PLUS-DAC:An Admission Control Scheme in IEEE 802.11e Wireless LANs.

M. Tech. Project Dissertation

Submitted in partial fulfillment of the requirements

for the degree of

Master of Technology

by

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2005

Dedicated to my mother

Abstract

With increasing demand of support for realtime applications, there is a compelling need for Quality of Service (QoS) in present day wireless LANs. IEEE 802.11 Medium Access Control (MAC) has become a defacto standard for wireless LANs, but there are many inherent QoS limitations in the base standard, as it was basically developed for best effort data services.

The IEEE 802.11 Task Group E (TGe), is about to ratify a QoS extension to the base 802.11 standard namely IEEE 802.11e. The IEEE 802.11e standard provides many mechanisms for QoS support at the MAC layer level. However, even the service differentiation provided in IEEE 802.11e is not enough to meet the QoS requirements of time bounded multimedia traffic at high load. These can be better satisfied, if we employ Admission Control and Bandwidth Reservation mechanisms.

Another important concern in WLANs is channel utilization. Generally, partitioning based reservation schemes do static division of bandwidth. When bandwidth is divided statically, often, more bandwidth can get allocated to a category which is currently not offering much traffic to the network, resulting in under-utilization of the bandwidth resources. More over, the bandwidth partitioning should not be purely based on the priority of the traffic.

We propose a measurement based distributed admission control mechanism, for the IEEE 802.11e Wireless Local Area Network (WLAN) functioning in infrastructure mode. We call the scheme PLUS-DAC (Priority, Load and Utilization based Scheme for Distributed Admission Control). PLUS-DAC measures the load and utilization in the BSS and adapts the Transmission Opportunity (TXOP) reservation dynamically. Our results show that, PLUS-DAC can achieve quasi-optimal utilization and continue to satisfy QoS guarantees given to multimedia flows.

Acknowledgements

I like to take this opportunity to express my deep sense of gratitude for **Prof. Varsha Apte** and **Prof. Sridhar Iyer**, for providing excellent guidance and support. It is because of their constant interest and assistance that this project has been successful. I would like to thank all the members of the **PerfNet Group** at CSE Department, IIT Bombay, for their valuable suggestions and helpful discussions.

I would also like to thank every member of **KReSIT family** who have been a source of encouragement and inspiration throughout the duration of this project.

I would like to thank Pierre Ansel, Qiang Ni and Thierry Turletti for making their FHCF Implementation in *ns-2* available, which we have extended in our Simulations.

Finally I would be thankful to my **family** and **friends** who have given me emotional support through out the duration of the project.

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Chapter 1

Introduction

1.1 Wireless and Convergence - The Future

As we move into the 21st century, it is becoming more apparent that IP networks are the next generation networks for all forms of communication. Industry surveys reveal that spending on *voice over IP* (VOIP), is likely to double every year in the next decade. As VoIP is becoming increasingly popular, the popularity will only grow as *Wireless LAN* (WLAN)s become more commonplace. The convergence of these two highly disruptive technologies will alter the way enterprises communicate and do business.

Although today the voice over WLAN market is a small and immature market it is also one with a significantly growing amount of interest and potential. A significant benefit of mixing telephone traffic with data on a WLAN is to make use of a common infrastructure and provide mobility. The support of a common system for both data and voice traffic is generally simpler and less expensive than two separate entities. Currently this application appeals to markets such as education, health-care and retail because they were amongst the first to roll out WLAN networks. In the longer term, all users of WLAN networks could eventually find a business case within the context of inter-operability between WLANs and 3G networks.

1.2 Challenges in Wireless Networks

Having said that the future lies with wireless converged networks, the transformation is not an easy process. More over the wireless community faces certain inherent challenges and constraints that are not imposed on their wired counterparts. We list few of the challenges here.

1. **Standards:** Major challenge is compliance with various existing standards and inter-operability among them. Presently, most of the VOIP solutions for wireless LANs are

proprietary. Various national and international frequency regulations have to be considered in making wireless devices suitable for global operation.

2. **Bandwidth:** Bandwidth is the one of the most scarce resource in wireless networks. Even with emerging high speed WLAN technologies, the available bandwidth in wireless networks is far less than the wired links.

3. **Link Errors:** Channel fading and interference cause link errors and these errors may sometimes be very severe. More over the effect of these errors is often global, i.e. not local to a single node, may effect the entire network.

4. **Mobility and Roaming:** Existing applications should continue to run over WLANs even while roaming the the network. The fact that wireless access and mobility should be hidden if not relevant.

5. **Inter-operability with wired Networks:** Already a lot of money has been invested on VOIP implementations in wired LANs. Hence new WLAN mechanisms must protect this investment by being inter-operable with the existing networks.

6. **Power Constraints:** Devices communicating via a WLAN are typically also wireless devices running on battery power. Hence, WLAN must implement special power saving modes and power management functions.

7. **Safety and security:** Another important concern is of safety and security. WLANs should be safe to operate, especially regarding low radiation. Furthermore, no users should be able to read personal data during transmission i.e., encryption mechanism should be integrated. The network should also take into account user privacy.

1.3 Need for Quality of Service

Quality of Service (QoS) is a broad term used to describe the overall experience the user or application will receive over a network. Generally QoS is achieved through giving importance to prioritized applications by means of “Controlled Unfairness”. VOIP and multimedia applications are loss and delay sensitive, and need strict QoS guarantees. For a good quality multimedia service, unidirectional latency should be less than $150ms$ and packet loss should be less than 10%. The LAN component of these requirements should be more stringent. More over end to end delay is non deterministic in nature due to variable processing and queuing delays, which might lead to high jitter.

The fraction of bandwidth required by high priority traffic compared to low priority traffic is low. For example, the bandwidth requirements of VOIP traffic with added overheads are less than 100 Kbps (e.g. G.711, G.723 codecs). Even video conferencing applications (H.261 and H.263 codecs) have bandwidth requirements between 100 Kbps to 400 Kbps. MPEG video streams have bandwidth requirements of 1-4 Mbps, but they are generally used for broadcast. Never the less, reserving bandwidth for high priority flows is required for meeting their QoS requirements as at high load conditions, low priority traffic tend to disturb the high priority flows.

1.4 QoS in IEEE 802.11 WLANs

The IEEE 802.11 WLAN standard [1] has become a de-facto standard for wireless data networks. It has been widely accepted in various environments because of its simplicity, flexibility and robustness against failures. With wireless LANs starting to be used for more than just data traffic, the need for QoS provisioning has grown tremendously in the recent years. But providing QoS guarantees in a legacy 802.11 LAN can be very difficult as it is basically designed for best effort data services.

A special task group IEEE 802.11e Task Group has been set up to develop an extension to the base IEEE 802.11 standard for supporting QoS mechanisms. The task group is finalizing work on IEEE 802.11e [2], a MAC level QoS standard, which will enable the administrator to specify a range of priorities for different kinds of packets and control the delay requirements of the traffic. The upcoming IEEE 802.11e provides priority based service differentiation based on a queue model in contrast to the station model of the IEEE 802.11 standard. Each Station (STA) supports multiple *Traffic Streams* and each of the traffic streams have different priorities. The service differentiation is implemented by choosing backoff parameters and inter-frame spaces in such a way as to give one traffic stream priority over the other [2, 3].

IEEE 802.11e supports a new Coordination function called Hybrid Coordination Function (HCF), which includes a contention based channel access known as Enhanced Distributed Channel Access (EDCA) as well as a polling based channel access known as HCF Controlled Channel Access (HCCA). EDCA extends the Distributed Co-ordination Function (DCF) of the

802.11 MAC, by allowing traffic streams to have priorities. The standard also gives provisions to support scheduling and traffic negotiation and timer management.

1.5 Problem Statement

For any network that tries to ensure QoS, simply implementing QoS-enabling scheduling algorithms is not enough. *Admission Control* mechanisms are also required, so that the offered load to the network can be kept under control. This is especially true about contention based access mechanisms such as EDCA. At high load, the performance of EDCA degrades considerably, and QoS guarantees of even high-priority traffic may not be met. Thus admission control mechanisms for the EDCA are necessary.

Another important concern in WLANs is channel utilization, any QoS provisioning scheme should try to achieve optimal channel utilization. Bandwidth reservation, is essential for giving QoS guarantees to real time traffic. However, an approach based on static partitioning is not efficient, when bandwidth is divided statically, often, more bandwidth gets allocated to a category which is currently not offering much traffic to the network, resulting in under-utilization of the bandwidth resources. More over, we claim that bandwidth partitioning should not be purely based on the priority of the traffic.

We propose a mechanism, called PLUS-DAC (*Priority, Load and Utilization-based Scheme for Distributed Admission Control*). PLUS-DAC is a flexible mechanism, which monitors load and priority and continuously adjusts the fractions of bandwidth reserved for each category to reflect actual requirement. Through simulation in various scenarios, we show that PLUS-DAC indeed outperforms static bandwidth reservation-based mechanisms - it is able to admit more streams, while still meeting QoS requirements.

1.6 Thesis outline

The main objectives of this thesis are,

- to give an overview of the upcoming IEEE 802.11e standard.
- to give an insight into the current work for QoS in IEEE 802.11 WLANs.
- to describe the PLUS-DAC mechanism for infrastructure based WLANs.

- to summarize the results of simulation in various scenarios considered.

The thesis is outlined as follows. In the next chapter we describe channel access in 802.11 and briefly discuss the problems with the legacy standard. In chapter 3, the currently discussed MAC enhancements to support QoS are summarized based on the status of the standard at the time this report is written.

In chapter 4, we discuss the need for admission control by looking in to various schemes suggested so far in admission control for IEEE 802.11e WLANs. Then in chapter 5, we propose a simple architecture to support admission control and explain the PLUS-DAC mechanism.

The various simulation scenarios and parameters used in the simulation are described in chapter 6. Following this, results of simulation and behaviour of performance metrics are summarized. The thesis ends in chapter 7 with conclusions and future directions that can be explored.

Chapter 2

IEEE 802.11 WLAN Standard

IEEE 802.11 MAC standard, which belongs to the family of IEEE 802.x LAN standards. This standard specifies the physical and medium access layer adapted to specific requirements of wireless LANs. This chapter gives a brief overview of the standard and and describes its limitations in providing QoS.

IEEE 802.11 MAC defines two medium access coordination functions, a mandatory coordination function called Distributed Coordination Function (DCF) and an optional coordination function called Point Coordination Function (PCF). DCF provides an asynchronous transmission based on CSMA/CA scheme. PCF provides synchronous transmission based on a centralized polling, but relies on the asynchronous service provided by DCF.

2.1 System Architecture

The basic service set (BSS) is the fundamental building block of the IEEE 802.11 architecture. A BSS is defined as a group of stations that are under the direct control of a single scheme (either DCF or PCF). The geographical area covered by the BSS is known as the basic service area (BSA). Conceptually, all stations in a BSS can communicate directly with all other stations in a BSS.

An adhoc network is a grouping of stations into a single BSS for the purposes of communications without the need for a centralized controlling entity. The IEEE 802.11 standard specifies the term Independent BSS (IBSS) for such an adhoc network. Figure 2.1 shows an IBSS. Any station can establish a direct communication session with any other station in the BSS, without the requirement of channeling all traffic through a centralized entity Access Point (AP).

Infrastructure networks are established to provide wireless users with specific services and explicit channel access. Infrastructure networks are established using APs. Figure 2.2 shows

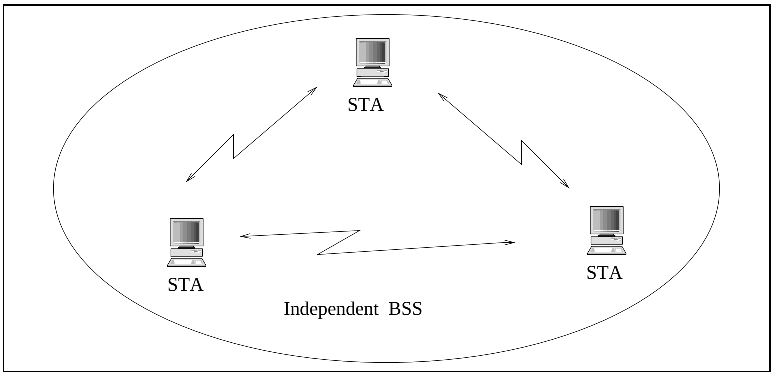

Figure 2.1: 802.11 AdHoc Network

an Infrastructure based network. Range extension is provided by introducing the integration points necessary for network connectivity between multiple BSSs. The entity thus formed is called an Extended Service Set (ESS). The ESS consists of multiple BSSs that are integrated together using a common distribution system (DS). The DS is kind of a backbone network that is responsible for MAC-level transport of MAC service data units (MSDUs). The DS, as specified by IEEE 802.11, is implementation independent i.e it could be either wired wired IEEE 802.3 Ethernet LAN, IEEE 802.4 token bus LAN, IEEE 802.5 token ring LAN, Fiber Distributed Data Interface (FDDI), Metropolitan Area Network (MAN) or another IEEE 802.11 wireless medium.

2.2 DCF: Distributed Coordination Function

Distributed Coordination Function operates based on the 1-persistent CSMA/CA (Carrier Sense Multiple Access with Collision Avoidance) mechanism [1]. Any station detecting the channel

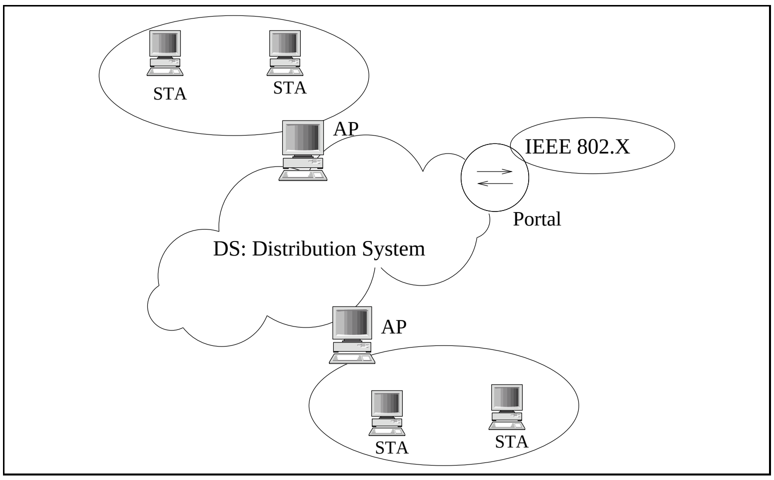

Figure 2.2: 802.11 Infrastructure Based Network

idle for a period of DCF Inter-frame space(DIFS), performs the backoff procedure. The duration of the backoff interval is determined by Contention Window(CW), which is a multiple of $rand[0, CW]$ and a slot time. CW varies from CW_{min} to CW_{max} and slot time depends on the PHY layer type. If the channel remain idle for a duration of DIFS plus backoff interval then the station is allowed to transmit one MSDU (MAC Service Data Unit). If two stations try to transmit at the same time, collision occurs. Each station acknowledges the successful transmission as there is no specific scheme for collision detection. Acknowledgment is transmitted after SIFS (Short Inter-frame space) interval, after receiving the packet. CW is set to CW_{min} after a successful transmission, and doubled after each unsuccessful transmission to avoid additional collisions. CW value is freezed when any other station gets the access to the channel. Carrier sensing can be physical or virtual. Physical carrier sensing is implemented as a function called CCA (Clear Channel Assessment) which is PHY dependent. Virtual carrier sensing mechanism is implemented with the help of NAV (Network Allocation Vector), which is a timer updated with the value of other stations' transmission duration.

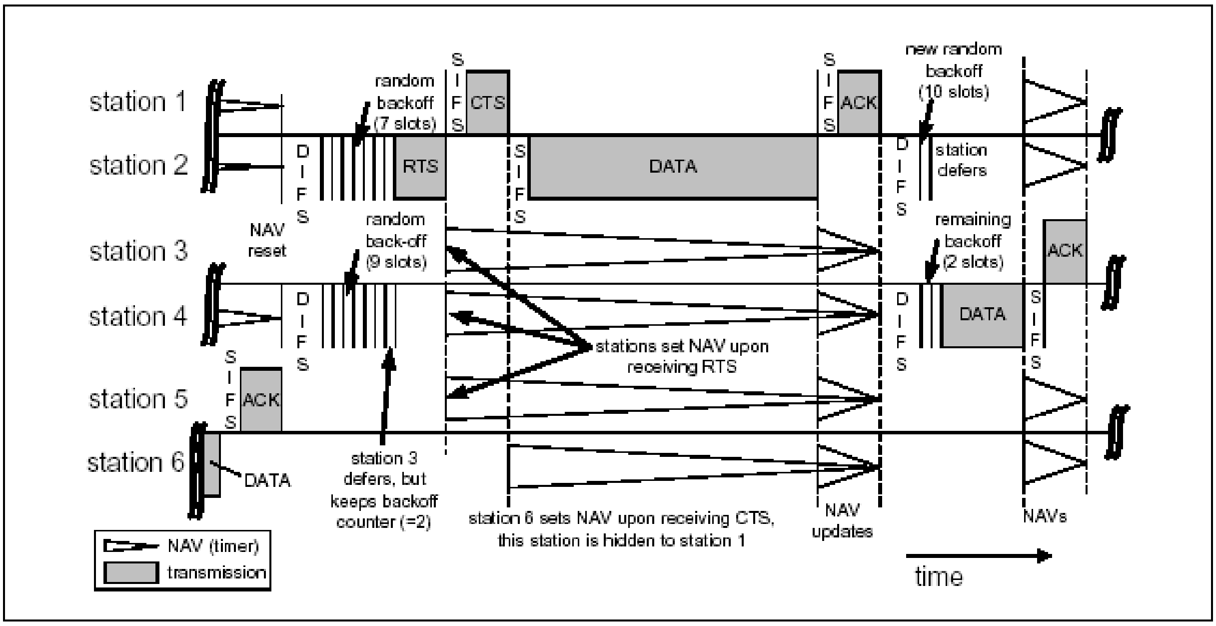

Figure 2.3: NAV updating in 802.11 DCF

The probability of collision generally increases with the length of the data frame. To reduce this effect, long data frames can be fragmented, and fragments can be transmitted sequentially as individual data frames. To avoid the hidden terminal problem [1], an optional RTS/CTS (Request to Send / Clear to Send) scheme can be used. The transmitting station sends a short

RTS frame before transmitting the MSDU and the receiving station responds with a CTS frame if it is ready to receive the MSDU. All other stations update their local NAV to the duration specified in either RTS or CTS as shown in Figure 2.3. To reduce the overheads appropriate *threshold* values (Fragmentation threshold and RTS/CTS threshold) have to configured. For further details refer to IEEE 802.11 standard [1].

QoS LIMITATIONS: As IEEE 802.11 is basically designed for Best Effort service, DCF has inherent QoS limitations. DCF does not provide any service differentiation between the traffic streams. The values of the parameters like DIFS, CW_{min}, and CW_{max} are globally same for all the stations. The variations of CW do not depend on network conditions and are not dynamic, i.e CW is always doubled after an unsuccessful transmission and set to CW_{min} after a successful transmission.

2.3 PCF:Point Coordination Function

PCF is an optional Coordination Function suggested in IEEE 802.11, to support time bounded services in Infrastructure mode. The radio channel is controlled by a point coordinator co-located with the Access Point. The time is divided into repeated periods called *superframes*, where each super frame starts with a beacon frame sent by the point coordinator. The PC gets priority over other stations as it waits only for PIFS (PCF Inter-Frame Space), rather than DIFS ($> PIFS$). But it does not interfere with any ongoing transmissions as SIFS is less than PIFS.

Each super frame is divided into Contention Free Period(CFP) and Contention Period(CP), with a requirement thatCP should be large enough to transmit at least one MSDU using DCF. A beacon frame is a management frame which is transmitted by the PC at regular intervals (start of each super frame). It contains values for various parameters required for time synchronization and power management. The beacon frame contains CFP_{max} and $TBTT$ (Target Beacon Turn around Time) values, which are used by the STAs(Stations) to set their NAV for synchronization purposes. CFP_{max} is the maximum duration of CFP, which can be terminated early by sending a CF-End frame. During CFP PC polls each station by sending a CF-Poll frame, which can be piggy backed on to the data frame for that station, if available. The polled station responds with an acknowledgment, and if there is no response from the polled station, after PIFS interval PC polls the next station. Each STA can specify the way it can be polled, by setting the CF-Pollable subfield of Capability Information field in Association Request and/or Re-association Request frames. For further details refer to [1].

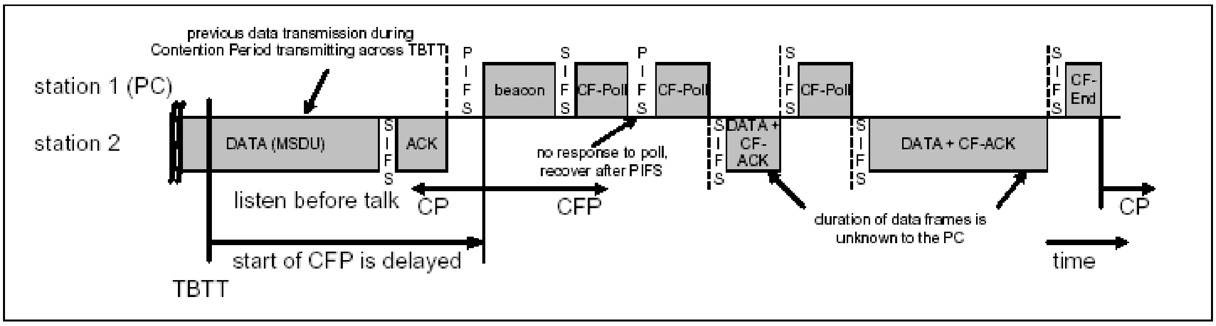

Figure 2.4: The PCF Limitations

QoS LIMITATIONS: PCF as it is, has various limitations. Though it is designed for providing time bounded service, the centralized polling scheme is highly complex and inefficient. PCF can not provide parameterized QoS, it can only allow the stations to have prioritized access to the wireless medium. According to IEEE 802.11 standard, all the communication during CFP has to go through the AP which is highly inefficient.

The beacon delays and the transmission duration of the polled stations are unpredictable. Generally at TBTT, all the stations set their NAV to a maximum value, thus not contending for the channel. But according to legacy IEEE 802.11standard, STAs can start transmission even if the MSDU delivery can not be finished before upcoming TBTT, which might result in a beacon frame getting delayed as shown in the Figure 2.4. When a station is polled, the transmission duration for which the STA may occupy channel is not under the control of PC as data frame may be fragmented. In 802.11a, different encoding and modulation schemes are defined, as a result the duration of MSDU delivery can be arbitrary. These limitations were detailed in [4, 3]. If a station misses the previous beacon, it doesn't have its NAV set, so it may interfere during CFP. Further it doesn't set its NAV at TBTT.

Chapter 3

Overview of IEEE 802.11e QoS Standard

As legacy IEEE 802.11 is inefficient for QoS, IEEE 802.11 *Task Group E*(TGe) defines mac level QoS enhancements to the base 802.11 MAC, referred to as IEEE 802.11e. and is about to ratify IEEE 802.11e very soon. The overview presented in this document is based on the draft-9 of the standard. A Station that operates according to IEEE 802.11e is called *QoS supporting Station* (QSTA). One of the QSTAs which may optionally work as a centralized coordinator for all stations in the *QoS supporting Basic Service Set* (QBSS) is called *Hybrid Coordinator* (HC), which is generally co-located with *QoS enhanced Access Point* (QAP).

HCF: The major enhancement of IEEE 802.11e is the new coordination function called *Hybrid Coordination Function* (HCF) , which specifies two mechanisms - HCCA (HCF Controlled Channel Access), which is a polling-based mechanism and EDCA (Enhanced Distributed Channel Access), which is a contention-based access mechanism. Controlled channel access can also be used during CP, which is referred to as *Controlled Access Phase* (CAP).

TXOP: The IEEE 802.11e introduces the notion of *Transmission Opportunity* (TXOP), which is an interval of time during which a station has a right to initiate transmissions. A TXOP is defined by a starting time and a maximum limit on the interval. TXOP can be obtained by either contention based channel access (called EDCA-TXOP) or controlled channel access. An EDCA-TXOP is limited by a QBSS wide parameter called *TXOPLimit*, which is broadcast by the HC in an information field of the *beacon frame*. For the controlled TXOP, TXOPLimit can be specified by the QoS enhanced Contention Free Poll (CF-Poll). As legacy stations do not understand the new information fields they may transmit for longer durations than allowed by the TXOPLimit [4].

In IEEE 802.11e, no backoff entity is allowed to transmit, if it can not finish before next TBTT. This gives HC a better control over the channel. Further, any backoff entity can directly communicate with other backoff entity with out the intervention of the QAP, called *Direct Link* (DiL). To establish DiL, a set-up procedure called *Direct Link Protocol* (DLP) has to be performed. In IEEE 802.11e data frames can be protected by using RTS/CTS, with out considering any threshold. similarly an MSDU can be fragmented into multiple MSDUs with any fragmentation size. But the condition in both the cases is that transmission duration must not exceed the TXOPLimit.

3.1 HCF Contention based Channel Access:EDCA

Enhanced Distributed Channel Access(EDCA) is the contention based channel access part of HCF. It provides service differentiation by introducing the notion of Access Category (AC) and parallel backoff entities with in each QSTA as shown in Fig 3.1.

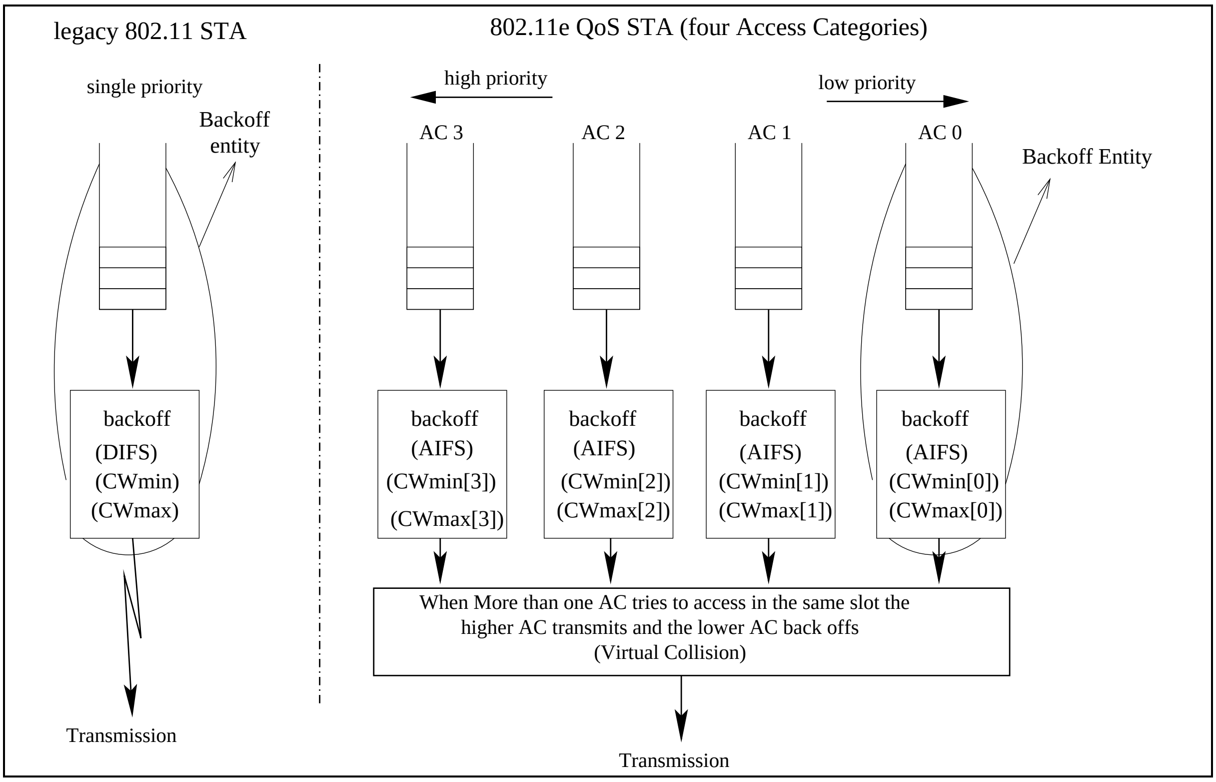

Figure 3.1: Queue model in the IEEE 802.11e QSTA

Each backoff entity is characterized by the AC specific parameters, called EDCF parameter sets. There are four different ACs, with four priorities AC 0 .. 3, which correspond to the priorities defined by IEEE 802.1D, as described in Table 3.1.

802.1D priority	**802.1D interpretations**	**802.11e AC**	**Service Type**
0	Best Effort	0	best effort
1	Back Ground	0	best effort
2	,,	0	best effort
3	Excellent Effort	1	video probe
4	Controlled Load	2	video
5	Video $< 100ms$ delay	2	video
6	Voice and Video $< 10ms$ delay	3	video / voice
7	Network Control	3	network control

Table 3.1: 802.1D Priority - AC mapping

These priorities can be realized by modifying the back-off procedure with EDCA parameter sets. Each back-off entity within a QSTA, which can be thought of as a virtual station, contends for TXOP independently. If the counters of two or more back-off entities reach zero at the same time, the scheduler inside the QSTA resolves this by granting the TXOP to the back-off entity with higher priority (virtual collision). Note that there is still a probability that the transmitted frame may get collided with the transmission of a backoff entity belonging to another QSTA (external collision).

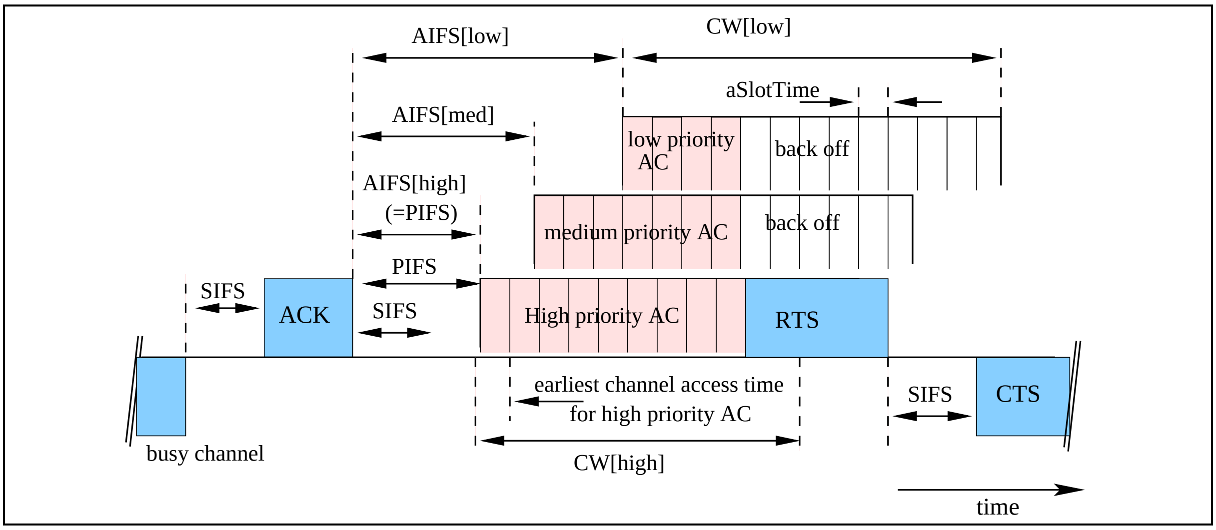

Figure 3.2: Channel Access in 802.11e

EDCA Parameters

In IEEE 802.11e, different backoff entities have different inter frame spaces, contention windows and other many other parameters. These values comprise the EDCF parameter sets per AC as shown in Figure 3.1. The values to be used by the backoff entity are defined by the HC and broadcast via information fields in the beacon frames. Different backoff entities of same AC use the same EDCF parameters . The default set of EDCA parameters are the *Arbitration Inter-Frame Space* ($AIFS[TC]$), the *Contention Window* ($CW_{min}[AC], CW_{max}[AC]$) and the *Maximum TXOP* ($TXOPLimit[AC]$).

- ARBITRATION INTER-FRAME SPACE (AIFS): In IEEE 802.11e, each backoff entity has a different Inter frame space called *Arbitration Inter-Frame Space* ($AIFS[AC]$). The $AIFS[AC]$ is at least PIFS and defined using Arbitration Inter-Frame Space Number ($AIFSN[AC]$) as below.

$$AIFS[AC] = SIFS + AIFSN[AC] \cdot \textit{aSlotTime}$$

- CONTENTION WINDOW: The contention window limits, ($CW_{min}[AC], CW_{max}[AC]$), are dependent on the AC. Unlike legacy IEEE 802.11, an IEEE 802.11e backoff entity chooses its backoff counter as a random number from the interval $[1, CW + 1]$ instead of $[0, CW]$. As a result, with the minimum $AIFS[AC]$ being PIFS, the earliest channel access time after the channel became idle is DIFS, similar to the legacy protocol. But priority over legacy stations can be achieved by setting $AIFSN[AC] = 1$ and $CW_{min}[AC]$ to a less value. Xiao [5] has shown that differentiating the inter frame space doesn't result in increase in the saturation throughput of the higher priority class. Thus differentiating the initial contention window size is better than differentiating inter frame space in terms of total throughput and delay. The smaller $CW_{min}[AC]$, the higher is the priority in channel access, but it has to be noted that the collision probability increases with smaller $CW_{min}[AC]$ if there are more than one backoff entity of the same AC. The positions of the contention windows are important factors in defining the relative priorities for channel access per AC. EDCF can not support strict priorities between ACs, though the initial contention windows are made not to overlap at all, as soon as CWs increase upon collisions, the strict differentiation is lost [4]. Similar to $CW_{min}[AC]$, the smaller the $CW_{max}[AC]$, the higher is the channel access priority, but a smaller $CW_{max}[AC]$

value may increase collision probability. It has to be noted that the retry counters limit the number of retransmissions and hence limit the maximum size of the CW.

- MAXIMUM TXOP (TXOPLIMIT): $TXOPlimit[AC]$ is also made a part of EDCF parameter set in addition to the backoff parameters. The larger the $TXOPlimit[AC]$, the larger is the share of channel capacity for the AC.

3.2 HCF Controlled Channel Access (HCCA)

In IEEE 802.11e, stations can also obtain TXOP, from HCF controlled channel access (HCCA) mechanism, in which case HC allocates the TXOPs to stations by sending a *QoS enhanced CF-Poll*. HCCA is similar to PCF, but more flexible. HCCA can operate both in CFP and CP, enabling the HC capable of giving strict QoS guarantees. A Typical super frame in IEEE 802.11e will be as shown in Figure 3.3. Each super frame contains an optional CFP and a mandatory CP. During CP HC is allowed to start Contention Free Burst (CFB) at any time, which is called Controlled Access Period (CAP). HC gets priority over other QSTAs as it waits for only PIFS, with out any backoff after the channel has become idle. Though HCCA can provide more strict guarantees than EDCF, the latter is mandatory in the standard as it is used to transmit the Traffic Specifications (TSPEC) between QSTA and QAP. The maximum duration of HCCA in a super frame is bounded by $T_{CAPlimit}$.

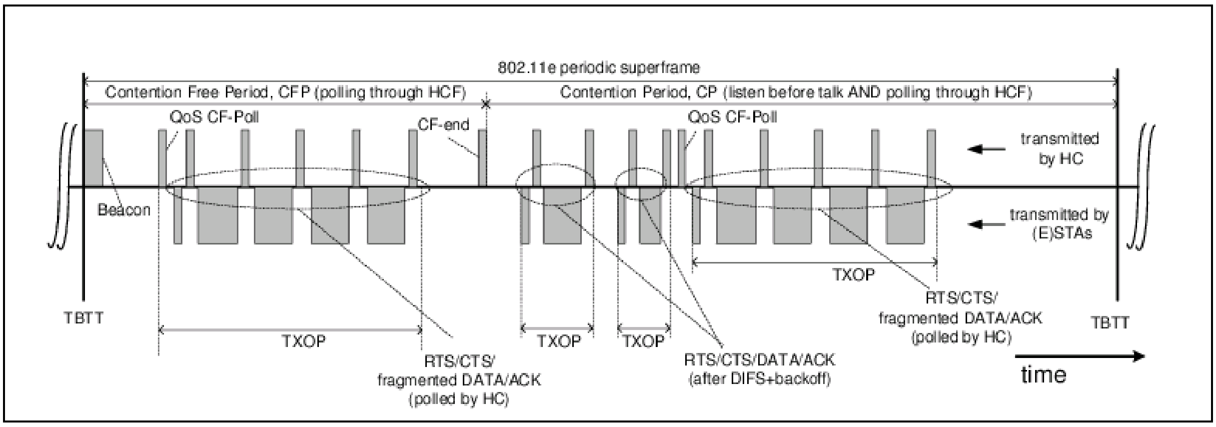

Figure 3.3: IEEE 802.11e super frame

To determine and classify MSDUs that are delivered with in a QBSS with certain QoS guarantees, IEEE 802.11e uses the concept of *Traffic Stream* (TS)s, which are identified by *Traffic Stream Identifier* (TSID). A traffic stream has to be established before any data transmission.

Each QSTA can have up to a maximum of eight TSs. Here it is to be noted that ACs and traffic streams are separated in the standard and use different MAC queues. To establish a traffic stream, a QSTA has to send a QoS request containing the corresponding TSPEC to the QAP. A TSPEC describes the QoS requirements of the station, such as , mean data rate, the maximum MSDU size, the delay bound and the maximum RSI (Required Service Interval). The maximum RSI, is the maximum time duration between the start of successive TXOPs that can be tolerated by the application. [2, 6]

After receiving all QoS requests from the QSTAs, QAP Scheduler first determines the minimum of all the maximum RSIs required by different Traffic Streams. Then it chooses the highest sub multiple of beacon interval, which is less than the minimum of maximum RSIs as the SI (Service Interval). Now beacon interval is cut into SIs and QSTAs are polled accordingly in each selected SI. Selected SI is the time between start of TXOPs allocated to a QSTA, which is same for all the stations. Once the value of SI is determined, HC calculates the different TXOP values allocated to different traffic streams for different QSTAs as follows.

Suppose the mean data rate request of the application from traffic stream j of QSTA i is $\overline{\rho}_{i,j}$ and the nominal maximum MSDU size for the queue is $M_{i,j}$, then the number of packets arriving in the traffic stream can be calculated as

$$N_{i,j} = \lceil \frac{\overline{\rho}_{i,j}.SI}{M_{i,j}} \rceil$$

Now the TXOP, $T_{i,j}$ allocated to Traffic stream j of QSTA i can be calculated as,

$$T_{i,j} = \max(\frac{N_{i,j} \cdot M_{i,j}}{R} + O, \frac{M_{max}}{R} + O)$$

where R is the PHY layer transmission rate, M_{max} is the maximum MSDU size and O refers to the transmission overheads, which here can be assumed as $2SIFS + T_{ACK}$.

Now QAP scheduler sums up all the TXOP values of different traffic streams of a QSTA i as

$$TXOP_i = \sum_{j=1}^{J_i} T_{i,j}$$

where J_i is the number of active traffic streams in QSTA i. HC allocate $TXOP_i$ to $QSTA_i$ and allows it to send multiple frames with in the interval.

A simple call admission control is also suggested in the standard. When there are K QSTAs in the beacon interval, a new request from a new traffic flow can be accepted by the HCCA, if the $TXOP_{K+1}$ of the new request plus all the current TXOP allocations are lower than or equal to maximum allowed fraction of time, that can be used by HCCA, i.e.,

$$\frac{TXOP_{K+1}}{SI} + \sum_{i=1}^{K} \frac{TXOP_i}{SI} \leq \frac{T_{CAPLimit}}{T_{Beacon}}$$

where $T_{CAPLimit}$ is the maximum bound on HCCA and T_{Beacon} is the length of beacon interval. The above scheduling and call admission control are very simplistic and based on the assumption that all types of the traffic are CBR(Constant Bit Rate).

3.3 QoS Control

IEEE 802.11e frame header has also been enhanced to allow implementation of QoS mechanisms. Specifically, it contains an additional 2 byte field, called *QoS Control* that, among other things, identifies the Traffic Category (TC) to which the frame belongs. The structure of the field in QoS data type frame sent by a non-AP QSTA is as shown in Figure 3.4.

0 - 3	4	5 - 6	7	8 - 15
TID	1	Ack Policy	Reserved	Queue size

Figure 3.4: Qos Control Field in 802.11e Frame Header sent by non-AP STA

The TID field identifies the Traffic Category (TC) to which the frame belongs to. The Ack policy identifies the acknowledgment policy that should be followed upon the delivery of the packet. The queue size is an 8-bit field that specifies the amount of buffered traffic for a given TC (identified by TID), at the non-AP STA sending the frame. Traffic categories pertain to user priorities defined in IP header. Eight different traffic categories are mapped to four access categories as per IEEE 802.1D mapping.

3.4 Traffic Specification (TSPEC) element

Another interesting feature of IEEE 802.11e is TSPEC negotiation, which allows an IEEE 802.11 LAN to become part of a larger network providing end-to-end QoS delivery, or to function as an independent network providing transport on a per-link basis with specified QoS commitments. This element contains the set of parameters that identify the characteristics and QoS expectations of the traffic flow. These set of parameters are more extensive than may be needed or available for any particular instance of parameterized QoS traffic, in which case they can be left unspecified. Most of the fields are ported from RSVP, and are optional.

Some of the main parameters that TSPEC include are:

- **Nominal MSDU Size (L):** nominal size of MAC Service Data Units (MSDU), in octets. The size of the MSDU may be fixed and equal to this size, which is indicated by the most significant bit of the field.
- **Maximum MSDU Size (M):** maximum size of MSDUs belonging to the traffic category, in octets.
- **Mean Data Rate (λ):** average data rate specified in bits per second. This does not include the MAC and PHY overheads.
- **Peak Data Rate (PR):** maximum allowable data rate in bits per second.
- **Delay bound (D):** maximum allowed time for the transmission of MSDU specified in microseconds. This also includes the relevant acknowledgment transmission time.
- **Minimum PHY Rate (mR):** desired minimum PHY rate required for the transport of MSDUs, specified in units of bits per second.
- **Maximum Burst Size (MB):** maximum burst size that could arrive at peak rate, specified in octets.
- **Minimum Service Interval:** minimum interval, in units of microseconds, between the start of two successive Sevice Period (SP)s.
- **Maximum Service Interval:** maximum interval, in units of microseconds, between the start of two successive SPs.

3.5 Enhancements to IEEE 802.11e

This section some enhancements over IEEE 802.11e suggested in the literature. One of the major limitations of EDCA is that it is not capable of adapting its parameters to network conditions.

More over each backoff entity acts as a virtual station increasing the collision rate at high load. Romdhani et al [7], suggests an scheme that adapts CW according to the network conditions. The scheme changes the way in which the CW is modified after a Successful Transmission or Unsuccessful Transmission. CW[AC] varies differently for each AC, depending on *persistence factor* which will be different for different access categories.

HARMONICA [8] is a scheme that tries to choose optimal EDCA parameters based on Link layer Quality Indicator (LQI), which constitutes the parameters: drop rate, link layer end-to-end delay and throughput. The scheme consists of two algorithms namely base algorithm and relative algorithm. The base algorithm chooses the EDCA parameters based on throughput calculations at longer intervals, where as the relative algorithm tries to adapt these EDCA parameters, based on drop rate and link layer delay calculations.

Xiao and Li [9] have also proposed a mechanism, what they call global parameter control, to adapt EDCA parameters dynamically. The access point measures the parameters: failed transmission time (FTT) and successful transmission time(STT) per AC and adapt the EDCA parameters for that AC accordingly.

The simplistic HCF scheduling algorithm, suggested in IEEE 802.11e can be efficient, if the transmitted traffic is CBR. But when real time applications generate VBR traffic, the algorithm may cause an increase in the queue length and a possible packet drop. Fair HCF (FHCF) is a more flexible scheme that adopts to the fluctuating arrival rates. FHCF [6] is composed of two schedulers: the QAP Scheduler and the node scheduler. QAP scheduler is used to estimate the varying queue length of each Traffic stream at the beginning of each SI. A node scheduler is used to redistribute the remaining TXOP duration among the traffic streams at the node. A simple admission control for FHCF is suggested in [10].

Many other efforts have been described in the literature to better the QoS guarantees in IEEE 802.11e compliant WLANs, Interested readers can refer to [11, 12, 13, 4]. A good survey of the efforts made in the literature for QoS in IEEE 802.11 WLANs can be found in [14, 15].

Chapter 4

Related Work

4.1 Need for Admission control

Although the EDCA mechanism of the 802.11e MAC enables differentiated service for different traffic categories, it can provide QoS only if the load on the network is reasonable. If the traffic on the LAN increases beyond control, QoS guarantees to even high-priority traffic will be violated [3, 9]. *Admission control mechanisms* prevent the network from being congested, by "accepting" or "rejecting" flows depending on whether QoS guarantees can be met.

More precisely, the problem of admission control can be defined as: *Given that there are N[AC] flows of each AC existing in the QoS enabled basic service set (QBSS), determine whether the new flow belonging to a particular AC should be admitted or not. An admitted flow should not affect the guarantees given to the existing flows and should get its own QoS requirements satisfied.*

Challenges: Any admission control mechanism requires an indicator of the current load on the network, together with a criterion that decides whether under current conditions, a new flow can be admitted. However, in the case of distributed media access mechanisms, such as the EDCA, there may not be any node that has knowledge of the state of the network. Nonetheless, it is necessary to define a notion of available bandwidth, and to devise a frame work for distributing network state information within the BSS. Several admission control mechanisms [9, 16, 8, 17, 18] have been proposed recently, that address these challenges.

4.2 Admission Control based on Achievable Throughput

Pong and Moors [17] use an analytical model based on collision probabilities for the admission control. They use the value of *transmission probability* as derived from collision probability using an analytical model [19] to calculate *achievable throughput*. They propose a centralized scheme in which access point is responsible for collision monitoring, throughput estimation and making admission decisions. The algorithm estimates the throughput that flows would achieve if a new flow with certain parameters was admitted, and so indicates whether such a new flow can be admitted while preserving the Quality of Service (QoS) of existing flows. The algorithm deals with the EDCA parameters of minimum contention window size and transmission opportunity duration, and indicates what values should be used for different flows. If a satisfactory set of parameters can not be found, the flow is rejected.

4.3 Admission Control based on Estimated Service Rate

Choi [18] proposes a centralized admission control scheme which models a traffic stream by the arrivals of bursts with constant inter-arrival time. The model assumes the burst size and the length of the burst period are variable. Generally , the delay performance of the traffic stream is degraded as the burst size, and the length of the burst period, are larger. The main idea of the scheme is to keep the maximum delay that the traffic stream experiences with the maximum burst size, which is specified in the traffic stream addition request message, to be within the delay bound specified in the traffic stream addition request message for the traffic stream. Choi derives the minimum service rate for satisfying the delay requirement of each traffic stream, and the admission decision for each traffic stream is based on the derived service rate and the current available service rate.

Both these schemes [17, 18] use sophisticated admission criteria, but rely on the accuracy of the underlying analytical models, which may be based on some assumptions and prone to approximation errors. Schemes that are more empirical in nature and work only with direct measurements of the state of the network have also been proposed.

4.4 HARMONICA

HARMONICA [8] is a centralized measurement based scheme, which defines a Link layer Quality Indicator (LQI) that constitutes the parameters: drop rate, link layer end-to-end delay and throughput. The scheme tries to select optimal EDCA parameters depending on the measured LQI. The scheme implements a simple admission control mechanism for real-time traffic flows. Whenever a new real-time flow requests for admission, it will be assigned to a traffic class that best matches its QoS requirement (in terms of drop rate limits and delay bounds). Now the admissibility of the flow depends on whether,

- the QoS of each real-time traffic class should be guaranteed.
- the bandwidth remaining for best-effort traffic is above a certain limit calculated from the admission policy being used.

4.5 Partitioning Based Distributed Admission Control

None of the schemes discussed so far, consider bandwidth reservation. Xiao et al. [9, 16] propose a distributed measurement based admission control scheme. As there is no clear notion of bandwidth in 802.11 WLANs, they consider TXOP as an equivalent measure to bandwidth. This scheme partitions the available time in the Beacon Interval (BI) among different ACs, which forms the Available TXOP Limit ($ATL[i]$) for each AC. The scheme depends on a parameter called $TXOPBudget[i]$, the amount of TXOP that has not been used by an AC in the last beacon interval, which is available for new flows in the current beacon interval. At the start of every beacon interval, the AP calculates the $TXOPBudget$ for each AC and sends to all the stations through the beacon frame. Now stations do a distributed admission control based on this value. If the $TXOPBudget[i]$ is zero, no new flows are admitted.

The $TXOPBudget$ is calculated as follows.

$$TXOPBudget[i] = \max(ATL[i] - TxTime[i] \times SF[i], 0)$$

here $TxTime[i]$ is the transmission time of the AC and $SF[i]$, the *surplus factor* represents the ratio of over the air bandwidth reserved for AC i to the bandwidth of the successful transmission of the AC. $ATL[i]$ and $SF[i]$ are fixed values to be configured by the administrator at AP, where as $TXOPBudget[i]$ change over time depending on $TxTime[i]$.

Xiao and Li's approach [9] essentially performs admission control based on bandwidth requirement. The advantages of this approach are its simplicity, and the absence of any assumptions. However, one drawback is the static partitioning of bandwidth that is implied by the choice of the $ATL[i]$ values that the network administrator has to make, which could lead to under-utilization of the channel.

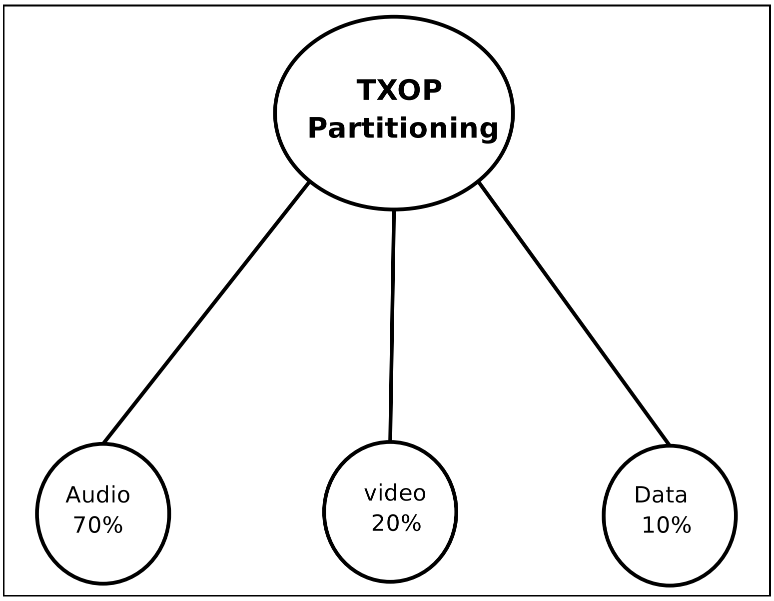

Figure 4.1: An Example TXOP partitioning

Example Scenario Consider a scenario in the Figure 4.1, in which $70\%, 20\%, 10\%$ of the bandwidth is reserved for voice, video and data traffic respectively. Now if we consider the length of beacon interval to be $100ms$, then ATL[3] (voice) will be $70ms$. Assume that there are 10 voice flows are currently present in the BSS. Considering that the target bandwidth requirement of voice traffic is at most 100Kbps (64 Kbps with added overheads), the average the TXOP requirement of Voice in a beacon interval will be approximately $30ms$. Now the $TXOPBudget$ for the coming beacon interval will be $40ms$. But this $TXOPBudget$ will not be used by any other category, resulting in under utilization of the channel. We can improve the utilization of the channel by adapting TXOP reservation such that the unused $TXOP\_Budget$ gets allocated to different access category. This can be done by partitioning the unused time, rather than partitioning the entire available time strictly. Consider the same scenario explained above and let the total unused time left in the previous beacon interval is $40ms$. Now $TXOP\_Budget[3]$ for the current beacon interval will be $28ms$ rather than $40ms$. Moreover we can adapt ATL[i] dynamically depending on the load requirement in the network.

In the next chapter, we present our approach in which we dynamically select the bandwidth partitioning factor, based on the bandwidth requirement of the traffic categories, as well as their priorities.

Chapter 5

PLUS-DAC: Proposed Scheme

In this chapter, we describe PLUS-DAC(*Priority, Load and Utilization-based Scheme for Distributed Admission Control*), a QAP assisted distributed admission control mechanism. PLUS-DAC is partly based on the admission control mechanism proposed by Xiao and Li. We specifically address one drawback of partitioning schemes: the static division of bandwidth. When bandwidth is divided statically, often, more bandwidth can get allocated to a category which is currently not offering much traffic to the network, resulting in under-utilization of the bandwidth resources.

PLUS-DAC is a flexible mechanism, which monitors load and priority and continuously adjusts the fractions of bandwidth reserved for each category to reflect actual requirement. As we have already mentioned, the goal of PLUS-DAC is to maximize the utilization, while simultaneously providing QoS guarantees to high priority traffic.

PLUS-DAC is a scheme similar to upper limit admission control schemes [20, 21], which considers the amount of TXOP that has been utilized by a traffic category in the previous beacon interval as the lower limit on the reserved TXOP. We calculate $TXOP\_Grant[i]$, the excess capacity that could be reserved for each access category by partitioning the unused time in the previous beacon interval based on the *effective weight (*$ew[i]$*)s*. The $TXOP\_Grant[i]$ value defines the upper limit on the reservation for each access category in the current beacon interval.

The effective weight, $ew[i]$ is calculated from other weights namely, *priority weight (pw[i]), load weight (lw[i]) and utilization weight (uw[i])*, which are normalized fractions of the measured values. Through effective weight calculation we give importance to traffic categories which have sufficient load and priority but have not utilized the channel to the required extent.

We first explain how QAP calculates various parameters and how the total available TXOP is partitioned among the access categories. Then we discuss how each QSTA use the information sent by the QAP to make admissibility decisions. We give an overview of the architecture, we have devised for distributing the status information in the BSS. Towards the end of the chapter we give implementation details of PLUS-DAC in ns2 [22].

5.1 TXOP Partitioning and Reservation

The QAP works as a centralized coordinator, which measures the load and utilization in the network and calculates $TXOP\_Grant[i]$ to be allocated to each access category as explained in the algorithm shown in Figure 5.1.

We define the priority weights as the configurable weights that can be set at the QAP by the administrator depending on the previous traffic profiles. Initially the total available TXOP in the beacon interval (BI) is partitioned based on these priority weights.

The QAP can measure the TXOP utilized by each of the access category (TX_Time[AC]) by looking at the *Duration/ID* field in the MAC header of the frames being transmitted in the BSS. We can calculate the total TXOP utilized in the last beacon interval as,

$$Total\_TXOP\_Used = \sum_i TX\_Time[i]$$

We define *utilization weight*, $uw[i]$ as the normalized fractions of the TXOP utilized by the particular access category traffic to total time utilized in the previous beacon interval, which can be calculated as,

$$uw[i] = \frac{TX\_TIME[i]}{Total\_TXOP\_Used}$$

We consider the buffered queue length of each access category at each QSTA as a measure of load, which is transmitted to QAP, through the *queuesize* sub-field of the QoS Control field in the MAC header. We can calculate the nominal time, $\tau[i]$ required for the transmission of an MSDU belonging to an AC i as,

$$\tau[i] = \frac{MSDU[i]}{R} + t_{ACK} + SIFS + AIFS[i]$$

Here $MSDU[i]$ is nominal MSDU size of AC i, t_{ACK} is the time required to transmit an acknowledgment and R is the physical transmission rate.

Let $queue\_length[j][i]$, be the queue length of the AC i, at STA j. We calculate the $TX\_Load[i]$ as,

$$TX\_Load[i] = \sum_j queue\_length[j][i] * \tau[i]$$

```
calculate utilization weights();
    /* fraction of time used by particular access category to total time utilized in the previous beacon interval
    uw[i] = TX_TIME[i] / Total_TXOP_Used
    */
Total_TXOP_Available=Time_in_CP - Total_TXOP_Used
calculate load weights();
    /* fraction of time required for queue length of particular access category to total time required by the queues as measured by Access Point
    lw[i] = TX_Load[i] / Total_TXOP_Needed
    */
if Total_Time_Needed is Zero then
    for Each Access Category do
        TXOP_Grant[i]=Total_TXOP_Available * pw[i]
        /* pw[i] is the priority weight of the Access Category, fraction of time reserved by the policy controller.
        */
    end for
else
    for Each Access Category do
        ew[i] = pw[i] · ((0.5 + α · lw[i]) / (1 + α · uw[i]))
        TXOP_Grant[i] = Total_TXOP_Available * ew'[i]
        /* ew'[i] is the normalized effective weight. */
    end for
end if
```

Figure 5.1: TXOP Grant Calculation

The total TXOP needed across ACs can be calculated as,

$$Total\_TXOP\_Needed = \sum_{i} TX\_Load[i]$$

Now, we define *load weight*, $lw[i]$ as the normalized fraction of TXOP load of a particular access category to total TXOP required to service the load as measured by the QAP. It can be calculated as follows.

$$lw[i] = \frac{TX\_Load[i]}{Total\_TXOP\_Needed}$$

Now, the *effective weight*, $ew[i]$ of each AC is calculated as a function of *load weight ($lw[i]$)*, *utilization weight ($uw[i]$)*, and *priority weight ($ew[i]$)* of the AC as,

$$ew[i] = pw[i] \cdot \left(\frac{0.5 + \alpha \cdot lw[i]}{1 + \alpha \cdot uw[i]} \right)$$

where α is the *balance factor*, which can be set by the administrator, depending on how much importance to be given to load in the network. When a particular priority is not using the TXOP allocated for it, the unused TXOP will be allocated to access categories which have enough load (indicated by a higher $lw[i]$), but not utilized the channel optimally (indicated by lower $uw[i]$) in the last beacon interval. The increase in the α value, enhances this effect. During initialization, the entire TXOP is partitioned based on the priority weights. As and when new flows come into the network the $lw[i]$ of medium and low priority traffic will increase, resulting in an increase in $ew[i]$. When the medium and low priority traffic are getting sufficient TXOP, which can be indicated by the increased uw[i] values, again more weight will be given to high priority traffic. The value 0.5 in the numerator indicates that approximately 50% weight will be given to priority even when the load in the network is negligible.

We estimate the $TXOP\_Grant[i]$ for each AC i at the start of each BI as,

$$TXOP\_Grant[i] = Total\_TXOP\_Available * ew'[i]$$

where $ew'[i]$ is the normalized effective weight. The QAP sends this $TXOP\_Grant[i]$ for each AC i to all the stations as a part of the beacon frame.

5.2 Distributed Admission Control at each QSTA

Each of the QSTA notes the announced $TXOP\_Grant$ at the start of each beacon interval. When a new flow starts in the present beacon interval, admission control will be done following the algorithm given in *Figure:5.2*.

We can estimate $\Delta[i]$, the nominal TXOP required by a new flow belonging to AC i, from the Traffic Specification negotiated. The nominal TXOP required for a traffic stream can simply be calculated as,

$$\Delta[i] = \frac{\lambda[i] \times T_{Beacon}}{R}$$

where $\lambda[i]$ is the arrival rate, T_{Beacon} is the length of beacon interval and R is the PHY transmission rate.

Thus a request for a new flow belonging to AC i can be admitted if the following inequality is satisfied.

$$TXOP\_Grant[i] \geq \Delta[i]$$

Note that we are assuming that there may not be more than one flow arrival of each category in a beacon interval. Even if occasionally multiple flows arrive, the effect will not be severe as the $TXOP\_Grant[i]$ value will be immediately adjusted in the next beacon interval, with decrease in unused time. If $TXOP\_Grant[i]$ is not sufficient, no new QSTA can gain transmission time for AC i, and all the existing QSTAs continue to use the allocated TXOP. Thus the guarantees given to existing flows are protected.

$nominal\_TXOP[i] = \dfrac{\lambda[i] \times T_{Beacon}}{R}$
/* T_Beacon is the length of Beacon interval */
if *new flow of AC i* **then**
    if $TXOP\_Grant[i] \geq nominal\_TXOP[i]$ **then**
        accept the flow.
    else
        reject the flow.
    end if
end if

Figure 5.2: Distributed Admission Control at QSTA

5.3 Proposed Architecture

We propose an architecture as shown in Figure: 5.3 to provide an efficient Admission Control scheme, which is not solely based on the priorities but also considers the present load in the BSS and the channel utilization by each Access Categories.

The proposed Architecture mainly consist of four important components as follows.

- *Policy Controller*, which resides at AP is responsible for assigning the priority weight to each access category, which forms the default partitioning of the available TXOP.

- *Load Monitor* overlooks into *queue size* sub-field of *QoS Control* field in the MAC header and update the status about the load in the BSS. It also measures the TXOP utilized by

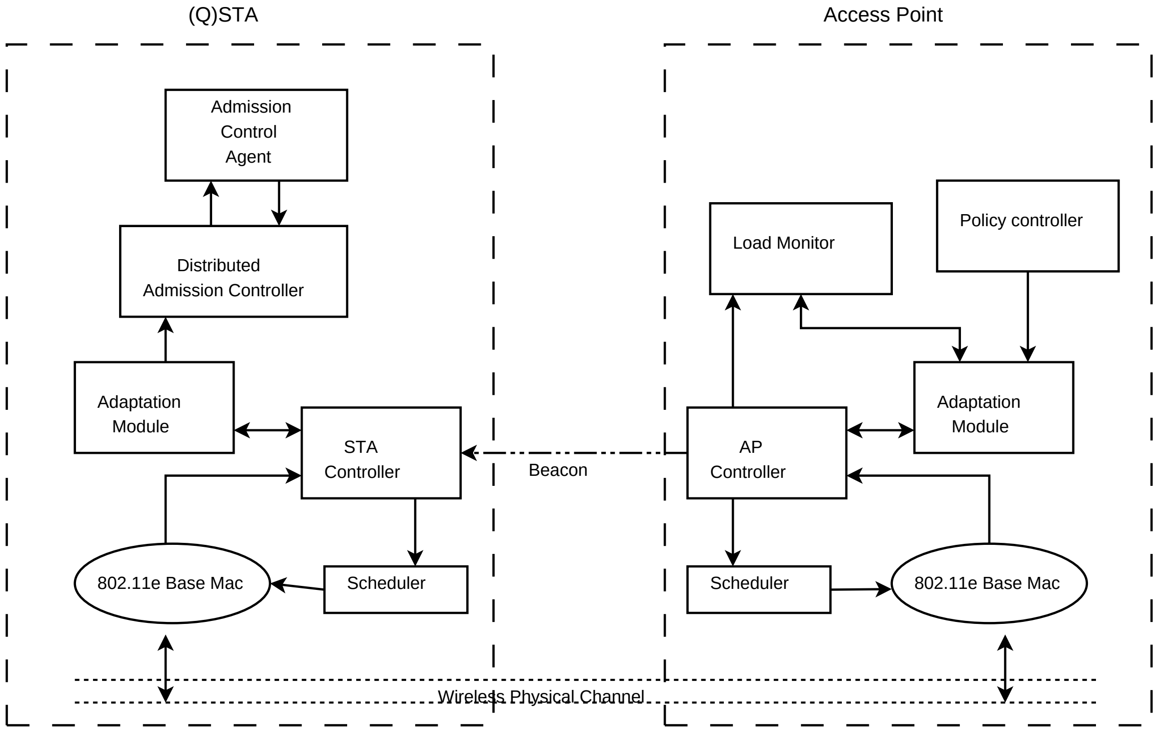

Figure 5.3: Proposed Architecture

each of the AC looking into the *Duration/ID* field in MAC header of the frames being transmitted in the BSS.

- *Adaptation Module* forms the core of the architecture, at AP it calculates the amount to TXOP to be allocated to each access category and informs the *Controller*, which in turn sends the information to all the stations through Beacon. At the each of the stations, *Adaptation Module* makes use of the $TXOP\_Grant$ sent through the beacon and updates the local state information.

- *Distributed Admission Controller* will use the updated state information to make decisions about admission of flows pertaining each access category.

5.4 Implementation Details

In this section we discuss the implementation issues that we faced and important code details. We also present the various decisions that we took during implementation and the justifications for the same.

We have implemented the PLUS-DAC mechanism in *ns-2* [22]. The FHCF ns-patch [23] is extended to support the admission control. A good introduction about various functions of IEEE 802.11 MAC implementation in ns2 can be found at [24].

5.4.1 Important Changes

Following are the important changes that we had to make to implement PLUS-DAC.

1. Accepted List:

   Assuming that there is only one flow of each traffic category at each, maintaining a simple boolean array by each STA to check whether a particular category at that node is accepted or not.

2. Traffic indication:

   A boolean array to indicate that the traffic of a particular category has just started arriving at that station. To differentiate a new flow from existing flows. The admissibility decision should be made only with respect to new flows.

3. resetTime list:

   A list of counters for each of the traffic category, which will be reset when ever a packet of that category is sent and decreased at the start of every beacon interval. The counters are initialized with number of beacon intervals that should be considered before assuming inactivity. If there is no traffic of a particular category at a station, i.e., the resetTime counter becomes zero, Traffic indication is changed (Indication of Stop of Flow).

4. Beacon Modifications :

   As discussed before, PLUS-DAC sends the $TXOP\_Grant$ information for all the access categories is transmitted through beacon. The existing beacon frame is modified to include an array of 8 fields to carry this information. So the partitioning is based on traffic categories, rather than access categories.

5. Class DCAC_Controller

   This class contains all the functionality that we described in the previous sections. Some of the important functions that this class contains to carry out the TXOP reservations and admission control are as follows.

- check admissible: This function is called from the MAC before sending any packet on to the channel. The traffic indication is verified to find out it is a new flow. The admissibility criteria is followed for new flows. For existing flows simply accepted[AC] is returned. So we achieve admission control by continuously dropping the packets of rejected flows.
- set_priority_weights: This function carries out the job of policy controller. The priority weights are read from configuration file and set accordingly during initialization.
- update_TX_Time: As every packet is broadcast and is received by all the stations, an AP, will update the channel utilization with the estimated time, before discarding the frame.
- update_queue_length: The queue length calculations from priority queue are noted when ever a QoS data or QoS Null packet is received by the MAC. Special care must be taken for flow having destination not same as AP.

Chapter 6

Simulation and Results

In this chapter we study the performance of PLUS scheme in comparison with a static admission control scheme and pure EDCA with no admission control. We have implemented the PLUS-DAC mechanism in *ns-2* [22]. The FHCF ns-patch [23] is extended to support the admission control.

The following sections explain about the types of traffic considered for simulation and various performance metrics considered to evaluate the schemes. We have considered two scenarios to test the PLUS-DAC mechanism. In both the scenario we start the simulation with light load conditions and increase the load in the network gradually.

6.1 Simulation Setup and Traffic Description

The design of the network we have considered in our simulation follows the conventional approach as shown in 6.1. Our topology consists of several wireless stations and an access point. The QAP serves as a direct sink for all the flows from various stations.

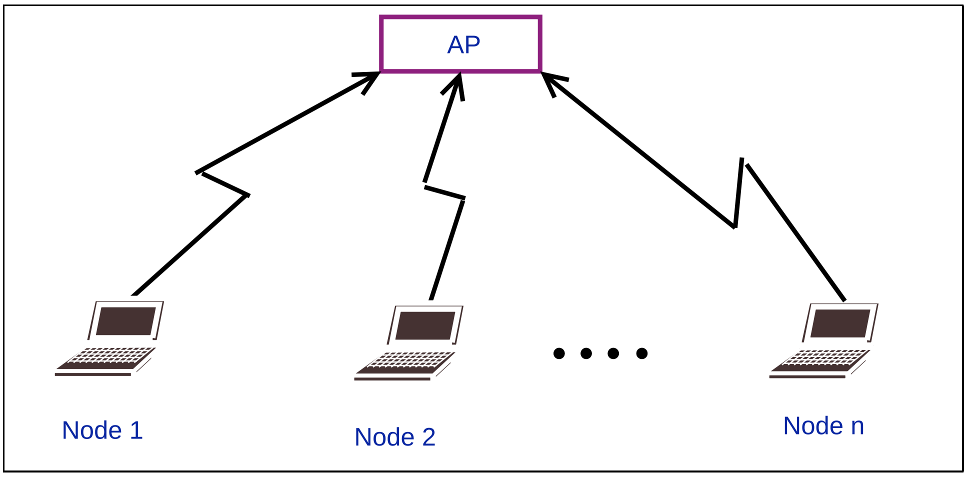

Figure 6.1: Simulation Setup

Each station can have a high priority exponential on-off audio flow $(64Kb/s)$ with $400ms$ burst time and $600ms$ idle time, a H.261 VBR video flow $(200Kb/s)$ with medium priority, a CBR MPEG video flow $(3.2Mb/s)$ with medium priority and a low priority poisson data flow $(1000Kb/s)$.

We mapped the traffic streams to three access categories: voice (AC 3), video (AC 2), data (AC 0). We have the following parameters for the traffic streams as described in TABLE 6.1.

Parameters	**Audio**	**H.261 video**	**MPEG4 video**	**Data**
Packet Size (bytes)	160	660	1000	1500
Arrival Period (ms)	4.7	26	2.5	12
Sending rate (Kbps)	64	200	3200	1000
AIFS (μs)	25	25	25	34
CW_{min}	7	31	31	127
CW_{max}	15	63	63	1023

Table 6.1: Description of Traffic streams

The MAC and PHY parameters used for the simulation are given in TABLE 6.2.

Parameters	**Value**
SIFS	16 μs
DIFS	34 μs
Slot Time	9μs
CCA Time	3μs
Beacon Interval	500ms
PHY Rate	54 Mb/s
Min. bandwidth	24 Mb/s
MAC header	38 bytes
PLCP header	4 bits
Preamble Length	20 bits

Table 6.2: PHY and MAC Parameters

6.2 Performance Metrics Considered

We compare the three schemes: 1) pure EDCA, 2) EDCA with static admission control (SDAC), and 3) EDCA with PLUS-DAC.

In order to evaluate the performance of PLUS-DAC, we have studied latency, bandwidth characteristics of different kinds of traffic with parameters such as,

- Mean Latency and Jitter: These are the average latency and jitter of all the flows that have the same priority in the different stations. These metric is used to evaluate how well the schemes can accommodate real-time flows. Real-time flows also require low average delay and bounded delay jitter.

- Latency distribution and Packet Loss Ratio: Latency distribution allows to trace the percentage of packets that have latency less than the maximum delay required by the applications. Mean packet loss ratio is used to evaluate whether the schemes are performing satisfactory in case of loss sensitive applications.

- Throughput per stream, and Total throughput: Throughput per stream variation show how well the accepted flows are protected. The total throughput gives a measure of channel utilization and the efficiency of the scheme.

For a good quality multimedia service, unidirectional latency should be less than $150ms$ and packet loss should be less than 10%. The LAN component of these requirements should be more stringent. We can observe from the results that PLUS-DAC performs better and achieves quasi-optimal channel utilization in various situations.

6.3 High Priority Scenario

In this scenario, only high and medium priority traffic. The goal of this scenario is to show that PLUS-DAC successfully give QoS guarantees to high priority flows while achieving better channel utilization. we have 21 station in the network and simulated audio and video traffic over a duration of 200 seconds. We have 20 audio, 20 H.261 VBR video flows and 15 CBR video flows.

Audio and VBR flows start at 0 seconds and new flows arrive periodically every 5 seconds till 50 seconds, then from 50 seconds to 100 seconds there are no new flows, and again from

100 seconds to 150 seconds the flows come in periodically. CBR video flows arrive periodically from 0 seconds to 150 seconds every 10 seconds. The priority weights considered for the scenario are : $pw[3] = 0.7$ and $pw[2] = 0.3$, and the balance factor selected for this scenario is 1;

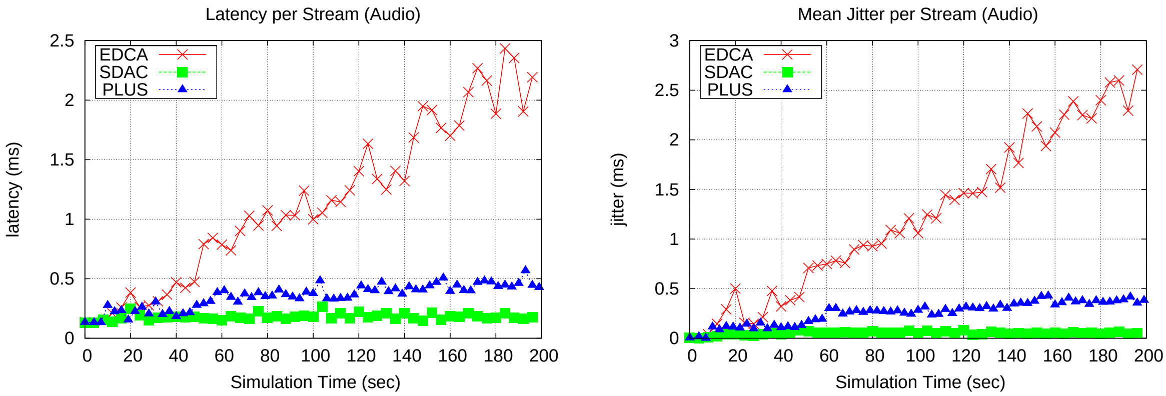

Figure 6.2: Audio latency characteristics

Latency Characteristics Figure 6.2 show the latency characteristics of audio using different schemes. As we can observe, the latency characteristics of PLUS-DAC and SDAC are almost similar, and are well with in the QoS limits of the flows($< 0.5ms$). Even the latency and jitter experienced by EDCA alone is not very high ($< 3ms$), this is because audio flows are of highest priority and the bandwidth requirements are very less compared to other flows.

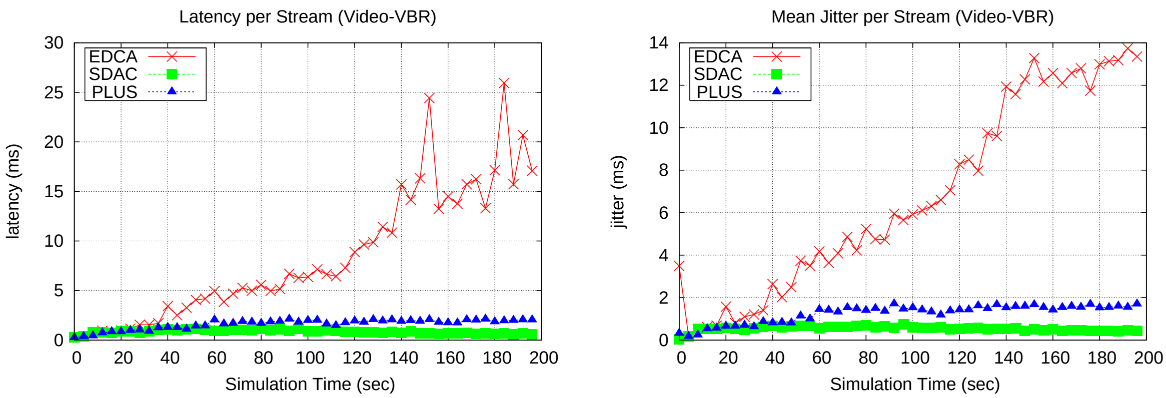

Figure 6.3: VBR latency characteristics

As we can observe, from Figure 6.3 in the latency characteristics of VBR traffic also PLUS-DAC and SDAC perform almost similar. But the latency and jitter experienced by pure EDCA alone is slightly high $(20 - 25ms)$ compared to admission control schemes.

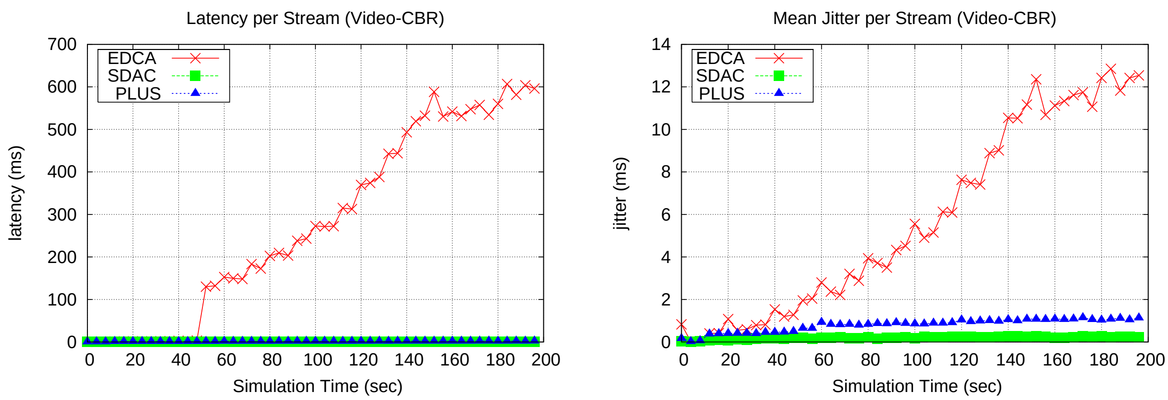

Figure 6.4: CBR latency characteristics

Figure 6.4 show the latency characteristics of CBR traffic. Once again, PLUS-DAC and SDAC perform almost similar. But we can observe that EDCA is completely unacceptable for MPEG video transmissions, since mean latency is crossing 100ms and gradually increasing. However the jitter characteristics are not severe as the traffic is CBR.

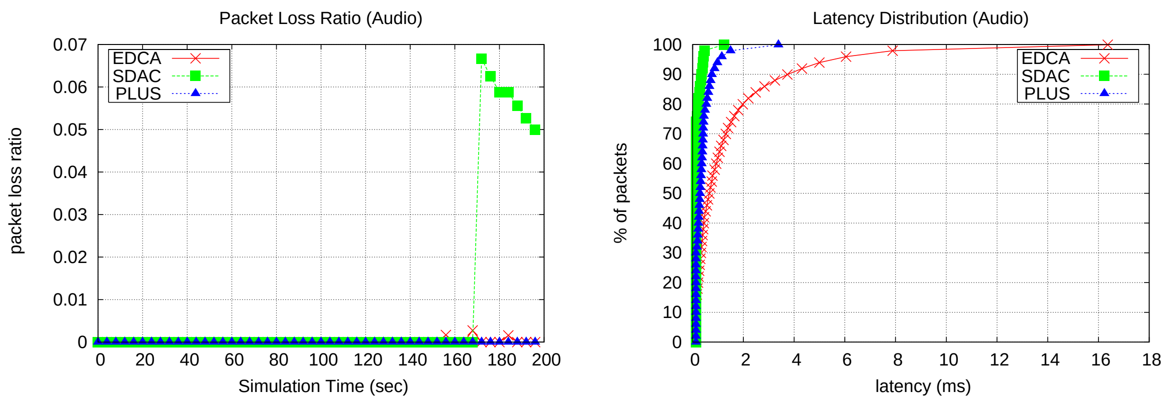

Figure 6.5: Audio packet loss and latency distribution

Packet Loss Ratio and Latency Distribution Figure 6.5 show that audio traffic hardly experienced any packet losses and we can observe from the latency distribution that the maximum latency experienced is very less (1̃0ms). Figure 6.6 show that PLUS-DAC and SDAC similar characteristics. Even EDCA has 95% of the packets experiencing a delay less than $50ms$ for H.261 traffic. But for MPEG video traffic having significant bandwidth requirements EDCA is not acceptable as we can observe from Figure 6.7. We can also observe that both the admission control schemes perform similar.

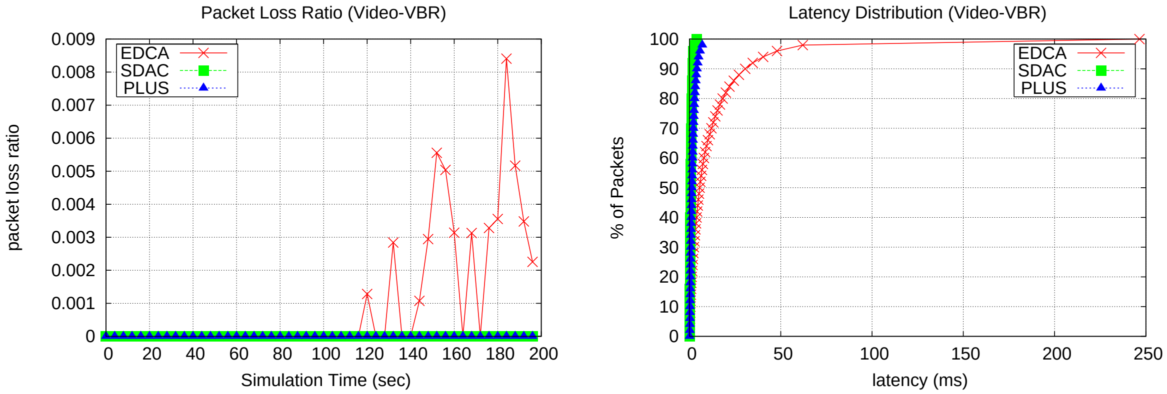

Figure 6.6: VBR packet loss and latency distribution

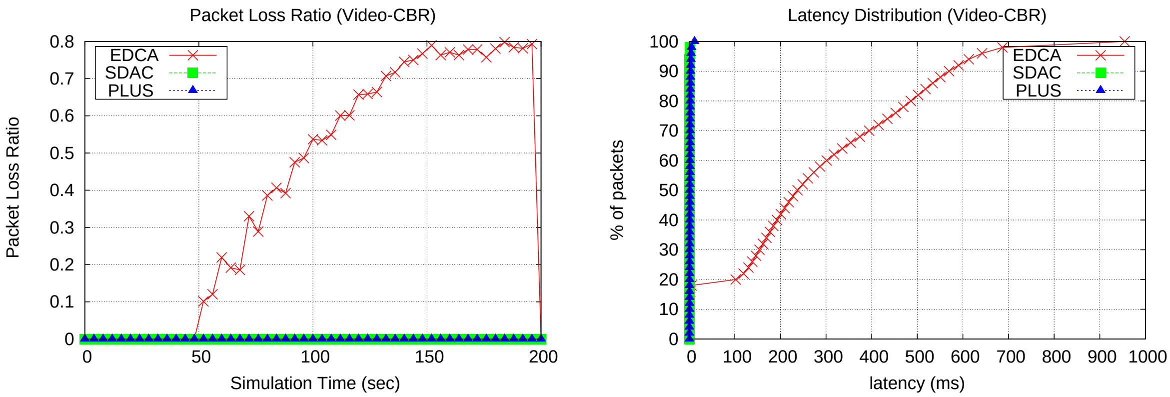

Figure 6.7: CBR packet loss and latency distribution

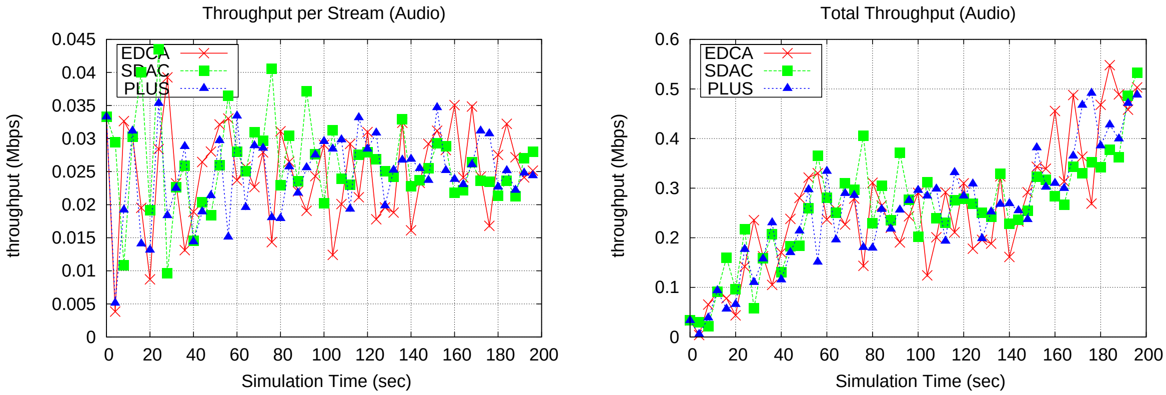

Figure 6.8: Audio throughput characteristics

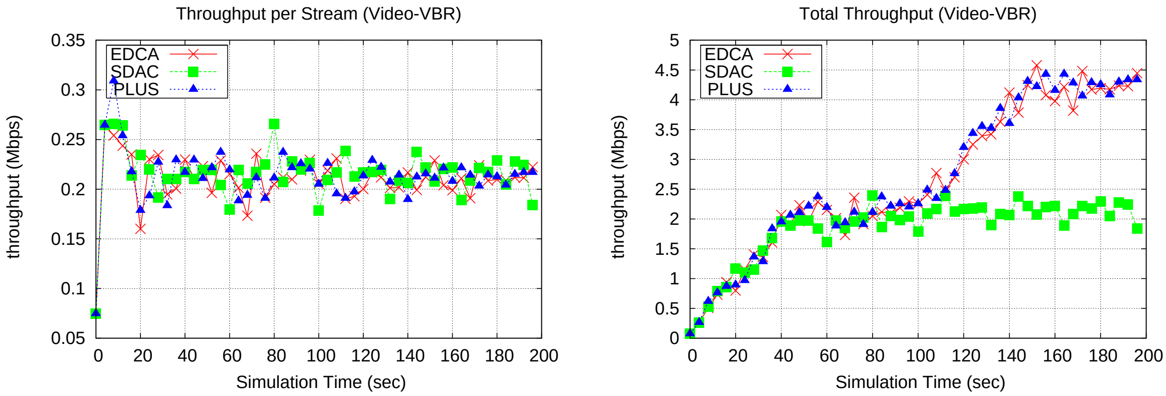

Figure 6.9: VBR throughput characteristics

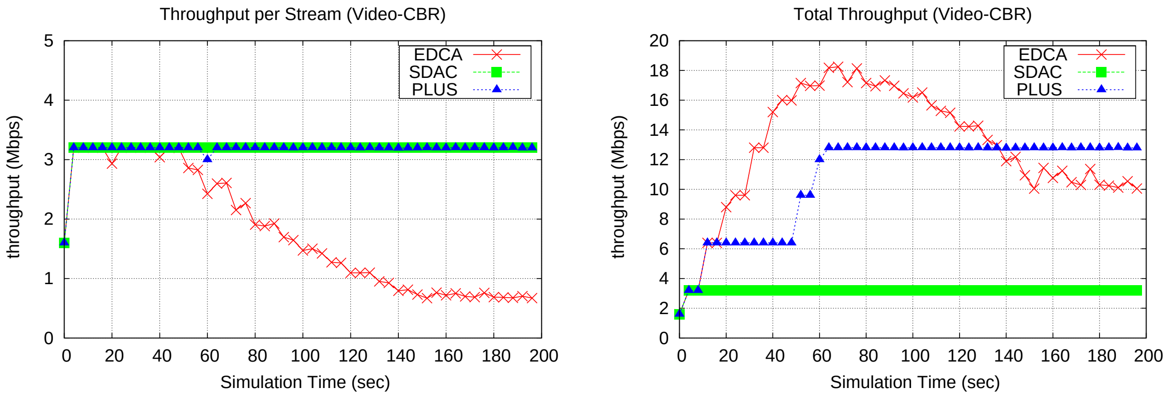

Figure 6.10: CBR throughput characteristics

Throughput Characteristics As we can see from Figure 6.8, the schemes hardly differ in their throughput characteristics. For VBR traffic, Figure 6.9 shows that PLUS-DAC achieves better utilization than the SDAC, though there is no difference in per stream throughput, SDAC accepted only half as many flows as that of PLUS-DAC leading to under-utilization. As we can observe from Figure 6.10, PLUS-DAC performs far better in case of CBR MPEG flows, which have significant bandwidth requirements. The throughput per stream in case of EDCA drops rapidly at low load conditions itself. SDAC has admitted only one CBR flow leading to under utilization of the channel, whereas PLUS-DAC admitted four flows achieving better channel utilization, while still meeting the latency requirements similar to SDAC.

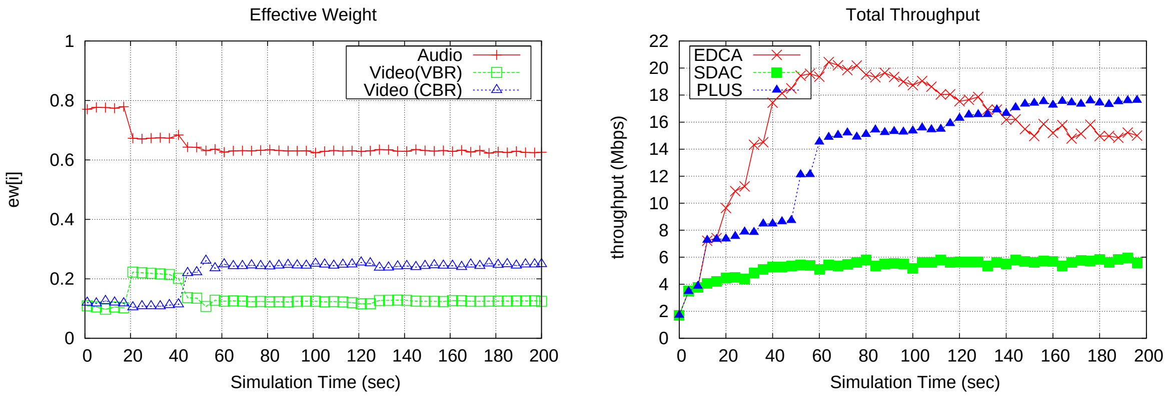

Figure 6.11: Variation of *ew[i]* and Total throughput

ew[i] variation As we can observe from Figure 6.11, the ew[i] value for voice is slightly decreased and gradually became constant giving importance to priority. In case of CBR video the value increased with increase in the load and stabilized once it accepted enough flows, resulting in better utilization of the channel. As for VBR flows, the requirement and priority weights are both low, ew[i] is almost constant. We can observe that total throughput achieved by PLUS-DAC is almost three times that of SDAC. This result is because CBR traffic has significant bandwidth requirements and reflects the total throughput. Through total throughput of EDCA also seem higher, it is not useful as the multimedia flows can not tolerate the latency and packet loss experienced. PLUS-DAC achieved better channel utilization while simultaneously guaranteeing the QoS.

6.4 Low priority scenario

In this scenario, we replace VBR traffic with poisson data traffic. The goal of this scenario is to show that PLUS-DAC protect from misbehaving low priority flows while still achieving better channel utilization. we have 31 stations in the network and duration of simulation is 200 seconds. We have 20 audio, 15 CBR video flows and 30 data flows.

Audio and at 0 seconds and new flows arrive periodically every 5 seconds till 100 seconds. CBR video flows also start from 0 seconds and new flows arrive periodically every 10 seconds till 100 seconds. Both these categories stabilize after 100ms at 20 and 10 flows respectively. Three Data flows will arrive at 0, 5 and 10 seconds respectively. Then from 100 seconds to 145 seconds the data flows come in periodically at a rate of 3 flows for 5 seconds. Again from 155 seconds the data flows start leaving the network with the same rate. The priority weights considered for the scenario are : $pw[3] = 0.7$ $pw[2] = 0.2$ and $pw[0] = 0.1$, and the balance factor selected for this scenario is 1;

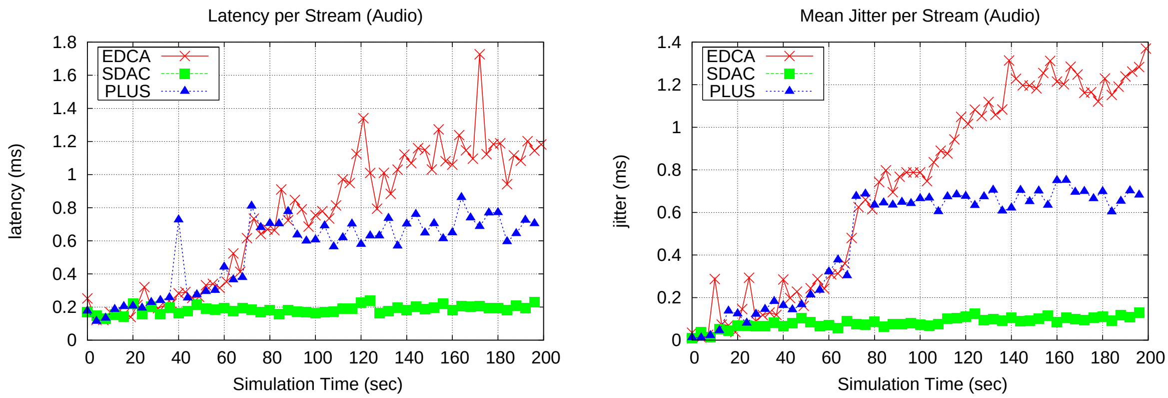

Figure 6.12: Audio latency characteristics

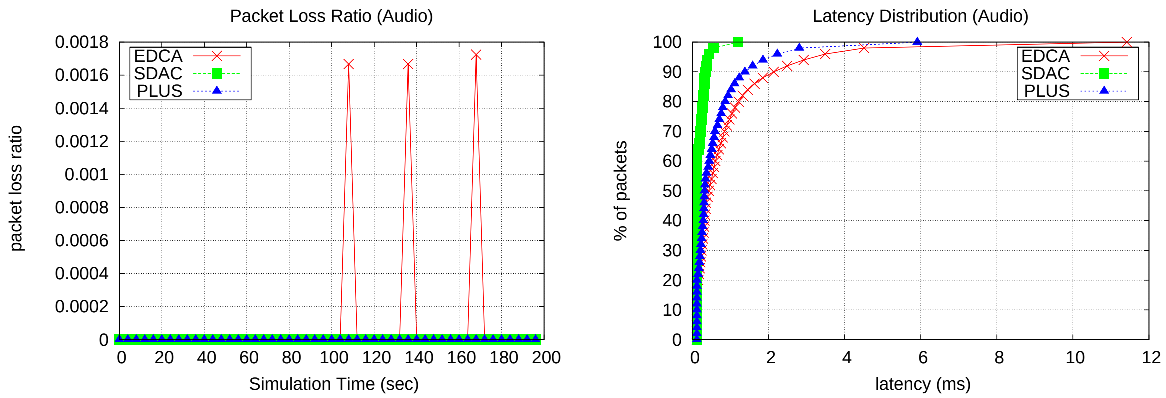

Figure 6.13: Audio packet loss and latency distribution

Audio Figure 6.12 show that the jitter and latency experienced by the audio traffic using different schemes are once again well with in the QoS limits. We can observe from Figure 6.13 that even the packet loss experienced is also similar. The maximum latency experienced is very less ($10ms$). This is because audio flows are of highest priority and the bandwidth requirements are very less compared to other flows. Hence the heavy data traffic is not effecting the audio traffic. This we can attribute to the fact that we are using strict EDCA parameters, with contention windows not overlapping.

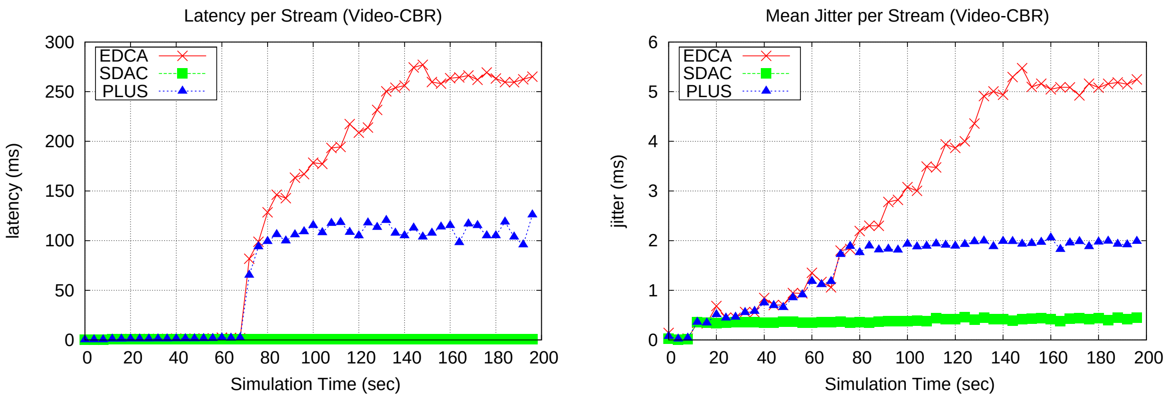

Figure 6.14: Video latency characteristics

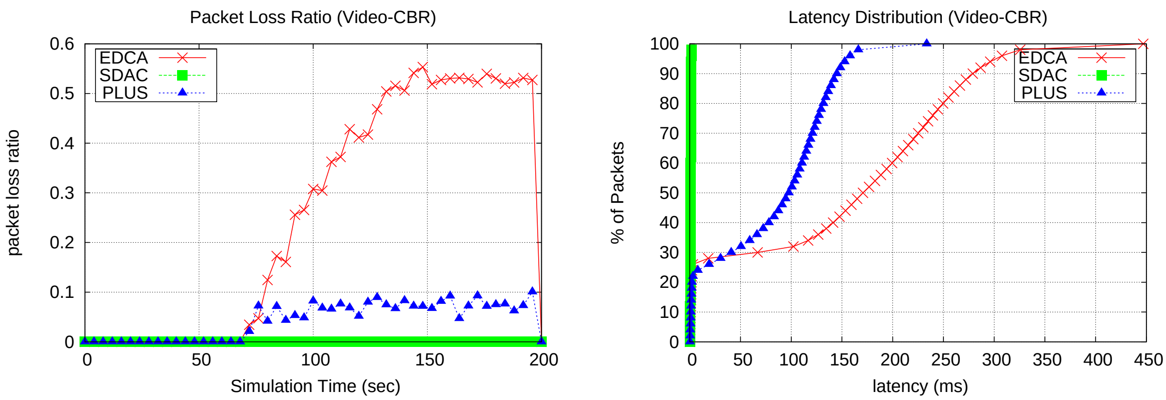

Figure 6.15: Video packet loss and latency distribution

Video As we can observe from Figure 6.14, PLUS-DAC gets effected by the low priority data traffic, as video traffic is having most of the bandwidth requirements. But the effect is not severe, we can see from Figure 6.15 that packet loss ratio ($\leq 10\%$) and maximum delay ($150ms$) are acceptable. Figure 6.16 show that PLUS-DAC has the best throughput characteristics. We can observe that per stream throughput is almost similar to SDAC and total throughput is almost four times that of SDAC. PLUS-DAC has admitted eight video flows compared to two flows admitted by SDAC.

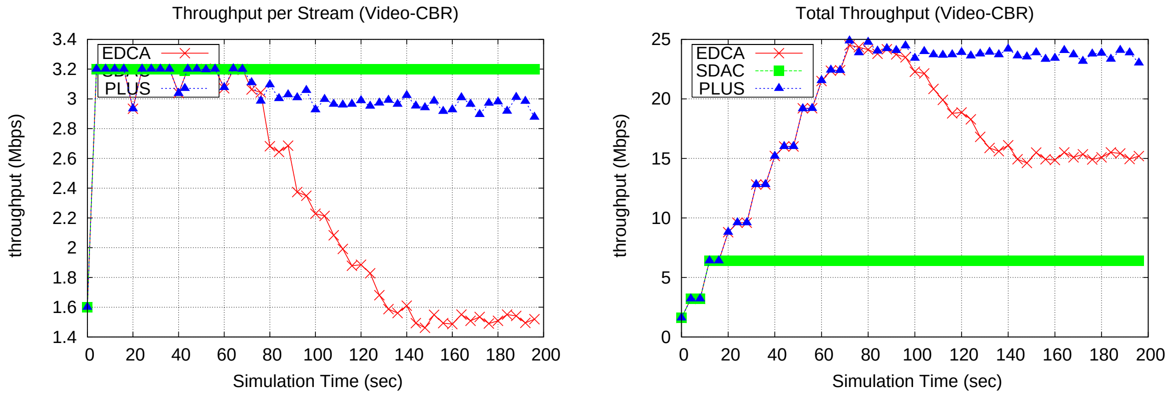

Figure 6.16: Video throughput characteristics

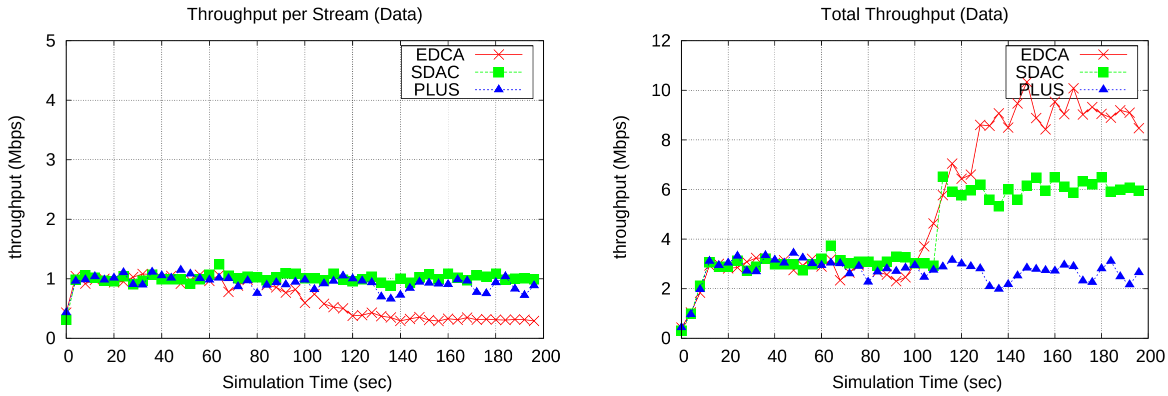

Figure 6.17: Data throughput characteristics

Data As we can see from Figure 6.17, that PLUS-DAC has good per stream throughput, but the total throughput is less. This is because PLUS-DAC has admitted Video flows by the time the data flows enter the network.

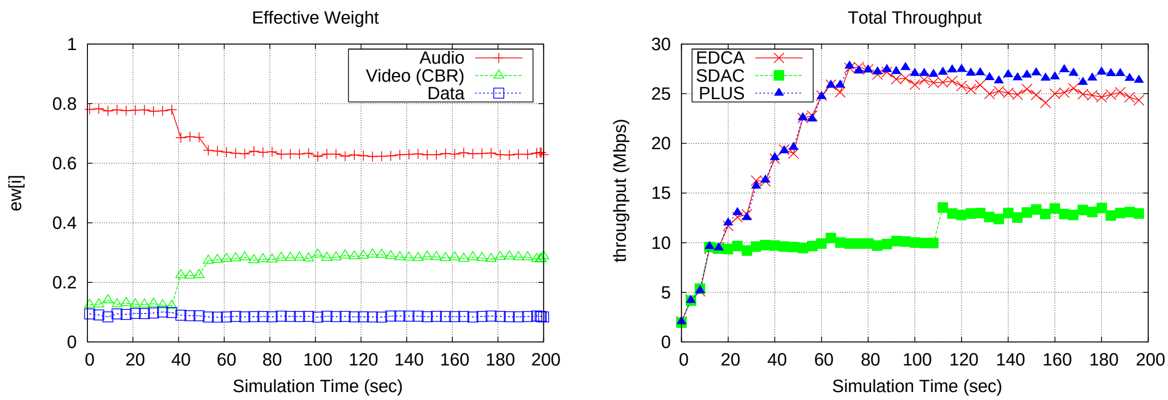

Figure 6.18: Variation of *ew[i]* and Total throughput

ew[i] variation As we can observe from Figure 6.11, the ew[i] value for voice is slightly decreased and gradually became constant giving importance to priority. The value of ew[i] for data traffic remained at constant because though it has load requirements, the priority is less. For CBR video the value increased with increase in the load and stabilized once it accepted enough flows. The ew[i] variation is resulting in CBR traffic stealing the unused bandwidth from audio traffic. We can observe that PLUS-DAC achieves the highest throughput. PLUS-DAC results in better optimal channel utilization than SDAC. PLUS-DAC is also successful in protecting the admitted flows in an acceptable manner.

Chapter 7

Conclusion and Future Research

In this work we have evaluated the performance of distributed admission control based on the upcoming IEEE 802.11e standard. We have shown that admission control is necessary to support real time traffic and given an overview of the features that can be used to support admission control in IEEE 802.11e standard. Our simulation results have shown that TXOP reservation and attention to load in the network are necessary. PLUS-DAC is able to achieve significant improvement in the channel utilization while satisfying the QoS guarantees of the real time traffic simultaneously.

The best thing about PLUS-DAC is that it strictly follows IEEE 802.11e with minimal overheads. PLUS-DAC is also compatible with schemes adapting EDCA Parameters. The policing and scheduling of packets at each station can be done by deferring the channel access to misbehaving flows in a manner similar to that of virtual collision.

PLUS-DAC presently work with only EDCA, which can be extended to integrate with HCF controlled channel access (HCCA). EDCA performs better at low load, but as the load in the network increases the collisions between back-off entities increases resulting in congestion. HCF may introduces delays at low load, but it performs more steadily at medium to high load conditions. The architecture suggested in PLUS-DAC can be used to measure the load in the BSS and switch from EDCA to HCCA once the load crosses a certain threshold.

In an Integrated Scheme for both EDCA and HCCA, the time left in any service interval can be reallocated to flows basically using EDCA but require the TXOP by explicitly polling them using HCCA.

PLUS-DAC is a first step towards adapting the TXOP reservation based on load and utilization. The algorithm needs to refined further. The policy controller can be enhanced to support various admission control policies. More over the scheme needs to extended to multi BSS scenario, and to incorporate mobility.

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