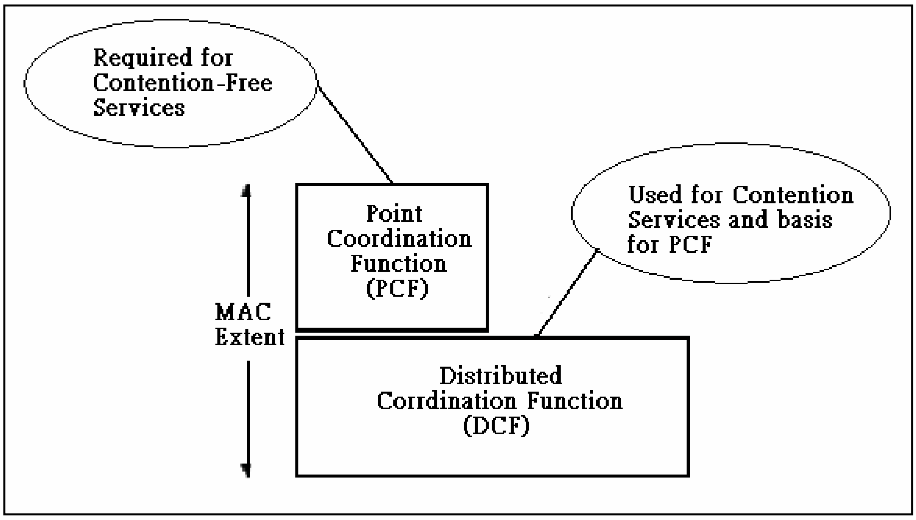

Figure 2. IEEE 802.11 MAC architecture

A DCF allows automatic medium sharing between compatible PHYs through the use of CSMA/CA and a random backoff time following a busy medium condition. In addition, all directed traffic uses immediate positive acknowledgment (ACK frame) where retransmission is scheduled by the sender if no ACK is received.

In PCF, the contention-free transfer protocol is based on a polling scheme controlled by a point coordinator (PC) operating at the AP of the BSS. Becoming a PC is optional to an AP, and it is also optional to a MS that responds to a contention-free poll (CF-Poll) received from a PC. When polled by the PC, a CF-Pollable MS may transmit only one MPDU, which can be to any destination (not just to the PC). If the data frame is not in turn acknowledged, the CF-Pollable MS shall not retransmit the frame unless it is polled again by the PC, or it decides to retransmit during the contention period (CP). A PC may perform a backoff on retransmission of an unacknowledged frame during the contention-free period (CFP).

The time interval between frames is called the IFS. A MS shall determine that the medium is idle through the use of the carrier-sense function for the interval specified. Four different IFSs are defined for access to the wireless media; they are listed in order, from the shortest to the longest.

1. Short IFS (SIFS): SIFS is the shortest of the interframe spaces, used for an ACK frame, a CTS frame, the second or subsequent MPDU of a fragment burst, and by a MS responding to any polling by the PCF. It may also be used by a PC for any types of frames during the CFP.

2. PCF IFS (PIFS): The PIFS is used only by STAs operating under the PCF to gain priority access to the medium at the start of the CFP. A MS using the PCF shall be allowed to transmit contention-free traffic after its carrier-sense

mechanism determines that the medium is idle at least PIFS duration.

3. DCF IFS (DIFS): The DIFS is used by STAs operating under the DCF to transmit data frames (MPDUs) and management frames (MMPDUs). A MS using the DCF shall be allowed to transmit if its carrier-sense mechanism determines that the medium is idle at least DIFS duration after a correctly received frame, and its backoff time has expired.

4. Extended IFS (EIFS): The EIFS, which is used by the DCF, begins following the indication by the PHY that the medium is idle after detection of the erroneous frame. If an error-free frame is received during the EIFS, the MS will terminates the EIFS and continues normal medium access (using DIFS and, if necessary, backoff).

Figure 3 shows some relationships between the IFS specifications, defined as time gaps on the medium.

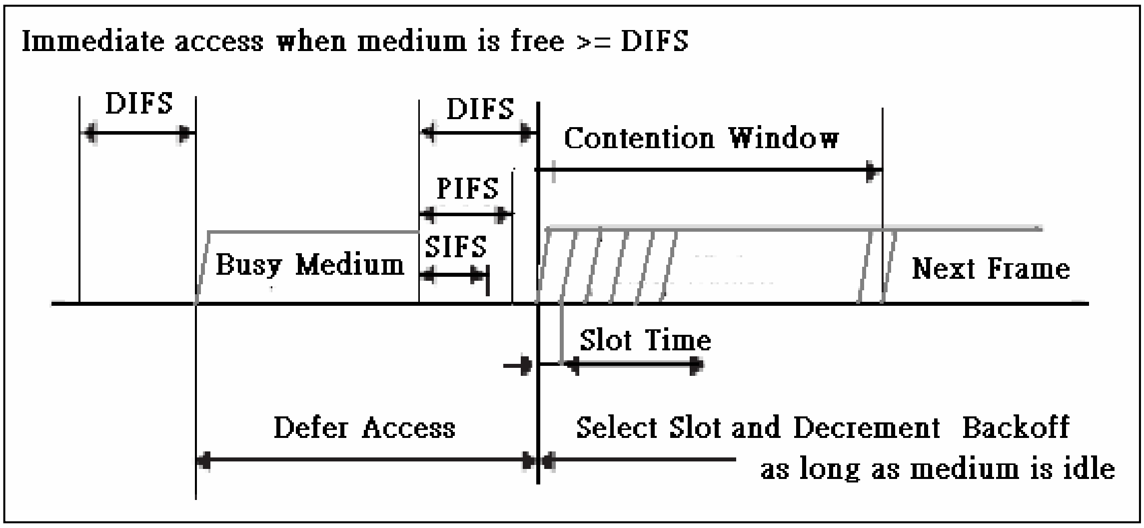

Figure 3. The relationships between the IFS in IEEE 802.11

Before transmission, a MS shall detect if the medium is idle. If the medium is busy, the MS will defer until the medium becomes idle without interruption for a DIFS or EIFS interval. After this medium idle time, the MS then generates a random backoff period for an additional deferral time before transmitting, unless the backoff timer already contains a nonzero value, in which case the selection of a random number is not needed and not performed. The Backoff period is calculated as follows:

$$\textbf{Backoff Time} = \textbf{Random}\ (0,CW) \times \textbf{aSlotTime} \qquad (1)$$

Random (0,CW) selects a number between the interval [0,CW], where contention window (CW) is an integer within the range of values of the PHY characteristics aCWmin and aCWmax. Initially, the value of CW is aCWmin, and then it increases every time an unsuccessful attempt to transmit an MPDU until the CW reaches the value of aCWmax. Once it reaches aCWmax, the CW remains at the value of aCWmax until a successful transmission and it is reset to aCWmin.

$$CW = 2^{(2+i)} - 1 \qquad (2)$$

where i is the number of transmission attempts, and the set of CW values shall be sequentially ascending integer powers of 2, minus 1.

2.2 IEEE 802.11(e) QoS Enhancements

The MAC architecture can be described as shown in Figure 4 as providing the PCF and hybrid coordination function (HCF) through the services of the DCF. PCF is optional in all STAs.

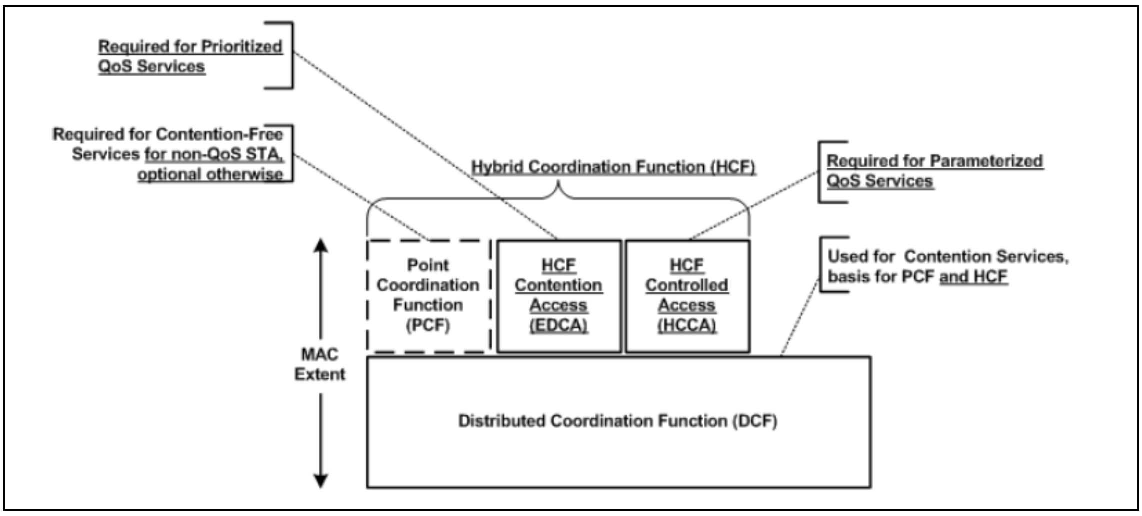

Figure 4. IEEE 802.11e MAC architecture

In IEEE 802.11e, an additional coordination function called HCF is usable in QoS network (QBSS) configurations and shall be implemented in all QSTAs. It combines functions from the DCF and PCF with some enhanced, QoS-specific mechanisms and frame subtypes. The HCF uses both a contention-based channel access method, called the enhanced distributed channel access (EDCA) mechanism for contention-based transfer and a controlled channel access, referred to as the HCF controlled channel access (HCCA) mechanism, for contention-free transfer.

The EDCA mechanism provides differentiated, distributed access to the WM for QSTAs using eight different user priorities (UPs). The EDCA mechanism defines four access categories (ACs) that provide support for the delivery of traffic with UPs at the QSTAs. The AC is derived from the UPs as shown in Table 1.

Priority	UP (Same as 802.1D user priority)	802.1D designation	AC	Designation (informative)
Lowest	1	BK	AC_BK	Background
	2	—	AC_BK	Background
	0	BE	AC_BE	Best Effort
	3	EE	AC_BE	Best Effort
	4	CL	AC_VI	Video
Highest	5	VI	AC_VI	Video
	6	VO	AC_VO	Voice
	7	NC	AC_VO	Voice

Table 1. UP-to-AC mappings

For a transmit queue of each AC, an independent EDCA function contends for transmission opportunities (TXOPs) using a distinct set of EDCA parameters as following:

1. Arbitration IFS: the minimum specified idle duration time is not the constant value (DIFS) as defined for DCF, but is a distinct value assigned either by a management entity or by a QAP. The duration AIFS[AC] is a duration derived from the value AIFSN[AC] by the relation:

$$\mathbf{AIFS[AC] = AIFSN[AC] \times aSlotTime + aSIFSTime} \qquad (3)$$

2. CWmin and CWman: the contention window limits, from which the random backoff is computed, are not fixed per PHY, as with DCF, but are variable and assigned by a management entity or by a QAP.

3. TXOP limit: during an EDCA TXOP, a QMS may initiate multiple frame exchange sequences within the same AC. The duration of this EDCA TXOP is called TXOP limit and bounded for an AC. A value of 0 for this duration means that the EDCA TXOP is limited to a single MSDU or MMPDU at any rate in the operational set of the QBSS.

4. Internal collisions: if collisions occur between contending EDCAFs within a QSTA, the data frames from the higher priority AC receives the TXOP and the data frames from the lower priority colliding AC(s) behave as if there were an external collision on the WM.

The default values used by QSTAs for the parameters in the EDCA Parameter Set element are defined in Table 2.

AC	CWmin	CWmax	AIFSN	TXOP limit		
				For PHYs defined in Clause 15 and Clause 18	For PHYs defined in Clause 17 and Clause 19	Other PHYs
AC_BK	aCWmin	aCWmax	7	0	0	0
AC_BE	aCWmin	aCWmax	3	0	0	0
AC_VI	(aCWmin+1)/2 – 1	aCWmin	2	6.016 ms	3.008 ms	0
AC_VO	(aCWmin+1)/4 – 1	(aCWmin+1)/2 – 1	2	3.264 ms	1.504 ms	0

Table 2. default EDCA parameter values

The HCCA mechanism uses a QoS-aware centralized coordinator, called a hybrid coordinator (HC). The HC is collocated with the QAP of the QBSS and uses the HC's higher priority of access to the WM to initiate frame exchange sequences and to allocate TXOPs to itself and other QSTAs in order to provide limited-duration controlled access phase (CAP) for contention-free transfer of QoS data.

The HC differs from the PC used in PCF in several significant ways, although it may optionally implement the functionality of a PC. Most important is that HCF frame exchange sequences may be used among QSTAs associated in a QBSS during both the CP and any locally generated CFP (generated optionally by the HC) to o meet the QoS requirements of a particular TC or TS. Another significant difference is that the HC grants a non-AP QMS a polled TXOP with duration specified in a QoS(+)CF-Poll frame. Non-AP QSTAs may transmit multiple frame exchange sequences within given polled TXOPs, subject to the limit on TXOP duration.

Five different IFSs are defined to provide priority levels for access to the wireless media. Arbitration interframe space is added in IEEE 802.11e for QoS facility. The relationships of these IFSs are shown as Figure 5.

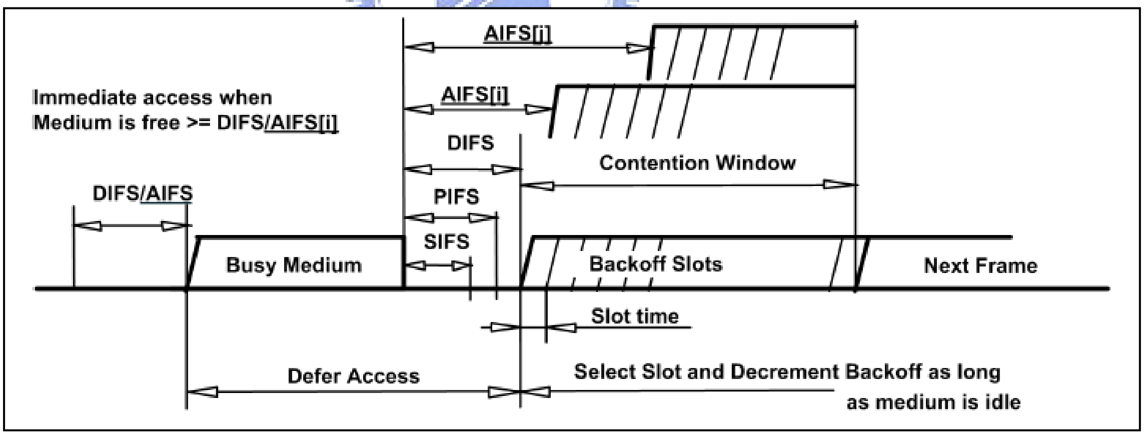

Figure 5. IEEE 802.11e IFS relationships

2.3 Admission Control at the HC

Admission control, in general, depends on vendors' implementations of schedulers, available channel capacity, link conditions, retransmission limits, and the scheduling requirements of a given TSPEC. It is required when a QMS desires guarantee on the amount of time that it can access the channel. The HC, which is in the QAP, is used to administer admission control in the network. As IEEE 802.11e supports two access mechanisms, there are two distinct admission control mechanisms: one for contention-based access and another for controlled access.

When the HC provides controlled channel access to non-AP QSTAs, it is responsible for granting or denying polling service to a TS based on the parameters in the associated TSPEC. If the TS is admitted, the HC is responsible for scheduling channel access to this TS based on the negotiated TSPEC parameters. The HC should not tear down a TS unless explicitly requested by the MS or at the expiry of the inactivity timer. The polling service based on admitted TS provides a "guaranteed channel access" from the scheduler in order to have its QoS requirements met. The nature of wireless communications may preclude absolute guarantees to satisfy QoS requirements. However, in a controlled environment (e.g., no interference), the behavior of the scheduler can be observed and verified to be compliant to meet the service schedule.

An ADDTS (add traffic stream) Request frame shall be transmitted by a non-AP QMS to the HC in order to request admission of traffic in any direction (i.e., uplink, downlink, direct, or bidirectional) employing an AC that requires admission control. The QAP shall respond to an ADDTS Request frame with an ADDTS Response frame that may be to accept or deny the request. On receipt of an ADDTS Request frame from a non-AP QSTA, the QAP shall make a determination about whether to

1. Accept the request, or
2. Deny the request.

When the HC aggregates the admitted TS, a QAP shall schedule the transmissions in

HCCA TXOPs and communicate the service schedule to the non-AP QSTA. The service schedule is communicated to the non-AP QMS in a Schedule element contained in an ADDTS Response frame. In the ADDTS Response frame, the modified service start time shall not exceed the requested service start time, if specified in ADDTS Request frame, by more than one maximum service interval (SI). The HC uses the maximum SI for the initial scheduling only as there may be situations that HC may not be able to service the TS at the scheduled timing, due to an EDCA or DCF transmission or other interferences interrupting the schedule. The Service Interval field value in the Schedule element shall be greater than the minimum SI. The service schedule could be subsequently updated by a QAP as long as it meets TSPEC requirements. A non-AP QMS may affect the service schedule by modifying or deleting its existing TS. Section 2.4 provides guidelines for deriving an aggregate service schedule for a single non-AP QMS from the non-AP QSTA's admitted TS. The schedule shall meet the QoS requirements specified in the TSPEC.

2.4 The Sample Scheduler and Admission Control Unit

In this section, the design of a simple scheduler and admission control unit (the unit that administers admission policy in the HC SME) meets the minimum performance requirements of controlled-access admission control and use the minimum set of mandatory TSPEC parameters.

The sample scheduler uses the mandatory set of TSPEC parameters to generate a schedule: Mean Data Rate, Nominal MSDU Size, and Maximum Service Interval or Delay Bound. If both Maximum Service Interval and Delay Bound parameters are specified by the non-AP QMS in the TSPEC, the scheduler uses the Maximum Service Interval parameter for the calculation of the schedule. The schedule for an admitted stream is calculated in two steps:

1. Calculate the scheduled SI.
2. Calculate the TXOP duration of the stream for a given SI.

In first step, the calculation of the scheduled service interval is done as follows: First, the scheduler calculates the minimum of all maximum SIs for all admitted streams. Let this minimum be m. Second, the scheduler chooses a number lower than m that is a submultiple of the beacon interval. This value is the scheduled SI for all non-AP QSTAs with admitted streams. See Figure 6.

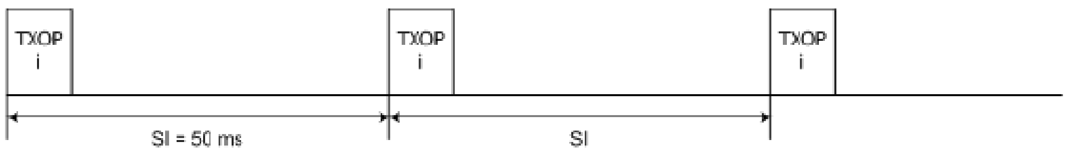

Figure 6. Schedule for stream from QMS *i*

For the calculation of the TXOP duration for an admitted stream, the scheduler uses the following parameters: Mean Data Rate (ρ) and Nominal MSDU Size (L) from the negotiated TSPEC, the Scheduled Service Interval (SI) calculated above, Physical Transmission Rate (R), Maximum Allowable Size of MSDU, i.e., 2304 bytes (M), and Overheads in time units (O). The physical transmission rate is the minimum PHY rate negotiated in the TSPEC. If the minimum PHY rate is not committed in the ADDTS Response frame, the scheduler can use the observed PHY rate as R. The overheads in time include IFSs, ACK frames and CF-Poll frames. For simplicity, details for the overhead calculations are omitted in this description. The TXOP duration is calculated as follows: First, the scheduler calculates the number of MSDUs that arrived at the mean data rate during the SI:

$$N_i = \left\lceil \frac{SI \times \rho_i}{L_i} \right\rceil$$

(4)

Then the scheduler calculates the TXOP duration as the maximum of

— Time to transmit *Ni* frames at *Ri* and

— Time to transmit one maximum size MSDU at *Ri* (plus overheads):

$$TXOP_i = max(\frac{N_i \times L_i}{R_i} + O, \frac{M}{R_i} + O) \quad \textbf{(5)}$$

An example is shown in Figure 6. Stream from QMS i is admitted. The beacon interval is 100 ms and the maximum SI for the stream is 60 ms. The scheduler calculates a scheduled SI (*SI*) equal to 50 ms using the steps above. The same process is repeated continuously while the maximum SI for the admitted stream is larger than the current SI. An example is shown in Figure 7.

If a new stream is admitted with a maximum SI smaller than the current SI, the scheduler needs to change the current SI to a smaller number than the maximum SI of the newly admitted stream. Therefore, the TXOP duration for the current admitted streams needs also to be recalculated with the new SI.

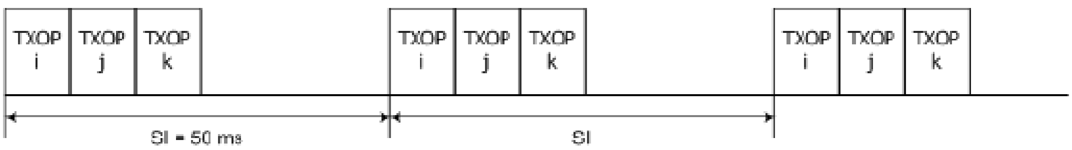

Figure 7. Schedule for streams from QMS *i* to *k*

An admission control unit (ACU) administers admission of TS. The ACU uses the same set of parameters that the sample scheduler uses. When a new stream requests admission, the admission control process is done in three steps:

1. The ACU calculates the number of MSDUs that arrive at the mean data rate during the scheduled SI. The scheduled SI (SI) is the one that the scheduler calculates for the stream as specified in K.3.3.1. For the calculation of the number of MSDUs, the ACU uses the equation for Ni shown in K.3.3.1.

2. The ACU calculates the TXOP duration that needs to be allocated for the stream. The ACU uses the equation for TXOPi shown in K.3.3.1.

3. The ACU determines that the stream can be admitted when the following inequality is satisfied:

$$\frac{TXOP_{k+1}}{SI} + \sum_{i=1}^{k} \frac{TXOP_i}{SI} \leq \frac{T - T_{CP}}{T} \qquad \textbf{(6)}$$

where

k is the number of existing streams

k + 1 is used as index for the newly arriving stream

T indicates the beacon interval

Tcp is the time used for EDCA traffic

The ACU ensures that all admitted streams have guaranteed access to the channel. Any modification can be implemented for the design of the ACU. For example, UP-based ACU is possible by examining the UP field in TSPEC to decide whether to admit, retain, or drop a stream. If the UP is not specified, a default value of 0 is used. If a higher UP stream needs to be serviced, an ACU might drop lower UP streams.

3. System Design and Implementation

This section is divided into two parts. The first one describes the architecture of the overall system, including the design of the MAC layer, which is necessary for the dynamic admission control unit and the priority-based scheduler. The second one describes the detailed implementation of the proposed scheduler and how the dynamic assignment works.

3.1 System Architecture

Figure 8 illustrates a model of a MAC implementation that adopts the regulate channel access procedures specified by the 802.11e standard. A MAC service data unit (MSDU) with its user priority (UP) is sent to the MAC layer from the upper application. At first, it is categorized as either EDCA or the HCCA procedure. The EDCA packets will be inserted to one of the four transmission queues depending on the UP field. For each transmission queue, the channel access is based on its EDCA parameters and the CSMA/CA algorithm. The HCCA traffic, however, is needed to be polled by the hybrid coordinator (HC). If the MAC layer receives an HCCA MSDU, it first recognizes the traffic stream to which the MSDU belongs and then dispatches the MSDU to a corresponding transmission queue. In the case that the determined traffic stream has not been registered in a HC yet, the MAC layer needs to send an ADDTS Request and waits for the decision of the HC.

A traffic controller in Figure 8 manages the register of TSs and other corresponding behavior. It also handles the polling service from a HC. Besides, the transmission coordinator in Figure 8 is responsible for the cooperation of the HCCA and EDCA channel access mechanisms. Suppose that both two channel access schemes inside a node want to access WM, which of them could get the access right first? If one of them wants to access the medium while the other is transmitting, how this conflict is solved? The transmission coordinator is used to deal with these problems and important to the efficiency of 802.11e MAC.

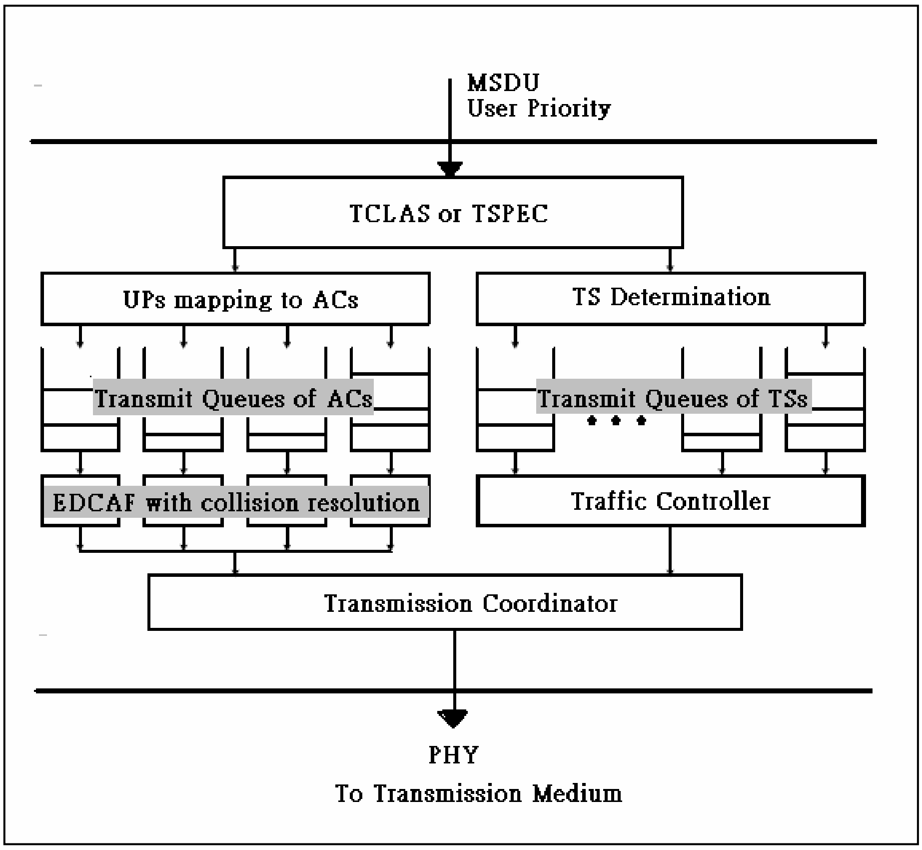

Figure 8. The MAC architecture of 802.11e

In the preceding discussion, a model of MAC layer is depicted. In addition, the network architecture is described in the following. In such a network, there are several access points operating in different channels and a number of mobile stations in a limited region. Because of the overlapping transmission ranges of theses access points, a mobile station may have more than one access point to select to do association. To enhance the channel utilization of each access point, the messages describing guaranteed throughputs in each access point are exchanged in wired links.

Based on the obtained information about the statuses of other access points, the current access point will try to decide which access point the traffic stream can be registered in after receiving an ADDTS Request which can not be served. If an access point is chosen by the distributed, priority-based algorithm, the current access point will send an modified ADDTS Request to the chosen access point over a wired network. When a correct response is answered, the current access point then notifies the mobile station which sends the original ADDTS Request of the chosen access point. In such case, the mobile station can re-associate with the chosen AP.

3.2 System Implementation

In the proposed scheme, some problems need to be taken into account, such as identifying that whether the network is fully overlapped or partially overlapped in terms of the coverage of access points, the mobility of mobile stations, etc. The solutions of these problems will be discussed in the following sections.

3.2.1 Basic Mechanism

According to the IEEE 802.11e standard, the traffic stream of HCCA will send an ADDTS Request to ask its associated AP for guaranteeing the bandwidth it requires. Nevertheless, it is possible that a number of mobile stations connect to the same access point, and thus this phenomenon will cause the starving problem of traffic streams in QoS provision. Using several dynamic assignment schemes, traffic streams can be moved from the current access point to a chosen one. The movements of traffic streams among access points will increase the QoS ability and total performances of the network. In next section, the schemes of the dynamic assignment are briefly introduced.

First of all, the access point information (AP_Info) packets are exchanged over wired links every one second or each time a scheduling is changed. Every access point has to maintain a list of the AP_info structures based on those exchanged packets and keep track of the latest statuses of other access points. Table 3 shows how an AP_info structure describes AP1 and also explains the meanings of those fields in an AP_info structure. Based on the information in Table 3, our dynamic admission schemes try to decide which AP can be chosen for re-register the unsatisfied traffic stream. The following schemes are used while the current access point does not have the ability to satisfy an incoming ADDTS Request.

Parameters	*Meanings*
BSSID	The Basic Service Set ID of AP1.
AP_addr	The MAC address of AP1.
Channel	The using channel of AP1.
Max_SI	The maximum service interval of AP1 scheduler.
TXOP_sum	The sum of transmission opportunities guaranteed by AP1.
Timestamp	The generation time of the latest AP_Info packet from AP1.
Bandwidth	The bandwidth of AP1.
Select	A value indicates AP1 has been selected and its status shall be refreshed before assigning another stream to AP1.

Table 3. The information of AP1 stored in the struct of AP_Info.

1. Scheme A: to find the target access point which can directly support the QoS requirement of a traffic stream, the scheduler checks every unselected access point in the list. It tries to find an access point which uses the smallest bandwidth and shall be freer than the current one. If such an access point exists, the scheduler will calculate the traffic stream's TXOP using the information of this access point to make sure that it has the ability of serving this traffic

stream. If so, the ADDTS Request is redirected to the chosen access point over a wired link. The chosen access point still has the right to admit or deny this ADDTS Request by responding an ADDTS Response to the current access point over the wired link. However, if the chosen access point accepts the ADDTS Request, the current access point will send a response to the mobile station owning the traffic stream and inform it of the chosen AP for re-association. If Scheme A fails, the scheduler will use the next schemes to handle the request.

2. Scheme B: first of all, the registered traffic streams which ask for smaller bandwidth than the incoming traffic stream does are picked out. The scheme detects if there is any of these traffic stream which can be moved out to satisfy the QoS requirement of the incoming traffic stream. In such a case, the scheduler needs to find another access point which is able to accept the moved-out traffic stream. After putting the selected traffic stream to another access point successfully, the current access point can accept the incoming traffic stream and add it into the polling schedule.

3. Scheme C: if the incoming traffic stream can be satisfied by neither Scheme A nor Scheme B, Scheme C just takes the utilization of each AP into account and moves the incoming traffic stream to an access point which has less utilization.

Scheme C leaves the TS-support decision to the target AP, which may result in vibration behavior that a mobile station repeatedly changes its associated access point. To solve this unsteadiness problem, the ADDTS Request needs to carry a timestamp, which indicates the time when the first ADDTS Request of this traffic stream generates. If an access point receives an ADDTS Request, the timestamp of which is older than an assigned value (one second in our implementation), the mobile station which sends this request will not be switched to other access points. This unsatisfied traffic stream will become a contention traffic stream under the current access point.

3.2.2 Priority

In the previous section, the proposed schemes operate without considering the priorities of user applications. In this section, those schemes are enhanced to set the user priorities properly. Table 4 shows an modified field, TXOP_sum, that should be included in AP_info structure.

Parameters	*Meanings*
TXOP_sum [4]	The sum of each ACs' TXOP guaranteed by AP1.

Table 4. The change of TXOP_sum parameter

1. Scheme A: the same as the one described in the previous section.

2. Scheme B: for the current AP, check if one or more lower-priority, registered traffic streams can be moved out to satisfy an incoming traffic stream. If such registered traffic streams exist, those traffic streams will be moved to a less-utilized access point without any asking.

3. Scheme C: like Scheme A, but only takes the TXOP which priority is greater or equal to the priority of the incoming traffic stream into account. In Scheme A, the scheduler considers the total TXOP with all priorities of other access points. Contrarily, in this scheme the scheduler takes the TXOP with priorities higher than or equal to that of the incoming traffic stream into consideration. If an

access point is chosen by Scheme C, it will kick out the registered traffic stream which has low priority to fit the requirement of the incoming traffic stream (as illustrated in Scheme B).

4. Scheme D: like Scheme B, but also check the registered traffic streams, the priority of which is equal to that of the incoming traffic stream. However, before moving out the registered traffic stream which has the same priority as the incoming one, a request-and-response process over wired links is needed for the current access point to make sure that this traffic stream can really be served by one of other access points.

5. Scheme E: like Scheme C illustrated in the previous section. This scheme considers the TXOP of all priorities in every access point and leaves the TS-support decision to the target AP.

Chapter 4 will explain the Schemes in detail using example cases and prove that these Schemes are practical to an overlapping 802.11e system.

3.2.3 Overlap and Mobility

The above sections assume that mobile stations can hear all access points in a wireless network. This means the transmission ranges of access points are fully overlapped. However, the fully-overlapped topologies are not general cases in the real world. To consider the locations of access points and mobile stations, some information must be stored in the struct AP_info as Table 5 shows. The next paragraph describes how this information is used in our system.

Parameters	*Meanings*
MS List	A list of MS struct, which recorded the status of mobile stations in the transmission rage of AP1, including MAC address and the number of associated times.

Table 5. The information about STAs in the range of AP1

Before association, a mobile station using active scan will send out Probe Request packets in every channel. To solve the overlapping problem, access points in the system need to multicast AP_Info packets when receiving Probe Request packets. A number of associated times is brought in a Probe Request packet. It is increased by 1 each time when the mobile station does re-association. In an AP_Info packet generated because of the receiving of a Probe Request packet, the MAC address of requesting mobile station and the number of associated times in the Probe Request packet are included, An AP_Info packet with a greater number of associated times means that the traffic stream of a mobile station has been moved between access points at least once.

While receiving an AP_Info packet of which the number of associated times is greater than zero, an access point scans the whole AP_info list and finds out the MS structs which has the same MAC address as that storing in the packet. If the number of association times in these MS structs is smaller than the number brought by the AP_Info packet, an access point deletes these structs and records a new one in the AP_info struct which represents the sending access point of this packet. An MS stuct with the smaller number of associated times means that this information is stored when the mobile station associated with an access point earlier. Since the mobile station has left the transmission range of the previous access point, the old record shall be cleaned.

For a registered traffic stream, if a mobile station leaves the coverage of the associated access point, it shall send an ADDTS Request again after re-associating with another access point. This procedure can be implemented by examining the frame types of sending packets. For an access point, an out-of-range traffic stream must be noticed and deleted by the access point itself. This mechanism can be done by recording the unacknowledged transmissions. If the access point has polled or sent to a mobile station for a certain times without any response, such as QoS Data, QoS Null, and QoS ACK, the scheduler of the access point will delete this traffic stream and the guaranteed bandwidth of the traffic stream can be re-allocated to other traffic streams.

4. Simulation Examples

All scenarios were implemented in NCTUns 3.0 with a medium bandwidth of 11 Mbps (802.11b). With 802.11b, an access point can support more or less 780 KByte/sec. In this chapter, the five schemes illustrated in Section 3.2 are explained by simple cases. In the next chapter, the complicated cases are shown and compared to the performance of traditional admission control in 802.11e.

In this chapter, all traffic streams are simulated as Table 6. To simplify examples, greedy UDP generators are used to keep transmission queues full. Since mobile stations ask for fixed bandwidth and should be guaranteed in these examples, which means no chances of becoming contention traffic, the results would be the same as using steady traffic sources. The schemes in Section 3.2.2 are performed as following.

Parameter	Traffic Stream
Traffic Type	CBR
Protocol	Greedy UDP
Direction	Uplink
Nominal MSDU Size	1052 bytes
Maximum MSDU Size	2304 bytes
Maximum Service Interval	10 ms
Minimum PHY Rate	11 Mbps
Delay Bound	Don't care

Table 6. Properties of traffic streams in Section 4.1

Figure 9 compares the overheads of dynamic assignment with successful assignment using the topology in Figure 10 (a). In this simulation, the length of each link is about

130 meters. If an incoming traffic stream cannot be supported by the current access point, the scheduler will start to find a suitable access point. When a suitable one exists, the current access point will transmit a request and wait for the reply. The line of "Success" means the time overhead of a traditional successful ADDTS process. The line of "Failure with asking" shows the time needed in a dynamic assignment with asking the suitable access point if it can accept the incoming stream before informing the mobile station to change its associated access point. The line of "Failure without asking" describes the overhead if the dynamic assignment directly assigns the traffic stream to the suitable access point without asking first.

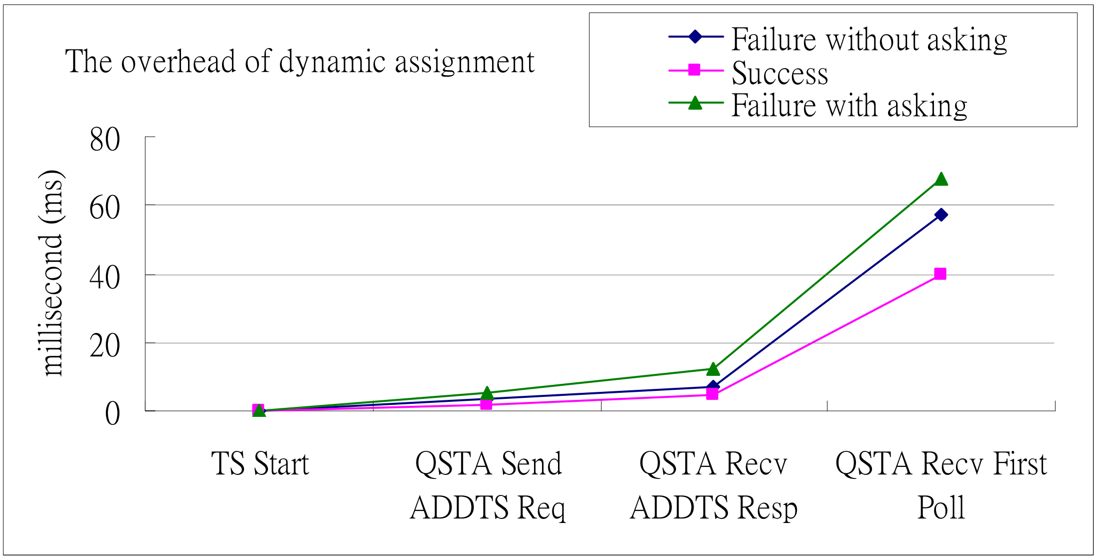

Figure 9. The overhead of changing associated AP

4.1 Scheme A

The topology of this Scheme is shown as Figure 10 (a). MS 5 and MS 6 both generated a traffic stream requiring the bandwidth of 500 KByte/sec to transmit to Node 1. As the simulation began, two mobile stations associated with AP 3. However, AP 3 could only permit one traffic stream and support its requirement. Scheme A worked and helped the other traffic stream to find that AP 4 could directly support the demand. In Figure 10 (b), MS 6 changed its associated access point according to Scheme A The distance from AP 3 to SWITCH 2, from AP 4 to SWITCH2, and from SWITCH 2 to HOST 1 is all about 130 meters in this simulating case.

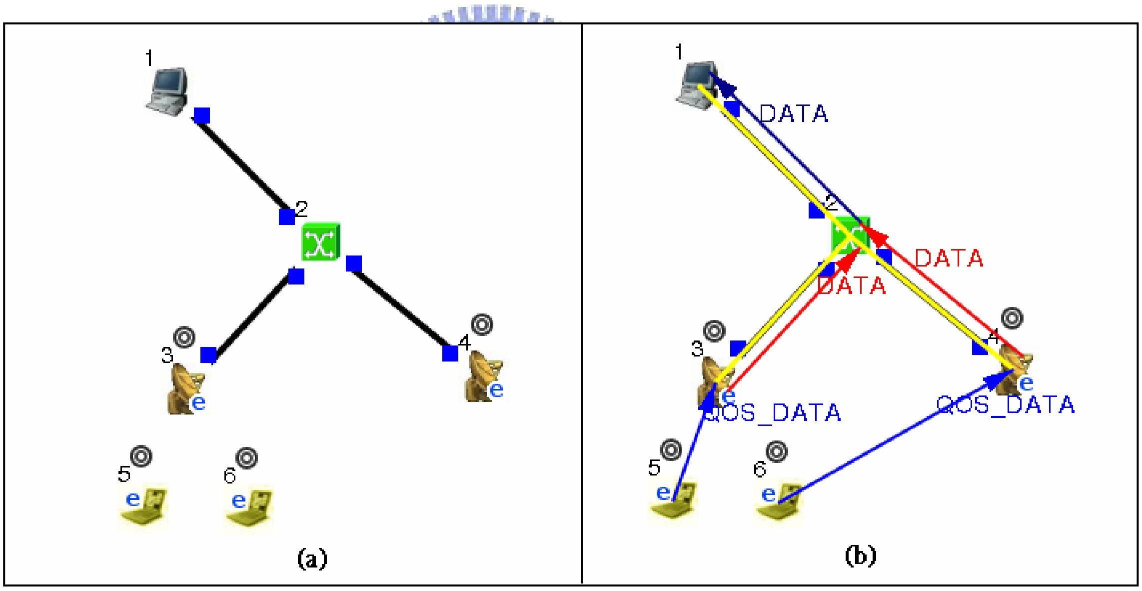

Figure 10 The topology of example A

Figure 11 displays the throughput of each traffic stream. Both traffic streams were started at 0 second in the example case. The simulation results told that Scheme A of the dynamic assignment had insignificant influence on the throughput of each traffic stream.

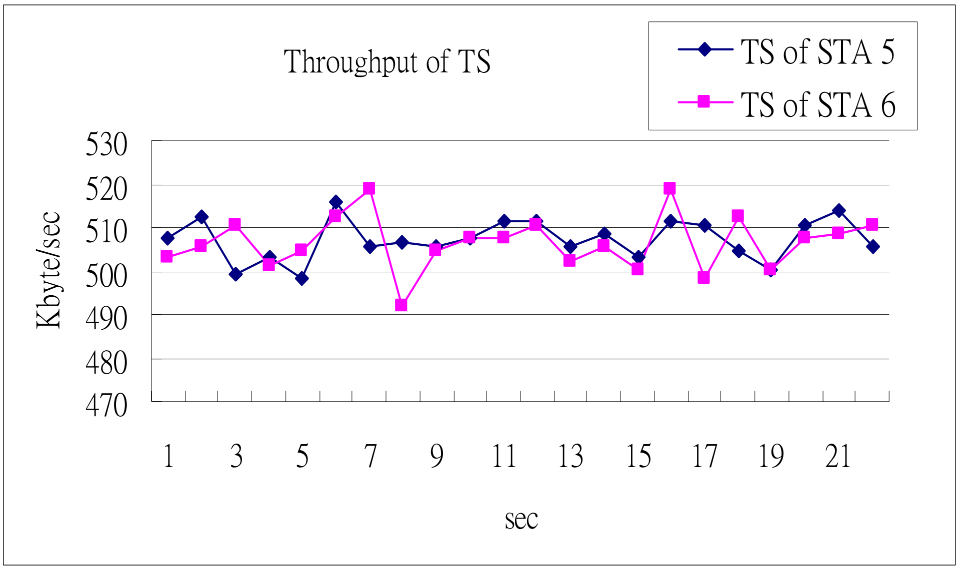

Figure 11. The throughput of each TS in Example A

4.2 Scheme B

Figure 12 (a) shows the topology of example B. There are three traffic streams explained in Table 7. TS 1 and TS 2 were started at 0 second, before the starting of TS 3. When TS 3 sent an ADDTS Request to AP 3, the scheduler of AP 3 found this traffic stream could not be supported, and tried to discover an adaptable AP. Both AP 3 and AP 4 had guaranteed the bandwidth of 500 Kbyte/sec. Using Scheme A, the scheduler could not find an access point which had enough bandwidth. Because MS 7 had higher priority than MS 5 did, using Scheme B the scheduler could delete the registered bandwidth of MS 5 and then accepted the ADDTS Request of MS 7.

TS	Sender	User Priority	Start Time	Mean Data Rate
1	MS 5	0	0 sec	500 Kbyte/sec
2	MS 6	0	0 sec	500 Kbyte/sec
3	MS 7	7	2 sec	300 Kbyte/sec

Table 7. Three TSs in example B

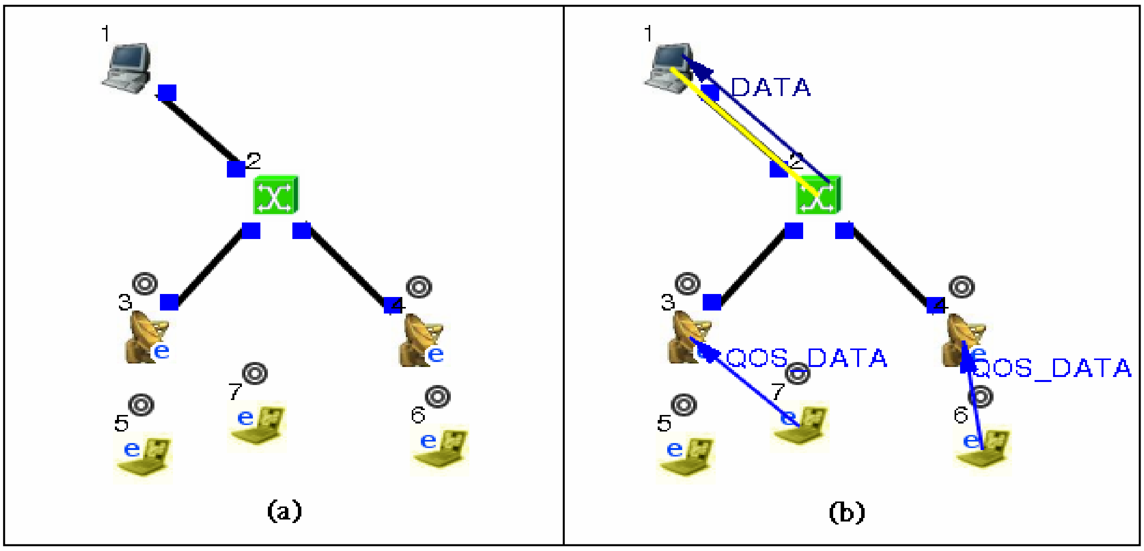

Figure 12. The topology of example B

Figure 13 shows the simulation results of Example B. TS 1 and TS 2 could get their required bandwidth at the beginning of the simulation. However, after TS 3 joined the system, TS 1 was declined by AP 3 and became a contention-based traffic flow, which made the severe degradation of throughput. The throughput of TS 1 got by contention was about 370 Kbyte/sec.

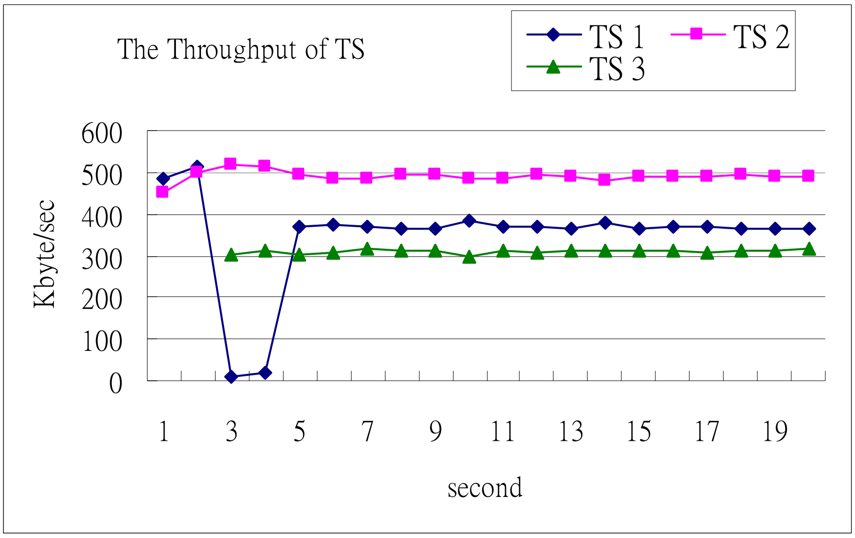

Figure 13. The throughput of each TS in Example B

4.3 Scheme C

The example of Scheme C is similar to Scheme B. The topology is the same as Figure 12 (a). There are also three traffic streams which had the same properties as shown in Table 7, but the priority of MS 5 was aggraded from 0 to 7. Scheme B does not fit this case anymore. Using Scheme C, the scheduler of AP 3 discovered that without counting in the lower priority TXOP, AP 4 had enough bandwidth to support MS 7. TS 2 was kicked by AP 4 and became a contention-based traffic flow.

Figure 14 shows the result of Example C. TS 1 and TS 2 got the required bandwidth at the beginning of the simulation. After TS 3 started to transmit, AP 3 queried AP 4 about the guaranteed bandwidth of TS 3. Because of the priority, TS 2 was declined by AP 4 and became a contention-based traffic flow. Like Example B, This rejection made a severe reduction of throughput. Two or three second latter, the throughput of TS 2 got by contention was about 370 Kbyte/sec. After the exchange of messages, MS 6 and MS 7 were associated with AP 4 while MS 5 was still associated with AP 3. TS 1 and TS 3 were admitted by their respective access point.

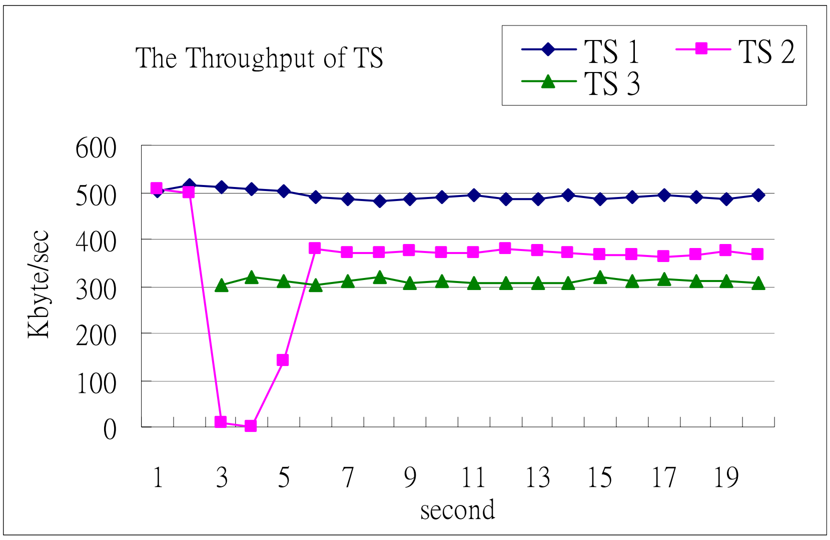

Figure 14. The throughput of each TS in Example C

4.4 Scheme D

The topology in this example is still like the one in Figure 12 (a). The traffic streams are described in Table 8. In this case, all traffic streams has the same priority. MS 5 associated with AP 3 and TS 1 had a guaranteed bandwidth of 400 Kbyte/sec. MS 6 associated with AP 4 and TS 2 had a guaranteed bandwidth of 300 Kbyte/sec. TS 3 started at 2 second and connected to AP 3. With Scheme A, the scheduler could not find an access point which had a sufficient bandwidth of 500 Kbyte/sec. With Scheme B, the current access point did not have any low priority traffic stream to move out. With Scheme C, the other access point (AP 4) did not have any low priority traffic stream either. With Scheme D, the scheduler found TS 1 which had the bandwidth of 400 Kbyte/sec (lower than TS 3) and the same priority as TS 3 did. According to Scheme D, the traffic stream of the same priority can not be kicked unless the scheduler found a suitable access point to move this traffic stream to. So before admitting TS 3, AP 3 queried AP 4 about the admission of TS 1. In this case, AP 3 got the positive answer from AP 4, and thus MS 5 changed its associated access point to AP 4. After the movement, TS 3 was admitted by AP 3.

TS	Sender	User Priority	Start Time	Mean Data Rate
1	MS 5	0	0 sec	400 Kbyte/sec
2	MS 6	0	0 sec	300 Kbyte/sec
3	MS 7	0	2 sec	500 Kbyte/sec

Table 8. Three TSs in example D

Figure 15 depicts the simulating status of Example D. After the dynamic assignment, MS 5 and MS 6 were associated with AP 4. MS 7 was associated with AP 3. Figure 16 shows the throughput of three traffic streams.

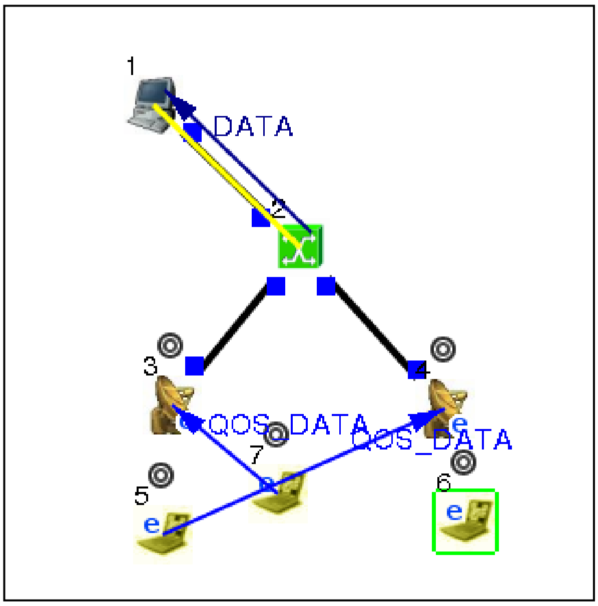

Figure 15. The status of simulating Example D

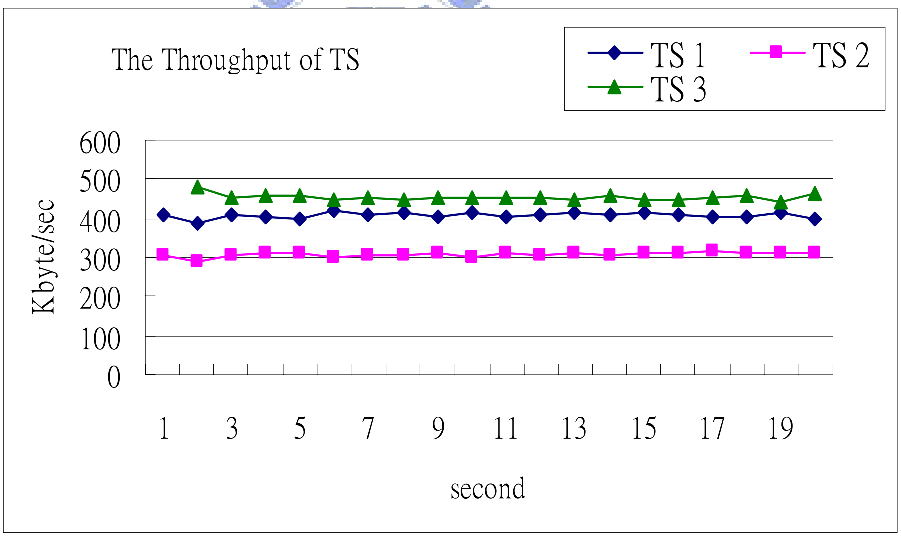

Figure 16. The throughput of each TS in Example D

4.5 Scheme E

Table 9 explains the traffic streams using in Example E. The topology remains the same as Scheme B. Because Scheme A to D was not suitable, Scheme E was used to solve this situation. TS 3 would be moved to a less-utilized access point. In this case, MS 7 was associated with AP 3. According to Scheme E, it would be re-associated to AP 4, because the utilization of AP 4 is less than the utilization of AP 3.

TS	Sender	User Priority	Start Time	Mean Data Rate
1	MS 5	0	0 sec	600 Kbyte/sec
2	MS 6	0	0 sec	500 Kbyte/sec
3	MS 7	0	2 sec	500 Kbyte/sec

Table 9. Three TSs in example E

Figure 17 describes the throughput of each traffic stream. TS 1 and TS 2 were guaranteed by their positive access points. TS 3 was become a contention-based traffic flow. Because AP 4 had only one contention node in its transmission range, the throughput of TS 3 stably maintained at about 250 Kbyte/sec.

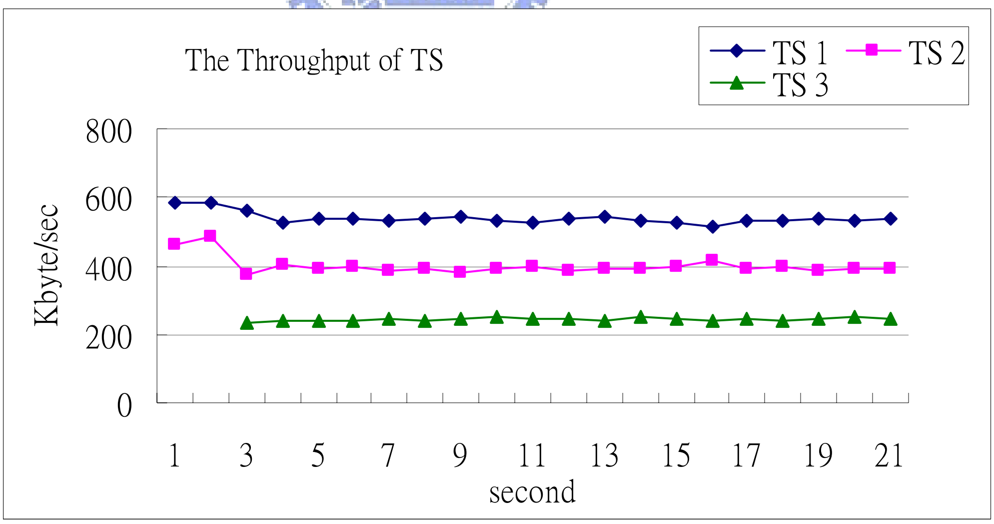

Figure 17. The throughput of each TS in Example E

4.6 Mobility

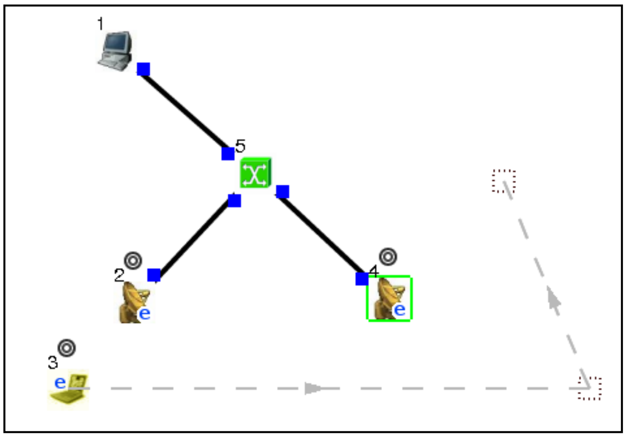

Figure 18. A simple case with mobility

Figure 18 shows a simple case. MS 3 using a rate of 10 m/s moved from the transmission range of AP 2 to AP4. A traffic stream of MS 3 formerly be guaranteed by AP 2 was changed to be admitted by AP 4. Figure 19 depicts the overhead of roaming from AP 2 to AP 4. While using the original access point policy, the interval between the last poll from AP 2 and the first Poll of AP 4 was approximately 3 seconds. In original AP module in NCTUns 3.0, stations check the connectivity with their associated access point by counting the duration of last received beacon. For the refinement, the duration of deleting traffic stream and removing an un-connecting access point are nearly the same, which could reduce the overhead almost 1 second.

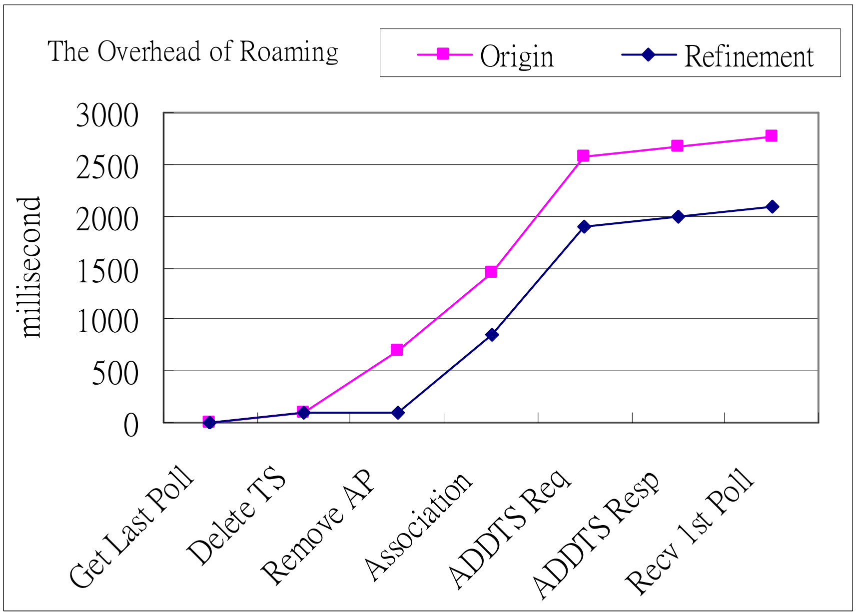

Figure 19. The overhead of roaming between APs

5. Simulation Settings and Results

In the following simulations, three types of traffic sources are considered: audio, video, and traditional file transmission.

5.1 Description of Traffic Sources

A trace of real MPEG-4 video stream is used for the video source model. The video trace is from a traffic stream of an e-learning session (high-quality Lecture Room-Cam video stream [17]). Besides MPEG-4, the Standard Definition Television (SDTV) with MPEG-2 is also described for the video traffic model.

Most VoIP-enabled endpoints today provide support for G.711 [18] and G.729 [19]. The G.711 coding scheme is most widely used due to its simplicity of implementation and its inherent compatibility with circuit-switched networks. G.711 codec is generated voice packets at a constant bit rate of 64 kbps. The size of each G.711 packet is 160 bytes and the interval of packets arriving time is 20ms.With RTP/UDP/IP header overhead of 28 bytes and MAC/PHY overhead of 60 bytes, the overall packet size transmitted reaches 248 bytes [20].

Traditional data transmission comprises of http, ftp, email and other non-real-time traffic. It may be modeled by constant traffic source or greedy traffic source and has lower priority than multimedia (video and audio) traffic.

VoIP sessions are bidirectional, which means each station is the source of an uplink flow and also the destination of a downlink flow. Video sessions are usually downlink flow in the real world, so in the simulations they are viewed as unidirectional downstream sessions. A highest priority is assigned to the VoIP traffic streams due to the properties of time-critical telephony services.

5.2 Simulation Parameters

The TSPECs of multimedia traffic stream are described in Table 10. The parameters of TSPECs are used in the HCCA mechanism. SDTV 1 and SDTV 2 denote two traffic streams with different average data rate. The EDCA parameters which are used by four access categories are listed in Table 11.

Sources / TSPEC	Audio	Video (VoD, IPTV)		
	G.711	SDTV 1	MPEG-4	SDTV 2
Mean data rate	8 KByte/s	230 KByte/s	70 KByte/s	460 KByte/s
Delay bound	50 ms	100 ms	100 ms	100 ms
Nominal MSDU size	188 bytes	1386 bytes	1048 bytes	1386 bytes
Max MSDU size	188 bytes	1386 bytes	1048 bytes	1386 bytes
Max service interval	10ms	10 ms	10 ms	10 ms
User priority	6	6	4	4

Table 10. HCCA Traffic Specifications of audio and video

	CWmin	CWmax	AIFSN	TXOPLimit
AC_BK	31	1023	7	0
AC_BE	31	1023	3	0
AC_VI	15	31	2	6.016 ms
AC_VO	7	15	2	3.264 ms

Table 11. EDCA contention parameters for ACs

5.3 Simulation Results

Using different topologies and traffic types as described in Section 5.1, we compare the performance of our UP-based, dynamic traffic stream assignment with the reference admission control and scheduler of IEEE 802.11e standard.

5.3.1 A Simple Case

The first simulation scenario is presented in Figure 20. There are total nine uplink traffic streams in this case. Node 1 to 9 are infrastructure mobile stations (MSs) and node 10 to 13 are access points, and both of them implement IEEE 802.11e standard. Node 15 to 23 are hosts which operates over wired links. Through a switch node, these nodes connect to each other. The arc dashed lines in Figure 20 represent the transmission range of each access point. In this case, all mobile stations are in the transmission ranges of four access points, which means the mobile stations can associate with any access points if they need.

The parameters, source and destination of each stream is described in Table 12. These traffic streams are all generated with some properties such as assuming a packet size of 1000 bytes, having the user priority of 0, transmitting in constant bit rate (CBR), using UDP protocol, and beginning at the same time.

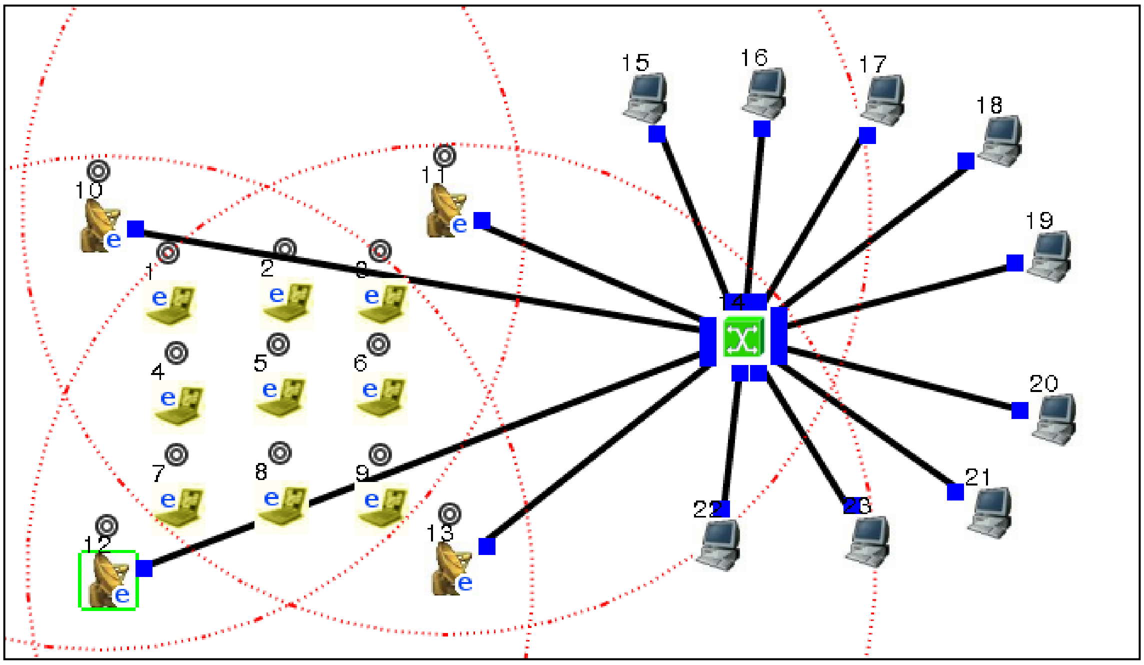

Figure 20. The topology of the sample case

TS	Source	Destination	First Association	Mean Data Rate
1	Node 1	Node 15	AP 10	200 KByte/sec
2	Node 2	Node 16	AP 11	300 KByte/sec
3	Node 3	Node 17	AP 13	400 KByte/sec
4	Node 4	Node 18	AP 12	500 KByte/sec
5	Node 5	Node 19	AP 13	100 KByte/sec
6	Node 6	Node 20	AP 13	200 KByte/sec
7	Node 7	Node 21	AP 13	300 KByte/sec
8	Node 8	Node 22	AP 13	400 KByte/sec
9	Node 9	Node 23	AP 13	500 KByte.sec

Table 12. The parameters of traffic streams in the sample case

In order to show the ability of solving the problems described in Section 1.2, we let MS 1 associated with AP 10, MS 2 associated with AP 11, MS 4 associated with AP 12, and all the other mobile stations associated with AP 13. One of the simulations showed the following steps:

Step 0: At 0 second, all mobile stations and the traffic-generated applications started.

Step 1: As described in Table 1, the coluMS of "Admitted Throughput" means that the total throughput the access point has responded the ADDTS Request from some mobile stations and has guaranteed. A mobile station may have associated with the access point, but does not send the ADDTS request at the current time. The representative of 1 means that the ADDTS Request from MS 1 has satisfied by its associated AP. The coluMS of "Failure ADDTS" means the ADDTS request which this AP cannot admit. The "Solution" field is based on the scheme proposed in Section 3.2. In this step, the value of "MS 7, 300 KB/sec" represents the failure ADDTS was from MS 7 and needed the bandwidth of 300 KByte/sec. According to the dynamic assignment, this problem could be solved by scheme A and the MS 7 needed to change its association to AP 10. Thus the value of "Solution" field is "(A), AP 10."

AP	Associated MSs	Admitted Throughput	Failure ADDTS	Solution
10	MS 1	200 KByte/sec		
11	MS 2	300 KByte/sec		
12	MS 4	500 KByte/sec		
13	MS 9, 5, 3, 6, 7, 8	100, 500 KByte/sec	MS 7, 300 KB/sec	(A), AP 10

Table 13. The situation of each AP in Step 1

Step 2: As shown in Table 14, MS 7 had already associated with AP 10, and the ADDTS Request from MN7 had also been admitted by AP 10. However, MS 8 had requested a bandwidth of 400 KByte/sec which could not be satisfied by AP 13. According to scheme A, MS 8 needed to change its association to AP 11.

AP	Associated MSs	Admitted Throughput	Failure ADDTS	Solution
10	MS 1, 7	200, 300 KByte/sec		
11	MS 2	300 KByte/sec		
12	MS 4	500 KByte/sec		
13	MS 9, 5, 3, 6, 8	100, 500 KByte/sec	MS 8, 400 KB/sec	(A), AP 11

Table 14. The situation of each AP in Step 2

Step 3: As shown in Table 15, MS 8 had already associated with AP 11, and the ADDTS Request from MS 8 had also been satisfied by AP 11. However, MS 6 had requested a bandwidth of 200 KByte/sec which AP 13 could not support. According to scheme A, MS 6 needed to change its associated AP to AP 12.

AP	Associated MSs	Admitted Throughput	Failure ADDTS	Solution
10	MS 1, 7	200, 300 KByte/sec		
11	MS 2, 8	300, 400 KByte/sec		
12	MS 4	500 KByte/sec		
13	MS 9, 5, 3, 6	100, 500 KByte/sec	MS 6, 200 KB/sec	(A), AP 12

Table 15. The situation of each AP in Step 3

Step 4: As shown in Table 16, MS 6 had already associated with AP 12. AP 12 had received ADDTS Request from MS 6 and then given sufficient bandwidth to MS 6. However, MS 3 had requested a bandwidth of 400 KByte/sec which AP 13 could not support. According to the scheme, AP 10, 11, and 12 had been selected and the refreshed AP info packets were not received yet. AP 13 just declined the

ADDTS Request from MS 6. This traffic stream became contention traffic, which contended the bandwidth unused by contention-free traffic.

AP	Associated MSs	Admitted Throughput	Failure ADDTS	Solution
10	MS 1, 7	200, 300 KByte/sec		
11	MS 2, 8	300, 400 KByte/sec		
12	MS 4, 6	500, 200 KByte/sec		
13	MS 9, 5, 3	100, 500 KByte/sec	MS 3, 400 KB/sec	(A), AP 12

Table 16. The situation of each AP in Step 4

In the simulation result above, only one traffic stream did not reach the data rate it requested, but the other eight traffic streams were supported. Figure 21 shows the system throughput of the traditional assignment in IEEE 802.11e and the proposed dynamic assignment. With all the same settings, it can be observed that using traditional approach the total throughput of the simple case is only 1660 KByte/sec, while using proposed dynamic approach the total throughput could achieve 2660 KByte/sec. The new approach could satisfy eight traffic streams, but the traditional scheme only supported five to six traffic streams.

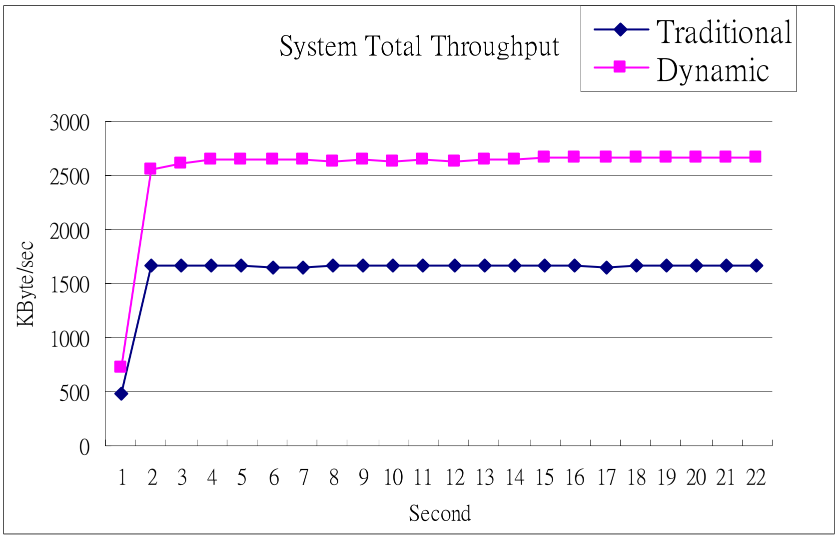

Figure 21. The comparison of system total throughput

5.3.2 A Overlapping Case

The topology of this case is performed as Figure 22. The transmission ranges of APs are not fully overlapping, and the association status is shown as Table 17.

TS	Source	Destination	First Association	Mean Data Rate
1	Node 1	Node 15	AP 10	200 KByte/sec
2	Node 2	Node 16	AP 11	300 KByte/sec
3	Node 3	Node 17	AP 11	400 KByte/sec
4	Node 4	Node 18	AP 12	500 KByte/sec
5	Node 5	Node 19	AP 13	100 KByte/sec
6	Node 6	Node 20	AP 13	200 KByte/sec
7	Node 7	Node 21	AP 12	300 KByte/sec
8	Node 8	Node 22	AP 13	400 KByte/sec
9	Node 9	Node 23	AP 13	500 KByte.sec

Table 17. The parameters of traffic streams in the overlapping case

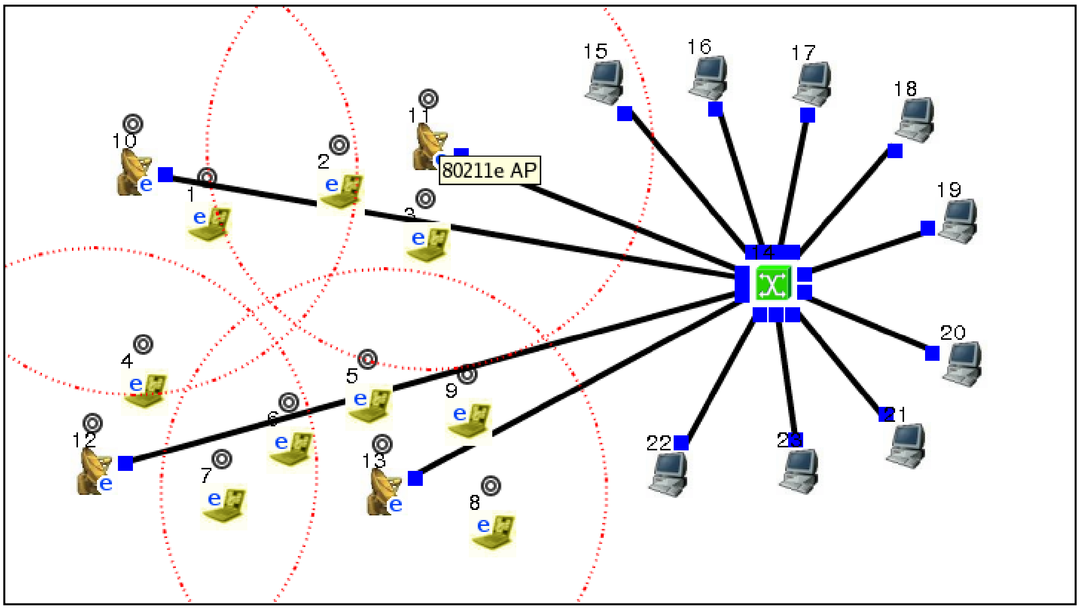

Figure 22. The topology of overlapping case

The simulation result follows the steps:

Step 0: After completing the association, all TSs started at the same time.

Step 1: As Table 18 shows, after the successful admission of five TSs, TS 7 could not be supported by AP 12. The location of MS 7 was inside the transmission range of AP 12 and AP 13, but both of them did not have the sufficient bandwidth, TS 7 was declined directly and thus became a contention-based traffic flow.

AP	Associated MSs	Admitted Throughput	Failure ADDTS	Solution
10	MS 1	200 KByte/sec		
11	MS 2, 3	300, 400 KByte/sec		
12	MS 4, 7	500 KByte/sec	MS 7, 300 KB/sec	Declined
13	MS 9, 5, 6, 8	500 KByte/sec		

Table 18. The status of each AP in Step 1

Step 2: Table 19 describes the ADDTS Request from MS 8. However, AP 13 did not have any channel space to guarantee TS 8. Because MS 8 was only in the range of AP 13, TS 8 was directly declined and contended the bandwidth.

AP	Associated MSs	Admitted Throughput	Failure ADDTS	Solution
10	MS 1	200 KByte/sec		
11	MS 2, 3	300, 400 KByte/sec		
12	MS 4, 7	500 KByte/sec		
13	MS 9, 5, 8, 6	100, 500 KByte/sec	MS 8, 400 KB/sec	Declined

Table 19. The status of each AP in Step 2

Step 3: In Table 20, MS 6 was asked for a bandwidth of 200 Kbyte/sec to AP 13. The scheduler of AP 13 could not support and began to find a suitable AP. Because MS 6 was also in the range of AP 12, Scheme A was useful to handle this event. After querying AP 12 for assurance, MS 6 was connected to AP 12, and got the guaranteed bandwidth for TS 6.

AP	Associated MSs	Admitted Throughput	Failure ADDTS	Solution
10	MS 1	200 KByte/sec		
11	MS 2, 3	300, 400 KByte/sec		
12	MS 4, 7	500 KByte/sec		
13	MS 9, 5, 8, 6	100, 500 KByte/sec	MS 6, 200 KB/sec	(A), AP 12

Table 20. The status of each AP in Step 3

Table 21 shows the final status of this simulation. Figure 23 compares the average data rate of each stream to the mean data rate of each stream. TS 7 and TS 8 contended the wireless medium by using EDCA parameters, so their mean data rate could no be guranteed.

AP	Associated MSs	Admitted Throughput	Contention MSs
10	MS 1	200 KByte/sec	
11	MS 2, 3	300, 400 KByte/sec	
12	MS 4, 7, 6	500, 200 KByte/sec	MS 7
13	MS 9, 5, 8	500, 100 KByte/sec	MS 8

Table 21. The final status of the overlapping case

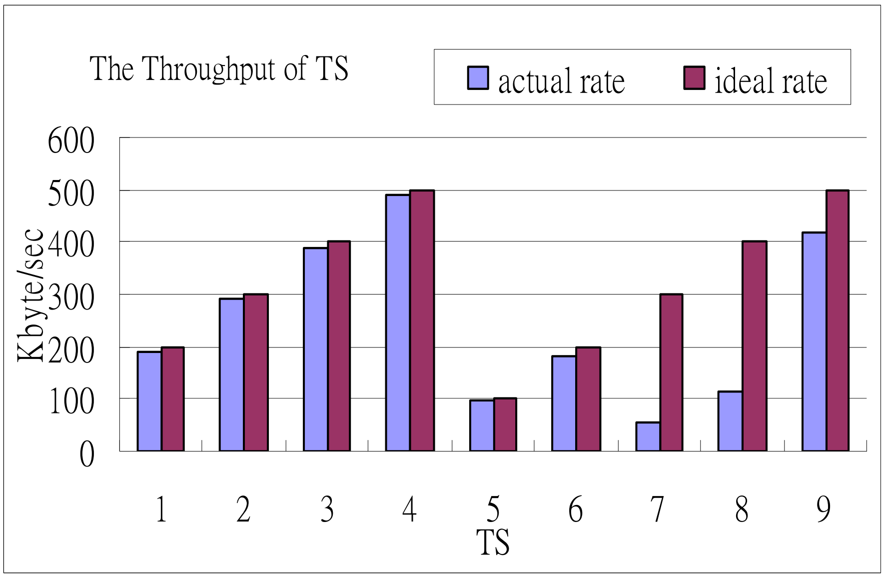

Figure 23. The throughput of each TS compared to required rate

5.3.3 A Multimedia Case

TS ID	Src.	Dst.	Direction	First AP	Traffic Type	Priority	Mean Data Rate
1	1	15	uplink	AP 10	SDTV 2	4	460
2	16	2	downlink	AP 10	SDTV 2	4	460
3	17	3	downlink	AP 10	MPEG-4	4	70
4	4	18	bidirectional	AP 12	G.711	6	8
5	5	19	uplink	AP 10	Data	3	200
6	6	20	uplink	AP 12	Data	3	300
7	21	7	downlink	AP 11	SDTV 1	4	230
8	22	8	bidirectional	AP 13	G.711	4	8
9	9	23	Downlink	AP 13	MPEG-4	6	70
10	24	27	uplink	AP 11	Data	1	300
11	25	28	uplink	AP 11	SDTV 1	4	230
12	26	29	uplink	AP 13	SDTV 1	4	230

Table 22. The parameters of traffic streams in this multimedia case

Table 22 specifies the properties of traffic stream using in this case. “Src” means the sender of a TS, and “Dst” means the receiver of a TS. “First AP” points to the first associated AP and also the first requested AP by a TS. “Traffic Type” can be audio (G.711), video (MPEG2, MPEG4, H.264), or traditional data. “Mean data rate” is the required data rate of a TS, in Kbyte/sec.

Figure 24 specifies the topology of this case. MS 1 moved with the speed of 10 m/s. MS1 would walk into the transmission range of AP 12. The area inside the circular lines was a transmission range of each AP, which was the center of a circle. An arrow was the moving paths of a station.

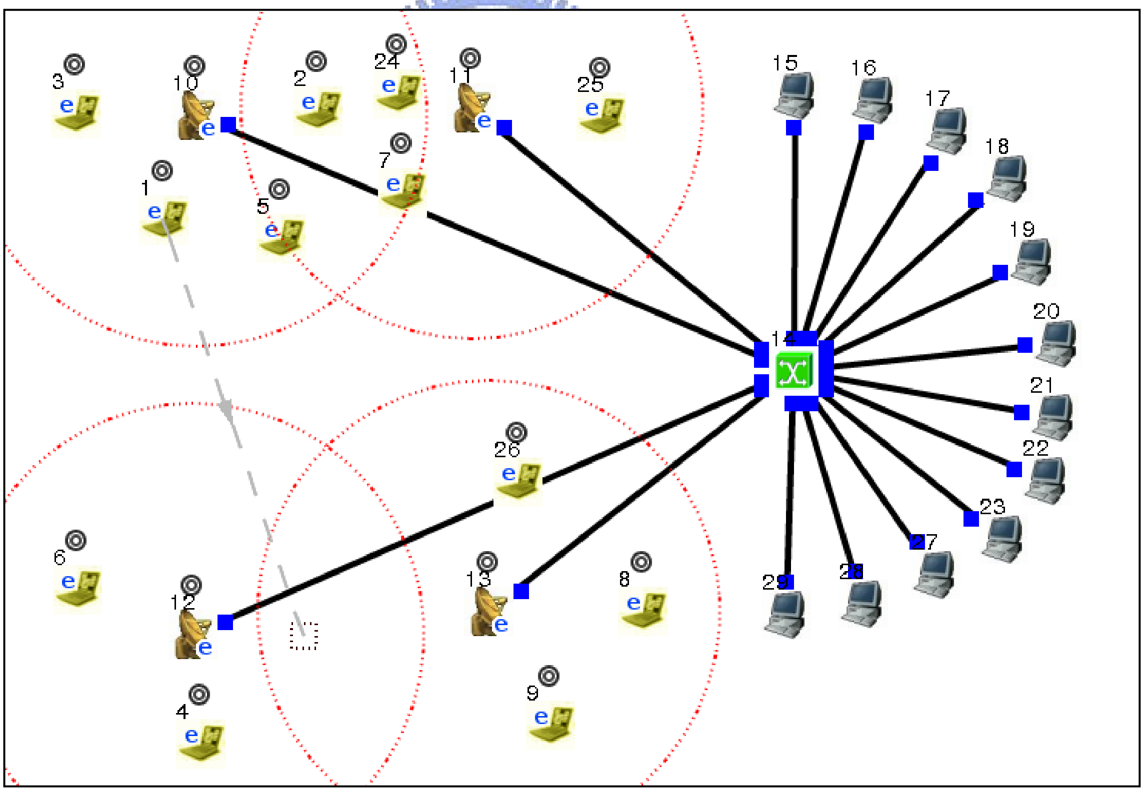

Figure 24. The topology of the Multimedia case

Step 0: After associating with APs, TSs started to request for desired bandwidth.

Step 1: As Table 23 shows, after admitting several TSs, MS 2 asked for the bandwidth of 460 Kbyte/sec. AP 10 could not support, so the scheduler tried to find a suitable AP. AP 11 was found using Scheme A.

AP	Associated MSs	Admitted Throughput	Failure ADDTS	Solution
10	MS 1, 2, 3, 5	460 KByte/sec	MS 2, 460 KB/sec	(A), AP 11
11	MS 7, 24, 25			
12	MS 4, 6			
13	MS 26, 8, 9	230 KByte/sec		

Table 23. The status of each AP in Step 1

Step 2: Table 24 shows another problem. MS 25 asked for the bandwidth of 230 KB/sec. AP 11 could not support this requesting. With Scheme D, the scheduler of AP 11 found a TS with the same priority as MS 25, TS 7, which can be re-associated with AP 10 and also be satisfied by AP 10.

AP	Associated MSs	Admitted Throughput	Failure ADDTS	Solution
10	MS 1, 5, 3	460, 200 KB/sec		
11	MS 2, 7, 25, 24	460, 230 KB/sec	MS 25, 230 KB/sec	(D), Del 7
12	MS 4, 6	8*2, 300 KB/sec		
13	MS 26, 8, 9	230, 8*2, 70 KB/sec		

Table 24. The status of each AP in Step 2

Step 3: In this step, MN7 was asking AP 10 for a guaranteed bandwidth. Using Scheme B, AP 10 delete a lower priority TS to support MN 7. TS 5 cannot be supported by any APs, so it became a contention traffic flow.

AP	Associated MSs	Admitted Throughput	Failure ADDTS	Solution
10	MS 1, 5, 7, 3	460, 200 KB/sec	MS 7, 230 KB/sec	(B), Del 5
11	MS 2, 25, 24	460, 230 KB/sec		
12	MS 4, 6	8*2, 300 KB/sec		
13	MS 26, 8, 9	230, 8*2, 70 KB/sec		

Table 25. The status of each AP in Step 3

Step 4: TS 3 cannot be supported by AP 10. After testing with schemes, the request from MS 3 was declined and TS 3 became contention traffic.

AP	Associated MSs	Admitted Throughput	Failure ADDTS	Solution
10	MS 1, 5, 7, 3	460, 230 KB/sec	MS 3, 70 KB/sec	Declined
11	MS 2, 25, 24	460, 230 KB/sec		
12	MS 4, 6	8*2, 300 KB/sec		
13	MS 26, 8, 9	230, 8*2, 70 KB/sec		

Table 26. The status of each AP in Step 4

Step 5: The request of MS 24 cannot be permitted by AP 11. With Scheme E, MS 24 re-associated with AP 10, but it still could not be supported by AP 10. The traffic stream of MS 24 became contention traffic.

AP	Associated MSs	Admitted Throughput	Failure ADDTS	Solution
10	MS 1, 5, 7, 3	460, 230 KB/sec		
11	MS 2, 25, 24	460, 230 KB/sec	MS 24, 300 KB/sec	(E), AP 10
12	MS 4, 6	8*2, 300 KB/sec		

13	MS 26, 8, 9	230, 8*2, 70 KB/sec		

Table 27. The status of each AP in Step 5

Step 6: In Table 28, MS 1 had moved from the transmission range of AP 10 to the range of AP 12. To support traffic stream of MS 1, TS 6 was deleted and contended to get the transmission opportunity.

AP	Associated MSs	Admitted Throughput	Failure ADDTS	Solution
10	MS 5, 7, 3, 24	230 KB/sec		
11	MS 2, 25	460, 230 KB/sec		
12	MS 4, 6, 1	8*2, 300 KB/sec	MS 1, 460 KB/sec	(B), Del 6
13	MS 26, 8, 9	230, 8*2, 70 KB/sec		

Table 28. The status of each AP in Step 6

Final: So the final status of each access points was shown as 錯誤! 找不到參照來源。.

AP	Associated MSs	Admitted Throughput	Failure ADDTS	Solution
10	MS 5, 7, 3, 24	230 KB/sec		
11	MS 2, 25	460, 230 KB/sec		
12	MS 4, 1, 6	8*2, 460 KB/sec		
13	MS 26, 8, 9	230, 8*2, 70 KB/sec		

Table 29. The final status of the Multimedia case

Future Work

In the mobility case, the roaming between access points would make traffic streams break down more than 2 seconds. However, in a system seeking for QoS guarantee, the seamless roaming is important for the Multimedia applications. While an access point is operated at the same channel as its adjacent access point, a moving station just needs to keep listening to beacons from all access points and selects a new access point while the power of beacons from its associated access point degrades significantly. In the general case, access points are assigned different channel to their neighbors to avoid interference. In the simulations above, a station did not believe that it had left the transmission range of its associated access point unless beacons from the access point were not received more than three times. After sensing the leaving, a station started to scan all channels to find a new access point. However, traffic streams would not be polled or received any packets between the interval between losing the connectivity and re-association with a new access point.

Many researchers have focused on the topic of fast handoff for 802.11 infrastructure network. Based on the neighbor graph (NG), the authors of [21] proposed a selective channel scanning and reduced the scanning delay drastically. In the proposed mechanism, an mobile station scans not all channels but channels selected by NG. Ishwar Ramani and Stefan Savage proposed SyncScan, a low-cost technique. SyncScan synchronizes stations with the timing of beacon broadcasts on each channel. After arranging these beacons, the clients can passively scan by switching channels exactly when a beacon is about to arrive.

To achieve the goal of seamless roaming, the system of dynamic assignment needs to consider the methods which had been proposed by researchers. However, the way to moving TSs from one access point to another smoothly is still an interesting topic, which will make the entire system more practical.

6. Conclusion

In this paper, a dynamic assignment scheme, which takes the properties of applications into account, is proposed to enhance the performances of the entire network. The IEEE 802.11e standard is developed for guarantee the quality of service, and the HCCA control medium scheme actually satisfies the required bandwidths for every applications. However, multimedia applications have their own distinction. For example, VoIP transmission was more time-critical than a VOD program. A reference scheduler and an admission unit are defined in 802.11e, but neither of them thinks of the priorities of traffic streams. Using different priority, we can specify the essential sequence and broken sensitivity of each traffic stream. A traffic stream with high priority shall be considered first and can not be disturbed by the ones with lower priorities.

In the real world, Internet Service Providers (ISPs) may give different priorities to users according to the amount of money they paid. Clients with high priorities will be guaranteed first and can not be interrupted by low-priority Clients. Our priority-based scheme can be used not only to point out the properties of traffic streams but also to indicate the rights of particular users. The simulation results show that our proposed scheme is practical to real world networks at the cost of few control message overheads

Reference

[1] Wireless LAN Medium Access Control (MAC) and Physical Layer (PIIY) specifications, IEEE Std 802.11: 1999 (E) Part 11, ISO/IEC 8802-11, 1999.

[2] Wireless LAN Medium Access Control (MAC) and Physical Layer (PIIY) specifications, Amendment 8: Medium Access Control (MAC) Quality of Service Enhancements, IEEE Std 802.11e, November 11, 2005.

[3] Yang Xiao, "Enhanced DCF of IEEE 802.11e to Support QoS," proc. IEEE WCNC, Mar. 2003.

[4] K. Xu, Q. Wang, and H. S. Hassanein, "Performance Analysis of Differentiated QoS Supported by IEEE 802.11e Enhanced Distributed Coordination Function (EDCF) in WLAN," IEEE Global Telecommunications Conference, December 2003.

[5] H. Zhu, and I. Chlamtac, "An Analytical Model for IEEE 802.11e EDCF Differential Services," In Proc. International Conference on Computer Communications and Networks (ICCCN), October 2003.

[6] J. W. Robinson, and T. S. Randhawa, "Saturation Throughput Analysis of IEEE 802.11e Enhanced Distributed Coordination Function," IEEE J. Select. Areas Communications, Vol. 22, No. 5, June 2004.

[7] Wong, G.W., and Donaldson, R.W., "Improving the QoS performance of EDCF in IEEE 802.11e wireless LANs," Communications, Computers and signal Processing, 2003.

[8] Claudio Casetti, and Carla-Fabiana Chiasserini, "Improving Fairness and Throughput for Voice Traffic in 802.11e EDCA," IEEE PIRMC'04, Barcellona, Spain, 5-8 September 2004.

[9] A. Ksentini, A. Guéroui, and M. Naimi, "Improving H.264 video transmission in 802.11e EDCA," In Proc of. IEEE ICCCN 2005.

[10] Qiang Ni, "Performance Analysis and Enhancements for IEEE 802.11e Wireless Networks," IEEE Network, Vol. 19, Issue 4, pp. 21-27, July/August

2005.

[11] Grilo A., Macedo M., and Nunes M, “A Scheduling Algorithm for QoS Support in IEEE 802.11e Networks,” IEEE Wireless Communications, pp. 36-43, June 2003.

[12] P. Ansel, Qiang Ni, and T. Turletti, "An Efficient Scheduling Scheme for IEEE 802.11e," in Proc. IEEE WiOpt 2004, Cambridge, UK, March 2004.

[13] A. Annese, et al., “Providing Delay Guarantees in IEEE 802.11e Networks,” in Proc. IEEE VTC Spring 2004, Milan, Italy, Amy 2004.

[14] T. Korakis, L. Tassioulas, “Providing quality of service guarantees in wireless LANs compliant with 802.11e,” in Computer Networks, Volume 47, Issue 2, February 2005.

[15] Deyun Gao and Jianfei Cai, “Admission Control with Physical Rate Measurement for IEEE 802.11e Controlled Channel Access,” IEEE Communications Letters, Vol. 9, NO. 8, August 2005

[16] Boris Makarevitch, “Scheduling and Admission Control for 802.11e Hybrid Coordinator,” IEEE Vehicular Technology Conference, June 2005.

[17] Video Traces for Network Performance Evaluation, available at http://www.eas.asu.edu/TRACE/trace.html

[18] ITU-T Recommendation G.711, “Pulse Code Modulation (PCM) of Voice Frequencies,” 1993.

[19] ITU-T Recommendation G.729 Annex A, “Reduced Complexity 8 kb/s CS-ACELP Speech Codec,” 1996.

[20] Sai Shankar N, Javier del Prado Pavon, and Patrik Wienert, “Optimal packing of VoIP calls in an IEEE 802.11 a/e WLAN in the presence of QoS constraints and channel errors,” GLOBECOM’04, IEEE, 29 Nov.-3 Dec. 2004.

[21] Sang-Hee Park, Hye-Soo Kim, Chun-Su Park, Jae-Won Kim, and Sung-Jea Ko, "Selective Channel Scanning for Fast Handoff in Wireless LAN Using Neighbor Graph," Lecture Notes in Computer Science, vol. 3260, pp.194-203,

Sep. 2004.

[22] Ishwar Ramani, and Stefan Savage, "SyncScan: Practical Fast Handoff for 802.11 Infrastructure Networks," Proceeding of the IEEE infocom Conference, Miami, FL, March 2005.