國立東華大學資訊工程學系

博士論文

指導教授：陳俊良　博士

無線網路服務品質確保之反饋式機制設計

Feedback Scheduling Discipline for QoS Guarantee in Wireless Network Applications

研究生：陳農坤　撰

中 華 民 國 九 十 七 年 一 月

無線網路服務品質確保之反饋式機制設計

Feedback Scheduling Discipline for QoS Guarantee in Wireless Network Applications

研究生: 陳農坤　　　　　　指導教授: 陳俊良 博士

Student: Nong-Kun Chen　　　Advisor: Dr. Jiann-Liang Chen

國立東華大學理工學院

資訊工程學系

博士論文

A Dissertation Submitted to

Department of Computer Science and Information Engineering

National Dong Hwa University

in Partial Fulfillment of the Requirements

for the Degree of

Doctor of Philosophy

in

Computer Science and Information Engineering

January 2008

Hualien, Taiwan, Republic of China

學位考試委員會審定書

國立東華大學 資訊工程學系

研究生 陳農坤 君所提之論文

(題目) 無線網路服務品質確保之反饋式機制設計

Feedback Scheduling Discipline for QoS Guarantee in Wireless Network Applications

經本委員會審查並舉行口試，認為

符合博士學位標準。

學位考試委員會召集人 ______ 簽章

委　員 ______ 簽章

委　員 ______ 簽章

委　員 ______ 簽章

委　員 ______ 簽章

委　員 ______ 簽章

委　員 ______ 簽章

指導教授 ______ 簽章

系主任（所長） ______ 簽章

中華民國 97 年 1 月 22 日

Department of Computer Science and Information Engineering
College of Science and Engineering
National Dong Hwa University
Hualien, Taiwan, R.O.C

As members of the Final Examination Committee, we certify that we have read the dissertation prepared by Nong-Kun Chen entitled Feedback Scheduling Discipline for QoS Guarantee in Wireless Network Applications

and recommend that it is accepted as fulfilling the dissertation requirement for the Degree of Doctor of Philosophy.

Dissertation Advisor: ______________________

Chairman: ______________________

Date: 2008/1/22

致謝

首先要感謝我的指導教授陳俊良博士，使我有機會在國立東華大學，順利完成我的碩士以及博士學業。於這段不算短的求學期間，在陳教授的悉心指導下，我學會了作學術研究與撰寫論文的能力。感謝在我求學過程中曾經指導、鼓勵我的每一位老師，以及在口試時口試委員教授們的指導。感謝 WNAI-Lab 實驗室歷年來的研究伙伴，使我們能夠完成各項計劃及研究工作。

感謝博士班同學明僑在各項行政業務上的幫忙，及在口試期間，學弟小馬和冠中在會場上的協助。

最後我要感謝我的父母親及家人，平日對我求學的支持與鼓勵。謹以此博士論文獻給我的家人及每一位關心我的朋友。

陳農坤　謹誌

中華民國九十七年一月廿三日

於國立東華大學資訊工程研究所

摘要

近年來隨著無線數據網路技術顯著進展，促使在無線網路上許多新的應用服務因應而生。無線網路具有使用者移動自由的特性，即使在使用者改變位置的情況下，仍可保持網路連線並繼續存取網路多媒體資源。因此，無線網路使用者皆引領企盼，不久後將能有不受時空限制的多媒體傳輸服務品質的功能，如電子化數位學習(e-learning)、行動式購物(m-shopping)及行動式需求視訊(m-VoD)等應用；我們確信這些功能在無線網路多媒體應用服務上，無論任何時間、地點，都能夠提供多元化的資訊服務，這些資訊應用都是擋不住的未來生活風潮。在無線網路的環境中，其最大的癥結在於通訊訊號易於受到外界因素的干擾而影響其通訊品質。一個網路服務系統最重要就是要能夠提供給使用者高滿意度的多媒體應用服務。

毫無疑問地，在無線行動網路系統上，使用者所傳送的 Traffic，將分為 Guarantee 和 Best-Effort 兩種。Guaranteed Traffic 在網路系統真正為其服務前，必須先建立它們之間的服務約定。一旦此 Traffic 被接受服務，系統在服務期間必須遵守先前所作之約定，即需要達到該 Traffic 的 QoS (Quality of Service)要求。

在無線行動網路中，影響多媒體應用服務的因素複雜，因此要在此系統上研發一個有效率且公平的 Resource Scheduling Discipline 是非常具有挑戰性的。在本論文中，針對 IEEE 802.11 無線網路架構，提出兩個解決問題機制能夠提供給使用者符合無線多媒體網路 QoS 的服務需求。第一個機制是開迴路資源規劃原則，在該原則我們研發出一個結合 WFQ 架構和 LaGrange λ-calculus 功能的 λWFQ 機制。此λWFQ 機制，主要考量重點在於一個新的 Traffic flow 要求服務時，將會以使用者最高的滿意度而配置系統資源給該 Traffic flow。另一個機制是

閉迴路資源規劃原則，該原則主要是針對具有 QoS 動態需求的無線通訊服務而設計的反饋式資源規劃機制。在設計反饋機制的控制器過程中，為了簡化系統的運算而使用 Laplace 轉換方法，將系統的時域(t)函數轉換到頻域(s)函數。在本論文中，設計四種控制器，即：比率控制器(P)、比率積分控制器(PI)、比率微分控制器(PD)、及比率積分微分控制器(PID)。由模擬結果顯示，若系統使用設計的控制器模組，將可快速獲得系統效能。除此之外，我們可發現 PID 控制器具有最好的效能，它較未使用控制器系統減少 11.44%的 delay 效能；PI 控制器效能優於 PD 控制器；而使用 PD 控制器也比未使用控制器減少 6.2%的 delay 效能。

關鍵詞： 服務品質保證，無線網路通訊，反饋式控制，開迴路資源規劃原則，閉迴路資源規劃原則

Abstract

The spectacular advancement of wireless network technologies has facilitated the introduction of many new wireless network services. Wireless networks can provide end-users with freedom of mobility, since they can roam around a building or outside areas while maintaining access to instant message, e-mail, voice, e-learning, m-shopping, m-VoD and other multimedia services. In the future, the wireless end-users can anticipate to obtain “anytime, anywhere” convenient transmission service, which is an indispensable in life style. However, wireless network environment always suffers from the adverse effect of surrounding conditions. Therefore, to satisfy user requirement is a significant issue.

The traffic flows may be categorized into guaranteed traffic and best-effort traffic. Before both guaranteed traffic and wireless network are setting up a communication, the QoS parameters must be restrained and established. After the process of both sides agreed with each other, the transmission data process must then accord to the parameters established and restrained to reach the assurance of serving of quality.

In this dissertation, two problem-solving mechanisms are proposed to provide high QoS services in IEEE 802.11 network system. First, the open-loop scheduling discipline is developed for a λWFQ scheme involving the WFQ mechanism and LaGrange λ–calculus. Second, the closed-loop scheduling primarily involves the design of a feedback mechanism for supporting wireless mobile communication services with dynamic QoS requirements. We present novel feedback controllers in IEEE 802.11 wireless networks for transmission multimedia QoS requirement traffic.

During the controllers design process, the time-domain is replaced by the *s*-domain, thus simplifying the calculation. This work presents four controllers namely Proportional (P), Proportional Integral (PI), Proportional Derivative (PD) and Proportional Integral Derivative (PID). Experimental results show that systems employing the proposed controllers can quickly achieve the required system performance. Additionally, the PID controller has the best performance, and can improve delay performance by a rate 11.44% than the one without the feedback controller. The PI controller is superior to the PD controller. The delay when using the PD is 6.2% less than that achieved without the feedback controller.

Keywords: quality-of-service guarantee, wireless network communications, feedback control, open-loop scheduling discipline, closed-loop scheduling discipline

Table of Contents

List of Figures

List of Tables

Chapter 1
Introduction

1.1 Motivation

The increasing development of the Internet is leading to various multimedia service applications. In the structure of wireless All-IP networks, communication traffic in the future will be able to reach convenient transmission, largely owing to the "anytime, anywhere" communication concept [1]. The growth of wireless network technology has led to the introduction of many new wireless network services. Wireless networks provide end-users with freedom of mobility, since they can roam around a building or outside areas while maintaining access to instant message, e-mail, VoIP, and other multimedia services [2,3]. Wireless systems continue to attract immense researches and developments effort among other advantages they provide the convenience and freedom of mobility. The recent boom of handheld and mobile devices has spurred the demand for new applications that will support human activities especially in the outdoor and working environment [4]. Along with the rapid development of wireless communications and Internet, various advanced mobile technologies are already available; they provide touch screens, increased battery lifetimes and open interface. Therefore, the personal communication services, such as e-learning, m-shopping and m-VoD, are becoming increasingly popular in our daily lives. The emergence of the UMTS/GPRS and the WLAN handoff techniques has shifted mobile communication services from analog audio to digital multimedia data transmission [5-7]. The developmental goal for wireless mobile communications is to provide high-quality Internet applications at anytime, anywhere for personal demand. The various high-quality applications may include voice, text data, pictures, and video information

[8]. Therefore, to offer a user's degree of higher satisfaction technology in wireless application service, the motive should a paramount communication network technology in the future.

1.2 Objectives

Wireless communications have been the fastest growing segment of the computer communications industry over the past years. The introduction of wireless broadband has contributed to the increase in wireless multimedia applications [9]. Wireless communications systems aim to provide users with radio access to services that are comparable to those currently offered by wired infrastructure, achieving seamless convergence of fixed and mobile services [10,11]. Undoubtedly, in the wireless mobile network system, the user traffic will divide into two kinds of guarantee and best-effort. Before guaranteed traffic is really served for it in the network system, it must set up the agreement between sender and receiver first. When this traffic is accepted the service, the systems must all be in accordance with the agreement made before during serving, namely need to reach QoS (Quality of Service) of this traffic to require [9]. In order to guarantee QoS of sensitive traffic, a lot of resource scheduling strategies have already been researched, and those methods have been used in the wired environment of Internet [12-15]. So far, the time is ripe for the resource scheduling developmental mechanism at wired network field, but the mechanism is just under researched and developed in wireless environment. However, the spectrum resource is very limited in wireless network, and thus many QoS provisioning mechanisms based on resource allocation schemes were proposed to effectively manage the spectrum and provide service assurances. Providing multiple services from limited resource of wireless networks is a significant challenge, because different types of applications need different amounts of bandwidth, and some need a large bandwidth [16]. The traffic amount in a network exceeds the network capacity subsequently degrading the service quality. Therefore, real-time or multimedia traffic must have a good QoS management, and the available bandwidth must be optimized. Good QoS mechanisms enable efficient management of network resources.

Under the structure of All-IP network, the performance of transmission traffic may become degraded on either a wired or wireless networks. The performance degradation in wired networks may result from the transmitted congestion. However, the degradation in the wireless network may result from wireless high bit error rates (BER), such as jitter, interference, and fading [17,18]. Hence, merely increasing the data bit rate of the network does not necessarily improve the network performance, but must be considerable another network conditions.

QoS checking is clearly not possible when traffic is transmitted from a wireless to a wired network. However, the transmitting traffic from a wired network to the wireless network leads to seriously insufficient resources, which greatly influences the quality of service. Hence, bandwidth is very valuable in a wireless network. This thesis therefore focuses on the QoS dynamic management in wireless networks. Adequate controlling wireless network environment and taking dynamic scheduling the wireless resources, in order to assure real-time traffic can reach QoS expected to require. In Chapter 3 will present a concept that feedback control theory is applied to wireless network services for the QoS dynamic management.

1.3 Contributions and Scope of the Dissertation

Effective network resource management is a very important issue to satisfy both the rapidly increasing number of network users and the high demand for mobility in wireless network. In this dissertation, we present network control based scheme to solve the problems of guarantee QoS requirement in a wireless IP network environment. Wired and air links differ significantly in that air media can display substantial radio link error rates, significantly affecting link capacity [9]. Clearly, a perfect mechanism is required to schedule network resources to avoid system congestion and achieve lower the Bit Error Rate (BER) to satisfy QoS requirements. In this dissertation, two problem-solving mechanisms were proposed to provide high QoS services in wireless communications: open-loop scheduling discipline and closed-loop scheduling discipline. The use of wireless network control in closed-loop schedule is a newer and emerging field of recently study. And the formulas for successful design and realized implementation are not readily available.

Open-loop scheduling focuses mainly on designing a schedule discipline to support wireless communications services with steady-state QoS requirements. This dissertation developed a λWFQ scheme involving the WFQ mechanism and LaGrange λ–calculus. Air resources are allocated using λ–calculus and the WFQ mechanism is then responsible for the transmission scheduling. The λWFQ discipline compensates for the penalty derived from the location-dependent errors using the equivalent efficiency concept. The discipline can generate a fair and maximum system QoS schedule for a diverse mix of traffic in a limited radio bandwidth.

The QoS system requirements do not use a measure of the system output that is controlled to compute the control action to be taken. Such system is said to have steady-state QoS requirements. The steady-state QoS requirements, also called open-loop QoS requirements in the proposed system, are only under the current state wireless multimedia application service requirements. However, mobile users always suffer from air interference when moving from one cell to another. When air interference occurs, the system is to become unstable. One advantage of the feedback control is that it causes the system to display self-correcting, self-stabilizing behavior on the unpredictable time-invariant system [19]. Furthermore, the robustness of the feedback controllers may help mobile users to obtain dynamic QoS requirements in the wireless network.

Closed-loop scheduling primarily involves the design of a feedback mechanism for supporting wireless mobile communication services with dynamic QoS requirements. This dissertation designs closed-loop architecture by cascading the open-loop schedule, the QoS probe, the Proportional-Integral-Derivative (PID) controller and a feedback control mechanism. In this architecture, the relationship between input and output is defined using a feedback control module. The module estimates the future QoS according to the current scheduling, while the controller parameters are tuned according to the system status to achieve dynamic scheduling. The QoS probe measures the QoS value of each flow.

The ability to provide guaranteed QoS is one of important issues of multimedia services for the wireless network applications. This dissertation presents both schemes which have been found to perform well for traffic QoS requirement in wireless network applications.

IEEE 802.11e standard had been already ratifying MAC layer QoS specification in 2005. But a wireless cell or a lot of cells communicate to Internet backbone network, traffic data deliver between the distributed networks whether it will still ensure the serving quality, it is not on the specification field of 802.11e. When a heterogeneous network serves the traffic communication, according to user's view, the QoS demand that must offer a set of entirely end-to-end service. In addition to QoS specification of IEEE 802.11e MAC layer, need to consider the service quality requirement that the traffic transmit via the distributed heterogeneous network. Therefore, the QoS requirement must relatively depend on the cooperation of the upper layer network protocol. Base on this paramount reason, this dissertation focuses on designing the feedback control mechanism, which can guarantee to make the applications in IEEE 802.11 wireless network, can reach entirely end-to-end QoS requirement.

To our best knowledge, the third generation (3G) mobile telecommunication has some merits, such as: large communication region, with high mobility, mini size device and handy portable. However, IEEE 802.11 network can provide higher transmission rate, low radiation power, small communication region, low mobile communication environment. This shows both heterogeneous networks with complementation of communication system. On the other hand, as regards the user's view, may not be certain all users have been in the service which has needed high moving or the high transmission rate all the time. Thus, the dissertation idea focuses on designed the end-to-end QoS mechanism based on IEEE 802.11 WLAN with infrastructure basic service set network.

1.4 Organization of the Dissertation

This dissertation is organized as follows. Chapter 2 introduces the wireless network and QoS technologies. Chapter 3 then gives overview of feedback control theory characteristics. Chapter 4 describes the proposed open-loop schedule for QoS guarantee. Chapter 5 discusses the proposed closed-loop schedule for QoS guarantee. The performance evaluation and analysis are dedicated to Chapter 6. Finally, Chapter 7 makes a conclusion and states future works.

Chapter 2
Wireless Network and QoS Issues

IEEE 802.11 is an evolving family of specifications for wireless local area networks (WLANs) developed by a working group of the Institute of Electrical and Electronics Engineers (IEEE). There are several specifications in the family and new ones are occasionally added. The working group has defined the standard of IEEE 802.11 network since 1997; thereafter in order to meet various demands of extensive wireless network applications, the working group develops out various kinds of IEEE 802.11 specifications editions successively. These new specifications, mostly inherit original IEEE 802.11 standard, even expand their functions. Wireless LAN is an indispensable technology in an All-IP network architecture to satisfy the "anytime and anywhere" communication requirement of end users [1]. As wireless network technology has been widely used, it makes applications of multimedia as thriving as spring bamboo shoots. Current advances in wireless communications and portable client devices enable mobile users to access multimedia content universally [20]. However, when multimedia content becomes wealthier, i.e., including video and audio traffic stream, it is difficult for wireless access to communicate due to the existence of many restrictions. The most important factor of all, wireless connections usually have a lower bandwidth compared to wired ones. Moreover, mobile users in wireless network applications often suffer from air interference when moving between cells, quality of service (QoS) requirement for them is more difficult to guarantee in a wireless network than in a wired network. In the following sections, firstly introduces the wireless network technology, and then surveys the QoS issues based on the wireless network. Finally, section 2.3 specifies the IntServ service and DiffServ service.

2.1 Wireless Network Technology

Recently, we can find by far Internet technology has a great growth deployment and application. Wireless Local Area Network (WLAN) allows that users connect and access to traditional wired LANs, as WALN can be seen as an extension of wired LAN but with the flexibility and mobility that characterizes wireless systems [21]. With the rapid growth in popularity of wireless data services and the increasing demand for multimedia applications, it is expected that future wireless networks will provide various services for many classes of traffic with different QoS requirements.

2.1.1 Wireless Network Service Architecture

In Figure 2.1, this wireless network architecture is a hierarchical structure consisting of a backbone network, Routers, Access Points (AP), Mobile Units (or Mobile Host, i.e. MH), and other 3G (third generation) cellular system. The backbone network is a wired network connecting the existing wired links to the Routers, Access Points, GGSN (General Packet Radio Service), SGSN (Serving GPRS Support Node), and BTSs (Base Transceiver Station). In wireless network, the transmissions employ radio channel as the transmission media. Generally, the MHs in a basic service set (BSS) communicate with the backbone network through an AP [22]. IEEE 802.11 defines the BSS as the basic building block of a wireless LAN (Fig. 2.2). AP will gradually become “gateway” for the mobile subscriber and wired user. The Router can integrate some APs connect to backbone network. The wireless segment “cell” provides mobility to a user while using the network. In the integrate network architecture, is called All-IP network, may connect various types devices, such as PC, notebook, PDA, mobile handset, and so on. Therefore, the Figure 2.1 may connect to the cellular network, such as GPRS [23,24], and 3G network. Even next generation entertainment electronic devices such DVB-H (Digital Video Broadcasting-Handheld), DVD player may be equipped with wireless network adaptors and connected with each other through wireless network. Under the wired environment, the network can offer very steady multimedia service. That is, the QoS of wired Internet can reach the users' requirement. However, the wired Internet services there are two greater defects, the first one is unable to move the location while user's traffic communication, and the other is the connected line cost and complexity are very high. The WLAN has avoided the above two kinds of puzzlement, not only can overcome environment connected line obstacle, but also it offers user for roaming function (for roaming user). The user can access the applications of the network anytime and anywhere possible in the wireless network.

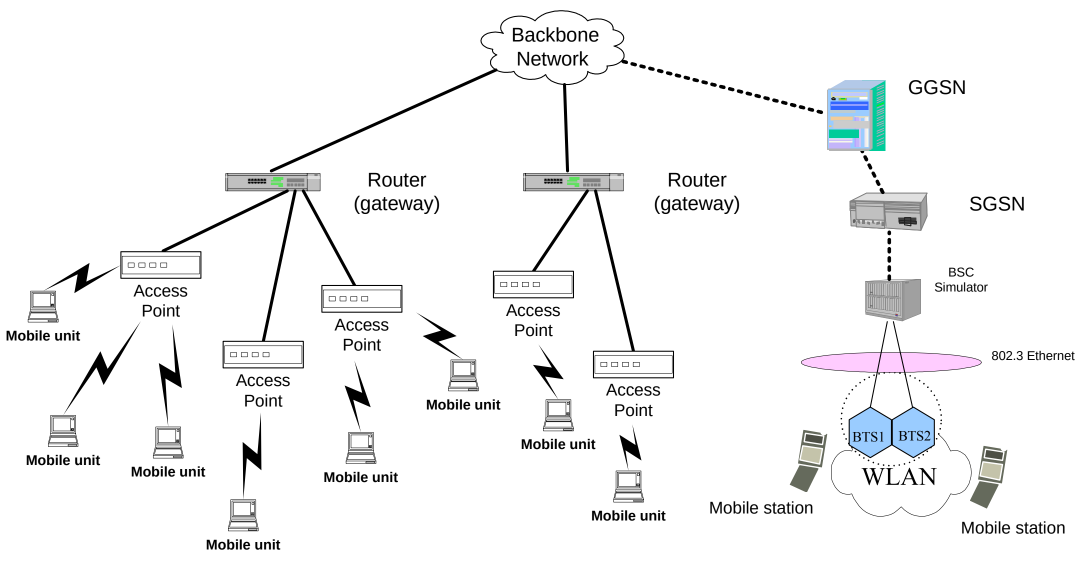


Figure 2.1: Wireless Network Structure

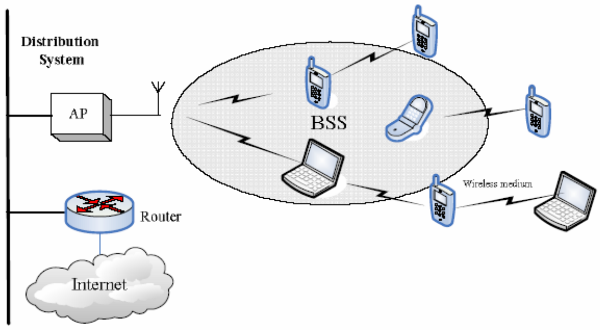


Figure 2.2: Infrastructure Basic Service Set

A working group of the IEEE released 802.11 first version standard in June 1997, which mainly made a employ radio technique standard. The standard can produce same functions of network similar to wired LAN. Employing wireless equipment can structure office or home network, it is really a quite simple and convenient way. IEEE 802.11 technology has some advantages, such as offers relatively long distance and/or larger bandwidth, compared with 3G (3 Generation) and Bluetooth network technology. Therefore, wireless LAN possesses the following preponderances:

- The convenient use of the user in the public area (such as the airport, exhibition field, hot-spot, the campus, and library, etc.).
- WLAN infrastructure does not constrain by geography environment (e.g., U.S 911 event rescue, the suburb, the mountain area or the old buildings)
- Take support system as the wired network.
- The construction is easy and the cost is low.
- Freedom and high mobility.

In general, wireless and mobile networks have some limitations also. The characteristics of wireless communication pose special problems that do not exist in wired networks. These limitations include:

- Limited power constrained.
- A high channel bit error rate.
- Wireless connections much lower bandwidth compared to wired ones.
- Location-dependent and time-varying wireless link capacity.

All of the above characteristics to make developing efficient scheduling algorithms for wireless networks are very challenging [25].

As states earlier, wireless LAN will be most popular transmission technology in the future, because the technology will bring very convenient for the users.

2.1.2 IEEE 802.11 Network Standards

Since IEEE 802.11 standard was proposed in 1997, afterward it elicited successively some other series standards. Such as 802.11b, 802.11a, 802.11g respectively. Unfortunately, the original version 802.11 only supported a maximum bandwidth of 2 Mbps, it is too slow data rate for most of applications recently. These succeeding standards all define the transmit data techniques. Those transmitter must accord with these forms by the data are transmitted, and then the data could be received by another end of the communication. The following Table 2.1 lists some of IEEE 802.11 family standards characteristics [26]:

Table 2.1: IEEE 802.11 family standards characteristics

parameters	802.11	802.11b	802.11a	802.11g
Standard Approved	July 1997	Sept. 1999	Sept. 1999	June 2003
Max Data Rate	2 Mbps	11 Mbps	54 Mbps	54 Mbps
Modulation	DSSS, FHSS	DSSS, CCK	OFDM	OFDM
Frequency band	2.4 GHz ISM	2.4 GHz ISM	5.7 GHz ISM	2.4 GHz ISM
Allocated Bandwidth	83.5 MHz	83.5 MHz	125 MHz	83.5 MHz
Transmitting Distance	100 m	100 m	50 m	100 m
Backward compatible	N/A	Yes	No	Yes

IEEE 802.11b utilizes the 2.4GHz industrial scientific and medical (ISM) unlicensed band, the max data rate is 11Mbps. The ISM band is commonly used for low cost radios and networks [27]. This is the most popular standard of all 802.11 versions. It was published in September 1999. Then 802.11a by using OFDM (Orthogonal Frequency-Division Multiplexing) modulation in the 5.7 GHz frequency band and U-NII band, the data rates vary from 6 to 54 Mbps. This standard supports higher data rates, compared to the other 802.11 versions. However, the 802.11a device cannot backward compatible the 802.11b device.

IEEE 802.11g is as same as 802.11b uses 2.4 GHz frequency band, modulation technology adopts the OFDM of frequency division of 802.11a, it can offer 802.11a device transmit data. The 802.11g device can backward compatible the 802.11b device, it need not upgrade equipment. Because 802.11g uses 2.4 GHz frequency band like as 802.11b usage. But IEEE 802.11g devices will receive the interference of other common electrical home appliances products. A lot of common electrical home appliances products use 2.4 GHz frequency band too, including radio telephone, microwave oven, etc.

Wireless data networks based on IEEE 802.11b standard, known also by the commercial trademark *Wi-Fi*, is evolving into the fastest-growing wireless data network applications. Selling at an estimated number of 1-1.5 million network interface cards per month, 802.11 networks are springing up not only in businesses and hot-spot public spaces, but also in residence homes [28].

2.1.3 MAC Technology in IEEE 802.11

To our best knowledge, CSMA/CD (Carrier Sense Multiple Access with Collisions Detection) was used in wired local area network, such as IEEE 802.3 Ethernet protocol. However, CSMA/CD is not used in wireless local network. Because an STA can not listen to the radio channel for collisions while it transmits data. Therefore, the STA senses the medium to check if it is free channel before it starts to transmit packets. CSMA/CA (Carrier Sense Multiple Access with Collisions Avoidance) is used in wireless local area network for access medium. While the wireless network delivers the packet data, to avoid the delivered data taking place collision, therefore the access method adopts CSMA/CA technology.

The IEEE 802.11 standard by IETF specified both physical (PHY) and Medium Access Control (MAC) layers. The MAC layer architecture is shown in Fig. 2.3. The MAC sub-layer is defined two access coordination mechanisms, the basic Distributed Coordination Function (DCF), which is mandatory and the optional Point

Coordination Function (PCF) [26,29]. The both functions of the MAC layer of the IEEE 802.11, DCF and PCF, are able to sharing access the radio medium resources. The PCF promises the STA for transmitting datagram by AP determines the order to transmit. PCF is a polling based scheme. Therefore AP needs a high performance polling scheme, according to the transmitting amount, deferring parameters, fairness, etc. AP is able to process the scheduling of polling the order, to reach the best transmission quality and efficiency.

However, the DCF asks each station only to send data packages when it gets the free channel through contention process. It can carry out in all stations (STAs) with asynchronous packets transferred at the method of "best-effort" and it allows multi-stations to communicate with each other without centre-controls [30]. Therefore, DCF function is a similar the Ethernet-like CSMA/CA protocol. But based on DCF, the transmitter must sense the wireless channel to ensure there is no other proceeding transmission before transmission. Each station chooses a random number between zero and Contention Window (CW) value for back-off time. While the channel is idle, the transmitter decreases the back-off counter after waiting for a DCF Inter-frame Space (DIFS) time period. The station can send out packets when back-off time decreases to zero [31]. Owing to the function promises all the stations share the channel and have the same contenting probability, the technology cannot guarantee the transmission quality for the real-time delay-sensitive traffic.

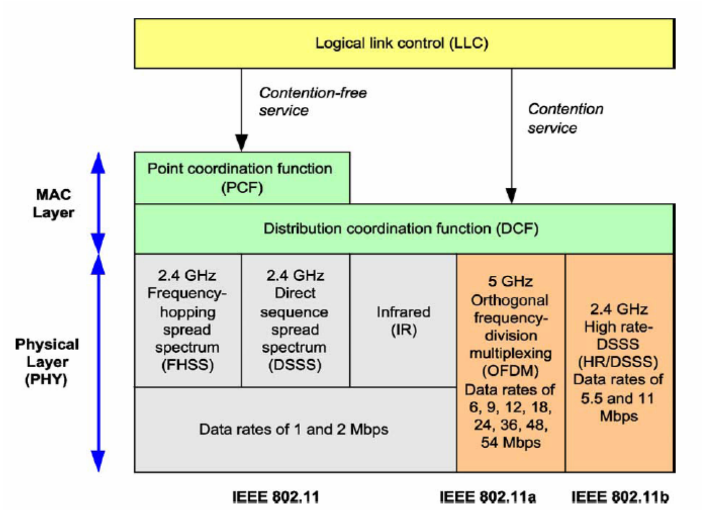


Figure 2.3: IEEE 802.11 PHY and MAC Architecture

However, IETF in order to solve the efficiency problem that a lot of STAs compete for accessing free air channel synchronously, and proposed Request-to-Send (RTS) and Clear-to-Send (CTS) mechanisms. The wireless network uses the RTS/CTS pair, rather than the data packet and acknowledgment pair, to test the states of wireless links. RTS and CTS are exchanged between the base station and a mobile host before a data packet is transmitted. RTS and CTS messages are usually shorter than data packets. If a link is in an error state, using RTS/CTS wastes less transmission bandwidth than data packets. However, if a link is in a good state, RTS/CTS impose extra overhead and delay on packet transmissions.

In Fig. 2.4 shows RTS/CTS reservation four-way handshake procedure logical figure, before data transmit, both sender and receiver must perform RTS/CTS handshake. Before a station wants to transmit a packet, it needs to sense the channel. To forbid sender directly transmits traffic to receiver, the method is to require sender firstly send a RTS package to receiver. Until sender receives a CTS package from receiver, then sender can make a connection and transmit the data. If the sender receives an ACK from the receiver, the transmission is successful. Therefore, the RTS and CTS mechanism within IEEE 802.11e is used to reserve a channel.

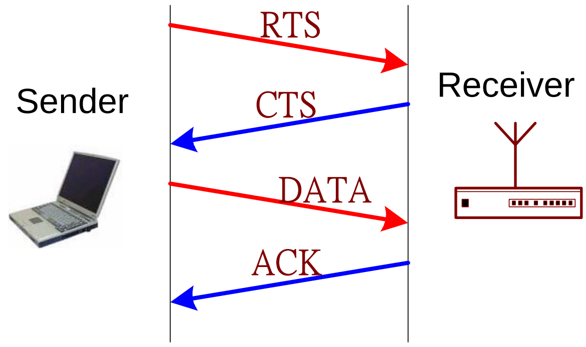


Figure 2.4: RTS/CTS Reservation Four-way Handshake

Distributed coordination function may use CTS/RTS to reduce the possibilities of collision and contention. As mentioned above, the collision detection is not used since a node is unable to detect the channel and transmit data simultaneously in the wireless network. A node listens to the channel before transmission to determine whether some one else is transmitting. In Fig. 2.5, DCF consists of a basis access mode as well as an optional RTS/CTS access mode. In basic access mode, the node senses the channel to determine whether another node is transmitting before initiating a transmission. If the medium is sensed to be free in a DCF inter-frame space (DIFS) time interval the transmission will be proceeded. The RTS/CTS access mode, the sender will send a RTS packet to announce the upcoming transmission. When the destination node receivers the RTS, it will send a CTS packet after a SIFS interval. Both the RTS and CTS packets are short control packets. The sending node is allowed to transmit its data packet only if it receives the CTS packet correctly. The purpose of this RTS/CTS exchange is to avoid long collision since we do not have collision detection.

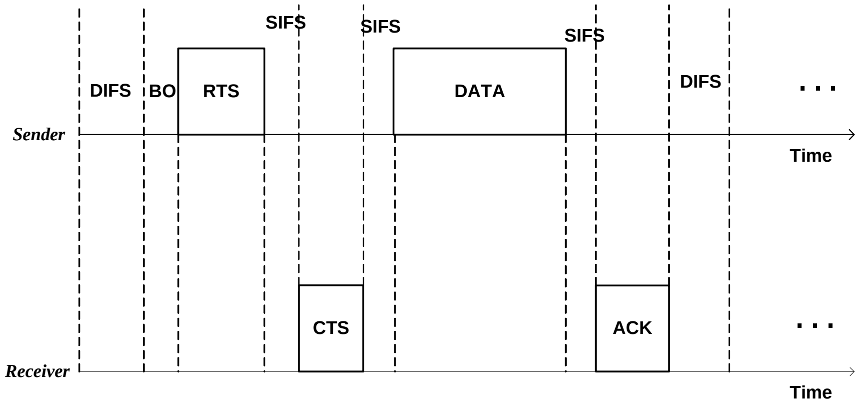


Figure 2.5: RTS/CTS Reservation Handshake Timeline

Recently, for serving the various multimedia traffic requirements, the IEEE 802.11 family standards have been proceeding the enhancive versions. Table 2.2 shows the evolution versions of the IEEE 802.11 WLAN specifications [32].

Table 2.2: Family of the IEEE 802.11 WLAN specifications

Specification	Descriptions & Factures	Date
802.11	The original WLAN standard. Supports 1 Mbps to 2 Mbps.	1997
802.11a	High speed WLAN standard for 5 GHz band. Supports 54Mbps.	1999
802.11b	WLAN standard for 2.4 GHz band. Supports 11Mbps.	1999
802.11e	Address quality of service requirements for all IEEE WLAN radio interfaces.	2005
802.11f	Defines inter-access point communications to facilitate multiple vendor-distributed WLAN networks.	2003
802.11g	Establishes an additional modulation technique for 2.4 GHz band. Intended to provide speeds up to 54 Mbps.	2003
802.11h	Defines the spectrum management of the 5 GHz band for use in Europe and in Asia Pacific.	1999
802.11i	Address the current security weaknesses for both authentication and encryption protocols. The standard encompasses 802.1X, TKIP, and AES protocols.	2004
802.11n	100Mbps bandwidth.	cooking

2.2 QoS Issues and MAC Technology in IEEE 802.11e

Nowadays the overwhelming majority (over 85%) of Internet traffic is TCP-based [33]. However, this situation will be more challenging in the nearly future. As wireless network technology fast-stepping develops, and user demand for multimedia services is springing up. Therefore, the fact is expected that wireless users' demands for multimedia mobile services will rapidly increase in the nearly future [34].

2.2.1 QoS Issues

As stated former section, with new wireless network application developments and convenient utilization, wireless network has become the popular network topology today. Due to bandwidth is the most precious and limited resource in wireless network, efficient resource management is the most crucial technology. Therefore, multimedia wireless network with QoS support has become one of the paramount important researches in recent year. QoS refers to traffic control and resource management mechanisms that guarantee performance to applications, traffic flows, and packets. Clearly to say, QoS must be able to provide guaranteed and differential services to different users' applications. In Fig. 2.6 shows the differential bandwidth requires based on the different user traffic type. QoS provisioning in wireless mobile networks is more challenging than in fixed networks. Certainly, QoS performance metrics such as latency, jitter, throughput, packet loss rate, minimum reserved traffic rate, and maximum sustained traffic rate in the wireless networks. Formally, several common applications are listed in Table 2.3 along with the stringency of their requirements in the common wired-network [29]. The parameters in this Table there are bandwidth, delay, jitter and reliability. The bandwidth term indicates the maximal data rate that is available for the flow. The delay term denotes the elapsed time for a packet to transit the network. The jitter term signifies the variation in delay for each packet. Lastly, the reliability term says the rate of packet loss, corruption, and recording within the flow. From the Table, as the service provided by default is often referred to as best effort. When a link is congested, packets are simply discarded as the queue overflow. Because most current practical network architectures treat all packets in the same way, that is, a single level of service. Therefore, if a packet needs a large bandwidth requirement, it has either the more delay or the more jitter. Even apparently, a packet needs the more bandwidth, it has the lower reliability. Since, the network treats all packets equally, any flows could be hit by congestion and this particularly impinges on wireless and mobile connections, commonly as a result of limited bandwidth [29].

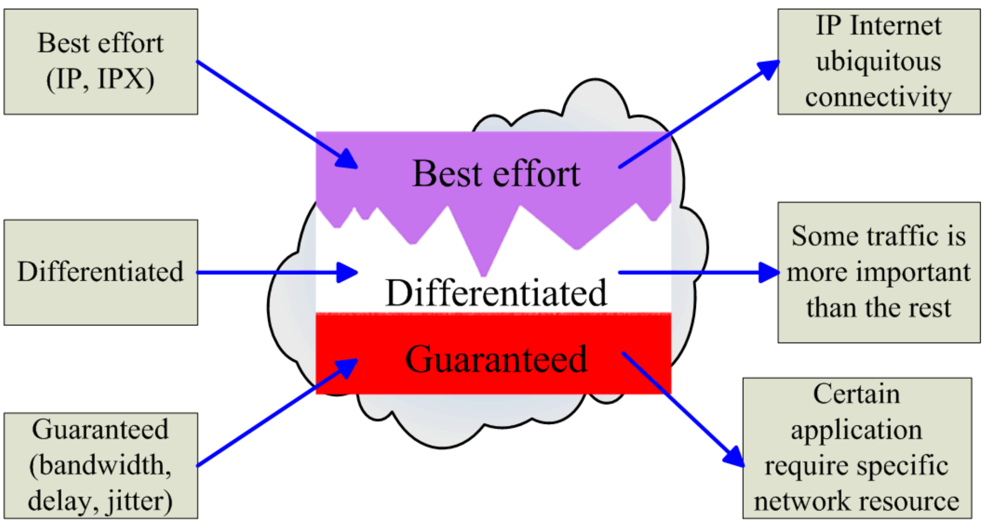


Figure 2.6: Bandwidth Requires Based on Different Traffic Type

Table 2.3: Common Wired-network Performance Characteristics

Application	Reliability	Delay	Jitter	Bandwidth
E-mail	High	Low	Low	Low
File transfer	High	Low	Low	Medium
Web access	High	Medium	Low	Medium
Remote login	High	Medium	Medium	Low
Audio on demand	Low	Low	High	Medium
Video on demand	Low	Low	High	High
Telephony	Low	High	High	Low
Videoconferencing	Low	High	High	High

2.2.2 MAC Technology in IEEE 802.11e

However, IEEE 802.11 cannot provide QoS support for the real-time applications without transmission priority and traffic differentiation. The IEEE 802.11e draft five version, which is a medium access control (MAC) technology enhancements for QoS support in IEEE 802.11 family specifications. IEEE 802.11e as an improvement of IEEE 802.11 provides more effective QoS guarantees, which makes it possible to implement end-to-end QoS [35]. As mentioned above, 802.11 MAC consists of PCF and DCF mode, but they are unable to offer any service quality guarantee. So, the development goal of 802.11e is to overcome this problem. The IEEE 802.11e standard introduces the Hybrid Coordination Function (HCF) as the medium access control scheme. While backward compatible with DCF and PCF, HCF provides stations with prioritized and parameterized QoS access to the wireless medium [28]. The extended MAC layer is showed in Fig. 2.7. HCF combines aspects of both the contention-based and the contention free access methods, where the contention-based channel access mechanism in HCF is known as the enhanced EDCA and its contention free counterpart is known as the HCF polling based channel access. EDCA provides differentiated and distributed access to the wireless medium with 4 access categories (AC), each corresponding to an individual prioritized output queue. In EDCF mode, there is eight Traffic Categories mapping to 4 ACs. Additionally, channel access priority of various types of packets is assured by both the Inter-Frame Space (IFS), which is the time a packet needs to defer before initiating its transmission or back-off procedure, as well as the amount of backoff time it takes before transmission. There are five different kinds of IFS: Short IFS (SIFS), Distributed coordination function IFS (DIFS), Point coordination function IFS (PIFS), Extended IFS (EIFS), and Arbitration IFS (AIFS) [28]. AIFS utilizes different interval time districts to separate out different priority. The time line of various IFSs, back-off procedure of EDCA is sketched in Fig. 2.8. Various ACs use different AIFS value and contention window size to contend for the channel (Table 2.4), where the value of AIFS is determined by the following equation:

$$\text{AIFS}[i] = \text{AIFS}_n\,[i] \times \text{SlotTime} + \text{aSIFStime} \tag{2.1}$$

where the value of AIFS_n dependents on the AC and aSlotTime/SIFS value dependents on the PHY layer used (Table 2.5). Therefore, classes with the smallest AIFS will have the highest priority. In the other words, the higher priority of the station, the shorter of the AIFS time. The authors in [36] also suggest three different ways to enhance 802.11 performance; by scaling the CW based on the priority factor of each station or by giving each priority level with a different value of DIFS or different maximum packet length [30].

Before both AP and STA are setting up a communication, the QoS parameters must be restrained and established. After the process of both sides agreed with each other, later the transmission data process must accord to the parameters to be established and restrained, to reach the assurance of serving of quality.

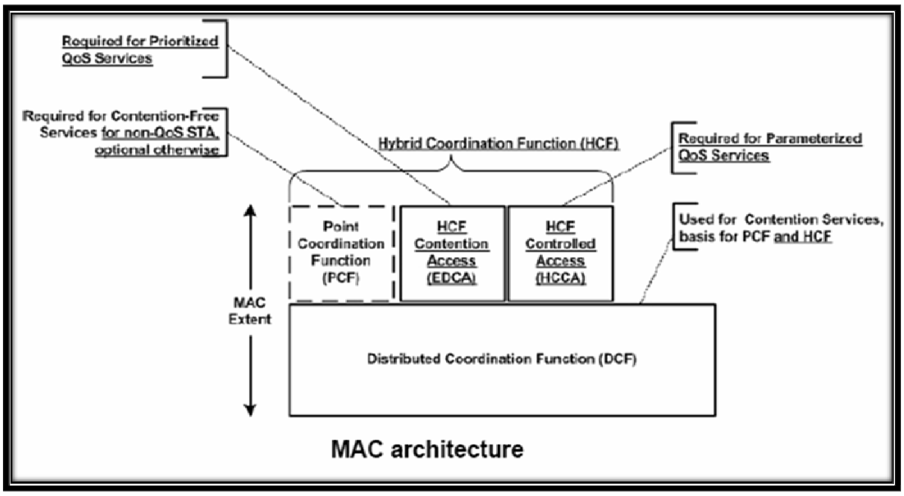


Figure 2.7: IEEE 802.11e MAC Extent Layer Architecture

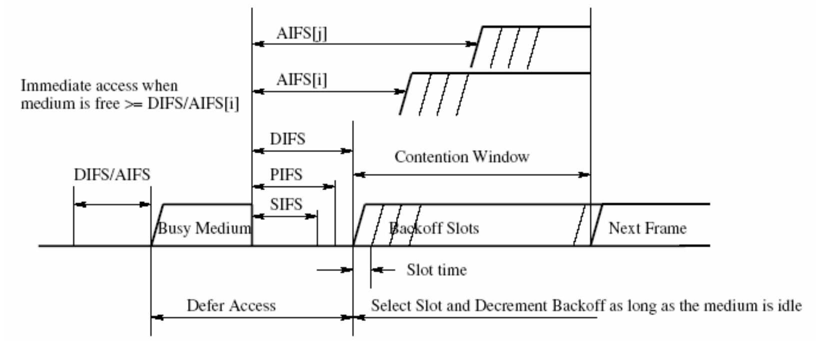


Figure 2.8: IFS relationships and EDCA channel access

Table 2.4: Default EDCA Parameters

AC	CW_{min}	CW_{max}	$AIFS_n$
0	aCW_{min}	aCW_{max}	3
1	aCW_{min}	aCW_{max}	7
2	$\frac{aCW_{min}+1}{2} - 1$	aCW_{min}	2
3	$\frac{aCW_{min}+1}{4} - 1$	$\frac{aCW_{min}+1}{2} - 1$	2

Table 2.5: Parameters in DSSS PHY

SIFS	10μs
DIFS	50μs
Slot Time	20μs
MAC Header	272bits
PHY Header	192bits
Payload	1500bytes
Channel Bit Rates	11Mbps

2.3 IntServ and DiffServ Architectures

As stated former section, in IEEE 802.11 DCF mode can only support best-effort services and does not provide any QoS guarantees for real-time delay-sensitive services. Although PCF has been designed by the IEEE Working Group to support time-bounded multimedia applications, this mode has some major problems, which leads to poor QoS performance [29]. For example, PCF mode is a central polling scheme, while the BSS with high traffic load will result in that the network is inefficient. Additionally, all communications have to pass through the AP which degrades the bandwidth performance [37].

For the different applications, the necessary quality of service characteristic is also not the identity. IETF has always been trying to increase QoS function in IP network in recent years. Work on QoS-enabled IP networks has mainly led to two distinct approaches: the Integrated Services (IntServ) architecture [38] and its accompanying signaling protocol, Resource ReSerVation Protocol (RSVP), and the Differentiated Services (DiffServ) architecture [39,40]. Furthermore, these two QoS guaranteed ways are applied to WLANs, namely parameterized and prioritized QoS [29,41,42].

Parameterized QoS is a strict QoS requirement, which is expressed in terms of quantitative values, such as data rate, delay bound, and jitter bound. In the IntServ model, these values are expected to be met by the MAC data service in support of the transfer of data frames between peer stations. In a prioritized QoS scheme, the values of QoS parameters are as same as IntServ. But these parameters results from a DiffServ model may vary during the transfer of data frames. Therefore, these parameters in DiffServ model there are no need to reserve the strict QoS requirement.

Although EDCA improves the quality of service of real-time traffic, the obtained performances are not optimal since EDCA parameters cannot be adapted to the network conditions dynamically [30,35]. The authors in [30] combine the IEEE 802.11e EDCA parameters and DiffServ architecture engine, and propose a new scheme called DFAC (Delay Feedback Adaptive Control) which is a preparation to realize end-to-end delay guarantee in multihop WLAN. The following two subsections will specify the IntServ and DiffServ architectures, respectively.

2.3.1 Integrated Services Architecture (IntServ)

IntServ architecture may schedule and manage resources of the network according to the QoS requirement of service applications. The architecture is based on RSVP protocol (RFC 2205), which is employed in IntServ to setup path and reserve resources. RSVP is a signaling protocol, rather than a routing protocol, that allows host to establish and tear down reservations for data flows.

IntServ provides individualized quality-of-service guarantees to individual application sessions by per-flow resource reservation, so it can guarantee end-to-end accurate service quality. In contrast, the all network routers along the data path must deal with increasing work load, because it must set up the QoS relevant parameters. It will calculate and store the relevant parameters constantly in each router along the path. Therefore, the architecture can support per-flow end-to-end QoS.

In Fig. 2.9, while the sender submits traffic for QoS requirement to the IntSverv network domain, firstly the PATH message may be issued to the network components. The PATH message contains the Traffic Specification (TSpec) that profile the data flow to be sent. Going to the receiver along the path based on IntServ domain, every Core routers and Edge routers make admission control the multimedia flow, and advance process the traffic classifier, policing, and scheduling. Finally, the receiver (destination) must response the RESV message to Core routers and Edge routers along the same path; the message contains resource reservation request parameters, such as Flow Spec and Filter Spec. Flow Spec consists of Service Class, TSpec, and RSpec. Then Filter Spec would consist of sender's IP and UDP/TCP Source port, these information could confirm to response the sender node. During connection establishment the QoS requirements of the sender are propagated hop by hop inside the sender's and receiver's IntServ domains. To support real-time communications, the implementations of routers inside an IntServ domain must be compliant with the guaranteed service specification or controlled-load service specification. The sender and receiver IntServ domains take part in providing QoS guarantees for individual flows. The IntServ architecture can provide end-to-end QoS for any flow [40]. Therefore, with the gradual expansion of the Internet IP-based network, the packages increase in a large amount. As to router is a great challenge, no matter what storing equipments or processing speeds for information. This is a critical problem all the time based on IntServ scalability question.

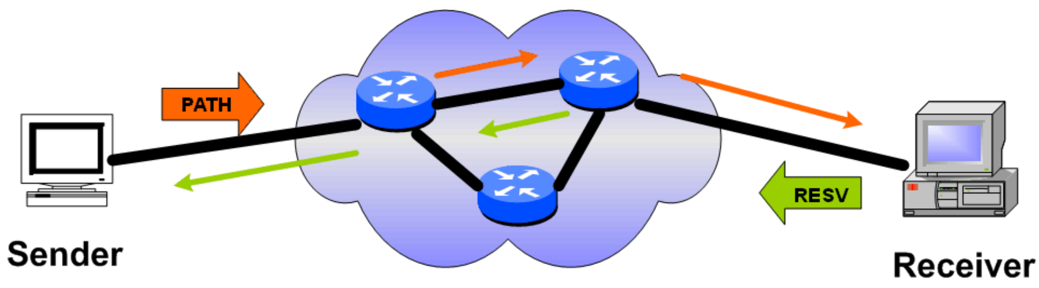


Figure 2.9: IntServ and RSVP Architecture

2.3.2 Differentiated Services Architecture (DiffServ)

DiffServ architecture, is defined in RFC 2474 and RFC 2475 [39], provides QoS guarantee in the Internet which is not belong to per-flow guarantees that IntServ provides. The DiffServ network architecture is designed to provide a simple, easy to implement. To implement the logic module in Edge router about the classifiable traffic type technology, combining the classifier and marker into router module, and integrating the meter and dropper into monitor module. Employ the queuing/scheduling module in order to implement the Shaper/Dropper function. According to the RFC 2475 definition, DiffServ engine consists of Classifier, Meter, Marker, and Shaper/Dropper elements in the Edge router (Fig. 2.10).

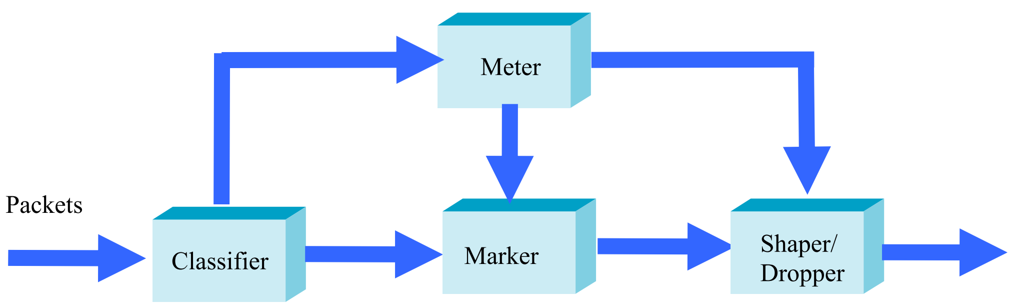


Figure 2.10: DiffServ Engine Components

The four engine components are simply described in the following:

- Classifier: an entity which selects packets based on the content of packet headers according to defined rules.
- Meter: monitors whether the incoming packet flow conforms to the negotiated traffic profile.
- Marker: a device that performs marking which the process of setting the DS CodePoint in a packet based on defined rules.
- Shaper/Dropper: Shaper is the process of delaying packets within a traffic stream to cause it to conform to some defined traffic profile. Dropper is the process of discarding packets based on specified rules.

In Fig. 2.11, DiffServ provides a scalable and flexible service differentiation to handle different classes of traffic in different ways within the DiffServ domain (DS domain). That is, a contiguous set of DS nodes which operate with a common service provisioning policy and set of per-hop behavior (PHB) group implemented on each node. The differential technology is simpler implementation than RSVP/IntServ, because it is no per-flow signaling or record state on all service traffic deliver path. DiffServ networks classify packets at the DS domain ingress into one or a small number of aggregated classes, based on the DiffServ CodePoint (DSCP) in the packet's IP header. This is known as behavior aggregate (BA) classification [40].

Edge routers mark packets of different classes with different DSCP in the IP packet header according to their service requirement. Those marked DSCP packets will be recognized by core routers and apply a particular treatment on those packets. Core routers treat packets with different level of services according to its DSCP. It has the lighter workload because it performs limited traffic conditioning functions.

DiffServ architecture designed main idea that is simplified the complexity of core routers. The idea made the complex admission control function into the Bandwidth Broker, in order to optimize the bandwidth management. To enlarge the DiffServ domains, it will communicate the service profile between the DS domains by having a service level agreement (SLA).

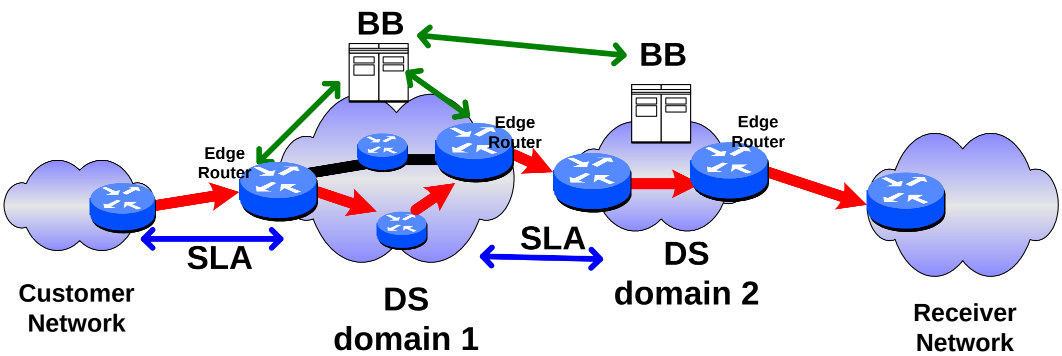


Figure 2.11: DiffServ Architecture

Finally, we list the different characteristics on the IntServ vs. DiffServ architectures in the Table 2.6.

Table 2.6: Characteristics on IntServ vs. DiffServ

Type / Characteristics	IntServ	DiffServ
Adaptability	Access network	Core network
Coordination for service differentiation	End-to-End	Local (Per-Hop)
Scope of service	A Unicast or Multicast	Anywhere in a network or

differentiation	path	in specific paths
Scalability	Limited by the number of flows	Limited by the number of classes of service
Network accounting	Based on flow characteristics and QoS requirement	Based on class usage
Network management	Similar to Circuit Switching networks	Similar to existing IP networks
Interdomain deployment	Multiateral Agreements	Bilateral Agreements

Chapter 3
Feedback Control Theory

In this Chapter, we describe the overview of feedback control theory. Feedback control is a very important theory in scientific applications. For instance, it is widely used in various dynamic systems, such as the temperature and humidity regulation in houses to provide comfortable living space. This theory also applies to automated highway systems, automated factories, smart homes, appliances, and so on. The system generally means some physical entity on which some action is performed by an input. The system reacts to this input producing an output. A dynamic system is a system which phenomena occur over a time-domain [43].

Separate three Sections as the following, Section 3.1 specifies the characteristics of feedback control system. And discuss about time response analysis of feedback control system in Section 3.2. Finally, we discuss various controllers of feedback control system.

3.1 Characteristics of Feedback Control Theory

In this section, firstly, we introduce some fundamental characteristics and the main components about feedback control theory. Control of dynamic systems is a very common concept with many characteristics. One of feedback control theory characteristic that can make a controlled system carry out efficiency before really decreases progressively. The other can predict in advance out its degree of decreasing progressively, and do systematic compensation or revision ahead of time. Control theory makes the controlled system reach the dynamic stability, means being guaranteed very ideally to QoS from beginning to finishing process, are not influenced for a long time by the external environment of the system.

The goal that the control system is designed has the following characteristics:

- ◈ The response speed is fast in a system.
- ◈ The accuracy is high.
- ◈ It is good to the stability.

In the following paragraphs there are two subsections. Subsection 3.1.1 introduces the components of feedback control system. In Subsection 3.1.2, we list the relative parameters of feedback control system.

3.1.1 Components of Feedback Control System

A complicated or dynamic system, to control it accurately and make it reach anticipated systematic goal, is a very difficulty for modeling it precisely. The main reason is that an external environment has a real condition that is interfered to the system, or limited resources of system are unable to employ efficiently. So if it is unsatisfactory to control the system, would make the system unable to reach stable state and obtain the anticipated reference target. Utilizing the control theory to develop a mathematic equation is a significant modeling technology for a system, to enable the system to reach the convergent goal. A feedback control system consists of controlled system, controller unit, QoS Probe unit, and actuator mechanism. In Fig. 3.1, the QoS Probe unit, one component of feedback control system, monitors system behavior (i.e., reaction) at every sample interval, and then it calculates value the best adaptive parameters via control algorithm. Such that, it makes controlled system reach the best efficiency. To describe these modules functions as following:

- *Controlled system* (i.e., plant): the component is the main role of a feedback control system. The functions of the other components may assistant this unit can work to reach the system reference.
- *QoS Probe* (i.e., monitor): the component unit can monitor or measure the controlled reaction value (ex. QoS index) and feed the sample data back to the controller.
- *Controller* (i.e., Gain) unit: the controller unit can affect the controlled system behavior. The component compares the system reference with the controlled reaction value to get the current error. If the error is over or less a tolerant value, according to the controlled system requirement, the controller calls an algorithm to compute the control value to actuator unit.
- *Actuator*: the component can change the manipulated variable based on the newly computed control input, given by the Controller unit.

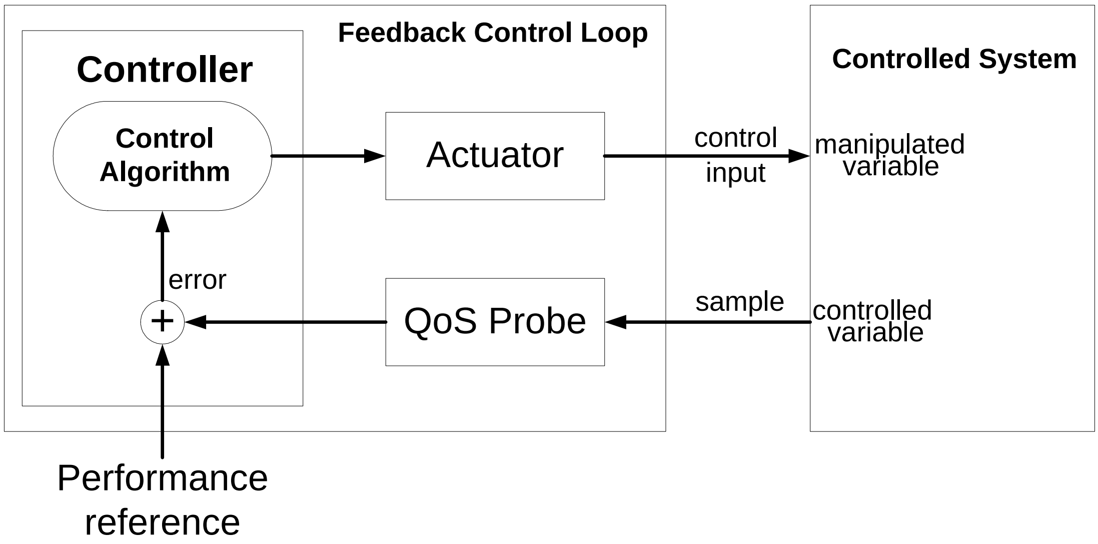


Figure 3.1: The Architecture of Feedback Control Scheme

3.1.2 Parameters of Feedback Control System

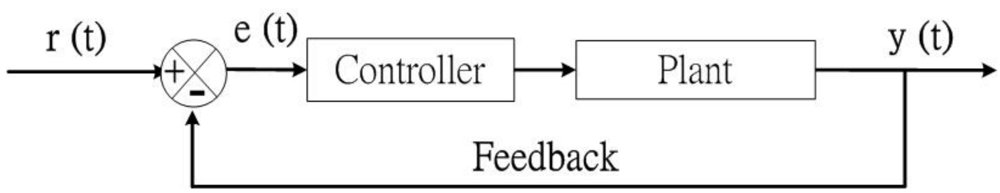
In the architecture of feedback control system, there are some principal variables related to the system workflows. These variables are described as follows [43].

- *Performance Reference*: the input of the whole system target requirement is called performance reference, which represents the desired system performance. The difference between the performance reference and the QoS Probe unit monitors really network condition index is called *error*.
- *Controlled variable*: the plant output value is called controlled variable. The value through the sample monitoring works, we can get the system condition index and feed it back to the controller unit. The feedback control function is designed to regulate the output so that it is maintained at the system reference value. The term of system condition index depends on the performance guarantees that need to be

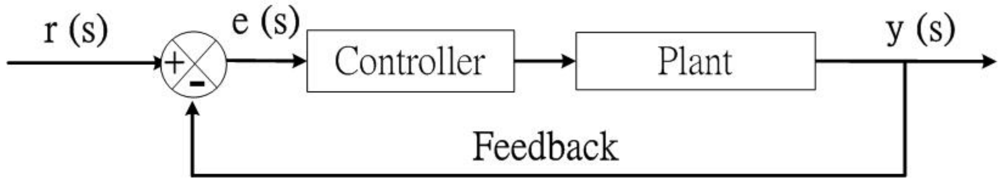
provided to the specific application of a control system. That is, the index may be temperature, humidity, highway vehicle condition, even real-time services in network condition information.

- *Manipulated variable*: the Feedback Control Loop unit output is called manipulated variable. The variable value is generated dynamically to feed the controlled system through the Actuator, and also is effective for performance of the system. The choice of manipulated variable should reflect the resource bottleneck of a system.

Furthermore, we can modify the Figure 3.1 into Figure 3.2. To abstract the concept of feedback control system and to understand clearly the relationship of parameters for the purpose of this modifies. The system external environment condition changes over time in the system work duration. Therefore, the feedback control technology is often adopted to perform the controlled system output condition mechanism, which uses a feedback control method that deploys the closed-loop structure. Figure 3.2 (a) shows the time-domain of the feedback control system. Figure 3.2 (b) depicts the control diagram of the s-domain by the Laplace transform of Figure 3.2 (a). In the figure, the time-based variable $r(t)$ represents the request value in the system, which here is labeled the reference value. The time-based variable $y(t)$ represents the output value in the system. And the variable $e(t)$ is a difference between input and output variables, that is, $e(t)=r(t)-y(t)$, which is noted the *error* term in the Figure 3.1.



(a) time-domain



(b) s-domain

Figure 3.2: Abstract Concept of Feedback Control System

Apart from the limited and randomly varying bandwidth resource in wireless networks, mobility causes difficulties such as variable bit error rate, possibility of asymmetric connectivity, and fluctuating transmission quality [23]. Therefore, wireless networks have less stable state connections than fixed networks. Wireless networks can be viewed a dynamic system inhabiting on a continuously changing environment over time. This research defines the wireless network system model as the function $f(t)$, which is a time-domain function. Furthermore, the related s-domain function is defined as $F(s)$. In the feedback control theory, the Laplace transform technique is generally applied to transfer the time-domain function into the s-domain function. The operation mainly simplifies the complicated the time-domain system calculation [19]. The Laplace transform equation must be used to simplify the calculation process, as follows:

$$F(s) = \pounds[f(t)] = \int_0^\infty f(t) \cdot e^{-st} dt \tag{3.1}$$

In an unexpected situation in a wireless network or other systems, the performance deviation quantity must be adjusted correctly by the feedback control in order to toward the system goal. If we have an over control behavior, the result should make the system goal be unstable, even insufficient revision makes the systematic efficiency become low. Therefore, good controller design leads to efficient bandwidth resource usage, and can even quickly stabilize the system.

3.2 Time Response Analysis of Feedback Control System

In feedback control system, one of the most important will consider the systematic error. It is good that the error is the less. Because some control systems are based on time domain, the time responds is the essential issue on computing system. In the control theory, the system output consists of transient response and steady-state response. Let $y(t)$, $y_t(t)$ and $y_{ss}(t)$ represent time response, transient response, and steady-state response, respectively. The relationship about three terms is: $y(t) = y_t(t) + y_{ss}(t)$.

◈ *Transient Response*:

(1) The transient response means the system output may converge to zero as the time change, that is,

$$\lim_{t \to \infty} y_t(t) = 0 \qquad (3.2)$$

(2) The performance specification that the transient response is divided into the time of rising, postponed time, peek time, overshoot, and steady state time. It is influenced that the performance specification will suffer the systematic constrains, such as: pole point position, zero point position, and initial value of the component. The performance specification is showed in Figure 3.3.

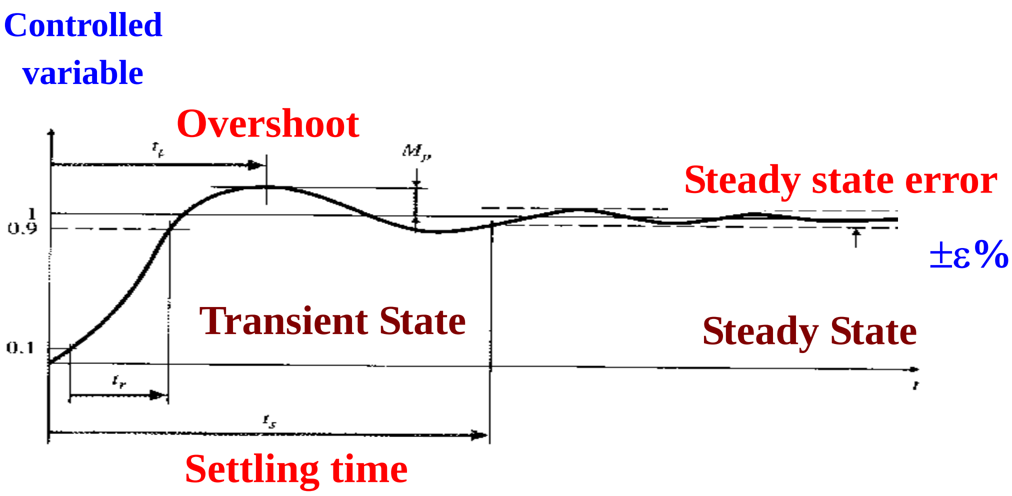


Figure 3.3: Performance Specification of the Transient Response

Specifications for a control system design often involve certain requirements associated with the time response of the system. The requirements for a step response are expressed in terms of the standard quantities illustrated in Fig. 3.3:

- The rise time (t_r) is the time it takes the system to reach the vicinity of its new set point.
- The settling time (t_s) is the time it takes the system transients to decay.
- The overshoot (M_p) is the maximum amount the system overshoots its final value divided by its final value (and often expressed as a percentage).
- The peak time (t_p) is the time it takes the system to reach the maximum overshoot point.

◈ *Steady-State Response*:

(1) In the system time responds, the remaining part after the time exclusive of transient response time. In Figure 3.4 shows the steady-state error response. That is,

$$y_{ss}(t) = \lim_{t \to \infty} y(t) \neq 0 \qquad (3.3)$$

and $$y_t(t) = y(t) - y_{ss}(t) \qquad (3.4)$$

(2) The performance specification that the steady-state response is stable degree and accuracy in the control system. The performance specification is relative with the pole position and system types.

(3) If steady-state response that system output is not in conformity with input steady-state part, namely the system possess of steady-state errors.

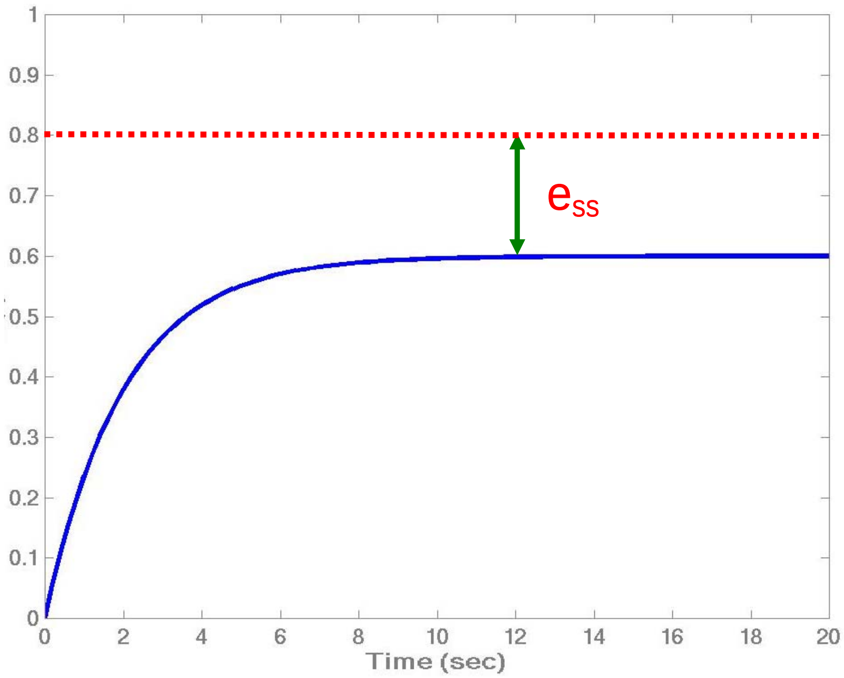


Figure 3.4: Steady State Error Response

3.3 Various Controllers of Feedback Control System

In the feedback control system, the controllers output determines the plant output performance. Under optimized condition, one controller must be designed to reach the system goal. The controller type may be Proportional (P), Integral (I), or Derivative (D), or may be a combination of any of these three types. The purpose of using the controller is that system utilizes *error* term (see Fig. 3.1) signal information to regulate the systematic response. It generally uses method such as enlarge or reduce the error, accumulates the error, and the variation tendency of considering the error.

Subsequently, we will define the *Transfer Function* term. In Figure 3.5 represents a block diagram of simple system. An immediate consequence of convolution is that an input of the form $R(s)$ results in an output $T(s)\bullet R(s)$. We can define Transfer Function is: the ratio of system input and system output by Laplace transform [19]. For example, Figure 3.5 shows the open-loop system input is $R(s)$, and the system output is $Y(s)$.

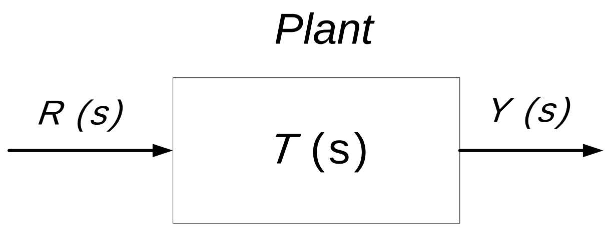


Figure 3.5: Block Diagram of Simple System

We can get the equation (3.5) from input and output information, $T(s)$ is the transfer function of the open-loop system.

$$\frac{Y(s)}{R(s)} = T(s) \qquad (3.5)$$

Therefore, we also show the transfer function $T(s)$ of the closed-loop system (Fig. 3.6) as following equation (3.6).

$$\frac{Y(s)}{R(s)} = \frac{G_C(s) \cdot G_P(s)}{1 + G_C(s) \cdot G_P(s)} = T(s) \tag{3.6}$$

The transfer function in the control system possessed the natures listing as following:

- It does only suit the Linear Time-Invariant (LTI) system.
- It represents the systematic behavior, is not related to the input reference.
- In the condition that zero is initial (make all initial value of the system equal to zero).
- System transformation function = (output response) / (input reference).

And then, we introduce the various controllers of feedback control system as following.

(1) Proportional Controller

The Proportional Controller can be abbreviated as *P* Controller. As gain unit is possessed of a constant ratio relationship between the input signals and output signals, this kind of control system is called the proportion gain (i.e., *P* controller). The system function is $G_c(s) = K_p$ in the proportion gain module. For example, Fig. 3.6 shows the input *R*(*s*), output *Y*(*s*), and *error* term is *E*(*s*).

Generally, by changing the gained level, the system can adjust the relatively stability and steady-state error (i.e., e_{ss}). Owing to characteristic of the *P* controller, unable to make the steady-state error reach goal value all the time (i.e., $e_{ss} = 0$). If enlarge the proportional constant, it makes improve the system gain. This condition also makes short its ascending time, and the response speed becomes fast. The type controller is unable to destroy the system steady-state error, and will usually cause relative stability to worse. Therefore, it must generally join other compensators together.

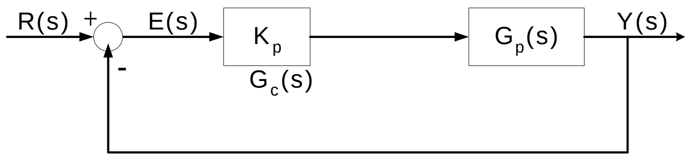


Figure 3.6: Control System with Proportional Controller

(2) Proportional-Integral Controller

The Proportional-Integral Controller can be abbreviated as *PI* Controller. As the control system joins Integral controller, it can increase system type. From the time domain consider, the controller can accumulate the response error. This situation to the system react is not obvious in initial stage, but can improve or destroy steady-state error e_{ss} under the error is accumulated, even can improve accuracy. But it has not obvious function to the transient response. We can use the Proportional-Integral Controller module (PI controller) to reach the goal of steady-state error e_{ss} = 0. The system function is $G_c(s)$ = $K_p + \frac{K_I}{S}$ in the Proportional-Integral gain module. For example, Fig. 3.7 shows the input $R(s)$, output $Y(s)$, and *error* term is $E(s)$.

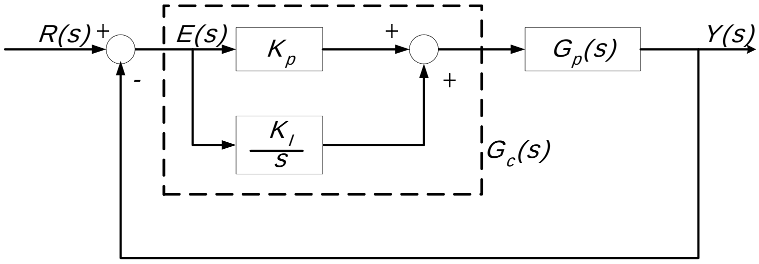


Figure 3.7: Control System with Proportional-Integral Controller

(3) Proportional-Integral-Derivation Controller

The Proportional-Integral-Derivation Controller can be abbreviated as *PID* Controller. Just as what was stated in *PI* controller characteristic, *PI* controller can usually cause transient response to worse, and react time to relatively long (namely settling time will become longer). To utilize the *PID* Controller will improve the system damping property and transient response. This type controller can offer the well steady-state error, and system react time will change quickly also.

Using the *PID* Controller that can obtain the following two advantages:

① Put *PID* controller to original control system, such that add one Pole point (this will make the system type increase and reduce the steady-state error to zero) and add two zero points on left side of *s* plane.

② The Integral technology can improve the steady-state error, but the Derivation technology can improve transient response behavior. However, PID controller is the association of *PI* controller and *PD* controller. Consequently, this type controller can improve the system transient response behavior, at the same time, and also improve the system steady- state error.

This type system function is $G_c(s) = K_P + \frac{K_I}{s} + K_D s$. For example, Fig. 3.8 shows the input *R*(*s*), output *Y*(*s*), and *error* term is *E*(*s*).

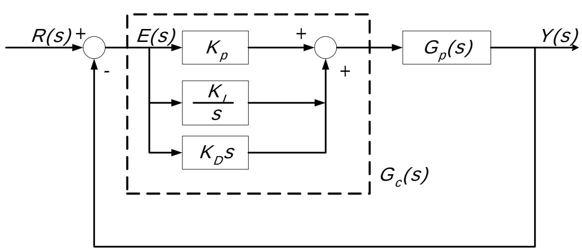


Figure 3.8: Control System with PID Controller

As follows to take into consideration in unit-step function feedback system (namely $R(s) = 1 / s$ or $r(t) = 1$), to specify and analysis the three kinds of controller modules, respectively. While K_P value is larger under P controller module, then the system can get the steady state error (i.e. e_{ss}) more approach to zero, but never equal to zero. While K_I, K_P values are larger under PI controller module, then the system can get the e_{ss} may equal to zero. While under PI controller module, the system can also get the e_{ss} may equal to zero.

In the Fig. 3.9, according to feedback control technology we can find the different characteristic between P controller, PI controller, and PID controller, such as steady-state error (e_{ss}), overshoot (M_p), settling time (t_s).

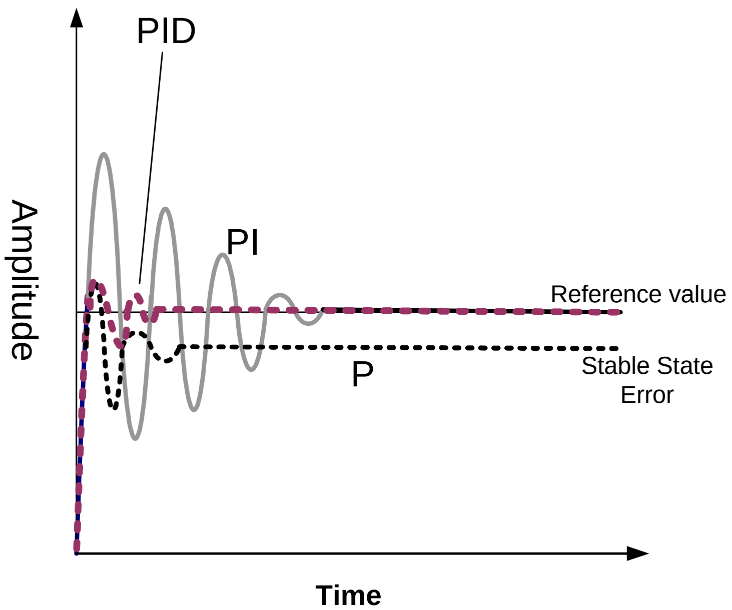


Figure 3.9: Responses of P, PI, and PID Control to Step Reference Input

If the controller does not use a measure of the system output being controlled in computing the control action to take, the system called open-loop control. If the controlled output signal is measured and fed back for use in the control computation, the system is called closed-loop or feedback control [19].

One advantage of the feedback control is that it causes the system to display self-correcting, self-stabilizing behavior on the unpredictable time-invariant system. Furthermore, the robustness of the feedback controllers may help end-users (or STAs) to obtain dynamic QoS requirements in the wireless network.

Enough to utilize and control wireless network environment, and take dynamic scheduling the wireless resources, in order to assure real-time traffic reach QoS expected to require. The following succeedingly Chapter 4 and Chapter 5 will discuss the open-loop scheduling and closed-loop scheduling for QoS guarantee in the wireless network, respectively.

Chapter 4
Open-Loop Scheduling for QoS Guarantee

In the subsection 2.2.2, we have described that 802.11e specification is the appending QoS function to 802.11 standard. The 802.11e specification is concerned about the network traffic quality of requirement; it can provide more effective QoS guarantees than 802.11 or 802.11b. However, EDCA coordination function parameters cannot be adapted to the network conditions, since it still can not guarantee the traffic for end-to-end QoS requirement. 802.11e specification utilizes the AIFS technology to assure the high priority traffic can access the radio channel prior to other. But this rough scheme may not realize the instantaneously network condition, it can not reach the optimal throughput [30]. We will consider another view about the QoS issue of wireless network application. In the dissertation we proposed a novel QoS guarantee technology, open-loop scheduling module (named λ WFQ scheme), for wireless network application.

Various WFQ-based algorithms developed from the error-free service model, the lead/lag model, the compensation model and slot/packet queue decoupling, have been proposed for adapting fair queuing to the wireless domain [11,44-46]. The error-free service model provides a reference for how much service a flow should receive in an ideal error-free channel environment. The lagging/leading flow denotes the amount of additional service that must be added/relinquished by the flow in the future to compensate for additional services received in the past. Moreover, the compensation model determines how lagging flows make up their lag and how leading flows give up their lead resource amount. In slot/packet queue decoupling, when a packet arrives in a flow queue, a corresponding slot is generated in the slot queue of the flow and tagged using a fair queuing algorithm.

This research proposes a novel scheduling discipline from the perspective of service providers, which achieves maximum acceptance by all wireless users to assist the WFQ in resource scheduling. Open-loop scheduling module is based on the characteristic of traffic, developed a λWFQ scheme which is responsible for the traffic transmission scheduling. Then traffic packet is according to the scheduling deliver to wireless communication network. Because of the interference in the wireless network, air interface among the end-user and AP will produce a lot of questions. The transmission error may result from the interference immediately. For the location-dependent errors, the open-loop resource scheduling scheme requires determining extra resources allocate to high-error wireless STAs, such that their QoS is supported.

In the following section 4.1 surveys the performances of IEEE 802.11, and investigates various types of WFQ mechanisms are applied in the wireless network. In section 4.2 then proposes the concept of user acceptance index and λWFQ discipline, which are fundamental algorithm for the open-loop scheduling scheme. In section 4.3 describes an algorithm for location-dependent error compensation for wireless networks.

4.1 Related Works

Because of rapid advances in wireless network technology recently, there have been a numerous researches in providing required bandwidth for the wireless network applications. With the explosive demand on wireless communications and the emergence of bandwidth-intensive multimedia applications, these applications require some form of performance assurances such as guarantees on timeline, availability, bandwidth, or jitter. From this view, QoS provisioning in wireless multimedia networks is becoming a more and more important issue.

QoS guarantees are not easily implemented in wireless networks because wireless channels have unique problems, such as location-dependent errors and fading, etc. Several works have thoroughly investigated this topic, covering for example Weight Fair Queue (WFQ), Idealized Wireless Fair Queuing (IWFQ), Channel-Condition Independent Packet Fair Queuing (CIF-Q), and the Server-Base Fair Approach (SBFA). These strategies can be applied to the wireless network environment, which suffers location-dependent error, but they all serve different requests; some emphasize equality, some ensure high efficiency and some emphasize the smoothness of operation. The following subsections describe these strategies, respectively.

4.1.1 DCF and EDCA based Scheme

The authors in [47] analyze the performance of the IEEE 802.11 DCF in the saturated traffic network condition, and consider the effects of packets size, the number of contention nodes, transmission collision probability and channel conditions. They further evaluate the system performance of the IEEE 802.11 DCF in ideal and error-prone channel condition. From their analysis found that: (1) IEEE 802.11 with RTS/CTS scheme performs better than naive CSMA/CA scheme under both the ideal channel and the error-prone channel, because short packets RTS/CTS reduce the collision cost. (2) The packet error can affect the throughput and delay. The throughput decreases and the delay increases with error network conditions; and the larger the error probability is, the worse is the performance degradation of the IEEE 802.11 DCF. (3) There exists an optimal packet length which maximizes the throughput under a given channel condition. The optimal packet sizes approximate 300 bytes from the simulation result. However, the study in [47] lacks to consider QoS scheme for traffic stream priority. It does not obtain the guaranteed QoS services liken to IEEE 802.11e function.

In [31], the authors represent both the network-level and application-level performance results based on comparing with wireless 802.11 DCF and 802.11e EDCA. The network-level QoS index metric is traced by throughput and end-to-end delay measurement. The application-level QoS index metric is traced by Peak Signal to Noise Ratio (PSNR) measurement. To evaluate performance with application-level metrics, real video and voices files in ns-2 simulation were used. However, there are some necessary processes before starting the simulation. Firstly, the raw video YUV file needs to encode using the H.264 encoder, which generates an H.264 bit-stream file. The audio exchange finally needs to be done to convert to G.729 codec. The encoded bit-stream file is generated by a G.729 encoder and packeted by the packetizer. Their simulation results show that the QoS wireless 802.11e mechanism performs better compared to the wireless 802.11 from their simulation scenario using ns-2 simulator.

However, in wireless network environment always suffers from surrounding conditions to interference system. In [31] performance evaluation is under the perfect channel conditions, there is not considered the existing error-prone air interface.

Actually, wireless link is error-prone essentially due to the variation in signal strength of wireless channel [47].

4.1.2 WFQ (Weighted Fair Queuing) Scheduling Discipline

Under no additional bandwidth environment is available for wireless multimedia application services, a simple strategy is the WFQ scheme, to provide resource scheduling [48]. Resource scheduling is a data queuing algorithm, designed to achieve the following. (1) The use the traffic characteristic to schedule the queuing data to reduce the delay. (2) The fair sharing of residual resources for data with a higher QoS requirement (Fig. 4.1).

WFQ strategy can assure that each queue for the bandwidth requirement is scheduled not to cause infinitely wait the services time [49]. Because WFQ differs from round robin in that each class may receive a *differential* amount of service in any interval of time. Even it can make communication traffic to get the more rational quality of service guarantee. Therefore, the sensitive delay class packet will assign to a higher weight queue, the higher priority queues yield lowest delay, delay jitter, and highest bandwidth.

The fair queuing algorithm, WFQ, is a scheduling and multiplexing discipline that can provide end-to-end delay and bandwidth guarantees on a per flow basis. WFQ works by simulating an idealized fluid flow system and serving packets according to their transmission times in the idealized fluid system. The WFQ scheduler distributes air resources according to the weights provided by a call scheduling module in a wireless service environment.

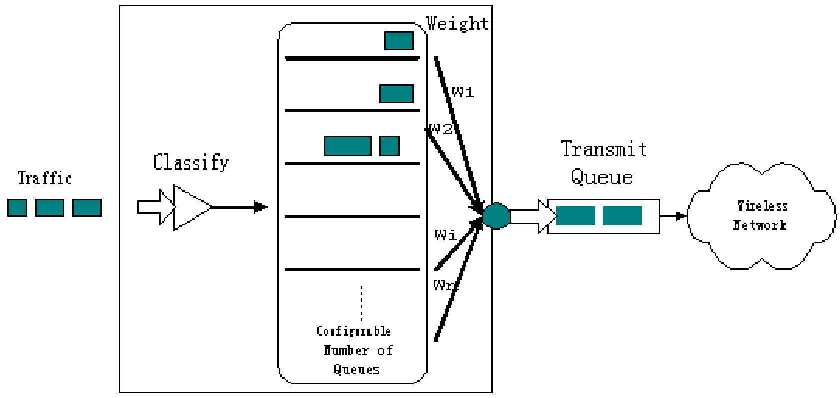


Figure 4.1: WFQ Scheduling Mechanism

4.1.3 IWFQ (Idealized Wireless Fair Queuing) Scheduling Discipline

Idealized Wireless Fair Queuing (IWFQ) is a kind of ideal wireless network scheduling algorithm [50]. It can take to try best throughput and equivalence depends on the difference amount of received different services flow. By the exchanged the bad slots of one flow is caused by interference with good slots of other flow. In IWFQ system, a received service flow will be compared with an error-free system, and there is one queue is arranged to each flow. If all packet links have not encountered any interference errors, its operation is like ordinary WFQ scheme. Once one link occurs the error, the package chosen to deliver fails to transmit because of linking error, result in other packages will be had priority to deliver. The following Fig. 4.2 shows the operation outline of this kind of mechanism.

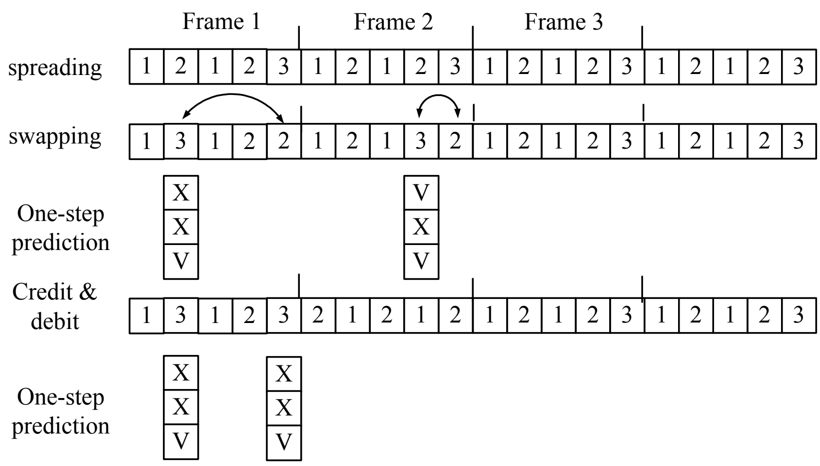


Figure 4.2: IWFQ Schedule Operating Scenario

4.1.4 C-IFQ (Channel-condition Independent Packet Fair Queuing)

C-IFQ is very similar to IWFQ in the sense that it also uses an error-free fair queuing reference system and tries to approximate the real service to the ideal error-free system [51]. In order to calculate one session the lost served quantity because of the link errors, a reference system which without error-free must be compared with real system. Every session is compared with imaginary time, to express this session should receive the quantity served to the reference system. C-IFQ serves the packet which has minimum imaginary time and be delivering service session. If this session does not lead, or although it leads and does not exceed a threshold value, the front package in the session queue will have priority to be transmitted. The main objective of CIF-Q is to address the fairness issue; therefore, link error detection, estimation, and implementation issues are not discussed.

The paramount advantage of CIF-Q is its well properties in long-term, short-term and limited delay fairness guarantees.

4.1.5 SBFA (Server-Based Fairness Approach) Scheduling Discipline

SBFA scheduling scheme except maintains two queues for each flow, Packet Queue (PQ) and Slot Queue (SQ), it adds the wireless bandwidth compensation server [52]. In the system called the bandwidth compensation server is Long-Term Fairness Server (LTFS). The LTFS maintains a part of bandwidth resource in a wireless system, the part bandwidth for compensation a flow whose packet transmissions are deferred because of link errors, and it shares the wireless channel with other regular data flows. In the scheme, LTFS server compensates the delay flow, the bandwidth is reserved in the system, other than by exchanging dynamically the slots between the lagged flow and leaded flow. Therefore, while a flow packet transmission is deferred because of link errors, the slot data will be transferred to LTFS. The structure of SBFA is simple and provides throughput guarantees. The LTFS as same as other queues, it may parallel deliver the flow data.

However, SBFA scheme has several drawbacks. Apparently, LTFS needs extra allocate bandwidth for the link error flow. And the algorithm does not work well if the packet size of a flow is variable. Figure 4.3 shows the operation scenario of SBFA scheme.

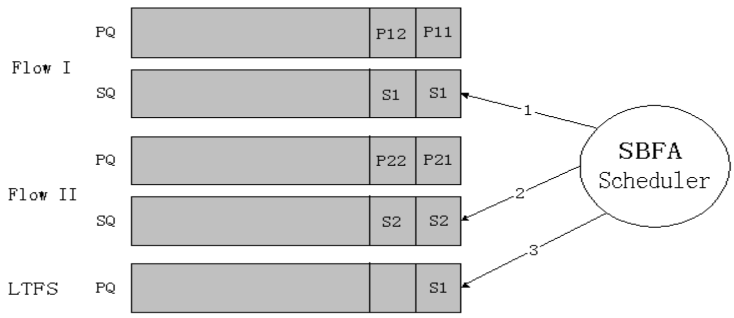


Figure 4.3: SBFA Scheduling Operation Scenario

4.2 Proposed Open-loop Scheduling Discipline

In this section we have newly proposed a fairness scheme, the λ WFQ mechanism and an extension of the WFQ scheme, which involves optimization theory and LaGrange λ-calculus is proposed for scheduling resources in wireless network services with QoS provisioning.

Open-loop scheduling primarily concerns designing a schedule discipline to support wireless communication services with steady-state QoS requirements. In Fig. 4.4, a λ WFQ scheme was developed involving the WFQ mechanism and LaGrange λ–calculus [49,53]. The air resources are allocated using λ–calculus, and the WFQ mechanism is then responsible for transmission scheduling. λ WFQ discipline employs the equivalent efficiency concept to compensate for the location-dependent error-related penalties. The schedule can generate a fair and optimal QoS schedule for a diverse mix of traffic in a limited radio bandwidth.

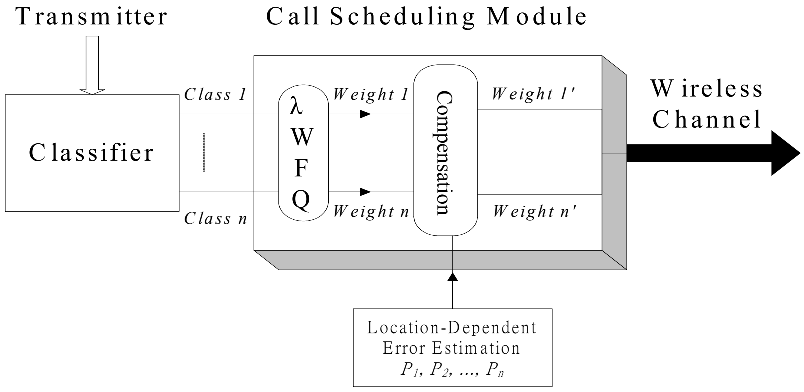


Figure 4.4: Open-loop Scheduling Architecture

4.2.1 User Acceptance Indication

A user's acceptance indication (or satisfaction indication) can represent his traffic QoS requirement level. Intuitively, the fact that the system can gain a higher total AI value implies that it possess a higher QoS level. The wireless services yield the reserved resources scheduled by the lambda WFQ scheme.

This study proposes a fairness scheme, which is a λ WFQ mechanism involving the LaGrange λ -calculus, for scheduling resources in wireless services with QoS provisioning. The scheduling issue can be identified using the following function and constraints.

- Objective function

  $\mathrm{Max}(AI_T), \quad AI_T = AI_1 + AI_2 + AI_3 + \ldots + AI_n$ (4.1)

  for n service requests

- Subject to

(1) $\sum_{j=1}^{n} C_{j,\,Allocate} \le C \Rightarrow \phi \cong 0 \le C - \sum_{j=1}^{n} C_{j,\,Allocate}$ (4.2)

(2) $C_{i,\,Min} \le C_{i,\,Allocate} \le C_{i,\,Max} \quad i=1,2,\ldots,n$ (4.3)

where

AI_i : acceptance indication of the *i*th service

C: total capacity in the system

$C_{i,\,Min}$: minimum required capacity at a request for the *i*th service

$C_{i,\,Max}$: maximum required capacity at a request for the *i*th service

$C_{i,\,Allocate}$: allocated capacity at a request for the *i*th service

Resource scheduling is a constrained optimization problem that can be approached formally using advanced calculus methods that involve the LaGrange λ-calculus. To establish the necessary conditions for an extreme AI_T value, the constraint function is added to the AI_T after $\varnothing$ is multiplied by a multiplier, λ.

$$\zeta = AI_{\mathrm{T}} + \lambda \varnothing \qquad (4.4)$$

The necessary conditions for an extreme AI_{T} value occur when the first derivative of the λ-calculus is calculated with respect to each of the independent values and the derivatives are set to zero. In the wireless application domain, the derivatives of the λ-calculus with respect to the $C_{i,Allocate}$ values at a given scheduling time is used to establish the set of equations as following,

$$\frac{\partial \zeta}{\partial C_{i,\,Allocate}} = \frac{\partial AI_i}{\partial C_{i,\,Allocate}} - \lambda = 0 \qquad i=1,2,\ldots,n \qquad (4.5)$$

$$\lambda = \frac{\partial AI_1}{\partial C_{1,\,Allocate}} = \frac{\partial AI_2}{\partial C_{2,\,Allocate}} = \cdots \qquad (4.6)$$

The necessary condition for the existence of a maximum AI_{T} for wireless services is that the incremental *AI* of all the users equal λ. This necessary condition must be added to the constraint equation and the sum of the $C_{i,Allocate}$ values must be less than or equal to C. Figure 4.5 illustrates the operating flow chart. The operating scenarios are described as follows.

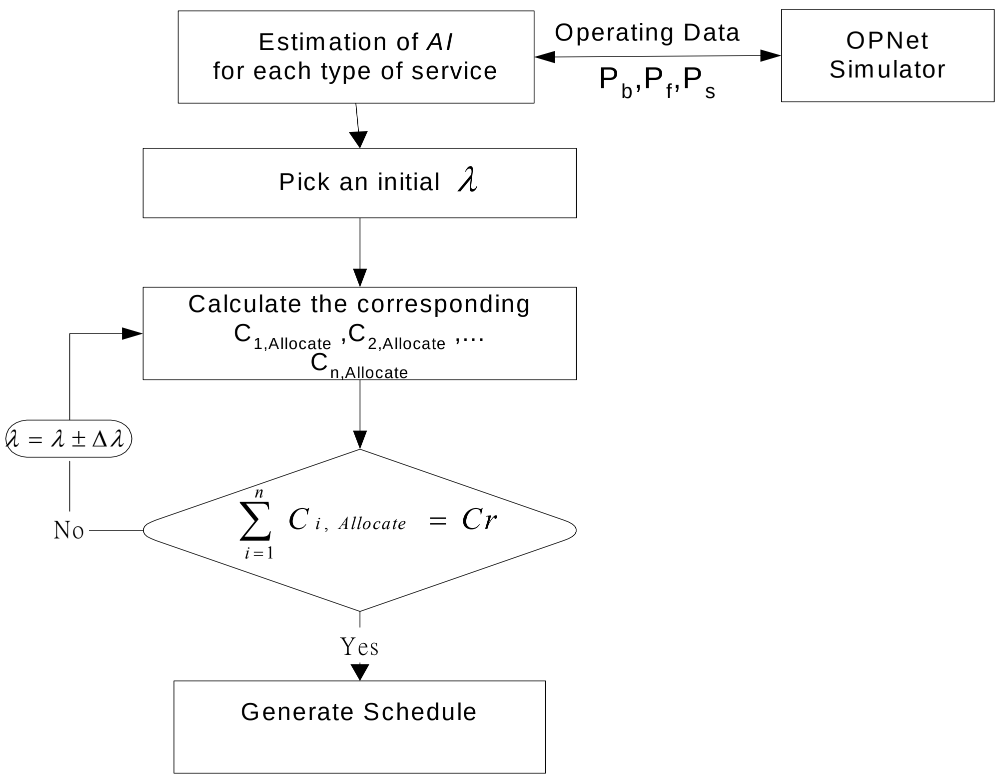


Figure 4.5: Flow Chart of λ-calculus

4.2.2 λ WFQ Scheduling Discipline

The λ WFQ scheduling discipline is composed of the following three steps.

(1) Estimation of AI for each type of service

Many treatments are performed using an OpNet Simulator or an *ns2* Simulator, according to the variation of $C_{i,Allocate}$, so a set of AI values may be estimated for the specified service class. To employ the curve fitting technique, so the AI function for each service class may be treated in the linear or quadratic rate case (Eq. 4.7). Where *a*, *b*, *c* are constants.

$$AI_i = a_i + b_i \cdot C_{i,Allocate} + c_i \cdot C_{i,Allocate}^2 + \cdots \qquad (4.7)$$

(2) λ -calculus process

In step (1), two types of services are assumed; their incremental AI values are represented by the following equations.

$$\frac{dAI_1}{dC_{1,\ Allocate}} = 2c_1\ C_{1,\ Allocate} + b_1 = \lambda \qquad (4.8)$$

$$\frac{dAI_2}{dC_{2,\ Allocate}} = 2c_2\ C_{2,\ Allocate} + b_2 = \lambda \qquad (4.9)$$

$$C_r = min\{C, C_{1,Max}+C_{2,Max}\} \qquad (4.10)$$

Therefore, $C_{1,Allocate}$ and $C_{2,Allocate}$ may be estimated for a specific λ value.

(3) Schedule generation

The iterative process of identifying the λ value was stopped when $\sum_{i=1}^{n} C_{i,\ Alloacte} = Cr$.

Two cases are discussed in the generating schedule.

Case 1: $C_r = (C_{1,Max}+C_{2,Max})$, thus

$C_{1,Allocate} = C_{1,Max}$

$C_{2,Allocate} = C_{2,Max}$

Case 2: $C_r = C$, so the inequality constraints are recognized, and the necessary conditions can then be expressed by the following set of equations;

$$\frac{dAI_i}{dC_{i,\,Allocate}} = \lambda \qquad \text{for} \quad C_{i,Min} < C_{i,Allocate} < C_{i,Max}$$

$$\frac{dAI_i}{dC_{i,\,Allocate}} \le \lambda \qquad \text{for} \quad C_{i,Allocate} = C_{i,Max}$$

$$\frac{dAI_i}{dC_{i,\,Allocate}} \ge \lambda \qquad \text{for } C_{i,Allocate} = C_{i,Min} \text{ or } 0 \quad \text{(Blocked)}$$

From Fig. 4.6, three situations are identified.

Situation I: $\lambda = \lambda_2$ or λ_3 , both $C_{1,Allocate}$ and $C_{2,Allocate}$ fall into the range $\{C_{i,Min}, C_{i,Max}\}$

Situation II: $\lambda = \lambda_1$, $C_{1,Allocate}$ is either $C_{i,Min}$ or 0 (blocked) because $\frac{dAI_1}{dC_{1,\,Allocate}} \ge \lambda_1$

Situation III: $\lambda = \lambda_4$, $C_{2,Allocate}$ equals $C_{2,Max}$ because $\frac{dAI_2}{dC_{2,\,Allocate}} \le \lambda_4$

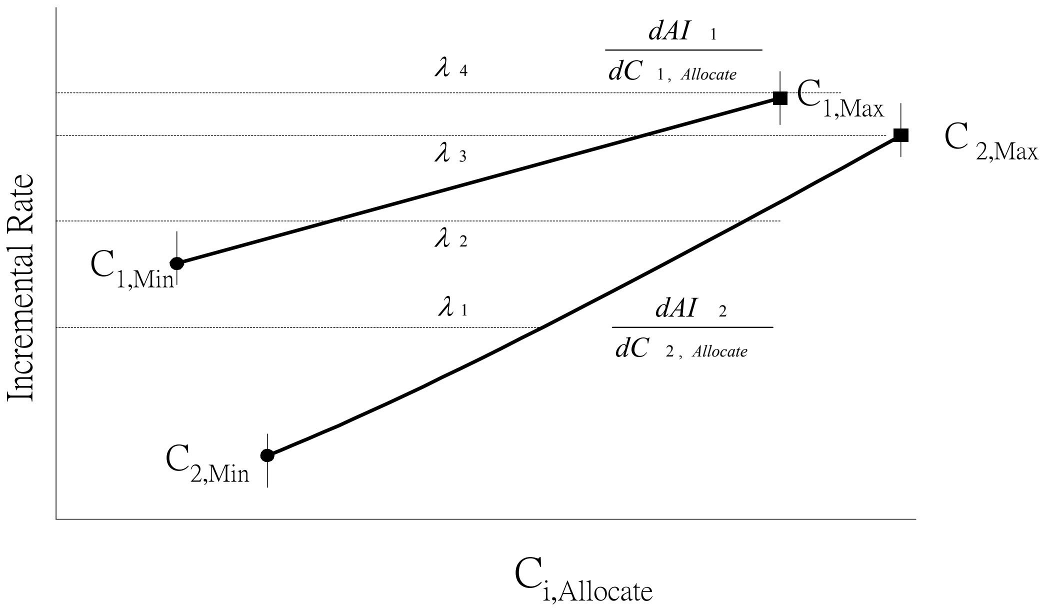


Figure 4.6: Incremental Rates with Constraints

4. 3 Location-dependent Error

The λ-WFQ scheduling discipline extends the WFQ algorithm by using dynamic weight adjustments to compensate for the penalty derived from location-dependent errors and improved service quality. The weight values are tuned according to equivalent efficiency. The compensation scenarios are described as follows.

(1) *Error-Free Environment*

Mobile wireless services are invoked in an error-free environment. That is, these services actually obtain the reserved resources scheduled by the λ-WFQ scheme.

(2) *Location-Dependent Error Environment*

Supporting QoS guarantees for multimedia services in service networks with location-dependent errors requires determining extra resources allocate to high-error mobile units, such that their QoS is supported.

The air interfaces create various interference-related problems for mobile units and BTSs. The interference instantaneously invokes data transmission errors. This study proposes an equivalent efficiency concept to achieve high AI. The real-time traffic and other guaranteed QoS services are well known to have a higher priority than the best-effort services. More resources may be added for the real-time and other guaranteed QoS services by subtracting the best-effort traffic resources. Figure 4.7 presents this algorithm for location-dependent error compensation. In other words, the amount of the compensating resources for the traffic with higher guarantee QoS is the mean amount that can be from the other traffics. The algorithm defines a penalty factor $\Im$ to compensate for the effect of location error.

$$\Im = \frac{n}{\frac{1}{1-P_1} + \frac{1}{1-P_2} + \ldots \frac{1}{1-P_n}} \tag{4.11}$$

where P_1, P_2, …, P_n represent the location error probabilities of the 1*st*, 2*nd*, …, and n*th* services.

On error estimating: /*estimate error rate for each service*/

for $\forall i \in \{1,2,3,\ldots,n\}$, $P_i = error\_calculor(i)$

on deciding weight: /*find the weight for each service*/

$\Im = n / \sum_{i \in B} \frac{1}{1-P_i}$; /*decide the penalty factor*/

$weight\_i' = weight\_i * \Im * 1/(1-P_i)$;

on allocating resource: /*allocate resource to each service*/

$R_{res-i} = B * weight\_i'$

if $R_{res-i} < Qos_i$

$add\_R_{res-i} = Qos_i - R_{res-i}$;

$R_{res-j} = R_{res-j} - \frac{R_{res-j}}{\sum_{j \in best\_effort} R_{res-j}} * \sum_{i \in Qos\_guaranteed} add\_R_{res-i}$;

else

do nothing;

on adjusting weight: /*adjust weight of each service*/

if $B * weight\_i' < Qos_i$

for $\forall i \in Qos\_guaranteed$, $weight\_i' = Qos_i / C$;

for $\forall j \in best\_effort$, $weight\_j' = R_{res-j} / C$;

else

for $\forall i \in \{1,2,3,\ldots,n\}$, $weight\_i = weight\_i'$;

Figure 4.7: Algorithm for Location-dependent Error Compensation

Chapter 5
Closed-Loop Scheduling for QoS Guarantee

In the network communication system, traffic data amounts dynamically change over time domain. The feedback control mechanism always is applied to network flow control services [48,53-59]. In Fig. 5.1 shows the mechanism model which uses a Closed-loop control method for a controlled network. While a network systematic output value *y* does not reach reference *r*, namely *Unstable* state, the sender will receive a feedback control message from sensor component. The message may trigger sender to adopt the proper compensation behavior in order to reach anticipated performance value *r*. The Fig. 5.2 shows the feedback control loop on stable and unstable state based on time domain.

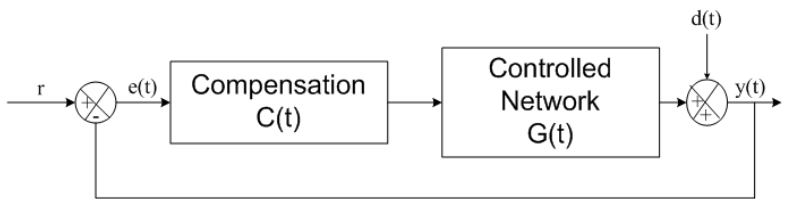


Figure 5.1: Closed-loop Control Model

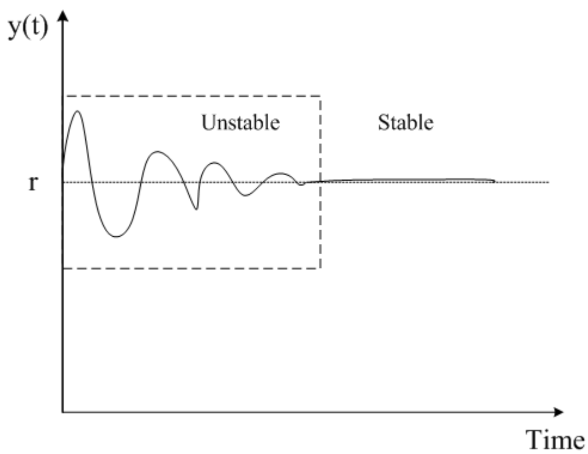


Figure 5.2: Feedback Control Loop States

In the thesis, the proposed feedback control scheme to solve the dynamic QoS requirement on the unpredicted time-variant system for wireless LAN multimedia services. This topic is a fresh application issue. Recently, there are many researchers and academics focus on this topic, such as Virginia [60], Michigan [61], Berkeley [54] and so on. Those related works will be described as the following section.

5.1 Related Works

To introduce some related investigative works based on feedback control technology application as following.

5.1.1 Feedback Control Real-time Scheduling (FCS) Scheme

In [60] the author applied feedback control technology to real-time CPU resource scheduling. In Fig. 5.3 shows Chenyang Lu proposed the FCS scheme, which scheme consists of Monitor, Controller, QoS Actuator, and Basic Scheduler. The function of every component is described as following.

- ◈ *Monitor*: the component is responsible for measuring the parameter values (ex. miss ratio and utilization). And it delivers the measure information to the Controller unit.
- ◈ *Controller*: the component compares the reference value with the measure data, to define the performance difference (ex. error). This component can adjust the input parameter based on the difference, and then it calculates the approximately optimal reference by the control function.

◈ *QoS Actuator*: the component dynamically adjusts the QoS scheduling, and adjusts the QoS parameters based on control input data.

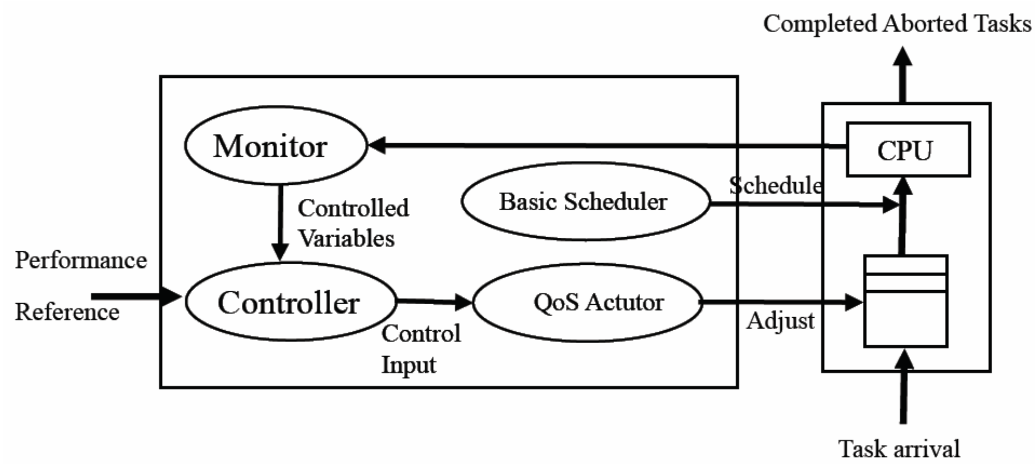
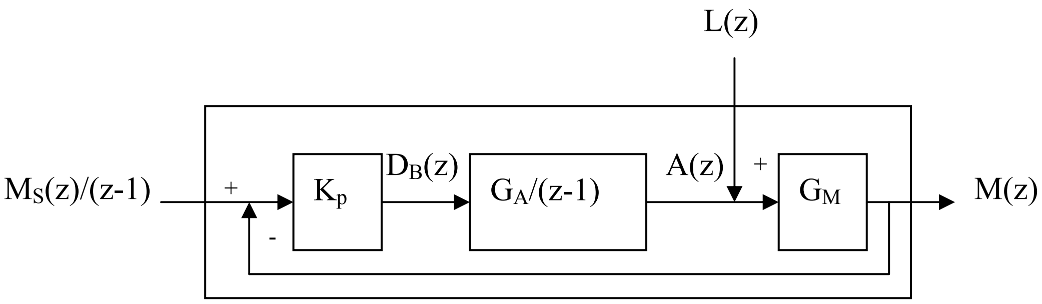
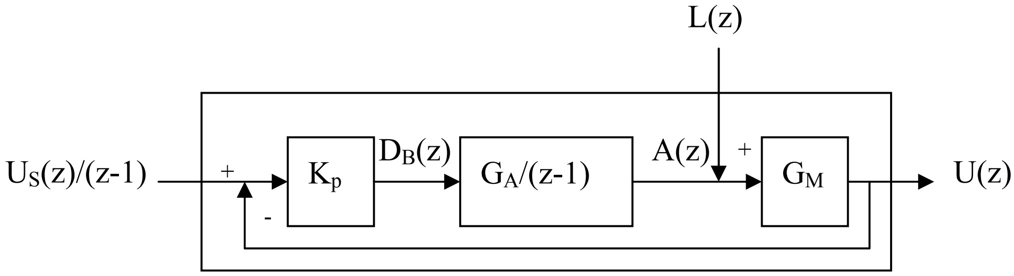


Figure 5.3: FCS Scheduling Architecture

The output data of FCS scheduling system are Miss ratio M(z) and Utilization U(z), while $M_S(z)$, $U_S(z)$ are input data of the system, and L(z) is system interference parameter. The controller block diagram shows in Fig. 5.4. While the Monitor module measures the parameters M(z), U(z), and then delivers the measure information to the Controller. Controller component compares the reference value with the measure data, to define the performance difference. After adjust procedure, then generate the $D_B(z)$ into QoS Actuator. The system can repeat the control loop procedure until the CPU can get the high performance.



(a) Miss Ratio Control



(b) Utilization Control

Figure 5.4: Feedback Control Loops Module Operation

5.1.2 Michigan University Proposed Feedback Control on Transport Control

In Fig. 5.5 shows that system architecture of Michigan university researcher proposed feedback control applied to transport control for wireless network [61]. The block functions in Fig. 5.5 described as follows.

- ◈ From Fig. 5.5 Block 1 has four input parameters, such as external interference (i.e. h(k)), path loss (i.e. ρ(k)), channel interference (i.e. N(k)), and feedback information (i.e. E(k)). And then the Block 1 function calculates the signal power by the following formula equation.

$$r(k) = F_{1(E(k),\ h(k),\ \rho(k),\ N(k))} = \frac{h(k)\rho(k)E(k)}{mnN(k)} \tag{5.1}$$

- ◈ Block 2 has two input parameters, such as the signal power (i.e. r(k)) from Block 1, and γ (k). And then the Block 2 function calculates the bit error probability (i.e. P_{be}(k)) by the following formula equation.

$$P_{be}(k) = F_2(r(k), \gamma(k)) = \frac{1+\gamma^2(k)}{1+\gamma^2(k)(2+r(k))} e^{-\frac{\gamma(k)}{1+\gamma^2(k)(2+r(k))}} \quad (5.2)$$

◈ Block 3 has two input parameters: one is from Block 2, namely P_{be}(k), and the other data rate, namely q(k), is from Feed-forward rate controller Block. And then the Block 3 function calculates the successful transmission probability (i.e. P_{st}(k)). To adjust successively q(k) makes improve the system efficiency P_{st}(k).

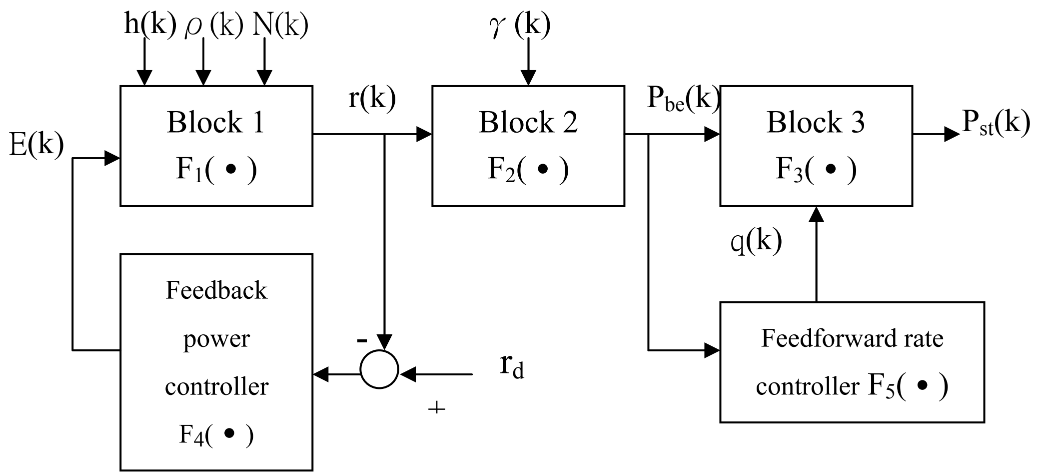


Figure 5.5: Feedback and Feed-forward Rate Control

5.1.3 Xiaoxiang Lu Proposed the Feedback Control on Video Application

In Fig. 5.6 reveals a point-to-point based video application system, which employ Feedback control to ensure the smoothly display video [62]. To reduce the transmission rate while the network occurs congestion condition, just only at least reach tolerate data rate. That adjustment situation will relieve the network congestion.

The system will recover the normal traffic data rate requirement until the network congestion condition disappeared or relieved.

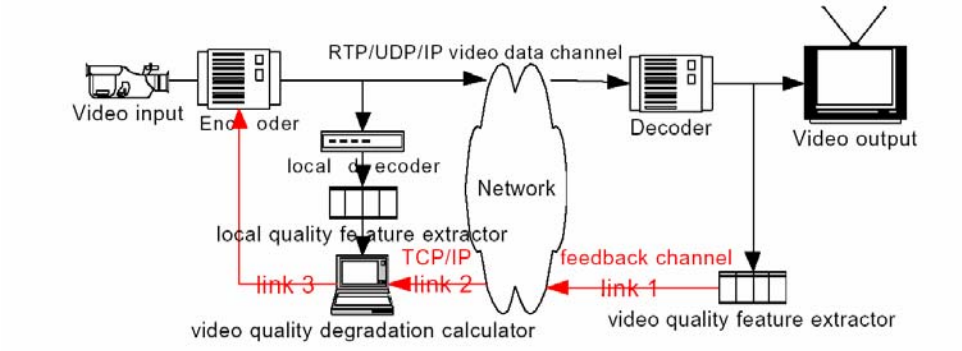


Figure 5.6: Video Application with Feedback Control

5.1.4 Delay Feedback Adaptive Control (DFAC) Scheme

In IEEE 802.11e, EDCA improves the QoS requirement of real-time traffic. But the performances obtain are not optimal by EDCA since the function parameters cannot be adapted to the network dynamic conditions. In [30] authors proposed an algorithm, Delay Feedback Adaptive Control (DFAC), is instead of IEEE 802.11e EDCA function. The DFAC scheme with the combination of DiffServ QoS and 802.11e EDCA, IP packets can be managed in network layer, enable to manage end-to-end QoS. The scheme can adaptively adjust the parameters of each traffic class according to the transmission delay.

DFAC adopts “delay feedback adaptive control” to change CW and AIFS adaptively according to the transmission. Therefore, the proposed DFAC algorithm can ensure the delay of traffic within the specific range. Also it can ensure the end-to-end delay assurances on the whole path. DFAC scheme keeps the high utilization bandwidth by reducing corresponding collision back-off time when best-effort traffic is the major portion of the whole application.

DFAC can adaptively adjust the values of CW and AIFS of traffic with low priority. This adjust can improve the throughput of traffic with high priority effectively, and can meet the QoS demand of high priority traffic. The simulation results show with DFAC can improve the throughput of traffic class with high priority, and provide delay assurance effectively for real-time traffic in single-hop.

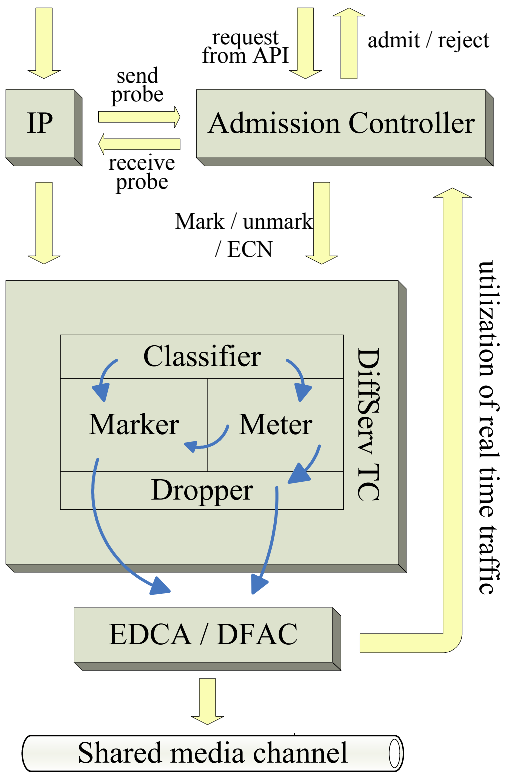


Figure 5.7: Combined QoS of DiffServ and 802.11e

5.1.5 Feedback based Dynamics scheduler for Hybrid Coordination Function (FDHCF)

In [63] authors propose a scheduler which considers the mean data rate for admission control and peak data rate for resource allocation, Feedback based Dynamics scheduler for Hybrid Coordination Function (FDHCF), capable of performance enhancement in both delay and throughput. The scheduler works dynamically and effectively depending upon the system load and can support VBR multimedia traffic stream. The service differentiation is attained by AIFS, CW, and TXOP based on IEEE 802.11e WLAN. In the scheduler, the FDHCF scheme can estimate the TXOP value to meet the QoS of each stream by the QAP. This estimation is based on the maximum queue length estimate which is obtained from the queue size feedback information and from the traffic nature. Simulation results show that the algorithm improves the system performance in terms of delay reduction and throughput enhancement.

In addition to above related works employ the closed-loop technology on the communication networks, recently there are other works also applied to wireless network services and real-time resource scheduling applications [16,55,61,64-66]. An access point (AP) in a wireless network application service is regarded as a node on an Internet connection. The main network bottleneck link is undoubtedly on the AP element. Author of [64] modeled WLAN APs as FIFS queuing systems to show that the adaptive-bandwidth of the AP link is used to calculate the AP throughput. Khatib propose a feedback control mechanism based on the throughput of a WLAN AP, but does not clearly identify the control function. In [16] the authors applied feedback control theory to wireless resource management in multi-service cellular networks. They formulated the wireless resource reservation problem as a discrete time dynamic feedback system, and aimed to keep the handoff failure rate below a target value. The author of [65] designed and implemented a decision feedback scheme for streaming video over UMTS transport channels. The feedback scheme receives the network quality information from the client, and adapts the transmission rate for video service. But Alexiou's scheme does not forethoughtfully survey the closed-loop controller design for dynamic QoS requirement.

To summarize above relative works, employing the feedback control mechanism to wireless application systems that will have the advantages as followings:

(1) To develop a mathematic dynamically model based on the wireless network application, and furthermore can control the network controlled system by the dynamically model calculation.
(2) To overcome violent variance in the wireless network environment, the system would employ the feedback controller to adjust the optimal system resource schedule. The system will quickly reach to stable state, and can obtain the system reference performance.
(3) The feedback control mechanism can predict that system performance is about to degrade before the degradation actually occurs. Afterward, the controlled system may take a compensation scheme for the best performance.
(4) A significant advantage of feedback control is that it causes system performance to exhibit a self-correcting, self-stabilizing behavior in the unstable environment time-variant network system.

5.2 Proposed Closed-Loop Scheduling Discipline

The closed-loop scheduling discipline is implemented using the feedback control mechanism in the thesis for IEEE 802.11 network. Air interference, an indispensable wireless network problem, destabilizes the system performance. Fortunately, the degradation of system performance may be predicted as long as using the feedback control technique in the system, before such degradation actually occurs. The feedback mechanism is used in the proposed system to enable it dynamically achieve the stable state.

This investigation focuses on designing a system controller mechanism for feedback control in an IEEE 802.11 wireless network. In Fig. 5.8, the feedback control-loop function diagram comprises controller module, QoS scheduler, wireless network system, and monitoring unit. The monitoring unit is triggered at regular some time intervals in the simulation. Through the sample monitoring works, we can get the service delay time and feed back to the controller unit. The feedback control-loop function is designed to regulate the output so that it is maintained at the system reference value. The disturbance input in Fig. 5.8 is likely to contain disturbances such as: air channel interferences each other, location-dependent error, fading, packet delay, and so on. The proposed method accomplishes effective wireless bandwidth resources management, and it meets the dynamic QoS requirement for the real-time traffic.

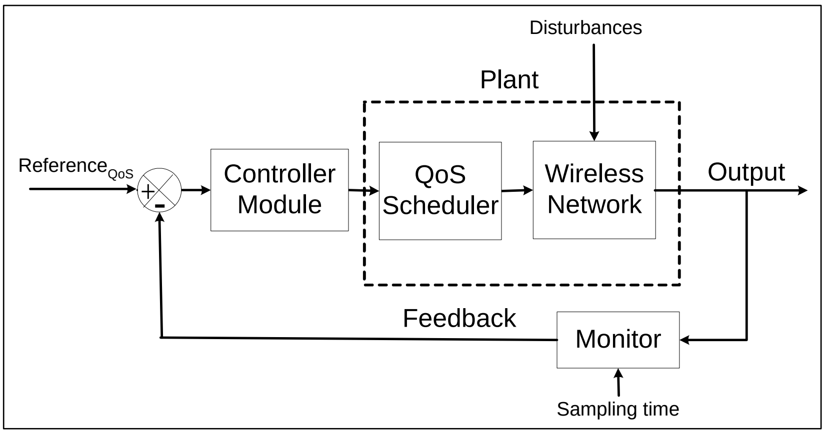


Figure 5.8: Feedback Control Function Diagram in Wireless Network

The closed-loop schedule concentrates mainly on designing a feedback mechanism for supporting wireless mobile communications services with dynamic QoS requirements [2,44,46,56,67]. Closed-loop architecture was developed by cascading the open-loop schedule, the QoS probe, the controller unit and the feedback mechanism (Fig. 5.9). In this architecture, traffic flow initially enters the open-loop scheduler, and is assigned system resource using the λ -calculus module. Furthermore, the QoS probe measures the QoS value of traffic flow, and then compares the system performance between the input and output references. The *Gain* module estimates the future QoS value using the current scheduling, and the parameters in the controller are tuned according to the system status, achieving dynamic scheduling.

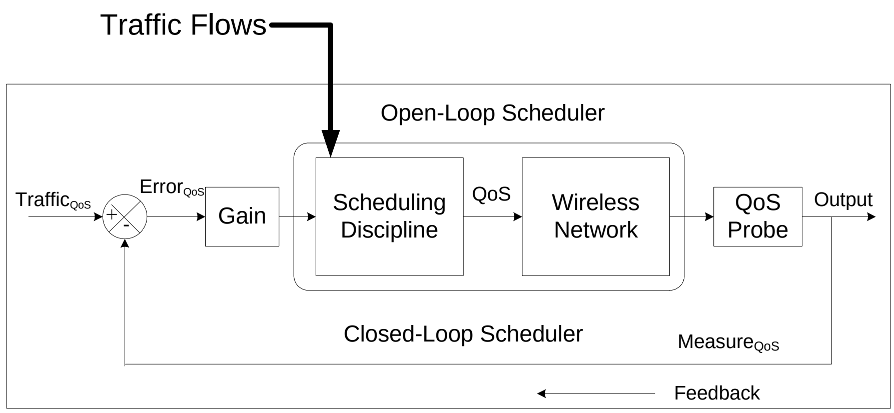


Figure 5.9: Closed-loop Scheduling for Traffic Flows

The P, PI and PID controllers are the components of the feedback mechanism; these controllers are designed to provide the control system performance. This work proposed the technology using these controllers. The symbols used to specify the feedback mechanism (Fig. 5.10) are defined as follows.

R(s): reference input parameter of the control system in the s-domain

Y(s): system output parameter of the control system in the s-domain

E(*s*): difference between the reference input and feedback signal in the s-domain

i.e., $E(s)=R(s)-Y(s)$

Circular symbols (+ or -): summing points of the feedback control system

K_p: proportional control parameter of the feedback control system

K_I/s: integral control parameter of the feedback control system

$K_D \cdot s$: derivative control parameter of the feedback control system

$G_c(s)$: PID transfer function of the control system in the s-domain

$G_p(s)$: controlled plant transfer function of the control system in the s-domain

Figure 5.10 illustrates the module, which is generally used to measure the QoS index parameters, such as delay, data loss, error and so on. In the system in this work, the delay parameter is taken as the QoS index. The *ns2* toolkit is employed to measure the delay for the wireless 802.11 data packets, and the flow traffic data are then combined for synchronal traffic (Fig. 5.11). After the delay has been measured, the delay data are fed back to the feedback controller for advance processing.

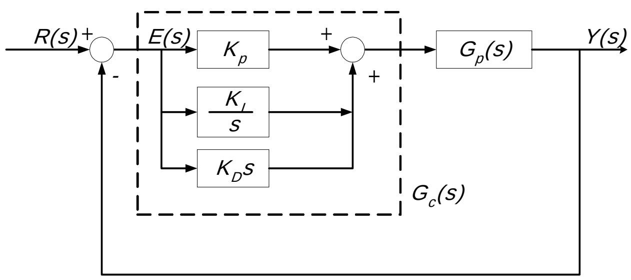


Figure 5.10: Operating Flow of PID Controller

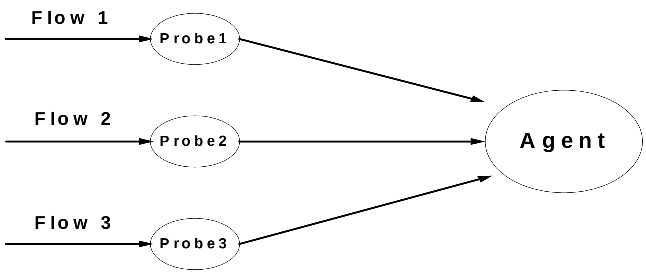


Figure 5.11: Operating Flow of QoS Probe Module

The closed-loop scheduling is performed by cascading the above modules and feedback mechanisms. Figure 5.12 illustrates an example involving a delay guarantee. The probe data are synchronously passed back to the Closed-loop schedule with an agent built in the QoS probe module. Figure 5.13 shows the concept of network system operating flow.

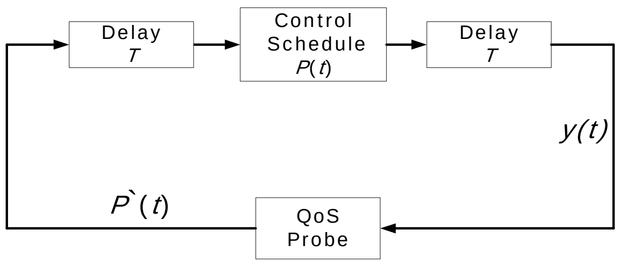


Figure 5.12: Example of Closed-loop Delay Control

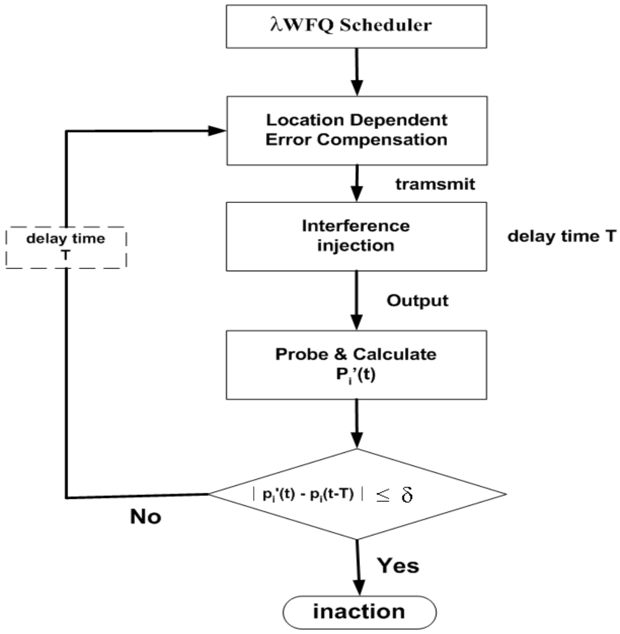


Figure 5.13: Concept of Operating Flow

5.3 Model and Algorithm Design

This section first presents the 802.11 wireless network model, and describes the relative system parameters. The controller equations are then obtained by the automatic control system mathematical model, which can improve the network system behavior. The following subsection will present the pseudo code of the adaptive QoS management algorithm.

5.3.1 Define Feedback Model for 802.11 Network

A feedback mechanism was designed to support wireless communications services with dynamic QoS requirements. The dynamic model system means to relative time-varying system. In the thesis, the system was regarded as linear time-invariant in order to apply the feedback control technique to it according to automatic control theory. Figure 5.14 shows the block diagram of the feedback control system in the *s*-domain.

The system parameters in Fig. 5.14 are defined as follows.

$D_R(s)$: system input reference value for delay in the *s*-domain

$Y(s)$: system output parameter of the control system in the *s*-domain

$D_A(s)$: traffic actual delay in the *s*-domain

$E_D(s)$: system delay error in the *s*-domain, $E_D(s) = D_R(s) - D_A(s)$, s.t. controlled variable

$B(s)$: manipulated variable, representing bandwidth measure

Circular symbols (+ or −): summing points of the feedback control system

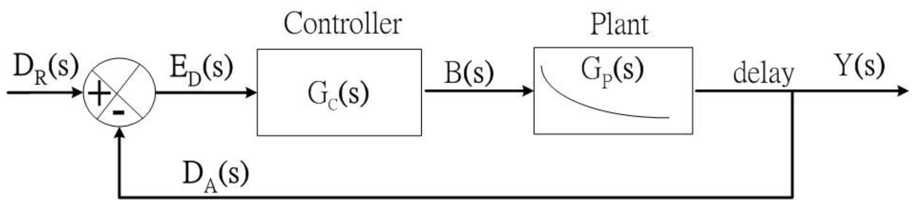


Figure 5.14: Block Diagram of Feedback Control System in *s*-domain

The proposed feedback mechanism detailed flow chart process is shown in Fig. 5.15. When a traffic flow initiate requests wireless bandwidth $B_{k,j}$ resource to serve which is one j*th* traffic flow in k*th* class of user service. Initially it must claim its QoS requirement. The proposed mechanism calculates the $C_{k,Allocate}$ value by λ-calculus technique for obtaining the user traffic satisfaction. The probe unit may sense the system delay output (e.g. at user station end). The delay information will feed back to sender to compute the difference (i.e. E_D) of the information and the reference. If the difference does not exceeded the tolerant delay (δ), the system does not compensate bandwidth to serve the traffic $B_{k,j}$. However, when the difference exceed the tolerant, the feedback controller must calculate the compensate bandwidth ΔB for $B_{k,j}$. When the system residual resource is not enough to compensate the $B_{k,j}$ requirement, the mechanism will retrieve the lack bandwidth from lowest priority class resource. However, if somewhat class resource is enough to compensate the $B_{k,j}$, then the system will distribute the resource to it.

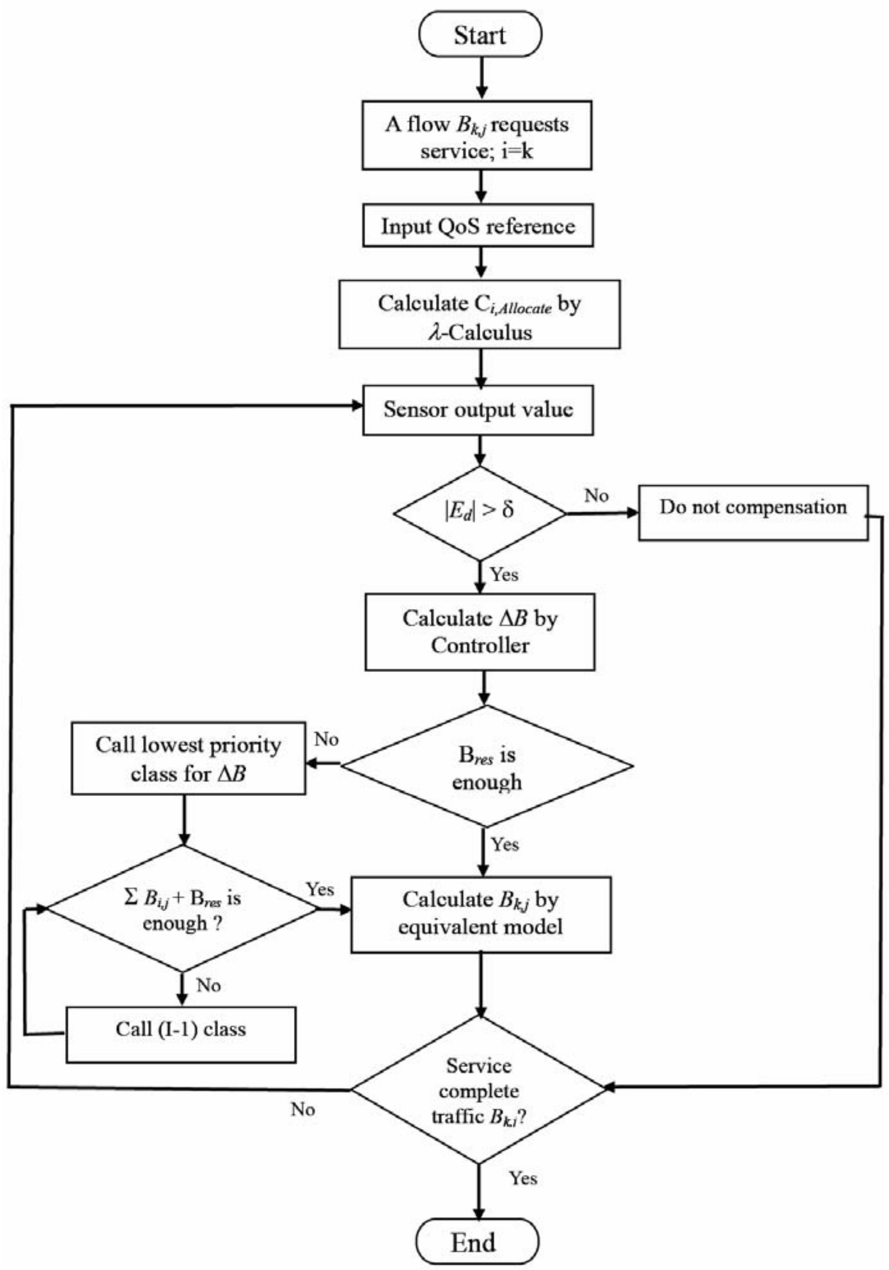


Figure 5.15: Proposed Feedback Mechanism Flow Chart

Figure 5.16 employs an *ns*-2 toolkit to measure the delay of wireless 802.11 data packets [14]. The Figure reveals that the service delay reverts to an acceptable level by increasing the service bandwidth. After the delay is measured, the delay data are fed back to the feedback controller for advance processing. The 802.11 network can be modeled by the following time-domain equation:

$$y(t) = 0.016x^2(t) - 0.11x(t) + 0.386 \qquad (5.3)$$

Wireless networks can be considered a dynamic system existing in a continuously changing environment over time. This study defines the allocated bandwidth function $x(t)$ in wireless network systems based on the time-domain. Because of mobile users always suffering air interferences, the system condition is unpredictable. This study finds that dynamically allocated bandwidth affects the delay time in the service system. The system delay output is related to the adaptive allocated bandwidth. This study defines the system delay time as $y(t)$.

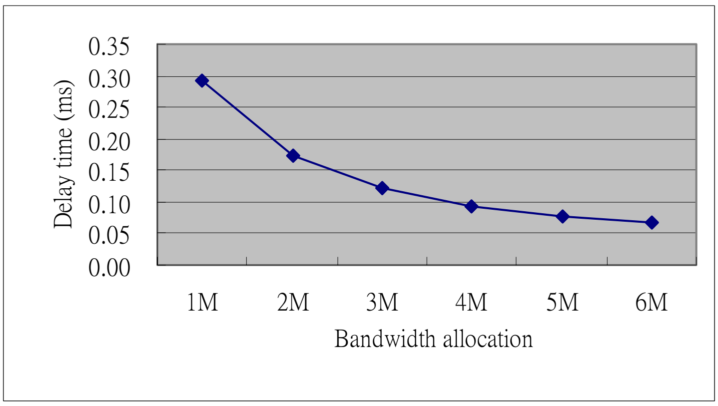


Figure 5.16: 802.11 Wireless Network Model

To take the system model in the s-domain, apply Eq. (1), and shift Eq. (5.3) to the s-domain, thus obtaining Eq. (5.4):

$$F(s) = \frac{0.386s^2 - 0.11s + 0.032}{s^3} \qquad (5.4)$$

In the closed-loop control system, the ratio between output and input is defined as the system transfer function $Y(s)/D_R(s)$. The module estimates the future QoS using the current scheduling, and the parameters in the controller are tuned according to the network condition, thus achieving dynamic QoS scheduling.

From the Fig. 5.9, we described that scheme only considers the traffic flows in one class of service. For generally, we modify that to multi-layer figure (Fig. 5.17). The Fig. 5.17 depicts the 802.11 network system supposes that system can serve many classes traffic flows. The system will collect all traffic requests and periodically update the estimated system available bandwidth, i.e. system residual bandwidth B_{res}. The total bandwidth in the system is B_{total} (i.e. in 802.11 network is 11Mbps). Suppose in the wireless network system there are I classes of service and the ith class of service has totally J_i traffic flows, the available bandwidth is the following equation:

$$B_{res} = B_{total} - \sum_{i=1}^{I} \sum_{j=1}^{J_i} B_{i,j} \qquad (5.5)$$

In which $B_{i,j}$ is the reserved bandwidth of the jth traffic flow in the ith class of service.

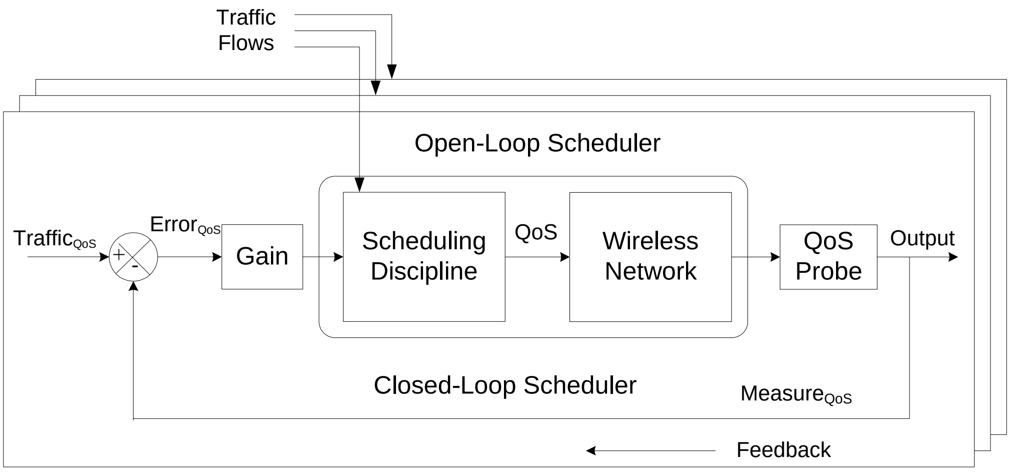


Figure 5.17: Closed-loop Scheduling for Multi Classes Traffic Flows

5.3.2 Algorithm for *P* Controller Scheme

P controller is the simplest component of controller units in feedback control mechanism. The controller may view as an amplifier component in a system. In Section 3.3 we have stated that if enlarge the proportional constant, it makes improve the system gain. This condition also makes short its ascending time, and the response speed becomes fast.

The manipulated variable on the closed-loop system is $B_{i,j}(t)$ (represented bandwidth); the controlled variable is the delay d_j[out], and the referred delay is d_j[ref]. Furthermore, the differential delay is $\Delta d_j = d_j[ref] - d_j[out]$. This work defines a tunable parameter *P*, used as the K_p value, in the time domain. The service performance in the mobile network system depends on the controller parameter *P*. The tuned bandwidth can be obtained as $\Delta B = -P \cdot \Delta\, d_j$. For example, when the system output value approximates the range [0.000173, 0.000292] and [0.000122, 0.000173], the control system assigns the values *P*=8.4 and 19.6, respectively. This work uses the feedback compensation algorithm to adjust $B_{i,j}$ for the *j*th traffic flow in the *i*th class of service. Figure 5.18 shows a compensation bandwidth algorithm for *P* controller that there is a traffic flow $B_{k,j}$ requests bandwidth resource for services.

```
i=k
Δd_j = d_j[ref] - d_j[out]
If Δd_j <0 and |Δd_j | > δ Then
   { ΔB = -K_p·Δd_j ;
      If (ΔB < B_res) Then
           { B_k,j = ΔB + B_k,j
             B_res = B_res - ΔB
      Else
            B_k,j = call class(i+1)
           }
   }
   ----------------------------------------------------------------------------------
SubRoutine class(i)
If i < I Then call class(i+1)
If ( ΔB ≤ Σ_{j=1}^{J} B_i,j + B_res ) Then
{    B_k,j = ΔB + B_k,j
     B_i,j = B_i,j − (B_i,j / Σ_{j=1}^{J} B_i,j)(Σ_{j=1}^{J} B_i,j − B_res)
     B_res = 0
     Return B_k,j
Else
     If (i>k) Then
     {    i = i-1
     Else
            Return 0 ;      //Do not compensate
     }
}
```

Figure 5.18: Feedback Compensation Bandwidth Algorithm for P Controller

The precise system utilization is unknown and the system is time-varying, so the total system utilization $U_{total}(t)$ may differ from the total estimated requested utilization $U_e(t)$, which is derived from the feedback compensation algorithm. The relationship between both utilization variables can be defined as follows;

$$U_{total}(t) = G(t)\ U_e(t) \qquad (5.6)$$

In which $G(t)$, the utilization ratio, is a time-variant ratio that represents the extent of service traffic variation in terms of actual service utilization. The term $G(t)$ is time variant so, the maximum possible value G_{max}=max$\{G(t)\}$, which is called the worst-case utilization ratio, should be used to approximate the actual system performance.

5.3.3 Algorithm for *PID* Controller Scheme

The feedback system controller estimates the traffic bandwidth requirement based on the current network condition. The *P*, *I* and *D* controllers are the components of the feedback control system. While K_P value is larger under *P* controller module, then the system can get the steady state error (i.e. e_{ss}) more quickly approach to zero, but never equal to zero. The type controller is unable to eliminate the system steady-state error, and will usually cause relative stability to worse. Therefore, it must generally join other compensators together. As stated in Section 3.3, the Integral technology can improve the steady-state error, but the Derivation technology can improve transient response behavior. However, *PID* controller is the association of *PI* controller and *PD* controller. Consequently, this type controller can improve the system transient response behavior, at the same time, and also improve the system steady- state error.

To derive the characteristic equation $\Delta(s)$ on the proposed system model, the transfer function as following:

$$Y(s)/R(s)=[G_c(s)\cdot G_p(s)]/\ [\ 1+G_c(s)\cdot G_p(s)] \qquad (5.7)$$

The equation must first be calculated on the closed-loop structure. The Routh array technique is then used to determine the range of systematic stability. Finally, the controller parameters are obtained. To simplify the calculation process, the time-domain can be shifted to the *s*-domain equation by the Laplace transform. The PD controller is eventually obtained as $G_c(s)= K_P +K_D\cdot s =c+3.5c\cdot s$, the PI controller is $G_c(s)= K_P+K_I/s=3.5c+c/s$, and the PID controller is $G_c(s)=K_P+K_I/s+ K_D\cdot s=3.5c+c/s+12.25c\cdot s$. The parameter c is a positive number.

Likely Figure 5.18, the Figure 5.19 shows a compensation bandwidth algorithm for PI, PD, PID Controllers. There is a traffic flow $B_{k,j}$ requests wireless network bandwidth resource for service.

```
C_type = Input a controller type;
D_A(s) = Actual system delay value;
D_R(s) = Input the reference value;
E_D(s) = D_A(s) – D_R(s);
If (E_D(s)<0 and |E_D(s)| > δ) Then
{     Select Case    C_type
              Case "PI"
                   ΔB =3.5c+c/E_D(s)
              Case "PD"
                   ΔB = c+3.5c• E_D(s)
              Case "PID"
                   ΔB = 3.5c+c/E_D(s)+12.25c• E_D(s)
       End Select;
       If (ΔB < B_res) Then
       {    B_k,j = ΔB + B_k,j
            B_res = B_res - ΔB            }
        Else
            B_k,j = call class(i+1)
}

--------------------------------------------------------------------------------------
SubRoutine class(i)
If i < I Then call class(i+1) ;
```

If ($\Delta B \le \sum_{j=1}^{J} B_{i,j} + B_{res}$) Then

{ $B_{k,j} = \Delta B + B_{k,j}$;

$$B_{i,j} = B_{i,j} - (B_{i,j} / \sum_{j=1}^{J} B_{i,j})(\sum_{j=1}^{J} B_{i,j} - B_{res});$$

```
    B_res = 0;
    Return B_k,j ;
Else
    If (i>k) Then
    {    i = i-1;
     Else
         Return 0;      //Do not compensate
    }
}
```

Figure 5.19: Feedback Compensation Bandwidth Algorithm
for PI, PD, PID Controllers

The *delta* (δ) presents the threshold measure in the system. If the controlled error measure is less than the parameter *delta*, to reduce the control event and calculate the time it is only necessary to maintain the original operating value of the parameter (namely the value of the last feedback loop). The *delta B* (ΔB) presents the compensative bandwidth calculated by the controller units. The QoS scheduler thus is responsible for estimating the allocated bandwidth resource using the *delta B*. Based on the controller instance estimation of the *delta B*, the system rapidly improves the output performance to satisfy the traffic QoS requirement. From Fig. 5.15, 5.18, and 5.19, we can find this dissertation uses a "passive" controller strategy method, meaning that the controller and QoS scheduler are triggered when the condition fits $|E_D(s)| > \delta$, rather than responding to periodic events. The significant concern may enable the system more efficient performance.

Chapter 6
Performance Evaluation and Analysis

This Chapter will reveal the simulation analysis and performance evaluation from the thesis proposes open-loop and closed-loop QoS mechanism applying to scheduling resource of IEEE 802.11 wireless networks. Firstly, we describe the related simulation scenarios assumption in Section 6.1. And then, Section 6.2 shows the accepted index function (*AI*) for various type traffic services and $C_{i,Allocate}$ for λ-calculus. Under 802.11 wireless network limited resource condition, in Section 6.3 shows simulation results to declare that the proposes λ-calculus technology and *P* controller scheme application have the optimal resource scheduling performance. To compare the various controllers' performance, the experiment results reveal the good performance in 6.4 Section.

6.1 Simulation Model for Open-loop Scheme

The proposes scheduling discipline is performed in the Access Point (AP) element for the 802.11 WLAN basic services set. The total bandwidth which is shared between the serviced traffics is 11Mbps. Three types of services traffic flows including interactive video, voice phone and file transfer, are requested at the scheduled time. The three type traffic characteristics are listed following Table 6.1. Suppose the three type traffics request the minimum and maximum resource requirement are (0, 5), (0, 3), (0, 2), respectively. Obviously, the service transmission rate of voice phone and interactive video flows must be guaranteed, we consider them as real-time traffic flows. In the other hand, the file transfer traffic could view as the non real-time traffic service.

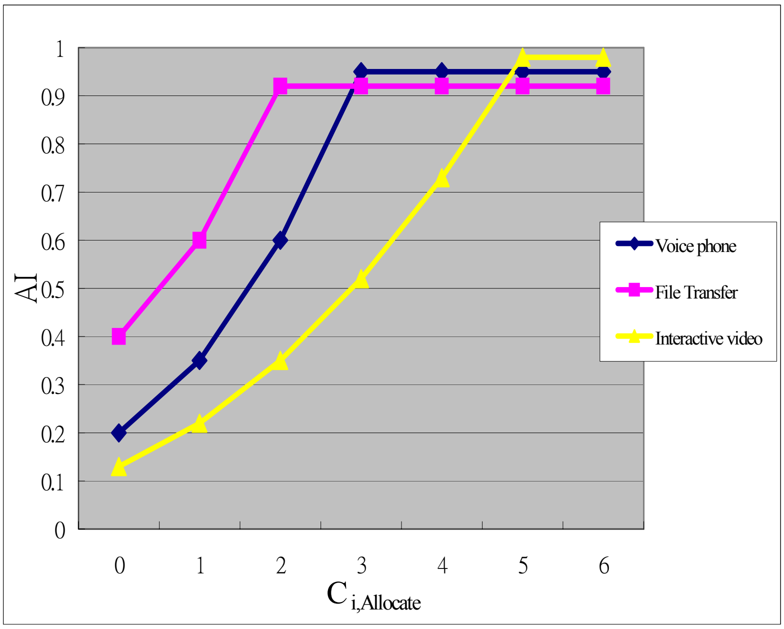
Table 6.1: Traffic Characteristics

Service Type	Class1	Class2	Class3
Example of each type	interactive Video	voice phone	file transfer
Packet Delay	Bounded	Bounded	Sensitive

6.2 Open-loop Schedule Simulation Analysis

6.2.1 Accepted Index Function

From the Chapter four, the operating data parameters (i.e. P_b, P_f, P_s) listed in Fig. 4.5 were measured and evaluated using an OpNet simulator. The relationship between AI_i and $C_{i,\ Allocate}$ was identified. Through the curve fitting techniques, the functions were fixed and shown in Fig. 6.1.



$$AI_{voice\_phone}=0.21+0.10*C_{i,Allocate}+0.05*C_{i,Allocate}^{2}$$

$$AI_{file\_transfer}=0.42+0.12*C_{i,Allocate}+0.08*C_{i,Allocate}^{2}$$

$$AI_{interactive\_video}=0.13+0.07*C_{i,Allocate}+0.02*C_{i,Allocate}^{2}$$

Figure 6.1: AI Function for Each Request

6.2.2 Simulation Result based on $C_{i,Allocate}$ for λ -Calculus

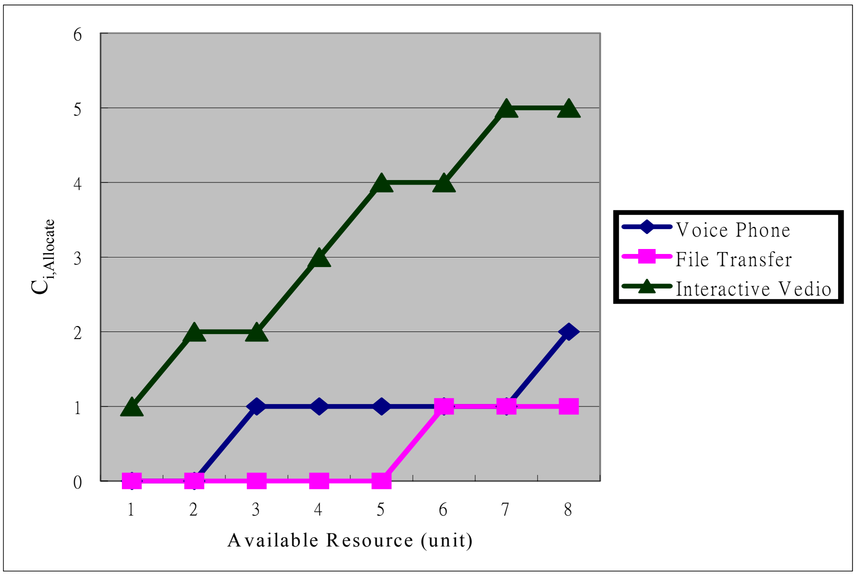


Figure 6.2: Resource Allocation based on Available Resource

Based on the individual *AI* functions of each request, we can observe that many available resources are allocated to interactive video and voice phone in the Fig. 6.2. A wireless user will expect for a higher quality of service for real-time services.

For approval the λ -calculus performance, we refer the resource allocation schemes groups as following. Group 1 defines a maximum resource allocation to a request. Group 2 defines a minimum resource allocation to a request. Group 3 defines a maximum resource allocation to a request unless there are not enough available resources. Group 4 defines the resource allocated according to the estimated blocking performance. Based on the group 3 conceptual model, we propose the λ -calculus for scheduling the 802.11 network. In Fig. 6.3 shows the incremental acceptance rate, i.e. λ, and reveals the fact that the more the available resources, the higher the rate.

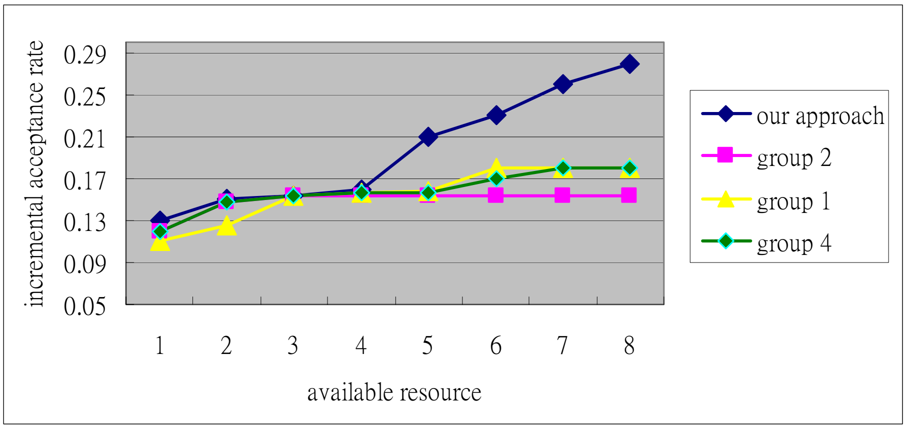


Figure 6.3: Acceptance Rate Comparison with Other Schemes

6.2.3 Performance Analysis for λ-Calculus

We define the AI_T as the QoS measurement based on λ-Calculus, and thus λ is an important index. In the comparison of λ with other schemes describes former subsection 6.2.2, it is found that the mean acceptance rate for our approach is better than that of other scheme. However, the group 2 schemes are a good choice if the traffic is heavy, because of the low blocking and force-terminated probability. Our approach has an advantage under light loads due to the high satisfaction rate. In general, service assurance is more important than service request in most types of services. Therefore, the λ-calculus of the group 1 and 4 schemes are greater than for group 2 schemes in moderate and light loads.

6.3 Performance Evaluation of λ- Calculus and *P* Control Scheme

The performance results, obtained by the proposed approach, were compared with those from two other methods. Method 1 is the traditional *WFQ* with the compensation scheme, and Method 2 is the λ-*WFQ* scheme with open-loop scheduling. Figure 6.4 and 6.5 show the simulation results in terms of service delay and system utilization, respectively. The closed-loop scheduling approach (Method 3) clearly achieves a better delay than other mechanisms at 25.91% for class 1 service. Meanwhile, the closed-loop scheduling approach also outperforms other mechanisms, with a system utilization of 3.5%.

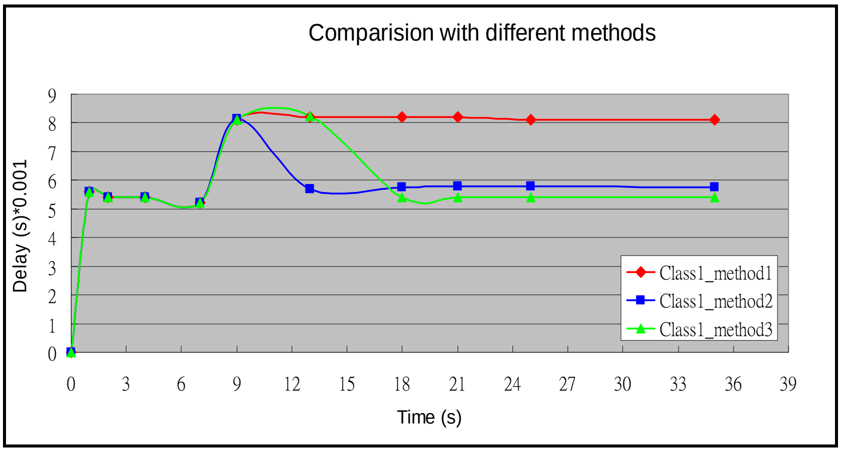


Figure 6.4: Analysis of Service Delay

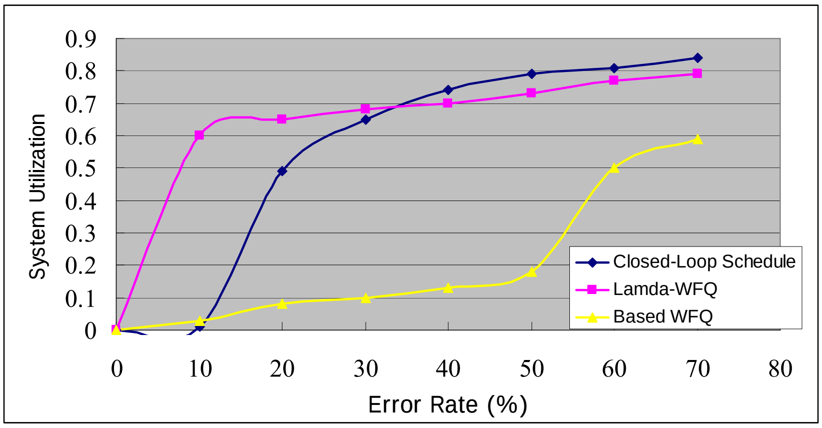


Figure 6.5: Analysis of System Utilization

6.4 Performance Evaluation Based on Various Controllers Scheme

The simulation in the Section was mainly concerned with studying the performance of the proposed feedback various controllers design method. The feedback control system was applied to the 802.11 networks. We suppose the traffic type in this simulation was categorized as real-time service (class1) and non real-time service (class2). In the Internet, the real-time traffic includes video streaming or VoIP services, and the non real-time traffic includes FTP, or HTTP services.

6.4.1 Simulation Model for Closed-loop

The experimental scenario assumes that class1 required twice the bandwidth of class2. That is the bandwidth requirement of class1 and class2 traffic is assumed to be 2Mbps and 1Mbps, respectively. The total bandwidth shared between class1 and class2, was 11Mbps. Therefore, if class1 had insufficient bandwidth, then it could be compensated from either class2 or the system remainder measure to reach its QoS requirement. Figure 5.19 shows the bandwidth adjust process. The reference delay D_R is represents the system stable delay measure. The actual delay D_A represents the delay measure resulting from the network condition, and was set to the average value of the traffic per class.

The simulation was run to investigate the performance of the proposed controller model. The experiments employed three types of controllers, namely PI, PD, and PID controllers. Figure 5.19 illustrates that the value of parameter c is very important, because it determines whether the system model is convergent or divergent. That is, the system may be prudent to select the constant c, such that the system will be stable. The system was found to be stable at c =0.005 depend on the network condition.

6.4.2 Performance Analysis

This subsection shows the excellent performance of the proposed controller module. In the scenario, five class1 data packets were introduced to the network, and continued to be serviced for 45 seconds. The five class2 data packets were transmitted 5 seconds after the class1 traffic began service in the network. The class2 traffic continued to be serviced for 25 seconds. The class1 traffic continued for 15 seconds after the class2 traffic left the network. Clearly, only the class1 traffic needs guaranteed QoS requirement. The network system was assumed to share the bandwidth resources among class1 and class2 traffic. Figure 6.6 shows the mutual effect of the two simulation services without feedback control technique. The entry of the class2 traffic into the network caused the class1 packets to fail their QoS tests. However, the class1 traffic met the QoS requirement once the class2 completed service.

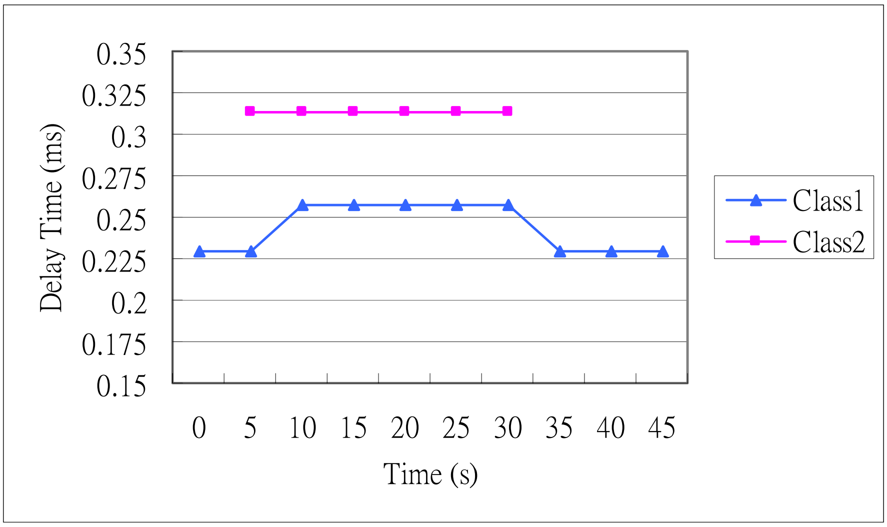


Figure 6.6: Delay Time without Feedback Control

Figure 6.7 displays the delay time change with two classes of network traffic. The feedback control mechanism was applied to the wireless network. Experimental results show that the controller can guarantee the real-time traffic QoS requirement, and quickly meet the reference value. Figure 6.8 displays a close-up of Fig. 6.7. Experimental results clearly indicate that the PI and the PID controllers are superior to the PD controller, since the PID and the PI controllers quickly reached the reference value. The PID controller was found to perform slightly better than the PI controller. Additionally, the novel feedback control mechanism by the PID controller clearly delay 11.44% less than the system without a control mechanism. While the delay with the PD controller system is 6.2% less than that achieved without the feedback control system.

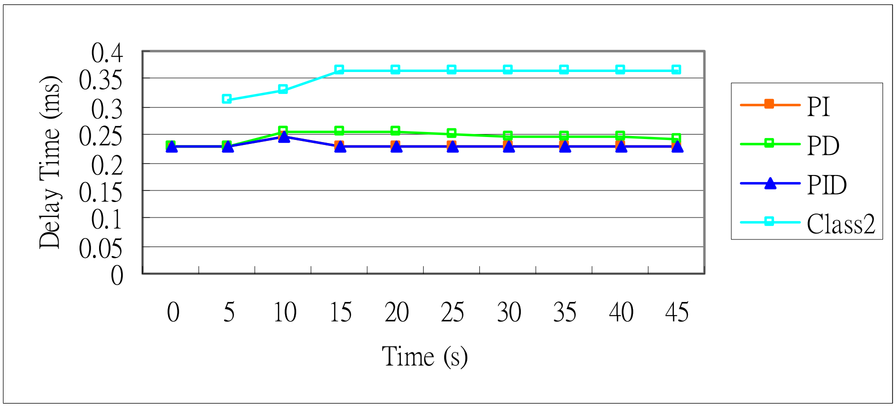


Figure 6.7: Delay time with Feedback Control

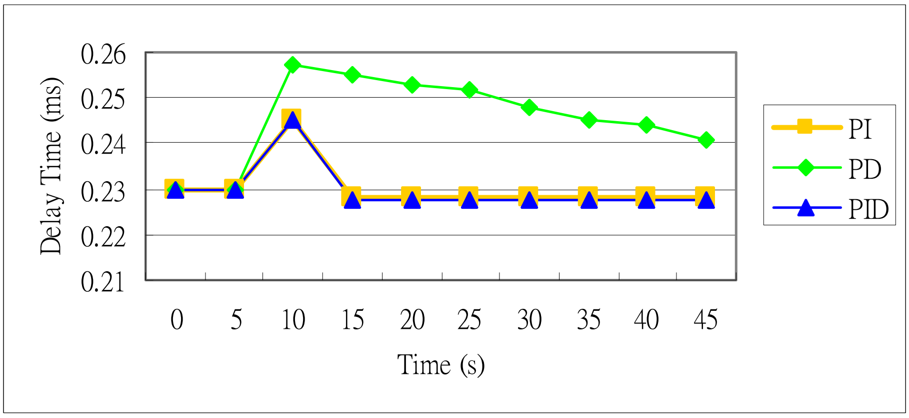


Figure 6.8: View of Close-up in Fig. 6.7

Chapter 7
Conclusions and Future Works

The proverb "wireless technology, limitless life" is the best description for our future life style. With the spectacular advancement of wireless network technologies have facilitated to the introduction of many new wireless network services. Wireless networks can provide end-users with freedom of mobility, since they can roam around a building or outside areas while maintaining access to instant message, e-mail, voice, and other multimedia services. In the future, the wireless end-users will anticipate to obtain "anytime, anywhere" convenient transmission service, which is an indispensable fashion in life style. As we have known, 802.11 network standard supports QoS requirement for real-time traffic that is a completely lack the capability network standard. After the 802.11e working group efforts, the 802.11e standard has released in 2005. The 802.11e standard is possessed the QoS guarantee for the real-time traffics. However, it is a scheme based on the link layer technology, the network performance obtainments are not optimal by EDCA and HCF. Since the 802.11e functions parameters cannot be adapted to the network dynamic conditions based on the time domain. For the accurately control the wireless networks environment, we must develop on the network layer or higher layer mechanism to control network. Therefore, the network system will satisfy to user requirement that is a significant issue. Base on the challenging issue, the dissertation proposes a combine the open-loop and closed-loop adjustable bandwidth mechanisms used to parameterize the traffic flow delay for a 802.11 wireless network service.

Open-loop scheduling focuses mainly on designing a schedule discipline to support wireless communication services with steady-state QoS requirements. The discipline is developed a λ *WFQ* scheme involving the *WFQ* mechanism and LaGrange λ–calculus. In the scheduling, a user's acceptance indication can represent his traffic QoS requirement level. To assign a higher AI value to a user, implies that the user possess a higher QoS level.

Closed-loop scheduling primarily involves the design of a feedback mechanism for supporting wireless mobile communication services with dynamic *QoS* requirements. This dissertation designs a closed-loop architecture by cascading the open-loop schedule, the QoS probe, the Proportional-Integral-Derivative (PID) controller and a feedback mechanism. The module estimates the future QoS according to the current scheduling, while the controller parameters are tuned according to the system status to achieve dynamic scheduling. The QoS probe measures the QoS value of each flow.

The performance of P controller and λ-Calculus based on open-loop scheme that we have compared, and also have compared the performance of three feedback controllers based on closed-loop scheme. From the open-loop simulation results showed that the proposed scheme provides a significantly lower service delay and higher system utilization than other approaches, at the expense of low time complexity. And then, the performance of various feedback controllers was compared in the closed-loop simulation results. The dissertation indicates that the designed controllers can significantly reduce the mean service delay for real-time traffic. Furthermore, the results reveal that both PID and PI controllers are superior to the PD controller. The PID controller has the best performance, and has a delay 11.44% less than that without a controller. The delay of the PD is also 6.2% smaller than the delay when a controller is not employed. Finally, the reference value in the wireless network system can quickly be reached by carefully tuning the constant parameter c.

As the number of wireless network end-users increases, broadband mobile wireless Internet communications is even on fast moving vehicles. And/or the wireless end-users may be in a large-scale mobile network area. Owing to wireless broadband WiMax technology possesses a large cover communication area. In the future work, we will apply the proposed novel feedback scheduling discipline to WiMax framework, and Mobile Router (MR) wireless technology. Therefore, the future work will achieve our “anytime, anywhere” future life style.

References

[1] V. Marques, R.L. Aguiar and M. Liebsch, "An IP-Based QoS Architecture for 4G Operator Scenarios," *IEEE Wireless Communications*, pp.54-62, June 2003.

[2] G. Ivano, D. Paolo and F. Paolo, "The Role of Internet Technology in Future Mobile Data Systems," *IEEE Communications Magazine*, Vol.38 No.11, pp.68-73, 2000.

[3] Y.B. Lin and I. Chlamtac, *Wireless and Mobile Network Architectures*, Wiley, 2000.

[4] G. Kousalya, P. Narayanasamy, "Dynamic Resource Management framework for Wireless LAN," *Proceedings of the Second IFIP International Conference on Wireless and Optical Communications Networks*, pp. 561-567, March 2005.

[5] M.M. Markou, C.G. Panayiotou, "Dynamic control and optimization of buffer size for short message transfer in GPRS/UMTS networks," *Proceedings of the Information and Communication Technologies: From Theory to Applications*, pp.209-210, April 2004.

[6] L. Huang, S. Kumar, and C.C.J. Kuo, "Adaptive resource allocation for multimedia QoS management in wireless networks," *IEEE Transactions on Vehicular Technology*, Vol.53, Issue 2, pp.547-558, March 2004.

[7] Li Ma, Fei Yu, V.C.M. Leung, and T. Randhawa, "A new method to support UMTS/WLAN vertical handover using SCTP," *IEEE Wireless Communications*, Vol.11, Issue 4, pp.44-51, Aug. 2004.

[8] Y. R. Haung, "Determining the Optimal Buffer Size for Short Message Transfer in a Heterogeneous GPRS/UMTS Network," *IEEE Transactions on Vehicular Technology*, Vol. 52, No. 1, 2003.

[9] M. Andrews, K. Kumaran, K. Ramanan, A. Stolyar, P. Whiting, R. Vijayakumar, "Providing Quality of Service over a Shared Wireless Link," *IEEE Communications Magazine*, Vol.39, No.2, pp.150-154, Feb. 2001.

[10] M. Shafl, W. Aamer, and K. Butterworth, "Next Generation Wireless Networks," *Proceedings of the IEEE International Symposium on Circuits and Systems*, pp.7.2.1-7.2.9, 2001.

[11] H. Fahmi, A. Ghafoor, M. Latif, R. Paul, and B. Shafiq, "Real-Time Resource Reservation for Synchronized Multimedia Object over Wireless LAN," *Proceedings of the IEEE Conference on Object-Oriented Real-Time Distributed Computing,* pp. 386-393, 2002.

[12] D.H. Summerville and L. Edmunds, "An Analysis of Resource Scheduling with Prioritization for QoS in LANs," *Proceedings of 25th Annual IEEE Conference on*

Local Computer Networks, pp.66-75, 2000.

[13] G. Guanqun, H. Hassanein, J. Zhao, and J. Wu, "Quality of Service Based End-to-End SiMO Routing Framework in Differentiated Services Networks," *Proceedings of IEEE International Conference on Performance, Computing and Communications*, pp.425-432, 2002.

[14] J.L. Chen and N.K. Chen, "Feedback Closed-loop Scheduling Discipline for QoS Guarantee in Mobile Applications," *ACM Wireless Networks*, Vol.12, No.2, pp. 223-232, 2006.

[15]D.E. Comer, *Internetworking with TCP/IP Principles, Protocols, and Architecture*, 4th Edition, 2000.

[16] M. Hossain, M. Hassan and H.R. Sirisena, "Adaptive Resource Management in Multi-Service Mobile Wireless Cellular Networks Using Feedback Control", *Proceedings of the IEEE 60th Vehicular Technology Conference*, Vol.6, pp.3984-3988, Sept. 2004.

[17] K. Xu, Y. Tian and N. Ansari, "TCP-Jersey for Wireless IP Communications," *IEEE Journal on Selected Areas in Communications*, Vol.22, No.4, pp.747-756, May 2004.

[18] M. Li, H. Zhu and S. Sathysmurthy, "End-to-End Framework for QoS Guarantee in Heterogeneous Wired-cum-Wireless Networks," *Proceedings of the First International Conference on Quality of Service in Heterogeneous Wired/Wireless Networks*, pp.140-147, 2004.

[19] F. Franklin, J. David Powell, and A.E. Naeini, *Feedback Control of Dynamic Systems*, Prentice Hall, 2002.

[20] Ashraf M. A. Ahmad, "Context and Resources based Mobile and Wireless Video Transcoding," *Proceedings of World Academy of Science, Engineering and Technology*, Vol. 16, pp. 49-54, Nov. 2006.

[21] M. Oliver, A. Escudero, *Study of different CSMA/CA IEEE 802.11-based implementations*, http://www.eunice-forum.org/euice99/027.pdf

[22] H. Zhu, I. Chlamtac, "Performance Analysis for IEEE 802.11e EDCF Service Differentiation," *IEEE Transactions on Wireless Communications*, Vol.4, No.4, pp.1779-1788, July 2005.

[23] N. Banerjee, "Mobility and Resource Adaptive Architecture and Protocols for Multimedia Applications in Ubiquitous Computing," Ph.D. dissertation, University of Texas at Arlington, 2004.

[24] T. Zhang, J. Chennikara, P. Agrawal, E.V.D. Berg and T. Kodama, "Autonomous Predictive Resource Reservation for Handoff in Multimedia Wireless Networks," *Proceedings of the Sixth IEEE Symposium on Computers and Communications*, pp. 230-236, 2001.

[25] Y. Cao and V.O.K. Li, "Scheduling Algorithms in Broad-band Wireless Networks," *Proceedings of the IEEE*, Vol.89, No.1, pp. 76-81, Jan. 2001.

[26] A. Athanasopoulos, E. Topalis, C.D. Antonopoulos, S. Koubias, "Evaluation Analysis of the Performance of IEEE 802.11b and IEEE 802.11g Standards," *Proceedings of the International Conference on Networking, Systems, Mobile Communications, Learning Technologies (ICNICONSMCL'06)*, pp.141-146, 2006.

[27] IEEE Std. 802.11: IEEE Standard for Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specification, 1997.

[28] Dongyan Chen et al., "Supporting Real-Time Traffic with QoS in IEEE 802.11e Based Home Networks," *Proceedings of the IEEE Consumer Communications and Networking*, pp. 205- 209, Jan. 2004.

[29] N. Baghaei, R. Hunt, "Review of Quality of Service Performance in Wireless LANs and 3G Multimedia Application Services," *Computer Communication*, Vol. 27, pp.1684-1692, 2004.

[30] F. Zhang, B. Huang, L. Tu, J. Zhang, "Adaptive MAC Scheme Ready for Delay Assurances in Wireless Networks," *Proceedings of the IEEE 7th International Conference on PDCAT'06*, pp.234-239, 2006.

[31] H. M. Liang, C. H. Ke and C. K. Shieh, "Performance Evaluation of 802.11e EDCF in Infrastructure Mode with Real Audio/Video Traffic," *Proceedings of International conference on Networking and Services (ICNS '06)*, pp.92-97, 2006.

[32] J.K. Choi, J.S. Park, J.H. Lee, K.S. Ryu, "Review on QoS Issues in IEEE 802.11 W-LAN," *Proceedings of the 10th International Conference on Advanced Communication Technology ICACT'2006*, PP. 2109-2113, 2006.

[33] D. Kliazovich, F. Granelli, "A Cross-layer Scheme for TCP Performance Improvement in Wireless LANs," *IEEE Communications Society Globecom*, pp.840-844, 2004.

[34] Y. Iraqi, R. Boutaba, "Resource Management issues in Future Wireless Multimedia Networks," *Journal of High Speed Networks*, Vol.9, No.3, pp. 231-260, 2000.

[35] S. Park, K. Kim and D. C. Kim et al., "Collaborative QoS Architecture between DiffServ and 802.11e Wireless LAN," *Proceeding of 57th Vehicular Technology Conference*, Vol. 2, pp. 945-949, April 2003.

[36] I. Aad, C. Castelluccia, "Differentiation mechanisms for IEEE 802.11," *Proceeding 20th Annual Joint Conference of the IEEE Computer and Communications Societies,* Vol. 1, pp. 209-218, April 2001.

[37] A. Lindgren, A. Almquist, O. Schelen, "Evaluation of quality of service schemes for IEEE 802.11 wireless LANs," *Proceedings of the 26th Annual IEEE Conference on Local Computer Networks*, pp. 348-351, Nov. 2001.

[38] R. Braden, D. Clark, and S. Shenker, "Integrated Services in the Internet Architecture: an Overview," *IETF RFC 1633*, June 1994.

[39] S. Blake et al., "An Architecture for Differentiated Services," *IETF RFC 2475*, Dec. 1998.

[40] Z. Mammeri, "Approach for End-to-End QoS Mapping and Handling," *Proceedings of the Wireless and Optical Communications Networks (WOCN 2005)*, pp. 265-269, 2005.

[41] Q. Ni, L. Romdhani, T. Turletti, I. Aad, "QoS Issues and Enhancements for IEEE 802.11Wireless LAN," *Report on Research*, *INRIA*, Nov. 2002.

[42] J.M. Ho, "Some Comments on 802.11e Draft 2.0," *IEEE 802.11e working document 80211-02/005r0*, Jan. 2002.

[43] G. Ferrari, "Applying Feedback Control to QoS Management", *Proceedings of the 7th CaberNet Radicals Workshop*, pp.13-16, October 2002.

[44] J.L. Chen, H.C. Cheng, and H.C. Chao, "Scheduling Disciplines in Cellular Data Services with Probabilistic Location Errors," *Lecture Notes in Computer Science*, pp. 307-316, 2001.

[45] D.A. Eckhardt and P. Steenkiste, "Effort-limited Fair (ELF) Scheduling for Wireless Networks," *Proceedings of the IEEE Conference on Computer and Communications*, pp. 26-30, 2000.

[46] S.L. Tsao, "Extending Earliest-due-date Scheduling Algorithms for Wireless Networks with Location-Dependent Errors," *Proceedings of the IEEE Conference on Vehicular Technology*, Vol.1, pp. 223-228, 2000.

[47] J. Yin, X. Wang and D.P. Agrawal, "Optimal Packet Size in Error-prone Channel for IEEE 802.11 Distributed Coordination Function," *Proceedings of the IEEE WCNC'2004*, pp. 1654-1659, 2004.

[48] T.F. Abdelzaher, J.A. Stankovic, C.Y. Lu, R.H. Zhang, and Y. Lu, "Feedback Performance Control in Software Services," *IEEE Control Systems Magazine* Vol.23, Issue 3, pp. 74-90, June 2003.

[49] G. Quadros, A. Alves, E. Monteiro, and F. Boavida, "How Unfair Can Weighted Fair Queuing be," *Proceedings of 5th IEEE Symposium on Computer and Communications*, pp.779-784, 2000.

[50] S. Lu, V. Bharghavan, and R. Srikant, "Fair Scheduling in Wireless Packet Networks," *ACM SIGCOMM*, pp.63-74, Aug. 1997.

[51] T. S Ng, I. Stoica, and H. Zhang. "Packet Fair Queueing Algorithms for Wireless Networks with Location-Dependent Errors," *Proceedings of the IEEE INFORCOM*, pp. 1103-1111, March 1998.

[52] P. Ramanathan and P. Agrawal, "Adapting Packet Fair Queuing Algorithms to Wireless Networks," *ACM MOBICOMM*, pp.1-9, Oct. 1998.

[53] P.E. Gill, W. Murray, and M.H. Wrigh, *Practical Optimization*, Academic Press, New York, 1981.

[54] I. King, K.C. Sia, "Relevance Feedback Based on Parameter Estimation of Target Distribution," *Proceedings of the 2002 International Joint Conference on Neural Networks*, Vol.2, pp.1974-1979, 2002.

[55] L. Ying, T. Abdelzaher, L. Chenyang, L. Sha and X. Liu, "Feedback Control with Queuing-theoretic Prediction for Relative Delay Guarantees in Web Servers," *Proceedings of the 9th IEEE Real-Time and Embedded Technology and Applications Symposium*, pp. 208–217, 2003.

[56] M. Amirijoo, J. Hansson and S.H. Son, "Specification and Management of QoS in Imprecise Real-time Databases," *Proceedings of the 7th International Database Engineering and Applications Symposium*, pp. 192-201, 2003.

[57] K. Ogata, *Modern Control Engineering*, Prentice-Hall, 1995.

[58] N.K. Chen, J.L. Chen, "Feedback QoS control scheme for wireless network applications," *Computers and Electrical Engineering Journal*, Vol. 33, Issue 3, pp. 221-229, May 2007.

[59] J.L. Chen , N.K. Chen, "Feedback Closed-loop Scheduling Discipline for QoS Guarantee in Mobile Applications," *Proceedings of the IASTED International Conference on Parallel, Distributed Computing and Networks*, pp.201-206, 2004.

[60] C. Lu, J.A. Stankovic, G. Tao and S.H. Son, "Feedback Control Real-Time Scheduling: Framework, Modeling, and Algorithms," *Journal of Real-Time Systems- Special Issue on Control-theoretical Approaches to Real-Time Computing*, pp. 85-126, July 2002.

[61] P.T. Kabamba, S.M. Meerkov, W.E. Stark and C.Y. Tang, "Feedforward Control of Data Rate in Wireless Networks," *Proceedings of the 40th IEEE Conference on Decision and Control,* Vol.2, pp.1043-1048, Dec. 2001.

[62] X. Lu, R.O. Morando and E. Zarki, "Understanding Video Quality and Its Use in Feedback Control," *Proceedings of the International Workshop on Packet Video*, pp.1-10, 2002.

[63]J. Jackson Juliet Roy, V. Vaidehi, S.Srikanth, "Feedback Based Dynamic Scheduler for VBR Multimedia Services in IEEE 802.11e WLAN," *Proceedings of the Wireless and Optical Communications Networks*, pages: 5, 2006.

[64] I. AI Khatib, "Wireless LAN Access Points as Link with Adaptive Bandwidth: Throughput and Feedback Control", *Proceedings of the IEEE 10th International Conference on Telecommunications,* Vol.1, pp.754-760, Feb. 2003.

[65] A.G. Alexiou, C.J. Bouras and V.G. Igglisis, "A Decision Feedback Scheme for Multimedia Transmission Over 3G Mobile Networks," *Proceedings of the Second IFIP International Conference on Wireless and Optical Communications*

Networks, pp.357-361, March 2005.

[66] H. Zhou, D. Hoang, P. Nhan and V. Mirchandani, "Introducing Feedback Congestion Control to a Network with IEEE 802.11 Wireless LAN," *Proceedings of the IEEE Wireless Telecommunications Symposium*, pp.61-66, May 2004.

[67] Q. Bi, G.I. Zysman, and H. Menkes, "Wireless Mobile Communications at the Start of the 21st Century," *IEEE Communications Magazine*, Vol.39, No.1, pp. 110-116, 2001.

Curriculum Vitae

Nong-Kun Chen received the B.S degree in Information and Computer Education from National Taiwan Normal University in 1992, and received his M.S degree in Computer Science and Information Engineering from National Dong Hwa University in 2000. He is currently a Ph.D. candidate in department of Computer Science and Information Engineering, National Dong Hwa University, Hualien, Taiwan. His research interests include the areas of mobile cellular networks, feedback control system, and RFID system.

Publication List

Journal papers

1. Jiann-Liang Chen, **Nong-Kun Chen**, "Feedback closed-loop scheduling discipline for QoS guarantee in mobile applications," *ACM Wireless Networks*, vol. 12, no. 2, pp.223-232, Mar. 2006. (SCI, IF=0.812)
2. **Nong-Kun Chen**, Jiann-Liang Chen, "Feedback QoS control scheme for wireless network applications," *Computers and Electrical Engineering*, vol. 33, no. 3, pp. 221-229, May 2007. (SCI, IF=0.154)
3. **Nong-Kun Chen**, Jiann-Liang Chen, Teng-Hsun Chang, Cheng-Yen Wu, "Reliable ALE Middleware for RFID Network Applications," under revision in *International Journal of Network Management*, (*NEM-07-0035.R1*), Nov. 2007. (EI)
4. **Nong-Kun Chen**, Jiann-Liang Chen and Cheng-Chun Lee, "Array-based Reader Anti-Collision Scheme for Highly Efficient RFID Network Applications," under revision in *Wireless Communications and Mobile Computing* (*WCM-07-0185*), Sep. 2007. (SCI)

Conference papers

1. H.W. Tzeng, J.L. Chen, and **N.K. Chen**, "Traffic Grooming in OWDM Network Using Genetic Algorithm," *Proceedings of the IEEE SMC Conference*, Vol. I, pp.1003-1006, 1999.
2. Jiann-Liang Chen, **Nong-Kun Chen**, "Feedback Closed-loop Scheduling Discipline for QoS Guarantee in Mobile Applications," *Proceeding of IASTED International Conference on Parallel and Distributed Computing and Networks*, Austria, pp.201-206, 2004.

3. Jiann-Liang Chen, **Nong-Kun Chen**, "Adaptive Radio Resource Scheduling in an Integrated GPRS/UMTS Service Network," *Proceeding of Sixth IASTED International Multi-Conference on Communication Systems and Applications*, Banff, pp. 157-161, July 2006.

4. **Nong-Kun Chen**, Jiann-Liang Chen, "Reliable ALE Middleware for RFID Network Applications," *Proceeding of the International Conference on EEE'07*, Las Vegas, pp. 183-189, June 25-28, 2007.