Quality of Service Provisioning with modified IEEE 802.11 MAC Protocol

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Quality of Service Provisioning with modified IEEE 802.11 MAC Protocol

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by

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To my family

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Certificate

This is to certify that the work in the thesis entitled ***Quality of Service Provisioning with modified IEEE 802.11 MAC Protocol***, submitted by ***Dillip Kumar Puthal*** is a record of an original research work carried out by him under our supervision and guidance in partial fulfillment of the requirements for the award of the degree of ***Master of Technology (Research)*** in Computer Science and Engineering during the session 2006–2008 in the department of Computer Science and Engineering, National Institute of Technology Rourkela. Neither this thesis nor any part of it has been submitted for any degree or academic award elsewhere.

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Abstract

Providing Quality of Service (QoS) in WLAN for time critical applications is one of the most important concern. QoS is referred as the capability to provide resource assurance in a network, which is a critical requirement for wireless based applications. Due to the scarcity of available bandwidth in WLAN leads to the problems to provide QoS for different types of time critical applications. Varieties of techniques are reported in literature to achieve QoS in WLAN. A required QoS for such applications can be archived by differentiating the service schemes, where the MAC layer service can be broadly categorized into two types: (i) station based, and (ii) queue based. This thesis adopts these MAC layer service categories with tunable parameter to design the schemes for better QoS in WLAN. Functionality of MAC layer protocols are modelled as finite state transition system for both PCF and DCF. The performances of the scheme with varying nodes have been studied using NS-2 simulator for *mean-time delay* and *throughput*.

A quality of service management (QoSM) scheme for priority based is proposed in this thesis, which divides the stations in to two groups as *priority* and *non-priority* by considering MAC address of the stations. This allows a strict packet forwarding mechanism to provide quality for real time traffic. Two further modifications have incorporated considering (i) slow contention window decrease and (ii) reservation based packet forwarding mechanism for priority and non-priority stations.

A modified MAC scheme have been studied with (i) a dual queue- one for real time traffic and other for best effort traffic, (ii) splitting the contention window into two equal halves with slow decrease in both the halves, and (iii) reservation based channel access with period restriction. An attempt was made to study the feasibility of hardware implementation of Quality of Service Management (QoSM) module on top of MAC controller without interpretation of CPU cycles. The proposed design of QoSM specified application is simulated using Xilinx. It is observed through extensive simulation and comparisons that the proposed schemes achieves better throughput for real time traffic in presence of best effort traffic than

802.11 and 802.11e.

The development in the thesis is genuinely supported by detailed literature survey and mathematics preliminaries leading to the proposed model of QoS algorithm. For shake of continuity each chapter has its relevant introduction and theory. The work is also supported by list of necessary references. Attempt is made to make the thesis self-content.

List of Acronyms

Acronym	Description
AC	Access Categories
ACK	Acknowlwdgement
AIFS	Arbitration Inter Frame Space
AP	Access Point
ARMA	Auto Regressive Moving Average
BC	Backoff Counter
BEB	Binary Exponential Backoff
BSS	Basic Service Set
CBR	Constant Bit Rate
CFP	Contention Free Period
CP	Contention Period
CRC	Cyclic redundancy Check
CSMA/CA	Carrier Sense Multiple Access / Collision Avoidance
CSMA/CD	Carrier Sense Multiple Access / Collision Detection
CTS	Clear to Send
CW	Contention Window
DCCA	Dual Channel Collision Avoidance
DCF	Distributed Coordination Function
DIFS	Distributed Inter Frame Space
DS	Distribution System
EDCA	Enhanced Distributed Channel Access
ESS	Extended Service Set
FCFS	First Come First Serve
FIFO	First In First Out
FTP	File Transmission Protocol
HCF	Hybrid Coordination Function
IBSS	Independent Basic Service Set
IEEE	Institute of Electrical and Electronics Engineers
IFS	Inter Frame Space
IP	Internet Protocol
LLC	Logical Link Control
MAC	Medium Access Controller
MFS	Model-based Frame Scheduling
MM	Multimedia Station
MSDU	MAC Service Data Unit
NAV	Network Allocation Vector
NoC	Network on Chip
NS	Network Simulator
PCF	Point Coordination Function
PHY	Physical Layer
QA	Queue Assignment
QEM	Quality Evaluation Module
QoS	Quality of Service
QoSM	Quality of Service Management
RTS	Request to Send
SD	Slow Contention Window Decrease
SIFS	Short Interframe Space
TCP	Transmission Control Protocol
TPC	Transmission Power Control
VMAC	Virtual Medium Access Controller
VoD	Video on Demand
VS	Virtual Source
WLAN	Wireless Local Area Network

List of Symbols

Symbol	Description
p	Transmission Probability
$1 - p$	Deferred Transmission Probability
λ	Packet arrival rate per second
μ	Packet service rate per second
p_i	State probability of Queueing system
$\sum$	Summation
$\overline{Y}$	Mean throughput of the system
n	Number of packets in the queueing system
τ	Mean time delay in the queueing system
δ	Contention window decrease factor
T_{MAX}	Maximum throughput of the system
D_{MIN}	Minimum delay of the systems
r_i	Channel bandwidth for i^{th} flow

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Chapter 1

Introduction

There has been a phenomenal increase in the demand of quality-of-service (QoS) in wireless networks over the years due to rapid growth in the number of wireless and mobile devices. Such devices are in use to access Internet and QoS aware applications such as video conferencing, voice-over IP, interactive video-on-demand and many other multimedia applications. wireless local area networks (WLANs) confirming to the IEEE 802.11 standard have become extremely popular at an unprecedented rate. As a result, WLAN networks are gaining the momentum and making their way into residential, commercial, industrial and public areas. These trends are more and more accelerated in places like airports, hotels and coffee shop, this typically has many floating end users. The time stringent applications are delay sensitive that require throughput and delay bound creates an urgent need for QoS support in WLANs.

The vision of next generation networks to provide ubiquitous access for inelastic and elastic applications over a common wireless infrastructure. There is a demand for such access as proved by the success of wireless technologies like cellular for carrying inelastic voice traffic, and WLAN for carrying elastic data traffic. However, instead of using a dedicated network for each type of traffic, we focus on supporting the transport of traffic with different QoS requirements over a common wireless infrastructure. In wireless environment QoS gain the popularity for time bound services interms of timely and correctly delivery where bandwidth is a major consideration. QoS (throughput and delay) is the key consideration for the real-time applications either in wired or wireless environment [1, 2, 15].

However due to lack of built-in QoS support, IEEE 802.11 experiences serious challenges to meet the demands of time critical applications. In particular, because of network bandwidth, timely delivery of multimedia data in presence of wireless fading and high bit error rate (BER) in WLAN applications are challenging problems. The primary issues in WLAN applications and services suggests the way of enhancement of QoS in WLAN. Recently the growing demand for multimedia applications in wireless focuses the interest of researchers to support a better quality of service. QoS in WLANs has become an important issue, in order to support ubiquitous end-to-end communication with scared availability of bandwidth and contention based channel access.

1.1 Defining Quality of Service

In this thesis, we have addressed the issue of QoS provisioning for the IEEE 802.11 MAC protocol. By QoS, we mean throughput differentiation among different flows because we believe the throughput attained by each flow or wireless node is the most important QoS metric. QoS is referred as the capability to provide resource assurance in a network, which is a critical requirement in order that new wireless based applications can operate within well-defined parameters. More is the applications and services used by different users, the worse is the status and quality of wireless network services. In consideration of QoS, it is very difficult to achieve the level of desired quality for the time stringent audio visual (AV) transmission and Voice over IP.

1.2 Issues of QoS

Why QoS is a challenging problem, can be described with reason as follows. First, limited network bandwidth. Second, timely delivery of real time multimedia data is difficult due to mobility, low power and service disruption because of link failure and/or security problems. Third, the wireless channel fading and high BER directly affect the throughput performance of the network [1, 2, 15].

Architectures of most network deal with all packets in the same way, a single level of service. However, applications have diverse requirements and may be sensitive to packet losses and latency. For example, interactive and real-time applications such as voice over Internet protocol (VoIP) and streaming services such as audio, video and interactive services such as web and transaction have a different level of requirement to the quality such as packet losses and latency. When the latency or packet loss rate exceeds certain levels, some applications and services become unusable [3, 37]. The traffic flow requirements for each type can be characterized by four parameters, *i.e.* reliability, delay, jitter and bandwidth.

In many wireless applications and services resource assurance is critical, as integrated services (IntServ) [68] and differentiated services (DiffServ) [69] paradigms figure predominantly as QoS solutions, they focus on the IP layer and it is necessary for the underlying layers to be able to respond and configure such IP-based service requirement in wireless network. Also routing algorithms (source, distributed and hierarchical routing) plays an important role in QoS. The complexity of finding a feasible path through the network depends on the number of constraints (for example delay, bandwidth, jitter and loss-ratio). The problem to find feasible paths with two independent types of constraints is NP-complete [22].

IEEE 802.11 uses of DCF in commercial products, which alone is neither capable nor suitable for fulfilling the QoS requirements of real-time applications like voice and video. Neither it provide any priority nor any service differentiation between different flows. Generally the proposed QoS schemes which are based on IEEE 802.11 try to improve MAC DCF functionality. The ways in which QoS is provided by modifying MAC DCF can be summarized as follows:

- Prioritization among different classes of traffic: Most of the techniques use different Inter Frame Space (IFSs) or different Contention Windows (CWs) or both [15, 30].

- Resource allocation to prioritized class of data: This is achieved by Weighted Fair Queuing (WFQ) [30].

- Admission control: QoS is provided by measurement and model admission control [30].

QoS enhancement can be supported by adding service differentiation into MAC.

The service differentiation at the MAC sublayer can be achieved by considering stations or queues. Figure 1.1 shows the classification of service differentiation based enhancement [3]:

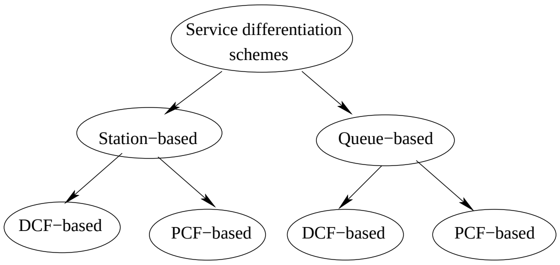


Figure 1.1: Service Differentiation Schemes

1.3 Motivation

Wireless technology is growing at a breath taking pace and is influencing the way people live and interact. A wireless system enables users to be connected and have access to systems with different levels of complexity ranging from voice communication to database retrieval on mobility. Handling of voice information has achieved some degree of maturity while data communication is just picking up the steam. The future of wireless communication seems to be very promising and is expected that any device can have an access to information from anywhere at anytime.

WLANs are increasingly use over the past few years and are making their way into residential, commercial, industrial and public areas. These trends are more and more accelerated to have various applications/services for common uses. The hand held devices also come up with features to support such applications. Flexibility in network configuration and low access cost has prompted the widespread use of WLAN in university campuses and conferences. E-mail, web browsing and Internet traffic constitutes the majority of traffic in WLAN, however real time multimedia applications like video conferencing, and on-line tutorial classes are gaining in popularity.

One of the major challenges faced by WLAN is the low availability of bandwidth. Different application running over the WLAN demands different QoS. Real time applications have stringent requirements in terms of delay, throughput, and bandwidth. Hence, the underlying network must support QoS to such applications. One way to achieve this in WLAN is to support QoS at the MAC layer and to fine tune some of the MAC layer parameters. IEEE 802.11 legacy MAC DCF only supports best-effort service and does not include the notion of QoS. WLANs are becoming increasing popular, therefore there must be an mechanism to support the minimum QoS requirement as demand by different applications. This thesis is an attempt towards provisioning QoS in WLAN with DCF as fundamental coordination function.

1.4 Problem Statement and Objectives

In Ethernet based local area networks QoS is a less interesting issue, due to the abundant availability bandwidth. However, this is not the case in WLAN environment, due to scarce bandwidth and shared medium access. It is expected that WLANs will eventually be integrated into broader communication networks. QoS provisioning in WLANs has become an important issue, in order to support ubiquitous end-to-end QoS.

The legacy MAC DCF does not differentiate between different category of traffic. Packets are forwarded on FIFO basis and do not support QoS. Legacy MAC DCF uses a binary exponential backoff (BEB) having CW range from CW_{min} to CW_{max} *i.e.* 32 to 1024. Every time a node send a packet its CW is modified as follows:

$\mathrm{CW} \longleftarrow \min(2 * \mathrm{CW}, \mathrm{CW}_{max})$ upon collision, and

$\mathrm{CW} \longleftarrow \mathrm{CW}_{min}$ upon success.

That is for each unsuccessful transmission the CW value is increased to the last value of CW multiplied by 2. This increase in the value of CW is exponential. For each successful transmission the CW value is reset to CW_{min}. It is assume that there is no congestion in the network after every successful transmission but normally congestion level is not likely drop too sharply. Moreover, legacy MAC DCF uses a contention-based channel access, where stations process MAC header for every frame while they are active. A single frame is sent according to contention based access control. After completion of previous transmission a station waits for DIFS and starts counting down the random backoff interval.

In this thesis, we propose a station based priority scheme with slow decrease of CW, and a reservation based packet forwarding. Further, we modified the MAC by splitting the CW between real-time and best-effort traffic. We use the reservation based channel access mechanism with a slow decrease of CW. Binary exponential backoff causes a long wait and suddenly reset to a minimum value after successful transmission. We tried to optimize the CW size after successful transmission to support priority based QoS. Accordingly we identify the objectives of the thesis and list them as follows:

- to model the MAC protocol as finite state transition,
- to provide a station based priority with slow decrease of CW and reservation based packet forwarding,
- to enrich the above MAC protocol to support QoS for real time traffic,
- to optimize the contention window size and backoff procedure,
- to propose reservation based channel access scheme to support prioritized traffic and delay constrained traffic in WLAN, and
- to study the performance of the above protocol through simulation.

1.5 Thesis Outline

The rest of the thesis organized into the following chapters :

Chapter 2, describes the survey of IEEE 802.11 legacy MAC protocol along with QoS related issues reported in literature on IEEE 802.11 modeling and enhancements.

Chapter 3 discusses the proposed finite state model of MAC protocol along with validation of the proposed scheme using NS-2 simulator.

In **Chapter 4**, a station based priority scheme with slow decrease of contention window and a reservation based packet forwarding mechanism is proposed to achieve better throughput.

Chapter 5 discusses a modified MAC protocol based on the splitting of contention window into equal halves between real time and non-real-time traffic.

An attempt was made in **Chapter 6**, to study the feasibility of hardware implementation of Quality of Service Management (*QoSM*) module on top of MAC controller.

Chapter 7 summarizes the main contributions of this thesis and comments on future directions for this research. Reference section includes detail list of necessary references used in this thesis work. Attempt is made to make the thesis self-content.

Chapter 2

802.11 WLAN: MAC Specification, QoS Issues, Performance Evaluation of DCF and Related Work

An overview of 802.11 WLAN with its MAC sublayer specifications is discussed in Section 2.1. MAC protocols are described in Section 2.2. Section 2.3 discusses about *quality of service (QoS)* related issues of MAC protocol by evaluating the performance of the DCF. Research works related to QoS (*i.e.* throughput model, devising new MAC algorithm, fine tuning the parameters and resource allocation) are also described in Section 2.4. Related work is broadly categorizes into two by considering the traffic class (*i.e.* (i) single traffic class, and (ii) multiple traffic class).

2.1 Introduction to IEEE 802.11

Wireless LAN belong to the IEEE 802 family and standardize by Institute of Electrical and Electronics Engineers (IEEE) as IEEE 802.11 [15, 31, 44]. Any LAN application, network operating system, or protocol including TCP/IP will run on 802.11 WLAN. The primary difference between WLANs and wired networks is the limited bandwidth as it uses radio frequency (RF) for transmission and the ever-changing topology due to node mobility. WLAN standard covers the MAC sub-layer and the physical layer of the TCP/IP protocol stack. This architecture provides a transparent interface to the higher layer users: stations (STAs) may move, roam through 802.11 WLAN and still appear as stationary to 802.2 LLC sub-layer and above. This allows existing TCP/IP protocol to run over IEEE

802.11, WLAN just like Ethernet deployed [3, 15, 72] with modifications in PHY and MAC sub-layer.

TCP/IP	IEEE 802.11
Application	Application
Transport Layer	Transport Layer (TCP, UDP)
Network Layer	Routing Protocol (DSDV, AODV, DSR, TORA)
Data Link Layer	802.1 Logical Link Control (LLC)
	802.11 Medium Access Control (MAC) (PCF, DCF)
Physical Layer	802.11 Physical Layer (Infrared, FHSS, DSSS, OFDM, HR−DSS)

Figure 2.1: The Layered Structure of TCP/IP and IEEE 802.11 WLAN

The layered structure of 802.11 with TCP/IP protocol suit shown in Figure 2.1. Different activities are addressed in IEEE 802.11 PHY and MAC layers, like access method in PHY and protocols used in MAC sub-layer [15, 28]. The data-link layer again divided in to two parts that is logical link control (LLC) and medium access control (MAC) [28, 72]. The LLC uses the standard defined by 802.2 but the MAC uses the standard specified by 802.11. In network layer it deals with the routing protocols like destination sequence distance vector (DSDV), ad-hoc on demand distance vector (AODV), dynamic source routing (DSR), temporary ordered routing algorithm (TORA). The physical layer uses specifications defined by 802.11 are Infrared, frequency hopping spread spectrum (FHSS), direct sequence spread spectrum (DSSS), orthogonal frequency division multiplexing (OFDM), and high rate direct sequence spread spectrum (HR-DSS) [3, 72].

IEEE 802.11 Family

IEEE 802.11 refers to a family of specifications developed by the IEEE for wireless LAN technology in 1997 [16]. This base standard allowed data transmission of up to 2 Mbps. The base IEEE 802.11 standard have undergoes many versions are standardized as 802.11a, 802.11b $\cdots$, and 802.11n. Table 2.1 describes the details of various standards related to 802.11 and shows the family of the IEEE 802.11 WLAN specifications [1, 15, 31].

Where 802.11a operates at radio frequencies between 5.15 and 5.875 GHz and a modulation scheme known as orthogonal frequency division multiplexing (OFDM) makes data speeds as high as 54 Mbps possible. The 802.11b specification was ratified by the IEEE in July 1999 [16] and operates at radio frequencies in the 2.4 to 2.497 GHz bandwidth of the radio spectrum. The modulation method selected for 802.11b is known as complementary direct sequence spread spectrum (DSSS) using complementary code keying (CCK) making data speeds as high as 11 Mbps. The 802.11a specification was also ratified in July 1999, but products did not become available until 2001 so it isn't as widely deployed as 802.11b [1, 3, 15, 31].

The specification 802.11g was ratified in June 2003. While 802.11g operates at radio frequencies in the 2.4 GHz to 2.497 GHz range, it utilizes the same OFDM modulation allowing for throughput up to 54 Mbps. This combination of performance and radio frequency allows those with existing 802.11b infrastructure a faster, less expensive path to a broader network connection. It is important to note that some 802.11b equipment would require a flash upgrade to be compatible with 802.11g products.

2.2 IEEE 802.11 WLAN MAC Protocols

IEEE 802.11 MAC is more complex in compared to other 802 MAC protocols as it supports wireless medium with mobility support. The MAC sublayer of WLAN supports two basic access methods: (i) contention-based distributed coordination function (DCF), and (ii) point coordination function (PCF) [1, 3, 15, 17, 18, 24, 35, 37, 39]. The base IEEE 802.11 standard have undergoes many revision are

Table 2.1: Family of IEEE 802.11 WLAN Specifications

Specification	**Description and Features**
802.11	The original WLAN Standard. Supports 1 Mbps to 2 Mbps.
802.11a	High speed WLAN standard for 5 GHz band. Supports 54 Mbps, unlicensed radio band by utilizing OFDM.
802.11b	WLAN standard for 2.4 GHz band. Supports 11 Mbps, unlicensed radio by utilizing HR/DSSS.
802.11c	Provides required information to ensure proper bridge operations, which is required when developing access points.
802.11d	Covers additional regulatory domains, which is especially important for operation in the 5GHz bands because the use of these frequencies differ widely from one country to another. As with 802.11c, 802.11c standards mostly applies to companies developing 802.11 products.
802.11e	Address QoS requirements for all IEEE WLAN radio interfaces. MAC enhancement for QoS such as HCF and EDCF.
802.11f	Defines inter-access point communications to facilitate multiple vendor distributed WLAN networks.
802.11g	Establishes an additional modulation technique for 2.4 GHz band. Intended to provide speeds up to 54 Mbps, unlicensed radio band with OFDM.
802.11h	Defines the spectrum management of the 5 GHz band for use in Europe and Asia Pacific.
802.11i	Address the current security weaknesses for both authentication and encryption protocols. The standard encompasses 802.1X, TKIP and AES protocols.
802.11n	Intended to provide speeds up to 500mbps. For high throughput environments.

standardized as 802.11a, 802.11b, $\cdots$, and 802.11y. Among them IEEE 802.11e is the standard for QoS, which employs a multiple service queue and balance access to the wireless medium in favor of applications that require better service quality known as hybrid coordination function (HCF) [44, 45].

2.2.1 Kinds of MAC Schemes

As WLAN standard can operate on MAC sub-layer and the physical layer of the OSI network reference model. In summary, it can view 802.11 WLAN as a wireless version of the wired Ethernet, which supports best-effort services [1, 3, 15, 16, 33]. As it deals with the wireless medium and MAC sub layer to be differentiate from LAN. The MAC protocol deals with the coordination functions, PCF, DCF of 802.11 and HCF of 802.11e. The IEEE 802.11 MAC protocol supports two types of transmission: asynchronous and synchronous [1, 15, 17]. Asynchronous transmission is provided by the DCF [33], and synchronous service is provided by PCF and implements a polling-based access method [5, 16, 33].

Characteristics of PCF

PCF differentiates between traffic of different priorities. It allow frames of high priority a faster access to the wireless medium. Access method in PCF is based on a central polling scheme controlled by an access point (AP), act as a point coordinator. The AP cyclically poll stations to give them the opportunity to transmit packets. Unlike the DCF, the implementation of the PCF is not mandatory. Once it acquires the channel, it cyclically pools high-priority stations and grants them the privilege of transmitting. Although the optional PCF is designed for delay-bounded services, it is centralized and can only be used in the network of infrastructure mode [7]. In addition, the loose specification of PCF leaves many issues unsolved (i) PCF experiences substantial delay at low load as the stations must always wait for pooling, even in an otherwise idle system (ii) science the AP needs to contend for the channel using DCF at the beginning of a CFP, the effective period of contention-free pooling may vary, and (iii) It is very difficult for the point coordinator to manage the pooling of a large number of interactive streams without harming the applications using DCF contention. Unlike the DCF, the implementation of the PCF is not mandatory [15, 40]. Furthermore, the PCF itself relies on the underlying asynchronous service provided by the DCF. Although providing different service functions, neither DCF nor DCF+PCF have the ability to offer true QoS over the wireless LAN applications [15].

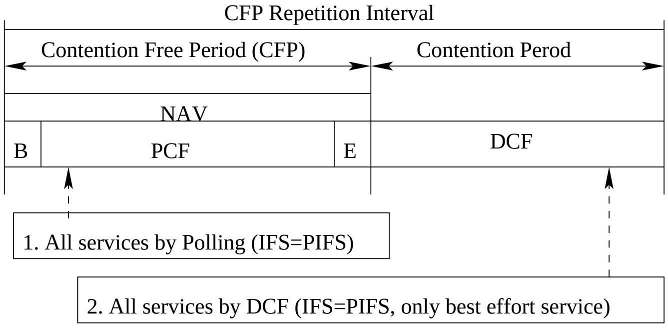


Figure 2.2: PCF and DCF channel access

PCF divides the wireless channel is into super-frames as shown in Figure 2.2 [6]. Each super-frame consists of a contention free period (CFP) for PCF and a contention period (CP) for DCF. At the beginning of CFP, the point coordinator (usually the AP) contends for access to the wireless channel. Once it acquires the channel, it cyclically pools high-priority stations and grants them the privilege of transmitting. Although the optional PCF is designed for delay-bounded services, it is centralized and can only be used in the network of infrastructure mode. In addition, the loose specification of PCF leaves many issues unsolved [31]:

- PCF experiences substantial delay at low load; stations must always wait for pooling, even in an otherwise idle system.
- The AP needs to contend for the channel using DCF at the beginning of a CFP, the effective period of contention-free pooling may vary.
- It is very difficult for the point coordinator to manage the pooling of a large number of interactive streams without harming the applications using DCF contention.

In addition, PCF is a centralized approach that suffers from location-dependent errors. There fore, PCF has not drawn much attention from either the research community or industry, and most existing schemes focus on the enhancement of DCF, which is a fully distributed protocol.

Characteristics of DCF

DCF is based on carrier sense multiple access with collision avoidance (CSMA/CA) [8, 10, 18, 19, 37, 38, 39, 40] instead of CSMA with collision detection (CSMA/CD) of LAN because stations cannot listen to the channel for collision while transmitting. In IEEE 802.11, carrier sensing (CS) is performed at both PHY and MAC layers: physical CS and MAC layer virtual CS. Request-to-send (RTS) and clear-to-send (CTS) are used by stations to solve the hidden terminal and exposed terminal problems [4]. A MAC protocol data unit (MPDU) contains header information, payload, and a 32-bit cyclic redundancy check (CRC)[44]. The duration field indicates the amount of time after the end of the present frame the channel will be used to complete successful transmission of the data or management frame. Stations use the information in the duration field to adjust their network allocation vector (NAV). DCF can operate in two modes, one is DCF with CSMA/CA and other uses a RTS/CTS mechanism.

DCF with CSMA/CA: As in Figure 2.3, if a packet arrives at an empty queue and the medium is found idle for an interval of time longer than a distributed inter-frame space (DIFS), the source station can transmit the packet immediately [15]. Mean while other stations defer their transmission by adjusting their NAVs, and a backoff process starts. In this backoff process, the station computes a random interval called backoff timer selected from the contention window (CW) [4, 5, 9, 19, 24, 31, 33]. The CW is incremented exponentially with an increasing number of attempts to retransmit the frame, $\left(i.e. CW_i = 2^{k+i-1} - 1\right)$, i no of attempts to transmit and k is a constant defining the minimum CW [9]. Upon receipt of a packet, the receiving stations waits a short inter frame space (SIFS which is less than DIFS) interval and transmits a positive acknowledgment frame (ACK) back to the source station, indicating transmission success. If ACK is not received, the sender assumes that the transmitted frame was collide, so it schedules a retransmission and enters into a backoff process. To reduce the probability of collisions, after each successful transmission, the CW_{max} is doubled until a predefined maximum value is reached. If collision occurs, a new backoff time slot is chosen and backoff procedure starts over until some time limit is exceeded. After successful transmission, the CW is reset to CW_{min}. For further increase of wireless channel utilization, payload length is divided into fragments of smaller size (if it exceeds the *Frag_ threshold*) before a packet is transmitted with one CW. The advantage of this technique is that if an error occurs during its transmission of a specific fragment, a station does not have to retransmit, wait to back off until the whole payload is transmitted. Also, it does not have to retransmit previous fragments that have been transmitted successfully. The range of *RTS_ threshold* is 0-2347 bytes (default), while the range of *Frag_ threshold* is 256-2312 bytes (default) [31].

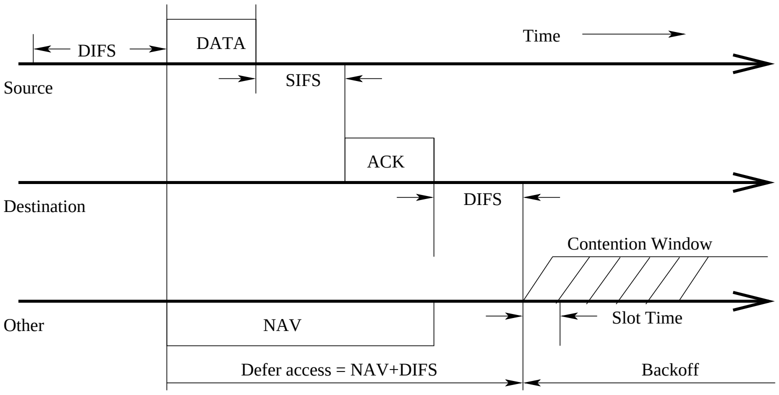


Figure 2.3: DCF with CSMA/CA

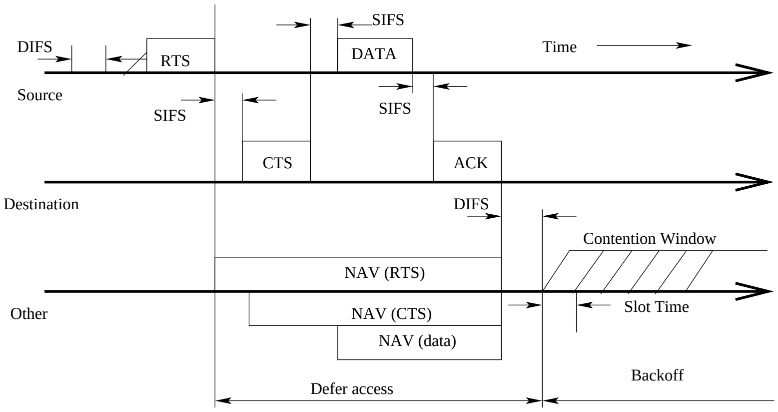


Figure 2.4: DCF with RTS/CTS

DCF with RTS/CTS: In order to solve the hidden terminal problem the RTS/CTS scheme is introduce as in Figure 2.4. Whenever a packet arrives it generates an RTS for destination station, and listens for an short inter frame space (SIFS), if it found to be idle then transmission of RTS to be send with a waiting for CTS, otherwise deferred until idle condition. Other stations defer their transmission with NAV. If CTS arrives then channel is reserved for transmission of data with a waiting for acknowledgment (ACK). If an ACK packet is not received after the data transmission, the packet is retransmitted after another random backoff. For each successful reception of a packet, the receiving station sends an ACK after SIFS. If ACK arrives then it goes to the starting state, otherwise after ACK timeout it goes for an exponential backoff.

Once an error occurs, a packet has to be retransmitted by the attempting station. Errors may be caused by many possible situations. For example, the corresponding CTS frame may not be returned after an RTS frame is transmitted. This may occur due to:

- Collision with the transmission of another station.
- Interference in the channel during the transmission of other RTS/CTS frames.
- The station receiving the RTS frame having an active virtual CS condition (indicating busy medium time period).

Two retry counters, the *short retry count* and *long retry count*, are defined to use in packet retransmission. Packets shorter than *RTS_ threshold* [8] are associated with the short retry count; others are associated with the long retry count. The retry counters begin at 0 and are incremented whenever a frame (or fragment) transmission fails. A frame is dropped if the retry count exceeds the maximum retry limit. The short count is reset to 0 when:

- A CTS is received in response to a transmitted RTS.
- An ACK is received after a non-fragmented transmission.
- A broadcast or multicast frame is received.

The long retry count is reset to 0 when:

- An ACK is received for a frame longer than RTS threshold.
- A broadcast or multicast frame is received.

In order to optimize the performance of DCF, a number of parameters are tunable in both the PHY and MAC layers of 802.11, few are selected and shown in Table 2.2 [31]. However these parameters are basically station-based and therefore cannot effectively differentiate multiple flows within a station. Furthermore, the effects of tuning these parameters are limited in terms of increasing/decreasing MAC throughput/delay, respectively. Therefore, additional resolutions are demanded to guarantee QoS in 802.11.

Table 2.2: Common tunable parameters in 802.11

Parameter	**Meaning & Units**	**Tuning Effect if Increased**	**Tuning Effect if Decreased**
Beacon interval	Number of Tus between transmission of beacon frames	Better throughput and longer battery life	Mobile stations can move faster and still maintain the n/w connectivity.
RTS threshold	Frames longer than the threshold use RTS/ CTS access method	Increasing the maximum theoretical throughput if no hidden terminal or interference	Higher throughput if there are a large no of hidden terminals.
Fragmentation threshold	Frames longer than the threshold are fragmented	Increasing throughput in error-free channel	Increasing throughput in error-prone channels.
Long/short retry limits	The max. no. of transmission allowed for frames shorter/longer than RTS threshold	Lower frames drop rate, but it may incur longer backoff and throttle the throughput	Higher frames drop rate, but smaller buffer required.

Characteristics of HCF

HCF is the coordination function for 802.11e standard for QoS [45]. The 802.11e task group was formed to come up with a priority based CSMA/CA scheme to provide differentiated services across different types of applications. The IEEE 802.11e MAC employs a channel access function, called hybrid co-ordination function (HCF), which includes a contention based channel access known as enhanced distributed channel access (EDCA) and a contention free channel access mechanism. EDCA has four access categories (ACs). Each AC obtains a differentiated channel access due to varying amount of time an AC would sense the channel to be idle and different length of the CW size during backoff. EDCA supports eight different priorities, which are further mapped into four ACs. Access Categories are achieved by differentiating the arbitration inter frame space (AIFS), the initial window size, and the maximum window size For the *AC[i]*, where $(i = 0, \cdots, 3)$, the initial backoff window size is $CW_{min}[i]$, the maximum backoff window size is $CW_{max}[i]$, and the arbitration inter frame space is *AIFS[i]*. Each AC acts as an independent virtual MAC entity and performs the same DCF function, with a different inter frame space (*AIFS [i]*), and a different CW. Each AC has its own backoff counter (*BC [i]*), which is independent of others. If more than one AC finishes the backoff at the same time, the highest priority AC frame is chosen for transmission by the virtual collision handler. Other lower priority AC frames go to the next round of backoff. Where AC constitutes *AC [0], AC [1], AC [2]* and *AC [3]* are used for background, best effort, video and voice respectively.

2.2.2 Services Supported in 802.11 MAC

For higher layer applications MAC functions of IEEE 802.11 can support nine types of services: (a) authentication, (b) association, (c) de-authentication, (d) disassociation, (e) distribution, (f) integration, (g) privacy, (h) re-association, and (i) MAC service data unit (MSDU) delivery, which can be divided into two categories of IEEE 802.11 MAC services the station service (SS) and the distributed system services (DSS) [7].

The SS is present in every IEEE 802.11 station (including APs, since APs include station functionality). The SS is specified for use by MAC sublayer entities, see Figure 2.5. All conferment station provides SSs. The SS includes: (a) authentication, (b) de-authentication, (c) privacy, and (d) MSDU delivery [7].

The DSS is presented in Figure 2.5, IEEE 802.11 service architecture by bi-directional arrows within the APs. The architectural component used to interconnect different basic service sets (BSS) is the distribution system (DS). The DSSs are provided by the DS. The AP provides stations with access to the DSS. By using DS, an IEEE 802.11 WLAN service area can be extended to an arbitrary size. A mobile station can move from BSS1 to BSS2 service area through the DSS without loosing connectivity to other stations. IEEE 802.11 refers to this type of network as the extended service set (ESS) network. It means that several interconnected BSSs from an ESS via a DS. The key point is that stations within an ESS can communicate with each other and mobile stations can roam from one BSS to another BSS within the same ESS. It means that the movements are transparent to the LLC layer. The DSS is made up of follows: (a) association, (b) disassociation, (c) distribution, (d) integration, and (e) re-association [7].

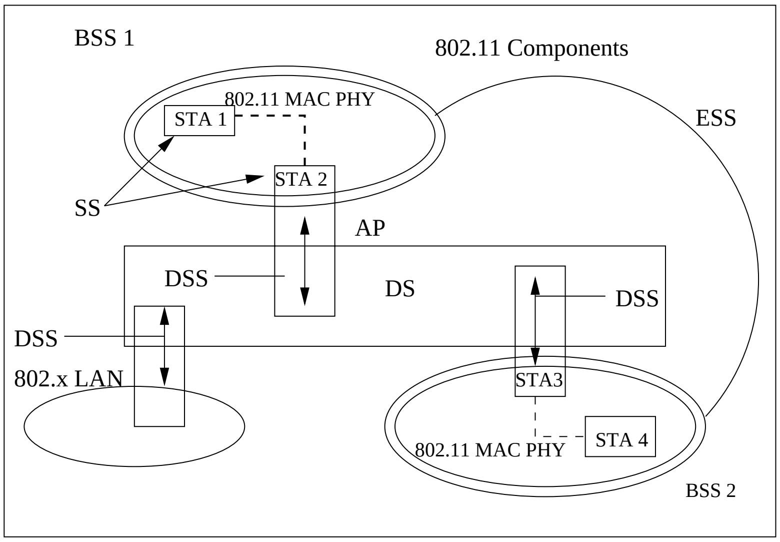


Figure 2.5: 802.11 Service Architecture

2.3 QoS Issues in IEEE 802.11 MAC Protocols

Wireless LAN links have specific characteristics such as reliability, bandwidth, packet delay and jitter. The wireless link characteristics are not constant and may vary over time and place. Mobility of users may cause the end-to-end path to change when users roam, and further, users will expect to receive the same QoS as they change from one AP to another. This implies the new path should also support the existing QoS by service reservation, and problems may arise when the new path cannot support such requirements.

There are two ways to characterize QoS in wireless LAN: parametrized or prioritized QoS [1, 3, 15]. Parametrized QoS is a strict QoS requirement, which is expressed in terms of quantitative values, such as data rate, delay bound, and jitter bound. In a Traffic Specification such as is used in the IntServ [68] 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 value of QoS parameters such as data rate, delay bound, and jitter bound-typically resulting from a DiffServ [69] model, may vary during the transfer of data frames. In this instance, there is no need to reserve the required resources by negotiating the Traffic Specification between the station and the AP as the DiffServ queue architecture is relied on to manage the QoS [1].

2.3.1 QoS Issues in PCF

PCF mode can deliver a certain level of guaranteed QoS service by centralized polling mechanism [16]. QoS mechanism in PCF is as follows:

- *Classification*: There is no classification mechanism or service differentiation provided.
- *Channel access*: Polling-based media access control mechanism using an AP.
- *Packet scheduling*: Packet scheduler uses FIFO mechanism directly related to the polling mechanism.

In order to offer a guaranteed level of QoS, PCF must define the following functions: (1) the polling sequence, (2) the polling frequency and (3) a QoS signaling mechanism.

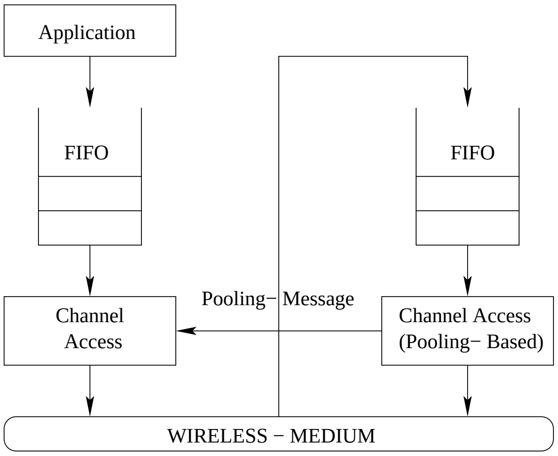


Figure 2.6: PCF QoS Architecture (Station and AP)

The receiving node and the AP implements different QoS architectures. The AP polls the stations and provides collision-free access to the channel for a given station. In the same station, all traffic is treated equally. PCF can deliver a certain level of guaranteed QoS service, which is suitable for real-time applications [32]. As it is shown in Figure 2.6 it uses a centralized pooling scheme [37] to provide certain level of QoS. Here AP plays a major role as a central system to access the stations [16].

Limitations: Though PCF has been designed to support time-bounded applications, this mode has some major problems, which lead to poor QoS performance [17]. In particular the central pooling scheme is inefficient and complex which causes deterioration of the performance of PCF high-priority traffic under load [16]. The transmission time of a polled station is difficult to control [10], when a pooled station is allowed to send a frame of length between 0 and 2346 bytes, it introduce the variation of transmission time. In addition all communications have to pass through the AP, which degraded the bandwidth performance [1, 3, 15, 31, 43]. Also the transmission time of the polled station is unknown [37].

2.3.2 QoS Issues in DCF

Fundamental channel access mechanism used for 802.11 MAC is DCF, for best effort services. Which uses carrier sense multiple access with collision avoidance (CSMA/CA) and optional virtual carrier sense using RTS, CTS control frames. From one point of view, the primary QoS mechanism in 802.11 networks is collision avoidance. In order to clearly understand the QoS support, we first examine the QoS mechanisms provided by IEEE 802.11 using DCF mode. It uses an Backoff Time algorithm $BackoffTime = rand\ [0, cw] * slot\_time$, where $CW_{min} < CW < CW_{max}$. If a collision occurs, it wait a random amount of time (*BackoffTime*) and try again later.It also supports asynchronous transmission.

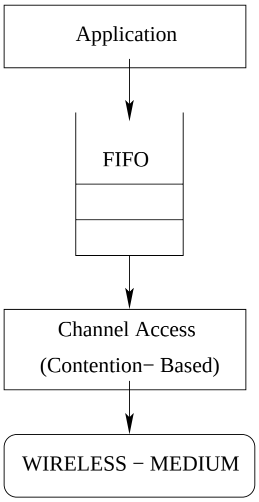


Figure 2.7: DCF QoS Architecture

Stations use the information in the duration field to adjust their network allocation vector (NAV), which indicates the amount of time that must elapse until the current transmission session is complete and the channel can be sensed again for idle status. QoS mechanism in DCF: (as shown in Figure 2.7)

- *Classification*: There is no classification mechanism or service differentiation provided.
- *Channel access*: Contention-based media access control mechanism.
- *Packet scheduling*: Packet scheduler uses FIFO mechanism.

The end host and the AP implements the same QoS architecture. DCF mode delivers best effort service. Stations equally content bandwidth. There is no service differentiation and no service guarantee in terms of bandwidth and delay. This operation mode is suitable for non-real time applications [32].

2.3.3 Simulation and Analysis of DCF

Simulation have made in order to evaluate the performance of 802.11 MAC DCF, using NS-2 [41]. Simulation topology consists of up to 15 stations operates at IEEE 802.11 physical mode and transmits two types of traffics (general and multimedia) to each other and the stations are mobile. The packet size of general is equal to 512 bytes and the inter packet arrival interval is 30ms. The multimedia packet size is 1024 bytes and the inter packet arrival interval is 50ms as shown in the Table 2.3 Simulation time is 10 simulated seconds and all traffics are constant bit rate (CBR) sources. We varying load by increasing the no of stations from 2 to 15. Stations having drop tail queue with maximum capacity 50. Each connection uses a CBR generator as a traffic source, and each traffic flow has assigned traffic CBR1 or CBR3. Other simulation parameters DIFS, SIFS, CW_{min} and CW_{max} (contention window minimum and maximum), RTS, CTS , ACK are mentioned in Table 2.4. Simulation is performed in both *Infrastructure* and *Ad-hoc mode*, which consists of different service sets (such as BSS, ESS and IBSS (or Ad-hoc))

Table 2.3: Traffic for Simulation

Traffic Type	**CBR1 (General)**	CBR3 (Multimedia)
Packet-size	512	1024
Interval(ms)	30	50

I. **Simulation of DCF in BSS mode:** It contains one AP, which connected to the wired backbone and the nodes or mobile station move inside the region of the AP, and nodes increases from 2 to 15. At the time of transmission at shares the common AP, through which all the communication has been made, as shown in Figure 2.8.

Table 2.4: Simulation Parameters and Its Values

Parameter	**Value**
Nodes	2 to 15
SIFS	$28\mu s$
DIFS	$128\mu s$
Slot Time	$50\mu s$
CW_{min}	31
CW_{max}	1023
Frame Types	**Size in byte**
RTS	20
CTS	14
ACK	14
MAC Header	34

II. **Simulation of DCF in ESS mode:** Here the simulation is carried out with two APs, shown in Figure 2.10 that are connected to the wired backbone and one among them known as home agent (HA) where other one is known as foreign agent (FA). Nodes or mobile stations move from HA to FA, from FA to HA or within the APs.

III. **Simulation of DCF in IBSS (or Ad-hoc) mode:** In Ad-hoc mode all stations are mobile as per Figure 2.12 and capable to transmitting and receiving the packets. Nodes are move within a specified region and communicate among themselves through one another. Here the problems associated is hidden station and exposed station problem. Nodes are increases from 2 to 15 in order to increase the network load.

A framework for DCF has been developed using NS-2 [41] to simulate the performance of DCF. From the simulation, the screen shots of BSS, ESS and Ad-hoc is shown in Figure 2.8, Figure 2.10, Figure 2.12, with the mentioned parameters as in Table 2.3 and Table 2.4 using NS-2, it is found that the DCF does not provide any service differentiation in any traffic pattern. The delay performance analysis of three modes for both the traffic pattern is not differentiated as shown in Figure 2.9, Figure 2.11, Figure 2.13. Also the average throughput of the two flows for a station is quasi-stable (*i.e.* the no of station is up to a limit). When the no of station increases, the throughput of two flows decreases. So this simulation clearly shows that there is neither throughput nor delay differentiation between the different flows. The reason is that all flow shares the same queue.

DCF only supports best-effort services but does not provide any QoS guarantee for time bounded applications such as real-time multimedia, videoconferencing etc. So DCF does not support any differentiation mechanism to guarantee bandwidth, packet delay and jitter for high-priority multimedia flows. These are the problem area in WLAN, which needs a greater attention for research. Some parameters of CW, Backoff Algorithm and Inter-frame spacing can be tunable to achieve the better service differentiation.

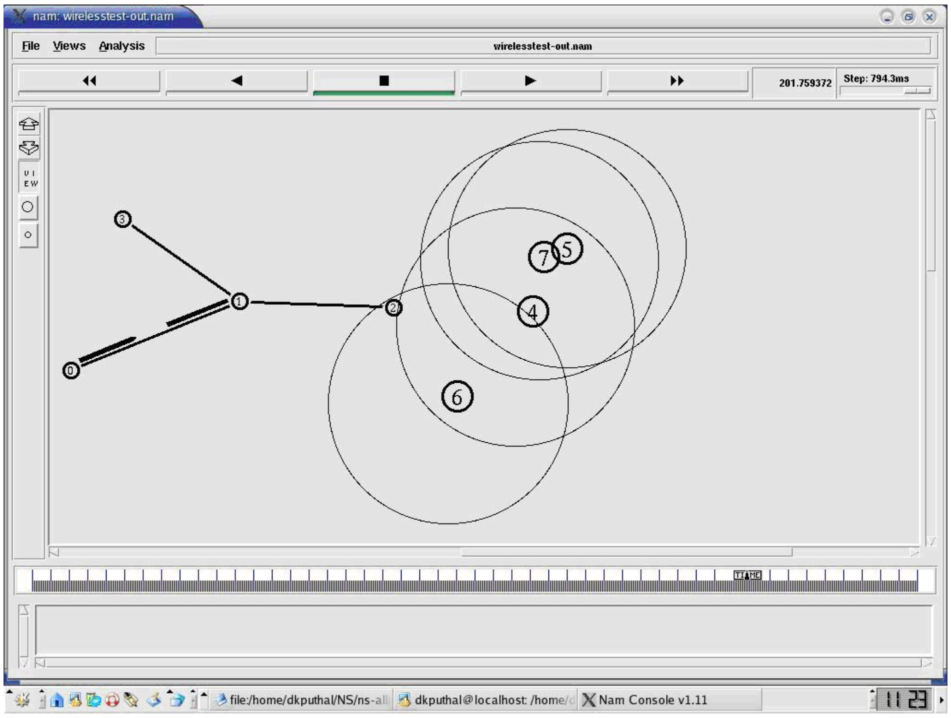
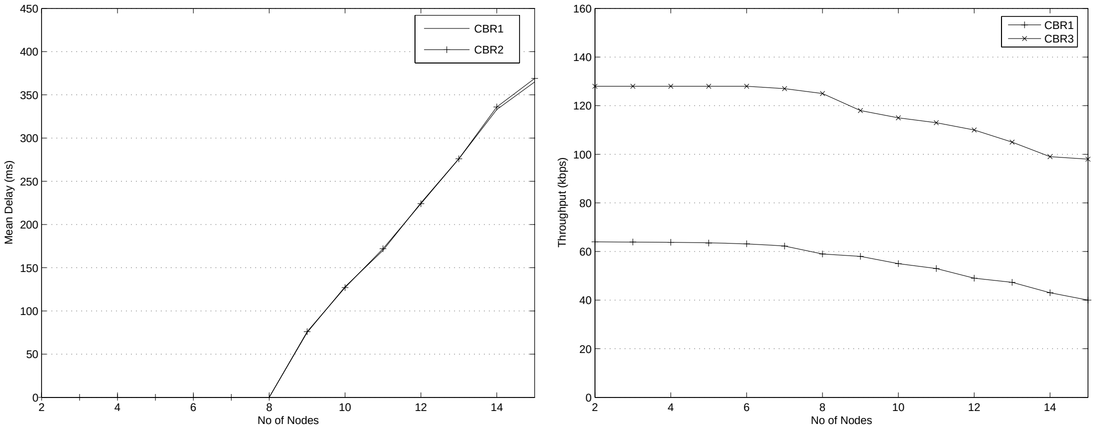


Figure 2.8: Screen shot of BSS



(a) (b)

Figure 2.9: (a) Delay and (b) Throughput analysis of DCF in BSS mode

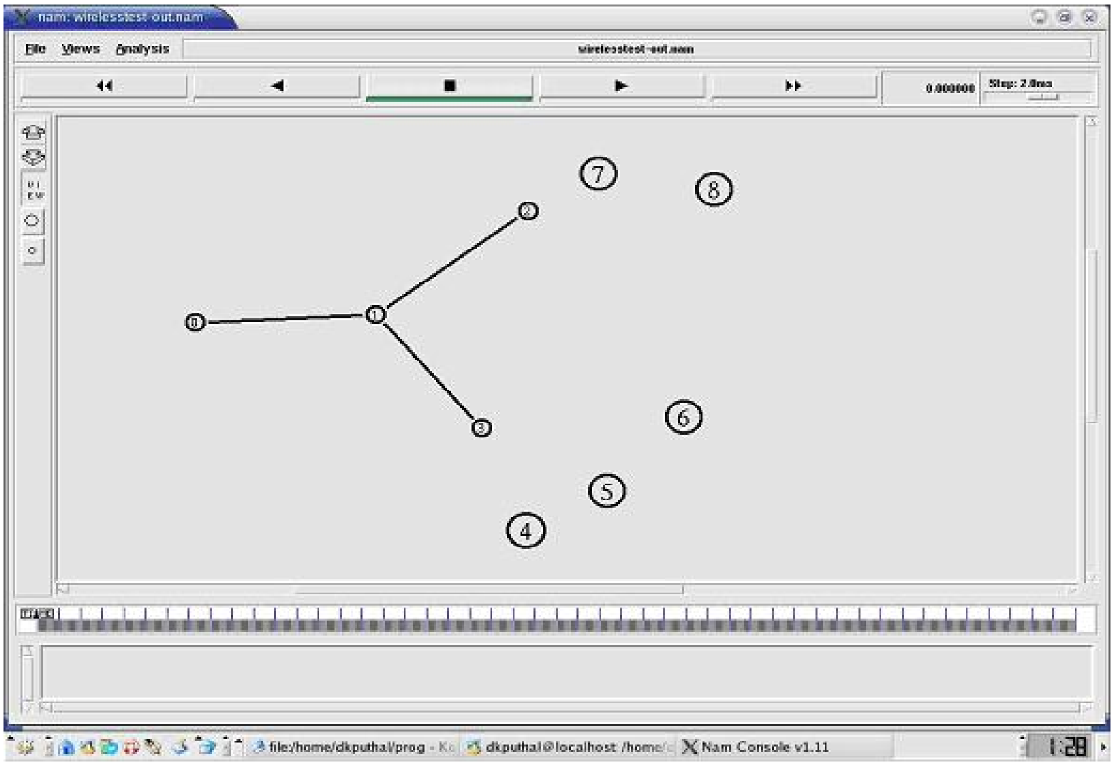
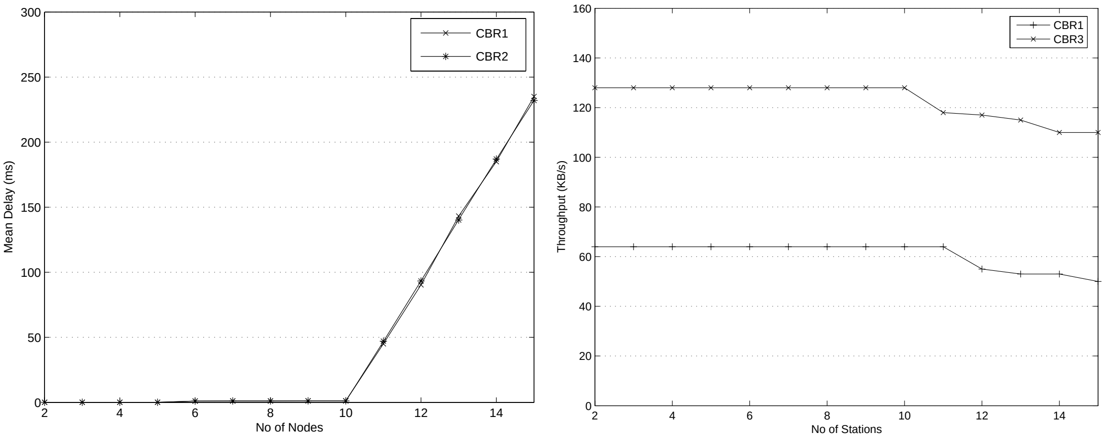


Figure 2.10: Screen shot of ESS



(a) (b)

Figure 2.11: (a) Delay and (b) Throughput analysis of DCF in ESS mode

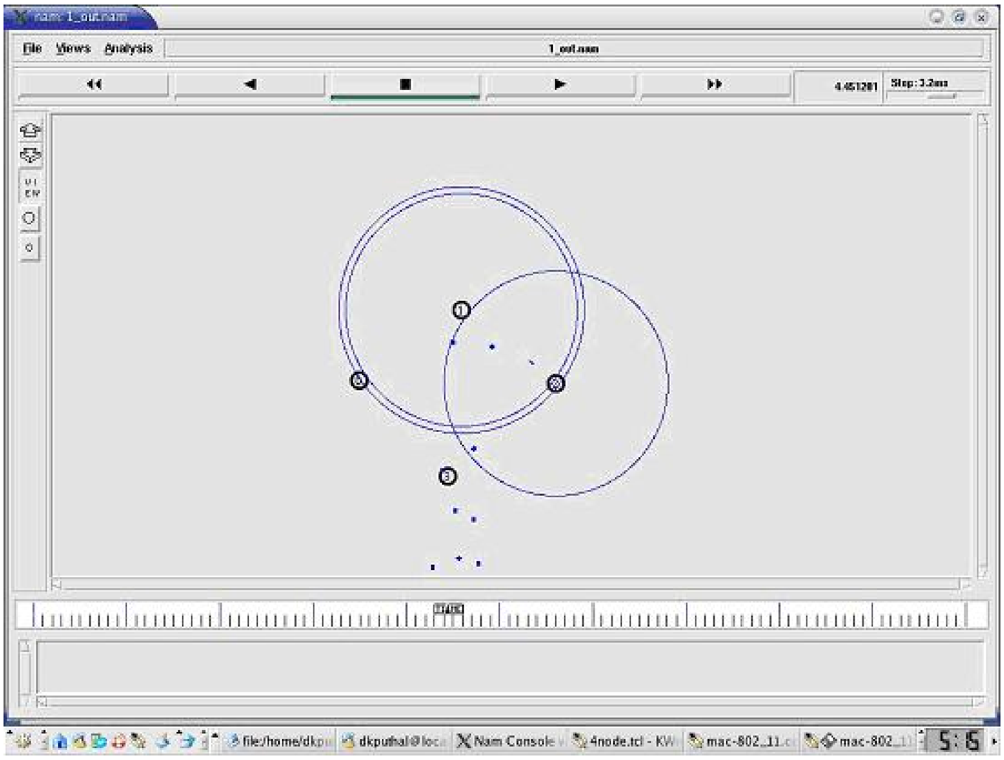
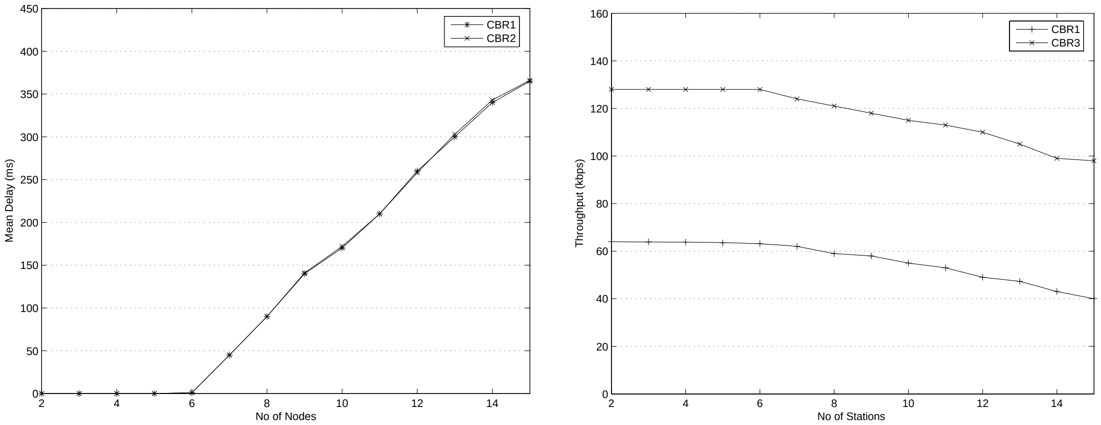


Figure 2.12: Screen shot of IBSS or Ad-hoc



(a) (b)

Figure 2.13: (a) Delay and (b) Throughput analysis of DCF in IBSS or Ad-hoc mode

2.4 Related Work

Science the publication of the first IEEE 802.11 standard in 1997, there have been quite a few works published in literature to provide performance analysis and enhancement. Most early works aim to provide theoretic models to analyze the channel performance with single traffic class as well as to modify the backoff mechanism to improve the channel utilization. Later on, with the popularity of WLANs as a natural extension to wire-line networks and the advance of research on QoS in wire-line networks, researchers start to study how to provide QoS differentiation or guarantees in WLANs. Table 2.5 shows the taxonomy of the QoS provisioning, by classify research works on QoS enhancement and modeling of 802.11 DCF and its variations. By considering the traffic class the works in literature can be broadly categorized in to two types (*i.e.* single traffic class and multiple traffic class).

2.4.1 Single Traffic Class with Model Based

Cali et al. [48] analyze the performance of the legacy IEEE 802.11 DCF protocol through a $p-persistent$ version 802.11 DCF MAC protocol. Each station transmits its frame in a slot (after the medium is sensed idle for an interval of DIFS) with probability p. Based on the analytical model, they observe that the system throughput only relies on the value of p and the number of active stations. They also show that with the current parameter settings of IEEE 802.11, the maximum achievable system throughput falls far beneath the theoretical capacity bound. As such, they suggest to incorporate a parameter tuning method in IEEE 802.11 so as to on-line infer parameters (*e.g.* the number of active stations) needed for computing the best protocol parameters (*e.g.* the CW size to be used) and achieve the capacity bound. On-line measurement algorithm to estimate the no of active stations through estimating *E(I)* and fine tune the transmission probability parameter p accordingly.

Bianchi [13] studies the performance of IEEE 802.11 MAC protocol through two steps. First, models the behavior of the binary backoff counter at one tagged station as a discrete Markov chain model and the transmission probability (t).

Table 2.5: Taxonomy of QoS provisioning work for IEEE 802.11

Author	**Based On**	**Traffic Class**	**QoS Support and Parameter**	**Approach**
Bianchi [13] Kumar et al. [47] Cali et al. [48] Carvalho et al.[49] Foh and Zukeman [50] Wu et al. [51]	Model Based	Single Class	Throughput Models	Analytical Model
Kim and Hou [59]	Model Based	Single Class	Capacity Improving/ QoS differentiated services	New MAC Algorithms
Bharghavan [56] Chao et al. [57] Fang and Bensaow [58]	Heuristic Based	Single Class	Capacity Improving/ supporting QoS differentiated services	New MAC Algorithms
Bianchi [63] Cali et al.[64]	Model Based	Single Class	Capacity Improving/ QoS differentiated services	Tuning of MAC parameters
Kwon et al.[65]	Heuristic	–do–	–do–	–do–
Xiao [52] Kumar et al.[47] Ge and Hou [53]	Model Based	Multiple Class	Throughput Model	Analytical Model
Vaidya et al.[60] Banchs and Perez [61]	Model and Fair queuing	Multiple Class	Capacity Improving/ QoS differentiated services	New MAC Algorithm
Veres et al.[62]	Heuristic	–do–	–do–	–do–
Ge and Hou [53] Qiao and Shin [67]	Model Based	Multiple class	Capacity Improving/ QoS differentiated services	Tuning of MAC Parameters
Qiao et al. [14] Pavaon and Choi [55]	Model Based	—	Resource Allocation	—

Second, analyzes the saturation throughput under the assumption that in each transmission attempt, regardless of the number of retransmissions, each packet collides with constant and independent probability p. It is intuitive that this assumption becomes more realistic when the number of stations and the individual CW sizes get larger. Although the model does not consider the case in which the backoff counter freezes (at the current value) when the medium is sensed busy due to the data transmission activities (initiated by other stations), it motivates a significant amount of subsequent analysis work. Kumar et al. [47] present a simplification and generalization of Bianchis analysis and give fixed-point solutions. In the case of a large number of nodes, they give explicit expressions for the collision probability, the aggregate attempt rate, and the aggregate throughput.

Carvalho et al. [49] present an analytical model which computes the average service time and jitter experienced by a packet in a saturated IEEE 802.11 ad-hoc network. They show that the existing binary backoff scheme is not appropriate for supporting delay constraints, and that use of a large and constant CW size is more efficient than binary backing off the window size. This suggests that the initial CW size CW_{min} should be set to a large enough value to avoid excessive backoff.

Foh and Zukerman [50] analyze, by leveraging the throughput analysis by Bianchi [13], the saturation throughput with a Markov chain with a single server. They assume that the number of active stations increases according to a Poisson process and decreases according to the state dependent service process. Wu et al. [51] also leverage Bianchis analysis to study the performance of reliable transport protocols over IEEE 802.11-operated WLANs. They extend the Markov chain model in [13] and incorporate the frame retransmission limit, and hence the revised model achieves better accuracy in characterizing the transmission activities of IEEE 802.11 DCF.

2.4.2 Single Traffic Class with new MAC Algorithm

Bharghavan [56] proposes two MAC algorithms: CSMA/CA-based dual channel collision avoidance (DCCA) and backoff-based Fair Collision Resolution Algorithm (FRCA). DCCA employs two channels: one is a control channel for signaling and the other is a data channel for data transmission. Since the control range is tuned to be much larger than the data transmission range, collisions in all the cases of hidden/exposed stations can be considerably avoided. FRCA implements a collision resolution method as follows: each station n keeps track of the number of RTS and CTS frames transmitted until a successful RTS/CTS handshake takes place, so as to correctly distinguish local collisions from remote ones. Station n then determines its backoff timer only taking into account of local collisions. It also advertises its backoff timer value to neighboring stations, by including the values in the header of all non-RTS packets. A neighboring station can then leverage the contention status experienced by station n and use the advertised value as an estimate of the initial CW size, rather than growing the CW from CW_{min}.

Chao et al. [57] propose a simple load-aware MAC protocol. Observing that the contention based IEEE 802.11 DCF scheme does not perform well and often renders excessive collisions (and subsequent retransmissions) when the system load is heavy, they propose to use IEEE 802.11 DCF when the overall system load is light, and a token based, contention-free scheme otherwise. Fang and Bensaow [58] study the issue of how to enforce among competing stations the same probability of successfully transmitting a packet within an optimal fair interval, *i.e.* the interval in which all the stations can have the chance of successfully sending one packet. They devise a new binary backoff algorithm for IEEE 802.11 DCF, and prove its stability as well as fairness with game-theoretic methods.

Kim and Hou [59] proposed an analytic model to characterize data transmission activities and a model-based frame scheduling (MFS) scheme that is laid as a thin layer between the link layer control (LLC) and MAC layers to improve the achievable throughput in WLANs. MFS operates as follows: each node estimates the current network status by keeping track of the number of collisions it encounters between its two consecutive successful frame transmissions. With the on-line measured parameters the station then estimates the number of active stations that attempt to transmit frames, and computes the current network utilization with the use of a rigorous fluid model. (In order to accurately calculate the current utilization in WLANs, they develop an analytical fluid model that characterizes data transmission activities in IEEE 802.11 operated WLANs with/without the RTS/CTS mechanism, and figures in all the control overhead incurred in the PHY and MAC layers and the other system parameters specified in IEEE 802.11.) The calculated result is then used to determine an (artificial) delay to be introduced before a station passes the frame down to IEEE 802.11 MAC. As long as the measured network status sustains, the delay introduced can reduce the likelihood of potential collisions. MFS does not require any change in IEEE 802.11 MAC (as it is implemented as a thin layer between the LLC and MAC layers) and is thus backward compatible with IEEE 802.11.

2.4.3 Single Traffic Class with Model Based Approach for Fine Tuning the Parameters

All the models with single traffic class (as shown in the Table 2.5) can essentially be used to tune the CW size (which in turns determines the attempt probability), in order to improve the protocol capacity. We have discussed several representative algorithms that leverage the analytic models. Based on the observation that the system throughput achievable by IEEE 802.11 DCF heavily depends on the number of active stations, Bianchi et al. [63] propose a method that on-line estimates the number of active stations under IEEE 802.11 MAC. They present that if the conditional collision probability p is estimated by an auto regressive moving average (ARMA) filter, then the number of active stations n can be estimated as

$$N = 1 + \frac{log(1-p)}{log\left(1 - \frac{2-(1-2p)}{(1-2p)(w+1)+p^w(1-(2p)^w)}\right)} \tag{2.1}$$

Where $w = CW_{min}$ and $m = log2(CW_{max}/CW_{min})$. Therefore, based on the estimated number of active stations, one can dynamically determine the CW size to avoid potential collisions.

As discussed in **Cali et al.**[64], the system throughput relies on the transmission probability, p, and the number of active stations. They also show that the average number of idle slots in a virtual transmission time (*i.e.* the time interval between two consecutive successful frame transmissions) can be expressed as a function of N and p. Based on these observations, Cali et al. [64] propose a p-persistent version of IEEE 802.11 MAC protocol with an adaptive backoff mechanism. In the proposed protocol, a frame is transmitted with a probability p, and is deferred transmission with a probability $1-p$, where the value of p is dynamically adjusted according to the channel status. The average idle period between two consecutive transmissions, $E(T_{idle})$, can be expressed as

$$E(T_{idle}) = \frac{(1-p)^n}{1-(1-p)^n} * t_{slot} \tag{2.2}$$

Where t_{slot} is the slot time (=20 μs in IEEE 802.11). When the attempt probability p used in the measurement period is known, one can infer the number of active stations by on-line measuring the idle period. With the on-line inferred parameter N, a station computes the optimal value of p using the analytic model. Cali et al. show that the computational overhead incurred in on-line measurement is not significant, and that with the value of p being on-line adjusted, the proposed protocol can achieve system throughput that is close to the theoretical protocol capacity limit derived in [48].

2.4.4 Single Traffic Class with Heuristic Based Approach for Fine Tuning the Parameters

Kwon et al. [65] propose to use a minimum CW size CW_{min} that is smaller than what is specified in IEEE 802.11 and a maximum CW size CW_{max} that is larger than what is specified in IEEE 802.11. Each station increases (doubles) the CW size up to CW_{max} when it detects a busy medium or when it experiences collisions in its transmission attempt, and decreases (halves) its current backoff timer value when it detects a fixed number of consecutive idle slots during the backoff procedure. The CW size is reset to CW_{min} when it successfully transmits a frame. To achieve fairness, the self-clocked fair queuing (SCFQ) algorithm [66] is used to track the service received by each station. When the service received by a station exceeds its fair share by a threshold, the station gives up its capture of the channel by setting its backoff timer to a value randomly generated from [0, CW_{max}]. As compared with the other fine tuning algorithms, this approach does not require estimates of the number of active stations and does not make any assumption on the traffic pattern (e.g. the asymptotic condition). However it is not clear whether or not the approach provides deterministic performance bounds in terms of system throughput and frame delays.

2.4.5 Multiple Traffic Classes with Model Based

Xiao [52] extends Bianchis model [13] to accommodate the case of multiple traffic classes, and incorporates three tunable parameters into the model: the initial

CW size, the retry limit, and the backoff window-increasing factor. However, the effects of AIFS and TXOP values are not figured in. With the use of the model, the performance of IEEE 802.11e in terms of saturation throughput, saturation delay and frame dropping probability is analytically derived.

Ge and Hou [53] extend the work by Cali et al. [48] and devise an analytical model for a multi-class, p-persistent version of IEEE 802.11 DCF. Based on the devised analytical model, they then derive the optimal value of the probability, pi, with which a station with class-i traffic attempts for transmission in a slot under the asymptotic condition. By optimality, they mean the protocol capacity is maximized, subject to the requirement that the ratio of the throughput attained by class-i traffic to that by class-1 traffic conforms to certain pre-determined value. The results derived in [53] can be readily applied to tune the CW size in the legacy IEEE 802.11 DCF, so as to optimize the protocol capacity in the case of multiple traffic classes.

2.4.6 Multiple Traffic Classes with Fair Queuing Based Approach for new MAC Algorithm

This class aims to provide weighted fairness (in terms of the throughput attained by different stations) and differentiated services.

Vaidya et al. [60] propose the distributed fair scheduling (DFS) algorithm based on the notion of weighted fair queuing to distribute channel bandwidth. It leverages the self-clocked fair queuing algorithm to determine the finish tag of each packet, decide in a distributed manner which packet has the smallest finish tag value, and assigns backoff interval values of head-of-queue packets proportional to the finish tag values of those packets.

Banchs and Perez [61] propose a distributed weighted fair queuing (DWFQ) algorithm. DWFQ aims to allocate the channel bandwidth, r_i, for a flow i, according to the weight, W_i, of the flow, *i.e.* $\frac{r_j}{w_j} = \frac{r_i}{w_i} \forall i, \forall j$
Every time a new packet is transmitted, r_i can be estimated with

$$r_i{}^{new} = \left(1 - e^{-t_i/k}\right) * \frac{l_i}{t_i} + e^{-t_i/k} * r_i{}^{old} \tag{2.3}$$

Where l_i and t_i are, respectively, the size and inter arrival time of transmitted packets, and K is a constant of 100 ms.

To achieve the goal, each station i maintains a label L_i, the label, which is calculated as $L_i = \frac{r_r}{w_i}$ and a CW scaling coefficient p. Each sending station includes its label in the header of its packet. For each observed packet, if the received label L_{rcv} in the header of the packet is smaller than the label of the station L_{own}, the station increases its scaling coefficient p by a small amount while in the opposite case it decreases p by a small amount. Each station maintains its CW, $CW_{802.11}$, following the rules in the standard IEEE 802.11 MAC protocol. However, when the station calculates the backoff window size, the actual CW size used, CW is derived by scaling $CW_{802.11}$ with the coefficient p. This proposed solution requires that all the stations in the BSS run the same fair scheduling algorithm, and the performance is contingent upon how to determine whether the channel is overloaded. More importantly, it is not clear whether the scheme shall always converge to a normal equilibrium state rather than an abnormal one (e.g. extremely low aggregated throughput being fairly shard among all flows). A flow with incoming rate lower than its fair share may keep posting abnormally small label values and may potentially force other flows to decrease their transmission rate leading to a low aggregated channel throughput.

2.4.7 Multiple Traffic Classes with Heuristic Based Approach for new MAC Algorithm

Veres et al. [62] present a delay model for IEEE 802.11 DCF to analyze the expected delay experienced by a station. Based on the model, they show that service differentiation can be achieved by using different CW values CW_{min}, CW_{max}, for each service class. However, they do not discuss how to select appropriate values for CW_{min} and CW_{max}. In addition, they propose two MAC algorithms: (i) virtual MAC (VMAC) that estimates the MAC-level service qualities, such as the delay, collision, and losses by emulating the operational behaviors of IEEE 802.11-compliant MAC, and (ii) virtual source (VS) that estimates the application-level delays caused by packetizing, encoding, and queuing on top of VMAC. They then propose a distributed admission control algorithm that exploits the estimates obtained in VMAC and VS, and show that the resulting MAC equipped with the admission control scheme can guarantee the performance required by each service class. The VMAC algorithm bears some similarity to the internal contention resolution algorithm in the IEEE 802.11e draft. However, VMAC is intended to be used as an estimation module in admission control rather than that for resolving frame collision.

2.4.8 Multiple Traffic Classes with Model Based Approaches for Fine Tuning the Parameters

Qiao and Shin [67] extend Bianchis Markov chain model to the case of multiple priority classes and propose a priority-based fair medium access control protocol *P-MAC*. *P-MAC* requires that each station keeps track of the activities on the wireless medium. Based on the measurements of the average number of consecutive idle slots on the wireless medium *avg_idle*, and the average number of time slots between two consecutive successful *class-i* frame transmissions, each station can estimate the number, f_i, of active stations of *class-i*, and approximately calculate the optimal CW size, ${CW_i}^*$, of class i.

Ge et al. [54] exploit their analytical model in [53] (which in turns is derived based on Calis model), and devise a multi-class, p-persistent version of IEEE 802.11 to achieve throughput differentiation among different traffic classes. Given the desirable ratio, r_{i1}, of the throughput attained by class i traffic to that attained by *class 1* traffic, they derive the relationship between the optimal values of attempt probabilities in a slot, p_i and p_1 (or equivalently the optimal window sizes, ${CW_i}^*$ and ${CW_1}^*$), for classes i and *1*. The protocol capacity can then be optimized by finding the optimal value of p_1, subject to the constraint of the relation between p_i and p_1. They also propose an on-line measurement mechanism to measure and infer the number of active stations of each class so as to calculate ${CW_i}^*$ and cope with network traffic dynamics.

2.4.9 Resource Allocation

In addition to devising new MAC protocols or fine-tuning their parameters, QoS provisioning can also be achieved by judiciously allocating wireless resources, *i.e.*

radio bandwidth and power, among wireless stations. Resource allocation in IEEE 802.11 is made possible by the fact that IEEE 802.11a and b/g support multiple physical rates and IEEE 802.11h enables transmission power control (TPC) in IEEE 802.11-compliant devices.

Pavaon and Choi [55] propose a link adaptation method to improve the network throughput by dynamically adjusting transmission rates according to the current link condition. The link condition is estimated by the received signal strength (RSS) of received frames, and the transmission rate is determined as the maximally allowable rate given in the current link condition. Several states are used to describe the link condition, each of which is delineated by a pair of threshold values of RSS. The threshold values are dynamically changed over time according to the success/failure status of frame transmission and the number of retransmissions. The current state which a station is in is also continuously adjusted (according to its RSS), every time each station receives the frames.

Qiao et al. [14] introduce an energy-efficient scheme, called *MiSer*, that controls both the transmission power and the transmission rate to optimize resource usage in IEEE 802.11a/h - compliant wireless networks. When a station equipped with *MiSer* transmits a frame, it uses the most energy-efficient pair of power and rate. For this purpose, an optimal rate-power combination table is established offline, and a station looks up the table for every frame transmission. The rate-power table is built upon an energy consumption model that specifies the amount of energy consumed for each protocol operation (*e.g.* the energy incurred in frame/ RTS/ CTS/ ACK transmission, in the backoff state, in the frozen state, and in frame retransmission). In order to mitigate interference *MiSer* transmits a CTS frame with a higher power level (strong CTS). Through simulation, they show that combined rate and power allocation outperforms either of the component scheme (power control without rate adaptation or rate adaptation without power control), and that rate adaptation is more effective than power control within *MiSer*.

2.5 Conclusion

This chapter introduced the basic concepts, terminology, quality issues and the state of art of MAC protocols. From the simulation result it shows that DCF can support best effort services, without any QoS guarantees. The delay for all types of traffics is same in BSS, ESS and IBSS, all of them shares a common queue with contention based channel access. Bandwidth is equally contented by stations. There is no service differentiation and no service guarantee in terms of throughput and delay. This operation mode is suitable for non-real time applications. In DCF model, all the stations compete for the resources and channel with the same priority, by sharing a common queue with FCFS service of the packets. There is no differentiation mechanism to guarantee bandwidth, delay and jitter for high-priority stations or multimedia flows.

Chapter 3

State Modelling of IEEE 802.11 WLAN MAC Protocol

Finite state modelling of the legacy MAC sublayer for PCF and DCF both the coordination functions, of IEEE 802.11 is described in Section 3.3. The state transition model of DCF is explained in details for sender station, receiver station, channel and the model validation in Section 3.4.

3.1 Introduction

The international standard IEEE 802.11 was developed in recognition of the increased demand for wireless local area networks which permit interoperability of heterogeneous communication devices. The MAC sublayer of 802.11 WLAN supports two basic access methods: (i) contention-based distributed coordination function (DCF) and (ii) point coordination function (PCF). DCF can operate in two modes, one is DCF with CSMA/CA and other uses a RTS/CTS mechanism. As the coordination functions (PCF and DCF) described in Section 2.2.1. PCF differentiates between traffic of different priorities. It allow frames of high priority for faster access to the wireless medium. Access method in PCF is based on a central polling scheme controlled by an access point (AP) which act as a point coordinator.

MAC access using RTS/CTS is described with correspondence to Figure 2.4 of Section 2.2.1, whose flow chart shown in Figure 3.1. With its starting sate represented by an arrow mark with state *SENSE*, to wait for a packet and remains in that state by default. Whenever a packet arrives it generates an RTS as in, and listens for an inter frame space (IFS), if it found to be idle then, the transmission

Figure 3.1: Flow chart DCF access scheme

of RTS to be done with a waiting for CTS, otherwise deferred until idle condition. If CTS arrives then Data has to transmit with a waiting for ACK. If ACK arrives then it goes to the starting state, otherwise after timeout it goes for the exponential backoff. After a differed time interval it goes to backoff [0, CW], then it listens for an IFS, if busy then deferred until idle condition, otherwise decrement the backoff (to 0) and listen by transmitting a RTS with waiting for CTS.

3.2 State Transition Model of IEEE 802.11 MAC Protocols

The modelling of a system's behavior is an aggregation of the behavioral models and its components. We consider a state transition model of the WLAN which models two colliding stations simultaneously trying to send messages and then entering to the randomized exponential backoff procedure. The proposed state transition model is time variant and analyzes the functionality of PCF and DCF.

3.2.1 PCF State Modelling of WLAN

The functionality of proposed time variant PCF state model as depicted in Figure 3.2 and Figure 3.3. These models are based on the timed automaton as suggested by Bordbar et al. [3, 4].The interaction with the access point, which makes use of PCF, is modelled as state transition for PCF. At the start of a contention free period, the medium gets busy as in Figure 3.3 with the signal access of state mode for PCF. There are *N* stations, *i.e.* $i = 1, \cdots, N$. Depending on the value of *i*, the down link *(data)* is meant to be delivered to the station number *i*.

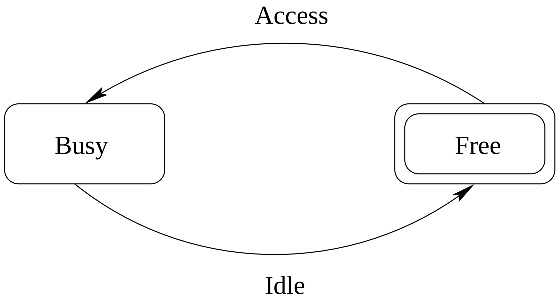


Figure 3.2: Medium state Model

The initial state operates with the value of $i=1$ and, it is incremented each time before the data is delivered to the next station. After gaining access to the medium, the PCF sends data to the destination station. The data sent by the DCF must be partitioned into units of maximum length of MSDU [1, 2]. *Sending_Data* state denotes the amount of time required for the MSDU to reach the destination. Depending on the value of *i*, the signal *data* is used in the Application Layer of Station *i*. When the transmission of data finishes, an urgent acting *CF-poll* signal is sent to mark the end of data. To notify the medium, an idle signal is sent

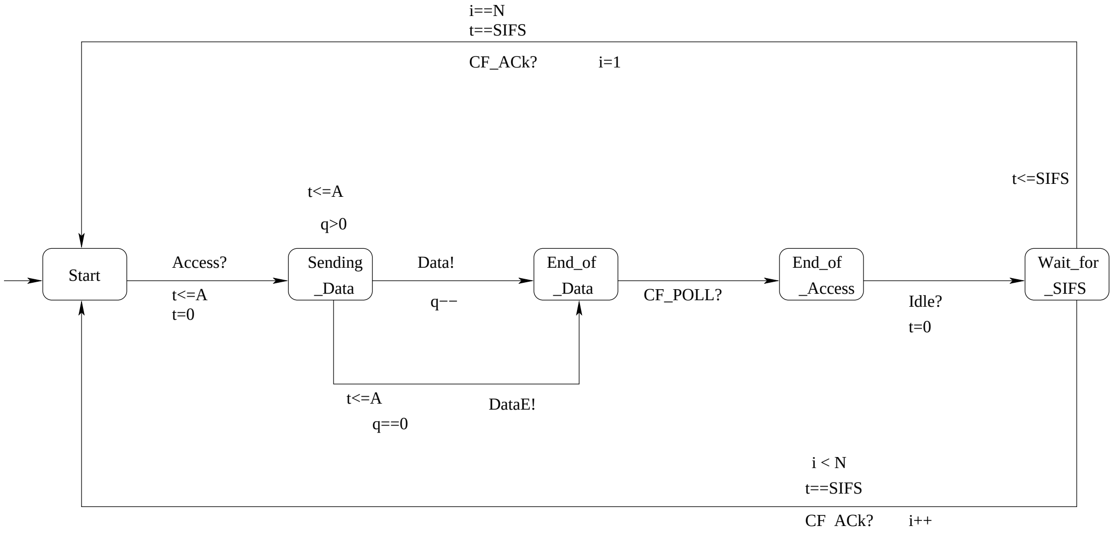


Figure 3.3: PCF state model

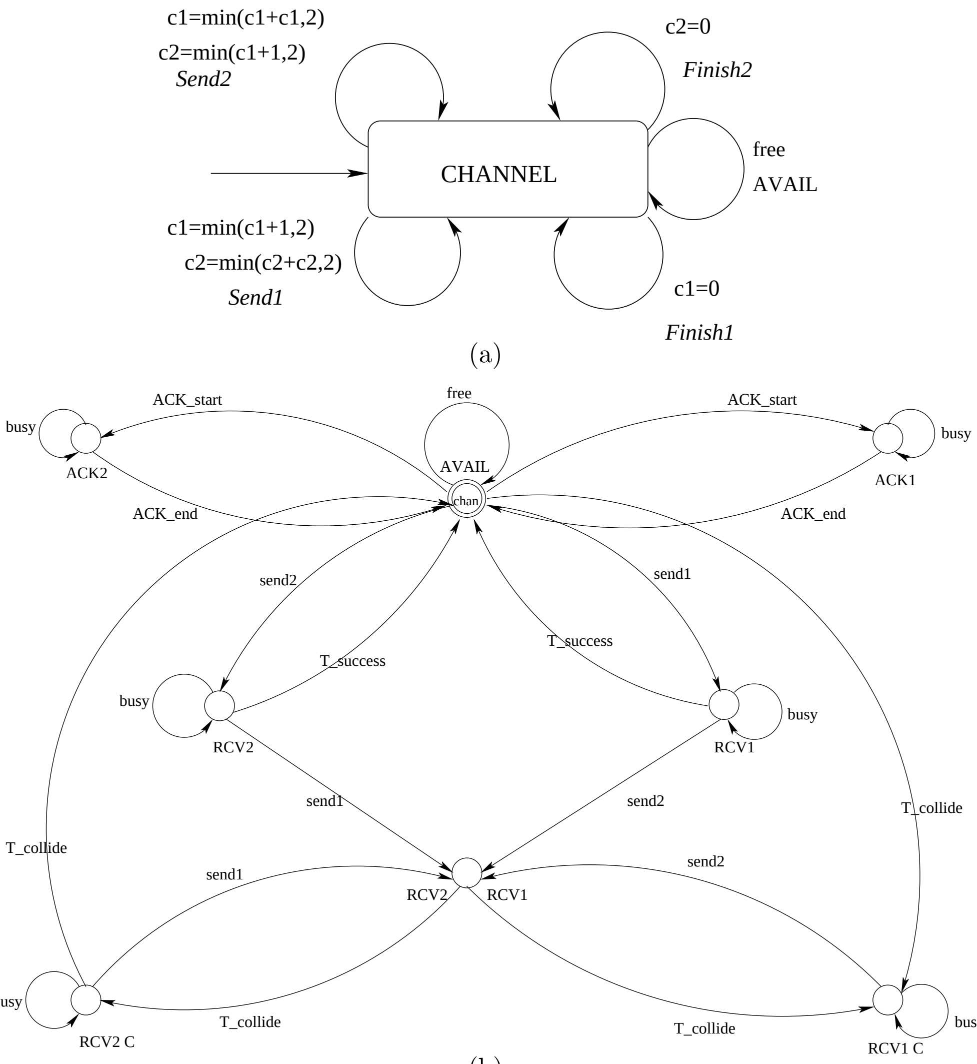
to mark the end of access. In the process the PCF waits for $SIFS = 10\mu s$ to complete. At exactly SIFS units it receives a *CF_ACK* signal from the Station that the data has been received. However, if $i < N$, in order to ensure that the next downstream goes to station *i+1*, the value of *i* is incremented. If *i =N*, this indicates that one contention free period is finished and a *CF_end* signal is sent. In this process, since no contention period is used, the CF-end is replaced with a simple acknowledgment signal *CF_ACK*. If the *CF_ACK* is sent a back-off period of SIFS is required.

3.2.2 DCF State Modelling of WLAN

The DCF state transition model is based upon the integer semantics. The mode consists of three components operating in parallel, namely *channel* (the channel), *sender_i* for *i=1, 2* (the sending stations) and *receiver* (destination station), with the value of parameters as given in Table 3.1.

Channel Model of WLAN MAC DCF

State transition model represents the channel is shown in Figure 3.4(a). This state transition model has two variables c_1 and c_2 which records the status of the packet being sent by node 1 and node 2 respectively, and updated both when, a node starts sending a packet (event *send*) or a station finishes sending a packet (event *finish*). The value of c_i ranges from within 0, 1 and 2. These variables have the following interpretation: c_i=0, nothing being sent by node i; c_i=1, packet from node i being sent correctly; c_i=2, packet from node i being sent falsified.



(a)

(b)

Figure 3.4: (a), (b) Channel Model

If $c_i > 0, i \in (1,2)$ then the channel is sensed to be busy, otherwise if the channel $c_i = 0, i \in (1,2)$ then it sensed to be idle or free. The value of c_1 is taken as minimum from $\{c_1 + 1, 2\}$, and c_2 value is chosen to be minimum value from $\{c_2 + c_2, 2\}$ for event send1. If c_1 is found to be 0 then the station has finished sending data for event Finish1 and has nothing to transmit. The value of c_1 is taken as minimum from $\{c_1 + c_1, 2\}$, and c_2 value is chosen to be minimum value from $\{c_1 + 1, 2\}$ for event *send2* but if c_2 is found to be 0 then the station has finished sending data for event Finish2.

As per the channel model in Figure 3.4(b), *free* corresponds to the case in which the channel is available. From that location, receipt of a packet data from *station1* (*send1* event, sent by send1) triggers the station to location RCV1, then this packet finishes successfully (*T_success* event, sent by send1 again) and returns the channel to the state *free*, or collide with *station 2* (*send2* event, sent by send2) and channel state proceed to *RCV1 RCV2*. From the latter location the event *T_collide* can remove the data packets from the channel. The state *ACK1* and *ACK2* of the model shows the receipt of acknowledgment on the channel. It is not modeled for the situation, in which an acknowledgment is sent at the same time as a data packet, when two acknowledgments collide.

Sender Station Model of WLAN MAC DCF

The state transition model of sending station *i.e. sender* is shown in Figure 3.5. The events *busy* and *free* are the urgent events of the sender. The initial state is indicated by an arrow mark. The sender begins in *SENSE* with a data packet ready to send, and senses the channel. If the channel remains free for DIFS ($50\mu s$), then the sender enters its vulnerable period and starts sending a packet (event *send*), otherwise the station enters backoff via an urgent transition. The time taken to send a packet is non deterministic (within*TTMIN* and *TTMAX*) *i.e.* transmission time minimum and transmission time maximum. The success of the transmission depends on whether a collision has occurred, and is recorded by setting the variable *status* to the value of the channel variable c_1.

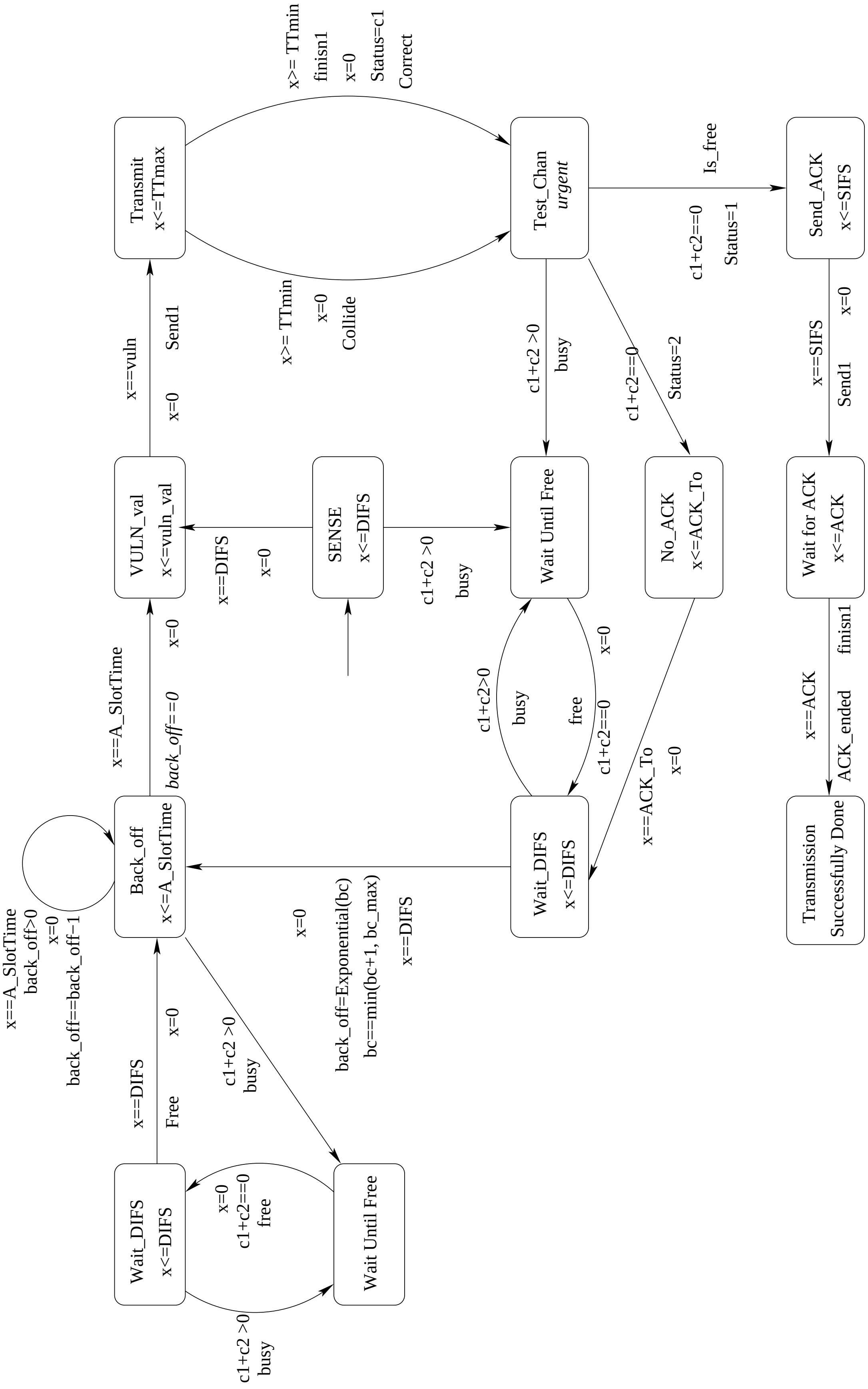


Figure 3.5: Sender Station Model

The sender then immediately tests the channel (represented by test channel urgent). If the channel is busy, the sender enters the backoff procedure; otherwise it waits for an acknowledgment. If the packet was sent correctly (*status =1*), then the destination station waits for *SIFS* and sends the acknowledgment; the sending station then receives this acknowledgment and completes the process. On the other hand, if the packet was not sent correctly (*status =2*), then the destination station does nothing. In this case, the sender station enters into times-out phase and executes the backoff procedure. In the backoff procedure, the sender first waits for the channel to be free for *DIFS* and then sets its backoff value according to the random assignment *backoff: =Random (bc)*, where bc, the backoff counter, is updated if its current value is less than its maximal value (CW_{max}). The state transition then decrements *backoff* by 1 if the channel remains free for $ASLOT\_Time$. However, if the channel is sensed busy within this slot, it waits until the channel becomes free and then waits for *DIFS* before resuming its *backoff* procedure. When the value of backoff reaches 0 the sender starts re-sending its data packet.

Receiver Station Model of WLAN MAC DCF

For the destination station as in Figure 3.6, having start state given by arrow mark, waits (*waiting* event) for an incoming packet. If a packet arrives correctly (*correct* event), then the destination station waits for *SIFS* and subsequently sends the acknowledgment (ACK_start). On the other hand, if the message arrives garbled (*collide* event), the destination station has to do nothing, *i.e.* it remains in the same state.

3.3 Model Validation

This model have been validate and the performance of 802.11 MAC DCF evaluated, using NS-2 simulator [41]. Simulation topology consists of up to 15 stations and transmits two types of traffics (general and multimedia) to each other and the stations are mobile. The packet size of general is equal to 512 bytes and the inter packet arrival interval is 30ms. The multimedia packet size is 1024 bytes and the

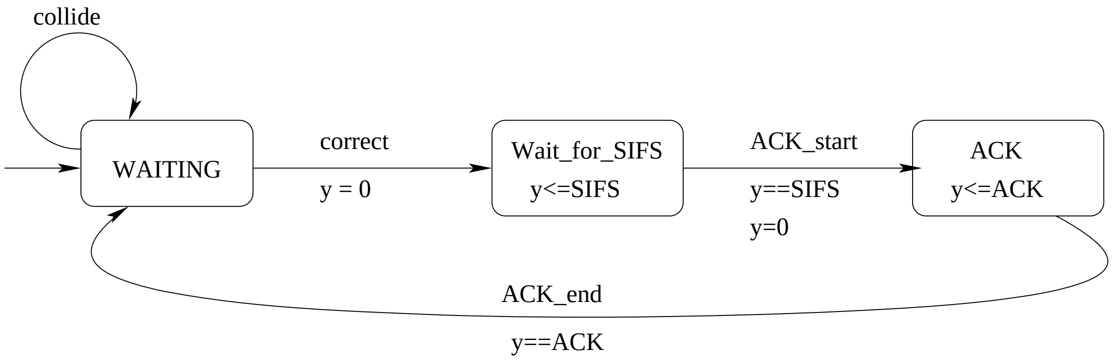


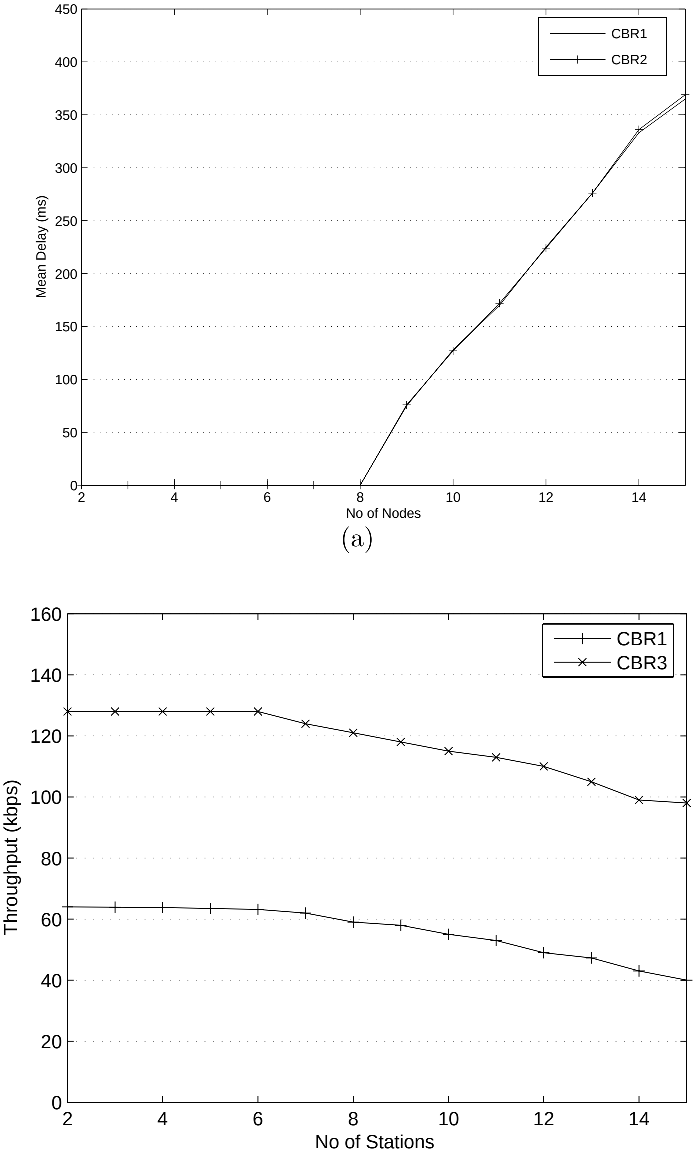
Figure 3.6: Receiver Station Model

inter packet arrival interval is 50ms. Simulation time is 10 simulated seconds and all traffics are from CBR sources. We varying load by increasing the no of stations from 2 to 15. Stations having drop tail queue with maximum capacity = 50. Each connection uses a CBR generator as a traffic source, and each traffic flow has assigned traffic CBR1 or CBR3.Other simulation parameters DIFS, SIFS, CW_{min} and CW_{max} (contention window minimum and maximum), RTS, CTS, ACK are mentioned in Table 3.1, transmission bit rate is 2Mbps.

In infrastructure mode all stations are mobile and capable to transmitting and receiving the packets. Nodes are move within a specified region and communicate among themselves through one another. Here the problems associated is hidden station and exposed station problem. Nodes are increases from 2 to 15 in order to increase the network load. As shown in Figure 3.7, when the no of station increases, the throughput of two flow decreases and delay increases. So this simulation clearly shows that there is neither throughput nor delay differentiation between the different flows. The reason is that all flow shares the same queue. So DCF cannot provide QoS, rather it provides only best-effort services.

Table 3.1: Simulation Parameter and it's Values

Variable	**Description**	**Values**
SIFS	short inter frame space	$10 \mu s$
DIFS	distributed inter frame space	$50 \mu s$
Slot Time	length of each backoff slot	$20 \mu s$
CW_{min}	Contention window minimum	31
CW_{max}	Contention window maximum	1023
ACK	Time to send an Acknowledgment	$205 \mu s$
ACK_TO	time sender waits for ACK before timing-out	$300 \mu s$
CCA	time receiver needs to asses the medium	$27 \mu s$
Turnaround	time a station needs to change from receiving to sending	$20 \mu s$
TT_MIN	minimum time to send a packet	$224 \mu s$
TT_MAX	maximum time to send a packet	$15{,}717 \mu s$
AIRPRO	the air propagation time	$1 \mu s$
VULN	vulnerable period (AIRPROP+CCA+Turnaround)	$48 \mu s$
Frame Type		**Size in byte**
RTS	Request to send	20
CTS	Clear to send	14
ACK	Acknowledgment	14
MAC Header		28



(a)

(b)

Figure 3.7: (a) Delay and (b) Throughput analysis of DCF in BSS mode

3.4 Conclusion

The chapter shows a finite state transition model of legacy MAC DCF and PCF. A framework for DCF has been developed using NS-2 to study the state transition behavior of DCF. As observe through the simulation, DCF provide service to different types of traffic with no service differentiation. State transition model presented can be alternate sub-protocol for IEEE 802.11 standard for WLANs. The use of modelling state transition diagram allows us to model asynchronous behavior of stations. Further work could lift several simplifying assumption that were made in this model: (i) such as fixed network topology in which sending station cannot also be destination station, (ii) the absence of the timing synchronization, and (iii) by increasing the number of participating stations etc. In DCF all stations compete for the channel with same priorities, also shares the common queue. There is no differentiation mechanism to guarantee bandwidth, packet delay and jitter for high-priority multimedia flows. These are the problem area in WLAN, which needs a greater attention for future research. There is no service differentiation policy is associated with different flows, so the delay for real time multimedia flows should be reduced for better performance.

In the next chapter, a priority station based with slow decrease of CW and reservation based channel access mechanism is proposed to provide QoS in WLAN.

Chapter 4

Station Based Priority for QoS Provisioning in WLAN

The proposed scheme for differentiating the traffic flows and providing service to the real-time traffic for priority stations is presented in this chapter. The *quality of service management (QoSM)* strategy is described in Section 4.3 with *slow contention window decrease scheme* subsiquently Subsection 4.3.3 describes a *reservation based packet forwarding* scheme. A *mathematical analysis* of the system is described in Section 4.4. The simulation compares the proposed scheme with the legacy MAC for real-time flow is described in Section 4.5. Finally, the chapter is concluded with a brief summary on simulation results for station based priority.

4.1 Introduction

For best-effort services IEEE 802.11 has gained popularity at an unprecedented rate. However, it lacks of the capability to support quality of services such as real-time, multimedia traffic properly. The proposed scheme on *station based priority* presents a simple approach to enhance the real-time traffic performance over the 802.11 WLAN. This is possible by implementing a QoSM for differentiating services with two queues on top of the MAC controller with slow decrease of CW and reservation based channel access. The proposed scheme is verified with the help of NS-2 and an improved performance for real-time multimedia service in the infrastructure-based WLAN with the coexistence of the best effort traffic has been achieved.

4.2 QoS in IEEE 802.11 MAC Protocols

Legacy MAC has two coordination function: PCF and DCF. 802.11 uses DCF as a mandatory coordination function other than PCF (polling based access). But all the traffic flows in DCF shares a single queue having first come first serve mechanism (FCFS) access mechanism. Though all the traffic shares a common queue with FCFS, neither it is able to categorize the traffic flow nor able to schedule the packets. There is no service differentiation or QoS guarantee provided by MAC DCF of 802.11 for real time multimedia services, as described in Section 2.3.

4.3 Quality of Service Management (QoSM) Strategy

In this approach a quality of service manager (QoSM) is implemented just above the MAC. The QoSM differentiate the flows and put them in the appropriate queue. As it is implemented above the 802.11 MAC controller, the packet scheduling can be performed above the MAC without modifying it. The Figure 4.1 shows the structure of QoSM, to support the quality by differentiating the incoming traffic. There is no service differentiation in the MAC [15], it uses a single queue with contention based channel access to transmit packets. When ever a packet arrives at AP is processed by the QoSM, QEM and sends it to the appropriate queue by the queue assignment (QA). Packet forwarding is done with a strict priority policy, then it goes to the MAC controller for transmission.

QoSM differentiate between the real-time multimedia packet and the general (FTP) packet and put it into the two FCFS queues, called quality queue (Q_q) and best-effort queue (BE_q). The MAC address between two groups, *i.e.* the stations having the range of address in first group can capable to handle real time data, called multimedia (MM) station and other range of can capable of send the FTP data called the data stations. Data stations can able to access the stored video in the video server also (which is known as video on demand, VoD). The current IP datagrams do not carry any information about corresponding applications or

QoS requirements, and hence proposed scheme uses the source MAC address and packet type to differentiate a multimedia packet and data packet [68, 69] .

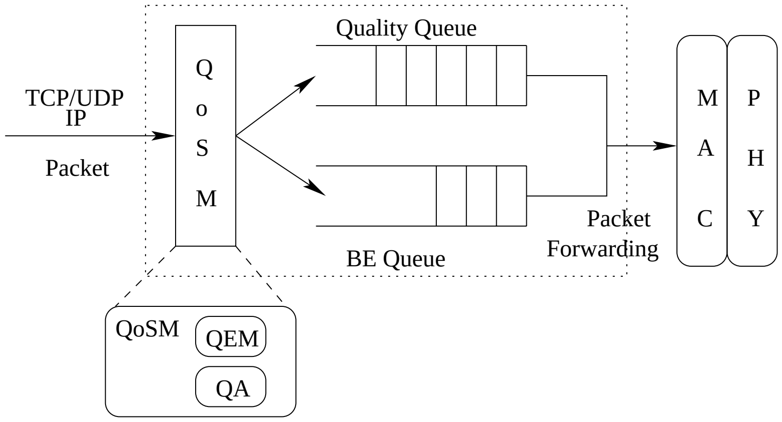


Figure 4.1: QoS Management Scheme

As shown in the Figure 4.1 QoSM contains two modules, quality evaluation module (QEM) and queue assignment (QA). In QEM, it differentiates the real-time multimedia flow and general FTP data flow and assigns packets to the corresponding Q_q or BE_q both are FCFS queue. The following algorithm describes basic functionality of QoSM and QEM.

P_i : i^{th} packet in transmission

P_t : packet type

Q_p : quality packet

BE_p : best effort packet

Algorithm 1 (QoSM)

```
Receive: $P_i$
$P_t = QEM(P_i)$
If ($P_t = Q_p$)
        If ($Q_q = full$)
          Then drop $P_i$
        Else QA ($P_i, Q_q$) /* Queue up packet $P_i$ to $Q_q$ */
Else If ($P_t = BE_p$)
        If ($BE_q = full$)
          Then drop $P_i$
        Else $QA(P_i, BEq)$ /* Queue up packet $P_i$ to $BE_q$ */
End If
```

Algorithm 2 (QEM (Differentiating Packet Type))

```
Receive: ($P_i$)
Process $P_i$ to find out the source address
If (source address within the classified range of first group)
        Then return ($Q_p$)
Else
        Return ($BE_p$)
End If
```

In accordance of the procedure described above, whenever QoSM receives a packet P_i it calls the QEM. The QEM contain the address ranges of the stations, which is used to classify the packets as described in the procedure, *i.e.* if the address comes under the first group then it returns a Q_p otherwise a BE_p. After getting the packet type from QEM,it do the queue assignment by the help of QA module if the queue is not full for both the type of packets. Packet forwarding is done in a strict priority policy *i.e.* whenever there is packet in the Q_q it will not transfer the packets from BE_q.

There are three cases at the time of forwarding the packets:

Case I. Whenever there are no packets in the quality queue, *i.e.* Q_q is empty. The transmission is being done from best effort queue only. As it uses the single queue with contention based channel access, it behaves as the legacy MAC.

Case II. Whenever there are no packets in the best effort queue, i.e BE_q is empty. The transmission of packets is being done from quality queue only. As it uses the single queue with contention based channel access, it behaves as the legacy MAC.

Case III. Whenever there are packets in both quality queue and best effort queue. The transmission of packet follows the packet forwarding policy (*i.e.* strict priority policy).

After forwarding the packet it goes to the MAC controller and it uses the legacy MAC channel access (contention based) to forward the packet from MAC to the physical layer.

4.3.1 Component Interaction Model

An illustration of the dynamic behavior and interaction of the three main components of the architecture, namely, QoSM, QEM and Queuing Assignment is described here. Suppose that QoSM receives a packet from a client. This reception of packet provides details of the interaction pattern and the required QoS for the client. This is denoted as Request for quality and return quality. Once it receives the packet, the task of the QoSM is to consider the requested packet of interaction within the components, *i.e.* in order to determine whether arrived packet can get the required quality or best-effort service. As shown in the Figure 4.2 the component interaction is as per the arrow marked in the diagram. Whenever a packet P_i arrives at QoSM it calls the QEM to find out the current quality of the packet (*i.e.* packet type P_t). QEM evaluates the quality type of the packet according to its source address and returns quality of the packet type as P_t, either it may be quality packet Q_p or best effort packet BE_p After getting the type of the packet, it calls the queue assignment (QA) module to assign the packet to the proper queue by the help of the quality type of the packet (P_t) it got from QEM. Then forwarding of packet is taken place with a strict priority policy, *i.e.* the best effort queue will not going to serve unless and until there is packet in quality queue. After the packet forwarded it goes to the MAC and transmission of the packet is done as per the legacy MAC with contention based channel access as like as from [1, 44, 46].

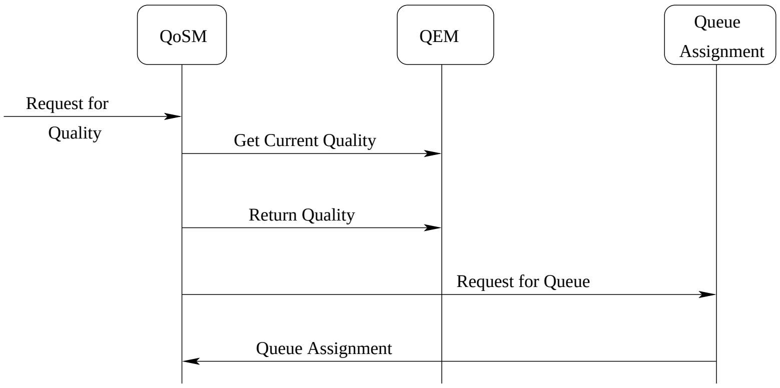


Figure 4.2: Component diagram of QoSM

This component interaction for the proposed model behaves in a deterministic way. As input to the QoSM is a packet for requesting to evaluate the quality as the out put from it. Queue assignment is performed by the quality it returns by QEM, then a strict packet forwarding mechanism is addressed.

4.3.2 Slow Contention Window Decrease (SD)

The legacy DCF follows a binary exponential backoff within the contention range (CW_{min} to CW_{max}). At first the transmission attempt of a packet, BEB selects a random slot with next CW = CW_{min} having the equal probability for transmission, where CW_{min} is the minimum contention window size. Every time a nodes packet is involved in a collision, the contention window size for that node is doubled up to its maximum value: CW_{max}, which as follows:

CW $\longleftarrow$ min (2* CW, CW$_{max}$) upon collision

CW $\longleftarrow$ CW$_{min}$ upon success

After each successful transmission the value of CW decreases to its minimum value. This process assumes that the channel congestion dropped suddenly, which is practically not true[44, 45]. The slow contention window decrease scheme for legacy DCF described in [11] achieves a higher throughput in comparison to BEB. This slow contention window decrease (SD) is applied in presence of QoSM and defined as:

CW $\longleftarrow$ max [$\delta * CW_{old}$,CW$_{min}$]

after each success transmission. Where δ chosen a value 0.5.

4.3.3 Reservation Based Packet Forwarding

Here the packet forwarding mechanism is modified to a reservation based, *i.e.* forwarding of packet with period restriction for QoS guarantee. Period restriction implies that Q_p is allowed to be transmitted only for the specified duration of *Period I*. The *Period II* allows to transmit both of the Q_p and BE_p. Where as the *Period I* and *Period II* constitute a super period. Super period is taken to be 1msec, and two periods are divided into two equal halves.

4.4 Mathematical Analysis

The QoS management scheme in Figure 4.1 based on Queuing model with two distinguished queue: Q_q and BE_q. As it uses strict priority policy *i.e.* it do not serve the BE packet as long as quality packets are available (analysis is done without considering the Reservation Based Packet Forwarding). It follows the preemptive process, *i.e.* priority packets do not have to wait. As the policy follows a strict priority, so analysis is done only for the priority queue. A system and user centric queuing model for IEEE 802.11 WLAN is described in [73]. The queuing delay of the Q_q can be calculated by analyzing the behavior of the model. So the process can be modeled with M/M/1/N, where the queue length is N and are drop tailed. Packets arrive with rate λ packets per second for states $i = 0, 1, 2, \cdots, N-1$, so inter-arrival time $\frac{1}{\lambda}$ second per packet. The packets get served with a rate of μ packets per second for states $i = 1, 2, 3, \cdots, N$. If N no of packets are in the queuing system, then the incoming requested packet is lost.

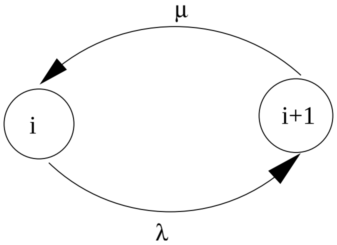


Figure 4.3: State Transition Diagram of Finite capacity (N) Queue

From the Figure 4.3, if $i = 0$ then it shows as idle condition. When the system is in i^{th} state with an arrival, it goes to $i+1^{th}$ state and after serving the packet at $i+1^{th}$ state, it returns to i^{th} states, where $0 \leq i \leq N$. We can represent the states of the system are $i = 0, 1, 2, \cdots, N$ and state probability of the process are: $p = [p0, p1, p2, \cdots pn]$ and $\sum p_i = 1$. Between each pair of adjacent states, the flow of probability flux from left to right with the flow probability flux from right to left yields the balance equations:

$\lambda p_0 = \mu p_1, \lambda p_1 = \mu p_2, \lambda p_2 = \mu p_3, \cdots, \lambda p_{n-1} = \mu p_n$

$\Rightarrow p_1 = (\frac{\lambda}{\mu})p_0, p_2 = (\frac{\lambda}{\mu})p_1 \cdots, p_n = (\frac{\lambda}{\mu})p_{n-1}$

By substituting these recursions into each other yields to

$$P_n = \left(\frac{\lambda}{\mu}\right)^n \times P_0, \qquad 0 \le n \le N \tag{4.1}$$

To calculate P_0 from $\sum_{n=0}^{N} P_n = 1$

$$P_0 = \frac{1}{\sum_{n=0}^{N} \left(\frac{\lambda}{\mu}\right)^n} \tag{4.2}$$

$$\Rightarrow P_0 = \frac{1 - \frac{\lambda}{\mu}}{1 - \left(\frac{\lambda}{\mu}\right)^{n+1}} \tag{4.3}$$

Putting Equation 4.3 in Equation 4.1

$$\Rightarrow P_n = \frac{1 - \frac{\lambda}{\mu}}{1 - \left(\frac{\lambda}{\mu}\right)^{n+1}} \left(\frac{\lambda}{\mu}\right)^n, \qquad 0 \le n \le N \tag{4.4}$$

4.4.1 Performance Measure in the Queuing System

Mean throughput

$$\overline{Y} = \sum_{n=1}^{N} \mu P_n = N\mu \tag{4.5}$$

where $\sum_{n=1}^{N} P_n = 1$

When $n = 0$, the queuing system is empty and there is no contribution to the throughput. Equation 4.5 computes the mean throughput of the queuing system, as a weighted average of service rates. Where the state probabilities serve as weights. Mean number of packets in the queuing system can found to be

$$\overline{n} = \sum_{n=1}^{N} nP_n \tag{4.6}$$

By applying the Little's Law to write the expression for mean time delay in queuing:

$$\overline{n} = \lambda\overline{\tau}$$

$$\Rightarrow \tau = \tfrac{\overline{n}}{\overline{Y}}$$

$$\tau = \frac{\sum_{n=1}^{N} nP_n}{N\mu} \tag{4.7}$$

4.4.2 Performance Measure of the System

T_{phy}	Transmission time of physical layer
T_{H_data}	Transmission time of MAC overhead
T_{data}	Transmission time of payload (actual data)
L_{data}	Payload size in byte
R_{data}	Data rate
P_d	Propagation delay
T_{DIFS}	DIFS Time
T_{SIFS}	SIFS Time

Propagation delay P_d = Time taken transmit between source to AP and AP to destination in addition with Queuing delay (τ). The Queuing delay τ is taken from the Equation 4.7. Throughput and delay formulation can be done as described in Equation 4.10 and Equation 4.11. But in a noisy channel, the throughput is expected to be less than the maximum throughput and the delay is expected to be larger than the minimum delay. A transmission cycle of DCF consists of DIFS deferral, backoff, data transmission, SIFS deferral and ACK transmission. Average Backoff Time as in [12]

$$BT_{avg} = \frac{CW_{min} \times T_{slot}}{2} \tag{4.8}$$

Data transmission delay can be expressed as:

$$T_{D\_data} = T_{phy} + T_{H\_data} + T\_data \tag{4.9}$$

and acknowledge transmission delay as:

$$T_{D\_ack} = T_{phy} + T_{ack} \tag{4.10}$$

So the maximum throughput (T_{MAX}) of the system is given as

$$T_{MAX} = \frac{L_{data} \times 8}{T_{D\_data} + T_{D\_ack} + 2P_d + T_{DIFS} + T_{SIFS+BT_{avg}}} \tag{4.11}$$

Where, the data packet size $L_{data} \times 8$ in bits.

Packet delay is the time elapsed between the transmission of a packet and its successful reception. The minimum delay (D_{MIN}) of the system is given as:

$$D_{MIN} = T_{D\_data} + P_d + T_{DIFS} + BT_{avg} \tag{4.12}$$

The performance of D_{MIN} and T_{MAX} has been studied with the help of NS-2 in next section.

4.5 Simulation and Analysis

Performance analysis of legacy MAC and QoSM is done with the help of NS-2 [41]. The scheme is tested for real time multimedia data stream. Table 4.1 shows the parameter for simulation. Two types of traffic flow has been taken for simulation namely *real time traffic* and *best effort traffic.*

Table 4.1: Simulation Parameters

Parameters	**Values**
MAC Header	34 byte
PHY header	16 byte
ACK	14 byte
RTS	20 byte
CTS	14 byte
Slot time	$50\mu s$
SIFS	$28\mu s$
DIFS	$128\mu s$
CW_{min}	31
CW_{max}	1023

Here we have use 802.11b PHY for simulation that can handle data up to 11 Mbits/s [44]. Two different types of traffic are used, multimedia and FTP/TCP data. Where queues are drop tailed and can accommodate 50 packets.

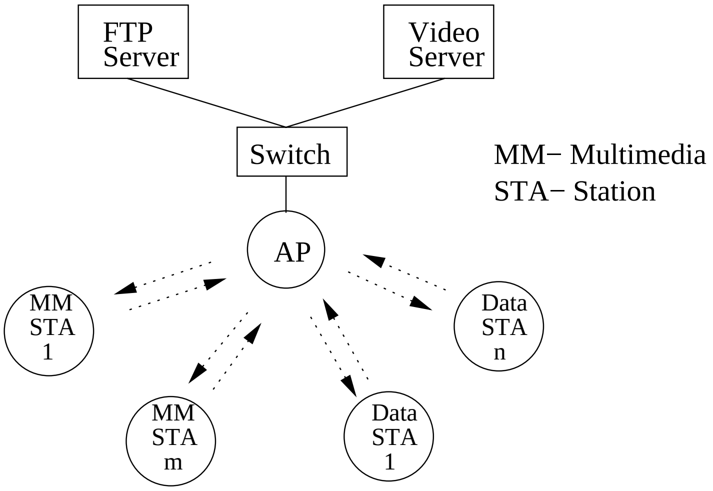


Figure 4.4: Network topology for simulation

The network topology for simulation is shown in Figure 4.4. All the stations can able to handle data rate of 2Mbits/s. Each MM station can generate and receives real-time multimedia data having packet size 1500 bytes but MM stations can receives the FTP data. The data stations can generate and receives the TCP/FTP packet with CBR, having packet size 1460 bytes. A video server is there at the wired backbone, where the stored videos are available. Data stations try to access the stored video from the server, and then it has to wait up-to the processing of the BE_q. Once the connection is established with the video server, it can send data through the Q_q.

The performance has been analyzed for throughput and delay of QoSM in comparison to legacy MAC with DCF for real-time multimedia data. On progress of transmission delay is added to the TCP/FTP data packets. Based on the parameters described in Table 4.1, with the multimedia data packet of size 1500 byte, the Figure 4.5 shows the delay analysis between QoSM and legacy MAC DCF. The delay performance of QoSM +MAC is decreased as compared to the legacy MAC. In Figure 4.6 the throughput analysis is described between QoSM +MAC and legacy MAC. As delay and throughput are directly proportional, so the decrease in delay affects to increase in throughput. The throughput is increased by using QoSM scheme as compared to legacy MAC for only real-time multimedia data.

Overall throughput (both real time traffic in presence of best effort traffic) analysis of the system is calculated by considering the both type of flows simultaneously (real-time and best effort flow), which remains same as the legacy MAC as shown in the Figure 4.7. As the scheme just provide service to real time traffic by adding delay to best effort traffic it gains throughput for the real-time multimedia traffic as in Figure 4.6, without any guaranteed service to best effort traffic.

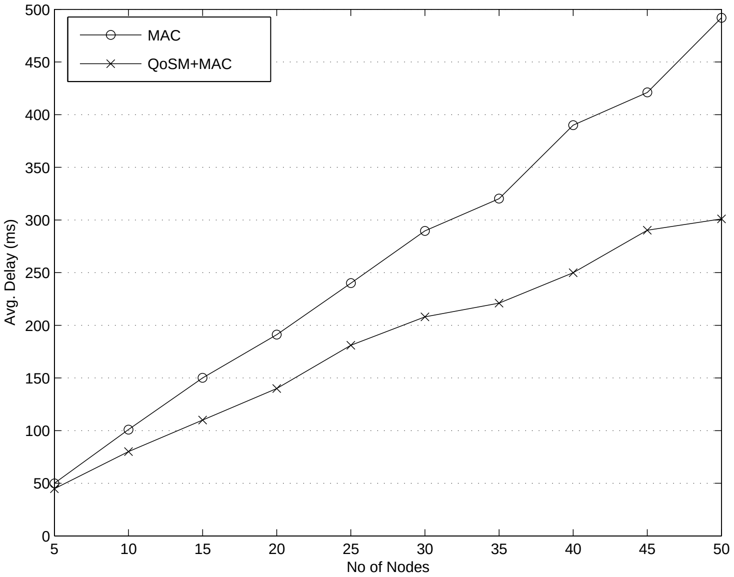


Figure 4.5: Delay performance Analysis

The slow decrease factor δ value of CW decrease as described in Section 4.3.2, is taken here as CW $\longleftarrow 0.5 * CW_{old}$, where $\delta = 0.5$ is the slow decrease scheme. The simulation result shows in Figure 4.8 (a) the throughput of 802.11 MAC with SD of CW achieves a better throughput in compare to legacy MAC. So CW decrease scheme shows a better performance, which is again applied to QoSM scheme. Figure 4.8 (b) shows that QoSM with SD of contention window gives a much better throughput as compared to 802.11 MAC, 802.11 MAC/SD and QoSM for real time traffic flow. 802.11 MAC with slow decrease of CW gives a better throughput than legacy MAC. As seen in Figure 4.9 the overall throughput of the QoSM/SD with reservation based packet forwarding achieves a better throughput as compared to legacy 802.11, in presence of both best *effort traffic* and *real time* *traffic.*

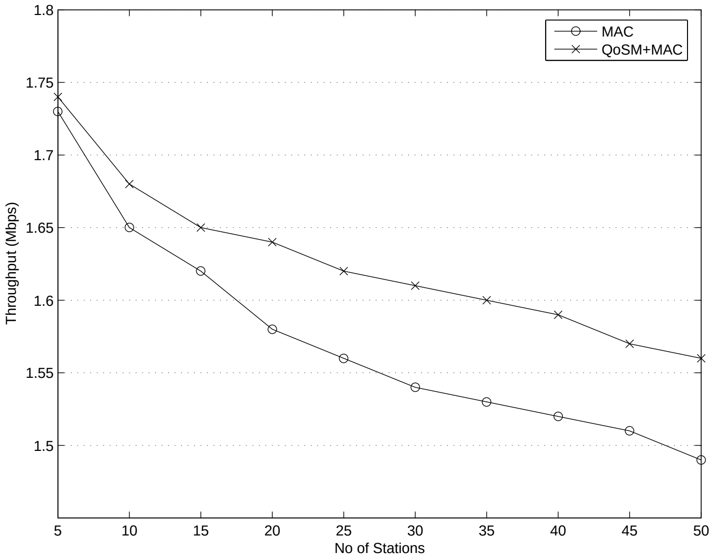


Figure 4.6: Throughput Analysis

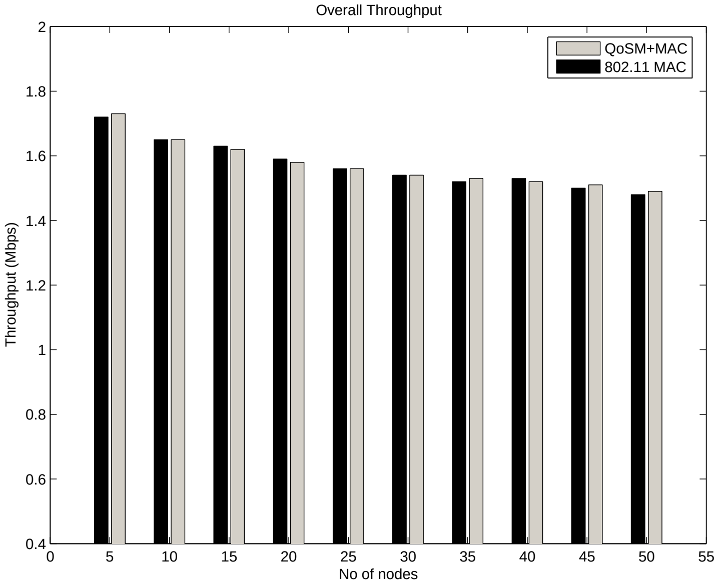
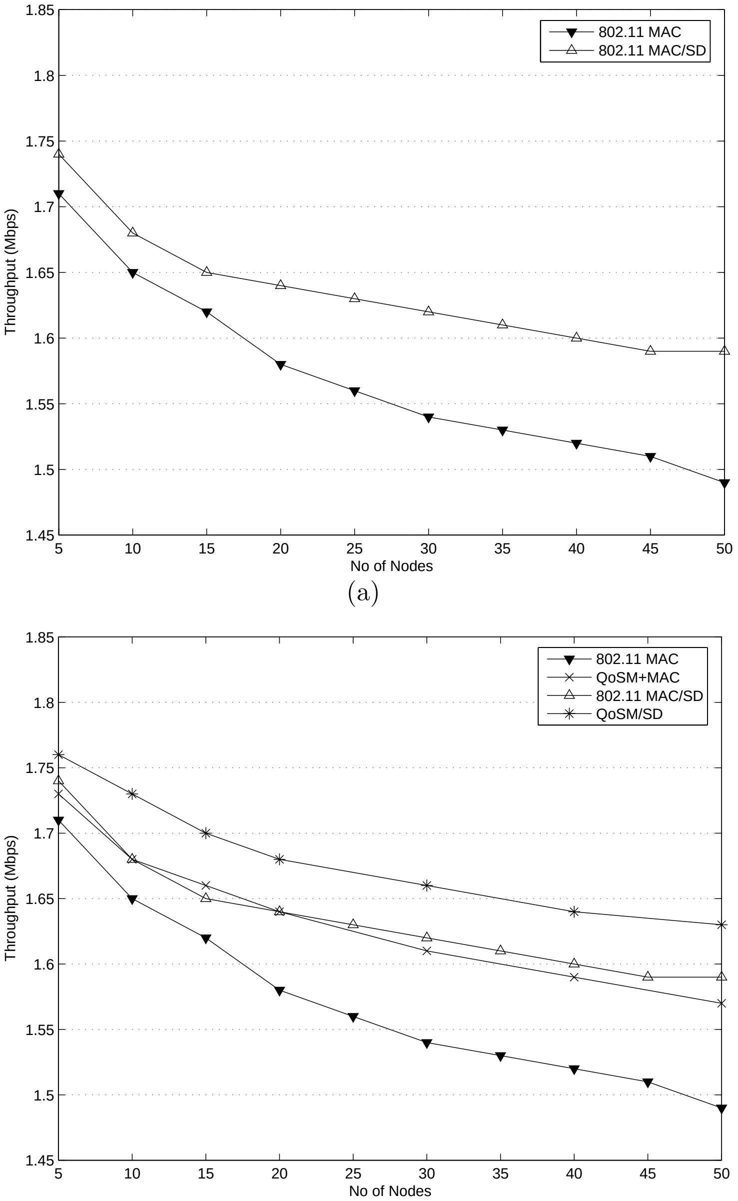


Figure 4.7: Overall Throughput of the system in presence of both the traffic



(a)

(b)

Figure 4.8: (a) Throughput analysis of 802.11 MAC with SD of Contention Window (b) Throughput analysis 802.11 MAC, QoSM, and 802.11 MAC with SD and QoSM with SD of contention Window for real time traffic

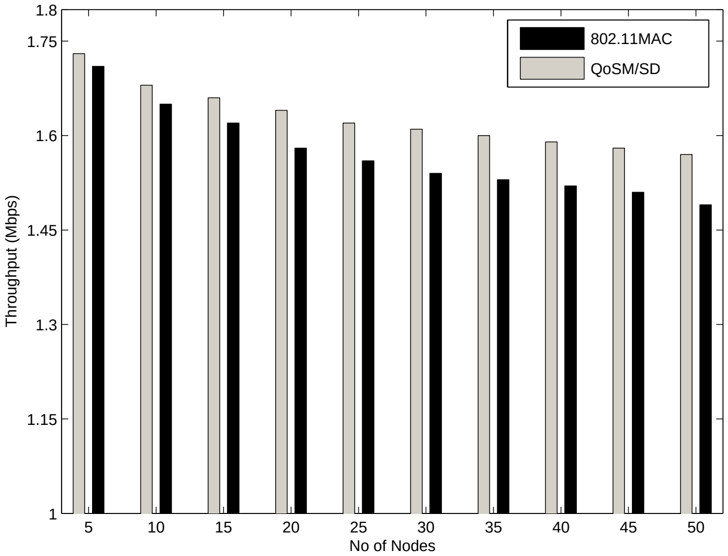


Figure 4.9: Overall Throughput of the system with Reservation Based Packet Forwarding

4.6 Conclusion

The QoSM scheme operates on the top of MAC controller. This demonstrates the performance of real-time traffic from priority stations can be enhanced significantly through the QoSM scheme when real-time multimedia and FTP traffic coexists. The simulation result shows that it gains a better throughput for real time traffic. The overall throughput of the system remains same as the legacy MAC because the scheme provides service to only real time traffic, and adding delay to best effort traffic. The analytical model for slow decrease of CW scheme gives a better performance then 802.11 MAC with SD and QoSM for only strict forwarding of real time traffic. The SD scheme significantly increases the throughput with a decrease factor ($\delta = 0.5$). The throughput of the QoSM/SD with reservation based packet forwarding achieves a better throughput as compared to legacy 802.11. The proposed method is limited to real-time multimedia and video on demand services. This scheme requires further enhancement to support voice traffic and FTP traffic. Also the parameters (contention window range) can be tuned to achieve greater throughput and a slotted channel access mechanism may be incorporated to provide the greater throughput for both real-time multimedia and best-effort traffic. In order not to overload the CPU, a hardware implementation of the QoSM scheme has been suggested in Chapter-6.

Chapter 5

Modified MAC for QoS Provisioning in WLAN

QoS to applications can achieved in WLAN through the modification and fine tune of the parameters of MAC layer. This chapter discusses a such modification to MAC protocol :*modified MAC*, which is based upon the *shortened contention window (CW)* and *reservation based channel access mechanism.* MAC is modified from single queue to dual queue for high and low priority traffic. A number of research have been done to adjust the contention window in order to provide differentiated quality of service in IEEE 802.11 based wireless networks is discussed in Section 5.2. Section 5.3 describes the proposed *shortened CW* algorithm with linear increase with slow decrease. Rather than using the basic contention based channel access mechanism, Section 5.4 describes a *reservation based channel access* mechanism. The simulation result is described in Section 5.5 and also compared with the IEEE 802.11e standard.

5.1 Introduction

Most commercial products only implement DCF which is simple and robust. However, it has been shown by researchers that the standard DCF cannot efficiently provide service to real time traffic and utilize the limited wireless channel bandwidth when there are many stations in the WLAN accessing the same channel [1, 7, 15, 30]. The major reason is that the contention window size and binary exponential backoff, is kept fixed regardless of traffic activity, where as ideally it should be large when the no of active stations is large and vice versa [31, 44, 45]. This chapter introduces a shortened contention window with a slow decrease and a reservation based channel access mechanism and comparison is made with QoS standard of IEEE 802.11e by NS-2.

5.2 Contention Window and Related Works

The main inefficiency of the DCF mechanism is the consequence of frequent collisions and the entailed wasted idle slots caused by backoff intervals associated to each contention stage. In fact, when the number of active stations increases, there are permanently too many stations backed-off with small contention windows since each successful transmission results in CW re-initialization. Actually, there are two major factors affecting the throughput in the IEEE 802.11: *(i) transmission failure* and, *(ii) the idle slots due to backoff during each contention period.* To resolve collisions of packets simultaneously transmitted by different stations, a slotted binary exponential backoff (BEB) algorithm is employed in DCF. In this process of transmission, BEB selects a random slot from the $CW = CW_{min}$ slots with equal probability, where CW_{min} is the minimum contention window size. Every time a node's packet is involved in a collision, the contention window size for that node is doubled up to its maximum CW_{max}, as follows:

CW $\longleftarrow$ min (2*CW, CW$_{max}$) upon collision
CW $\longleftarrow$ CW$_{min}$ upon success

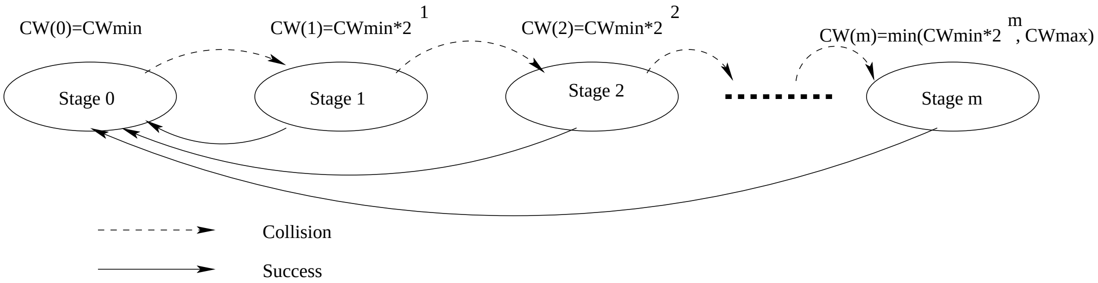


Figure 5.1: Binary Exponential Backoff

The new contention window is used for the following transmission attempt. A node resets its contention window to the minimum after a successful transmission, or when the total no of transmission attempts for a packet reaches the limit m (m = 7 for basic access mechanism and m = 4 for the request-to-send/clear-to-send

(RTS/CTS) exchange mechanism). However, the contention window resetting mechanism causes a very large variation of the contention window size, thus degrades the performance of the network when it is heavily loaded. Since each new packet starts with the minimum contention window, which can be too small for the heavy network load. Figure 5.1 illustrates the backoff mechanism of BEB, where $CW_{min} = 16$ and $CW_{max} = 1024$ (m = 7). On the one hand low values of CW_{min} (e.g. 31) gives excellent throughput in case of small number of contending stations. On the other hand, large values of CW_{min} (*i.e.* 1023) gives reverse effect.

$$CW_{opt} = N\sqrt{2T_c} \tag{5.1}$$

Where T_c is the time wasted by collision and N is the number of active stations.

To address the fairness problem in the BEB scheme, the multiplicative increase and linear decrease (MILD) algorithm was introduced in the MACAWA scheme [27] In the MILD scheme, a collided node increases its CW by multiplying it by 1.5. A successful node decreases its CW by one unit, where a unit is defined as the transmission time of the RTS packet. The MACAWA protocol assumes that a successful node has a CW value, that is related to the contention level of the local area. The current CW is included in each transmitted packet and a contention window copy mechanism is implemented at each overhearing node to copy the CW of the overheard successful transmission into its local CW. The operation of the MILD scheme can be summarized as follows:

CW $\longleftarrow$ min (1.5*CW, CW$_{max}$) upon collision
CW $\longleftarrow$ CW$_{packet}$ upon overhearing successful packets
CW $\longleftarrow$ max (CW-1, CW$_{min}$) upon success

Where, CW_{packet} is the CW value included in the overheard (successful) packet transmission. Also there described a multiplicative increase and multiplicative decrease (MIMD) algorithm to change the contention window, *i.e.* the contention window is double (halved) when a node experiences a collision. In linear/multiplicative increase and linear decrease (LMILD) backoff algorithm, upon collision increases its CW by multiplying a factor m_c. Any node overhearing a collision the CW increased by l_c units (slots). When a successful transmission takes place the CW decreases by l_s units [27]. The operation of the LMILD algorithm can be summarized as follows:

CW $\longleftarrow$ min (m_c*CW, CW$_{max}$) upon collision
CW $\longleftarrow$ min ($CW + l_c$*CW, CW$_{max}$) upon overhearing collisions
CW $\longleftarrow$ max ($CW + l_s$*CW, CW$_{min}$) upon success

On optimizing the backoff interval by sensing backoff algorithm (SBA), as in [26] multiplies its backoff interval by α $(\alpha > 1)$ upon collision, for successful transmission the backoff interval multiplies by Θ $(\Theta < 1)$, upon sensing a successful packet at neighbor backoff interval decreases by β steps, where a step is defined as a transmission time of packet (γ).

An exponential increase and exponential decrease (EIED) backoff algorithm suggested in [25] better performance, which can be represented as

CW $\longleftarrow$ min ($r1 * CW$, CW$_{max}$) upon collision
CW $\longleftarrow$ max (CW/rd, CW$_{min}$) upon success

Where r1 and rd takes a value 2 and $\sqrt{2}$ respectively. Our proposed scheme is based on the multiplicative slow contention window decrease (SD) scheme of [11], where:

CW_{new} $\longleftarrow$ 2* CW$_{old}$ upon collision
CW_{new} $\longleftarrow$ max ($\delta * CW_{old}$, CW$_{min}$) upon success

Where, δ is the constant slow decrease factor in the range of (0, 1).

5.3 Protocol Description (Shortened CW with Slow Decrease)

This protocol is designed to provide two levels of priorities. To provide quality of service to the high priority class, the protocol is trying to adjust the contention window in order to achieve the throughput. MAC sublayer is modified into two separate queues that contains *the high priority* and *low priority traffic* Figure 5.2. High priority can be used for real-time applications. The low priority can be used by regular best effort based application like FTP etc. It uses contention window based differentiation mechanism to provide priorities to real-time traffic flows. Basically, it specifies two different CW ranges for two priority levels. As shown in the Figure 5.3 high priority class occupies the lower half of the Contention Window, whereas the low priority occupies the upper half.

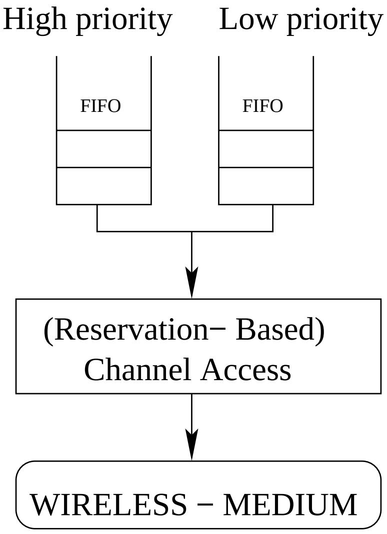


Figure 5.2: Modified MAC

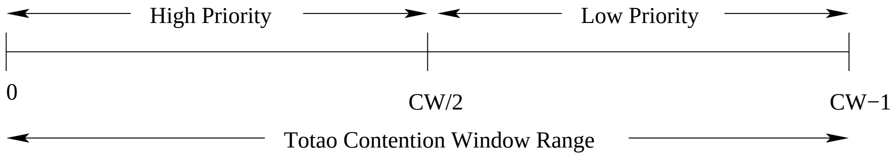


Figure 5.3: CW Ranges for Different Priority Classes

Higher priority class takes a backoff from lower half of the contention window range (0 to CW/2). This allows higher priority traffic with a smaller backoff interval than the lower priority traffic. So, the average delay of low priority traffic should be more than that of high priority traffic. Since the delay is low for high priority, it gains relatively higher throughput than the lower priority one. So this protocol provides a better quality of service to the higher priority class in comparison to the lower priority class.

5.3.1 Backoff and Collision Resolution

In legacy MAC DCF, when a collision occurs, the *CW* range is doubled. Stations involved in collision has to choose a backoff value from the larger range, this lowers the probability of collision. But in this protocol, the contention range is increased in a linear fashion. After every unsuccessful transmission, an attempt is made to increase the *CW*. The contention window for low priority class is the lower half of the *CW* (*i.e.* from 0 to CW/2) and the contention window for the higher priority class is the upper half (*i.e. CW/2 to CW-1*) as shown in Figure 5.3.

In protocol of 802.11 and 802.11e, the increase in CW size after collision is exponential. This decreases the probability of further collision between the same stations. As stated in [4] the probability of stations going through four or more successive collision is negligible. Also the probability of having three successive collisions is quite low. Moreover the first two rounds of backoff in exponential and linear increase scheme will result the same contention window size. So the performance difference between the two schemes may not be that significant. Linear increase in contention window size helps reducing the delay difference between packets sent from different rounds of backoff, while reducing the probability of collision in subsequent round.

In the proposed scheme, the frames belong to the low priority always choose a higher value (i.e. $CW/2$ to $CW - 1$) than the high priority one (i.e. 0 to $CW/2$). This behaves as unfair for low priority flows. As it chooses a higher CW, the back off time is longer than the high priority.

5.3.2 Contention Window Management

In general, a backoff algorithm decreases the backoff interval at the successful transmitter and increases that at the collided transmitter. An important design issue is to determine how fast these changes should be and how other nodes should respond to the channel activities. The BEB scheme tends to favor the last successful transmitter and other nodes do not change their backoff intervals. The MILD scheme varies the backoff interval more gently, while allowing other nodes to copy the backoff interval value from the successful packet transmission. The backoff interval mechanism improves the fairness performance of the MILD scheme, but it introduces a new problem, namely, the backoff interval migration.

As described above, the service differentiation based on contention window assigned to two priority ranges. The protocol is similar to legacy IEEE 802.11 MAC. Let CW_i denote the total contention window size in the i^{th} backoff round. When $i = 0$, $CW_i = CW_{min}$ is the minimum contention window size, which is taken as 32 (default for 802.11 DCF). So the operation can be summarized as follows:

CW $\longleftarrow$ min [$(i * CW_{min})$ if i is odd
else $(2i + 1/2 * CW_{min})$, CW$_{max}$] upon collision
CW $\longleftarrow$ max [$\delta * CW$,CW$_{min}$] upon success
Let δ be the constant slow decrease factor in the range $0 \leq \delta \leq 1$.
As in the BEB, after each successful transmission the CW resets to it minimum value of CW. For the next transmission it assumes the congestion level decreasing and it starts transmission from value CW_{min}. Therefore the CW value should be kept the same as long as the congestion level remains the same. Normally, congestion level is not likely to drop sharply. By resetting the CW to CW_{min}, a node takes the risk of experiencing collision and retransmission until it reaches the high CW value again, wasting time and channel bandwidth. The disadvantage is keeping high CW values when congestion level sharply drops, increasing the overhead and may be decrease the throughput.

5.3.3 Reservation Based Channel Access

Here the channel access mechanism is just modified to a reservation based channel access, *i.e.* accessing with period restriction for QoS guarantee. Period restriction implies that priority traffic is allowed to be transmitted only for the specified duration in Period I.

Figure 5.4 shows the working of the channel access of proposed scheme . The super-period is divided in to two periods: period I and period II. In period I it transmits only high priority flows and in period II it transmits both high priority

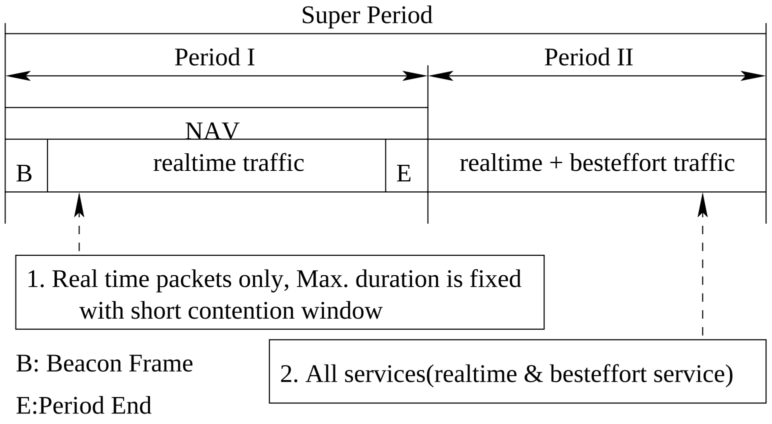


Figure 5.4: Proposed Channel Access Mechanism

and low priority. At the end of period I, all classes of traffic are allowed to contend for transmission and period II starts. In period II, two coordination functions are operating simultaneously with the same basic inter frame space (IFS) of distributed inter frame space (DIFS), thus providing the classified operation in acquiring medium. Figure 5.4 shows the reservation based access mechanism as describe in Section 2.2, Period I it allows high priority (real time traffic) having shortened CW, slow CW decrease and Period II allows both high and low priority (real time and best effort traffic) with shortened CW and slow decrease of CW. If there is no real time traffic, then it sends the best effort traffic in both of the periods.

5.4 Simulation and Analysis

Performance of the proposed protocol is evaluated by simulating in NS-2 [41]. We have compared our scheme with IEEE 802.11e [45]. As for the simulation of 802.11e AC [0], AC [1], AC [2] and AC [3] are used for background, best effort, video and voice respectively. Other parameters of 802.11e taken to be, CW_{min}, CW_{max} and IFS for all access categories are different. To build our protocol the legacy 802.11 MAC is modified. We have taken two types of traffic in our simulation, *i.e.* real time multimedia traffic and best effort traffic. The duration of the super period is set to be 1Msec and equally divided for period I and II.

The simulation topology here is taken as BSS (one access point and five wireless nodes). As shown in Table 5.1, the parameters of 802.11e are taken with their default values. The parameter values in our protocol as: for real time traffic CW value ranges from 32 to 512, IFS value is 2 and for best effort traffic CW value ranges from 512 to 1024, IFS value is 2. The slow decrease of CW value is taken as δ=0.5. Two node runs real time traffic as high priority and all other nodes run best effort traffic. The total load offered to the network is 6Mbps, one real time flow gives load about 1.5Mbps and rest of the load is offered by best effort traffic. Two types of traffic has been taken for simulation namely *real time traffic* and *best effort traffic*.

Table 5.1: Simulation Parameters of 802.11e

Type	**AC**	CW_{min}	CW_{max}	**IFS**
BG	AC[0]	32	1024	7
BE	AC[1]	32	1024	3
Video	AC[2]	16	32	2
Voice	AC[3]	8	16	2

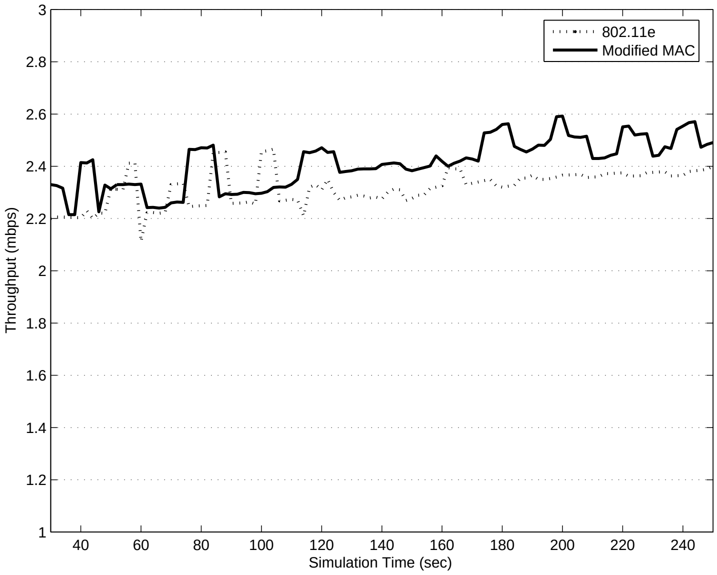


Figure 5.5: Throughput of Real time Traffic

The modified MAC protocol constitutes two level priority queue (high and low), each of the priority deals with shortened contention window with slow decrease and reservation based channel access mechanism as describe in Section 5.3. Throughput achieved for the real time traffic of the modified MAC in comparison to 802.11e as in Figure 5.5. Figure 5.6 shows the throughput of the proposed MAC is almost equal to that of 802.11e. This is because, throughput of BE traffic at the node which sends both real time traffic and best effort traffic is much lower than the other nodes which are carrying only best effort traffic. Under high load condition, throughput for the best effort traffic is seems to be lower than that of 802.11e but in any load condition the real time traffic achieves better throughput then 802.11e.

If the load given is low, one node is dealing the real time traffic (1.5Mbps) and total load offered to network is 3.5Mbps. As per Figure 5.7 the throughput achieved by the modified MAC is almost similar to 802.11e.

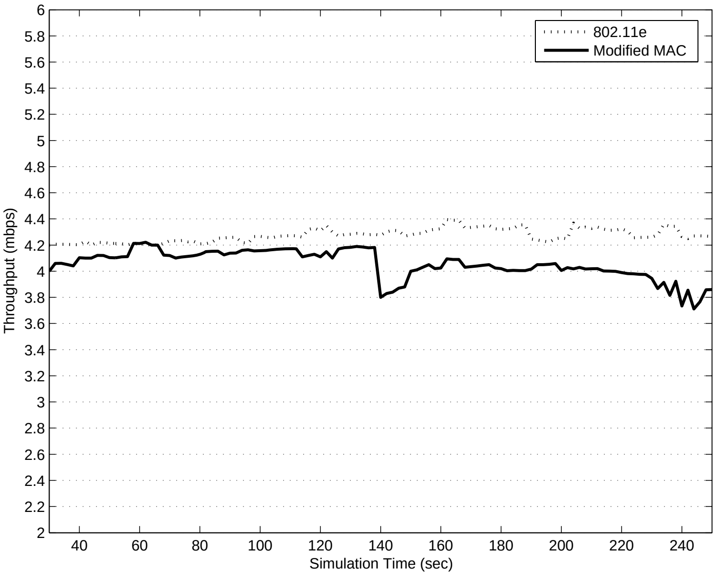


Figure 5.6: Throughput of Best effort Traffic in presence of Real time Traffic

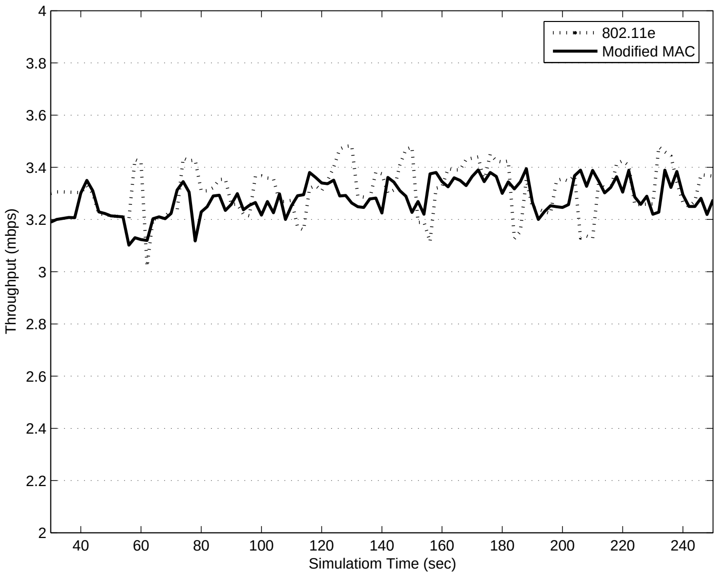


Figure 5.7: Throughput of Best effort Traffic in presence of real time traffic(low load)

5.5 Conclusion

The proposed 802.11 based MAC protocol provides QoS to real time traffic. The MAC classifies the traffic by employing dual queue, shortened contention window with slow decrease and reservation based channel access, to provide priority to real time flows. The model shows that high priority traffic gets more service than best effort traffic. Also it employs a priority with shortened contention window and non priority with shortened contention window as two fundamental coordination functions operating with period restriction. The simulation experiment provides quantitative results, which shows the proposed MAC operation preserves the traffic classification with the increased throughput, thus ensuring the QoS of real time traffic. Performance of the proposed protocol is effective then 802.11e for real time traffic. Under low load condition the throughput achieved by the modified MAC protocol is almost similar to that of 802.11e.

In the next chapter, describes a hardware implementation of QoSM.

Chapter 6

Hardware Implementation of QoSM

A *quality of service management (QoSM)* module (as described in Section 4.3) is explained in Section 6.2 for hardware implementation. *Hardware* implementation of *QoSM* scheme with its simulation results is described in Section 6.4. Section 6.5 concludes the chapter.

6.1 Introduction

To develop real time multimedia WLAN system, various discrete components like, wireless MAC, wireless PHY, and other user interface logic will be required. Therefore, complexity and cost of the system are increased in case of making multimedia WLAN system with each component needed. To overcome these problems, hardware implementation integrates a number of components or modules into a single chip to make multimedia communications using WLAN spread in the real life and also make time earlier. The hardware implementation of a notion of network on a chip (NoC): an asynchronous VLSI architecture for simulation of wireless network is discussed in [29]. We have implemented the proposed protocol in as hardware architecture using Xilinx in order to provide real time multimedia services over WLAN. The hardware implementation of the software upgrade-based approach as described in Section 4.3 to provide QoS for real-time multimedia service enhancement over the 802.11 WLAN. The prime objective of the architecture is to provide stations within WLAN with an ability to watch live programs, and on-demand video services. In this scheme it implements a QoSM with Q_q and BE_q on top of the 802.11 MAC controller. Basically, the Q_p and BE_p packets are classified and queue up into one of the two queues. Then after a strict priority policy is used to forward the packets from two queues in order to give a priority to quality (real-time multimedia) packets from Q_q, the BE_q queue is never served as long as the Q_q is non-empty.

6.2 Quality of Service Management (QoSM) Module

QoSM differentiates the flows and put them in the appropriate memory module as shown in Figure 6.1. This is implemented above the 802.11 MAC controller, so that the packet differentiation can be performed above the MAC without modifying it. As described in Section 4.3, QoSM to support the quality by differentiating the flows come to it. Legacy Mac uses a single queue to store and forward packets. In QoSM method, when ever a packet arrives at AP is processed and sends it to the appropriate queue by the help of queue assignment (QA) and forwarded to the MAC controller for transmission with strict priority policy.

QoSM differentiate between the real-time multimedia packet and the general (FTP) packet and put it into the two FIFO memory modules, called *module 1* for Quality packet and *module 2* for Best-Effort packets. Stations are grouped in to two *i.e.* (i) the stations having the range of address in first group, can capable to send real time data and (ii) other range of address, that can capable of sending the FTP data but can able to access the stored video in the video server (which is known as Video on Demand, VoD). The Figure 6.1 above QoSM contains two modules, quality evaluation module (QEM) and queue assignment (QA). In QEM, it differentiates the real-time multimedia flow and general TCP flow and assigns packets to the corresponding memory *module 1 or 2* both are FIFO in nature.

The QoSM Algorithm 1 and Algorithm 2 in Section 4.3 describes basic functionality of QoSM and QEM. According to the algorithm, whenever QoSM receives a packet P_i it calls the QEM. The QEM contain the address ranges of the stations, which is used to classify the packets as described in the procedure. The decision has to taken according to the first bit value of the packet, the starting bit value

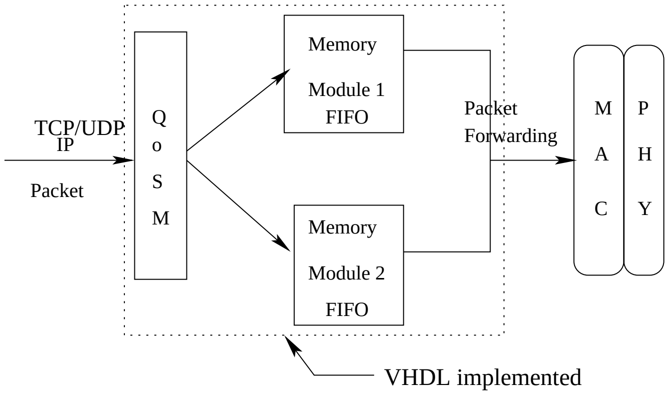


Figure 6.1: QoS Management Module

is 0 then it goes to the memory *module 1* otherwise to goes to memory *module 2*. As the memory modules are FIFO in nature then it forwards the data in a sequential manner of input. It forwards the data from *module 1* as long as the status of *module 1* is not empty. If it encounters an empty state of *module 1* then it transfers data from *module 2*. When ever it encounters that the memory module is full of data then dropping of data taken place.

As in Figure 4.2 of Chapter 4 the component interaction is as per the arrow marked in the diagram. Whenever QoSM receives a packet it calls the QEM as shown to find out the quality of the packet and after it calls the Queue assignment module to assign the packet to the proper queue, then forwarding of packet is taken place. Here the transmission of the packet is done as per the legacy MAC with contention based channel access [44].

6.3 Hardware Implementation of QoSM System

This section describes the hardware implementation of the QoSM strategy, as shown in Figure 6.1 and Section 6.2. The QoSM hardware was design using VHDL as per the design flow in Figure 6.1 . Although it is not explicitly shown in Figure 6.1 , it is a first in first out memory with strict forwarding mechanism. Taking into consideration the constraints of the target application, hardware implementation of each block has developed using Xilinx. The specified service architecture for multimedia applications require particular hardware implementations that operate at high clocking frequencies. It requires two memory modules with first in first out/first come first serve (FIFO/FCFS) mechanism for two queues (Q_q and BE_q). The input to the two memory blocks is assigned after checking whether it comes from the upper half of the address range or from the lower half of the address range. It also checks the memory status whether it is full or empty, if memory is full then it drops the packet. Forwarding of the packet is done in the FIFO manner as the memory modules are FIFO in nature,where memory module has to choose to forward the packet (as it follows a strict forwarding mechanism). It forwards the packets from memory *module 1* as long as it founds packet in *module 1* or status of memory *module1* is not empty, otherwise (if status of memory module1 is empty) it forwards packet from memory *module 2*.

6.4 Simulation of QoSM

The proposed model simulated using Xilinx 9.1i [74] with devices and design having Family- Spartan2, Device- XC2S15, Package- CS144, Source Type- HDL, Synthesis Tool- XST (VHDL/Verilog), Simulator- ISE Simulator (VHDL/Verilog), Language- VHDL. The simulation time is taken to be 1000ns.

In this architecture the memory module is created having ports address, data, read/write chip select, write/read enable, output enable. Writing data to memory module takes input data and stores it. Reading of data is done with a FIFO manner, which is too much sequential. All these are working with the clock pulse. The status of the memory block can be checked with full or empty ports. The two instance of the memory module is created for two queues (*module 1* and *module 2*). The output of data from the memory is done by checking the status of the memory port full and empty, *i.e.* if the port empty having value 0 then the forwarding of data is done from memory *module 1* otherwise forwarding of data is done from memory *module 2*.

The hardware implementation is being done using VHDL [75] and its related register transfer level (RTL) schematic, RTL schematic modules, test bench wave form and technology schematic is generated as in shown in the Figure 6.2, 6.3, 6.4 and 6.5 respectively. Figure 6.2 shows the RTL schematic with the ports taken for simulation in VHDL. Figure 6.3 shows the modular logic diagram of the RTL schematic, that how the input stream is recognized and assigned to the appropriate FIFO queue, output of the data from the memory is being done as per the status of the port empty and dropping of data can be found out by checking the status of the full port of memory *module 1* and memory *module 2* sends data out only when it found that port empty is high and encounters dropping of data when full1 is high. Test bench waveform generated from the VHDL simulation shown in Figure 6.4 and Figure 6.5 shows the technology schematic generated from the VHDL simulation.

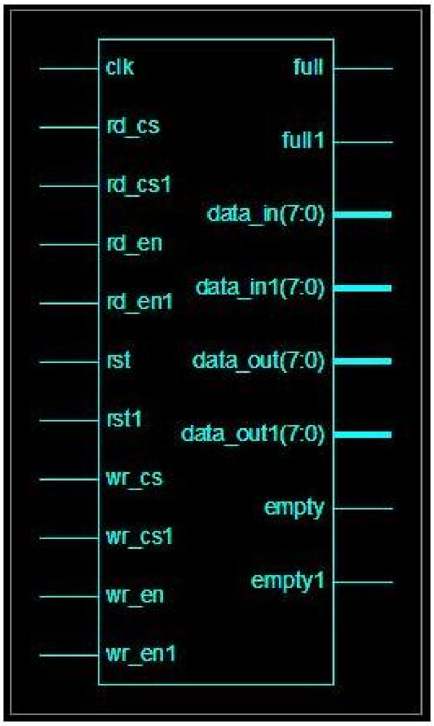


Figure 6.2: RTL Schematic

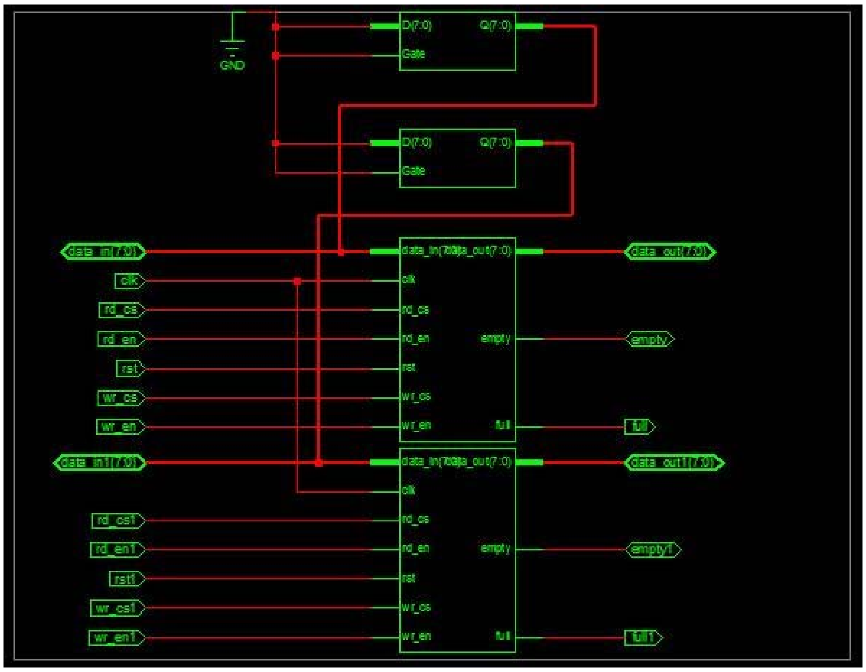


Figure 6.3: Modules of RTL Schematic

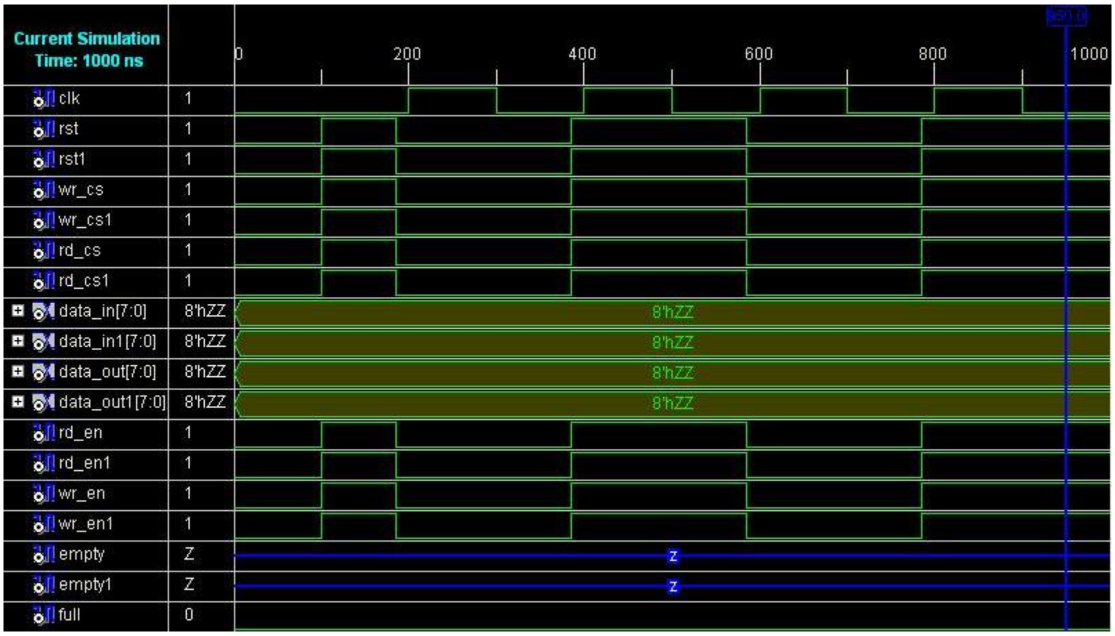


Figure 6.4: Test Bench WaveForm

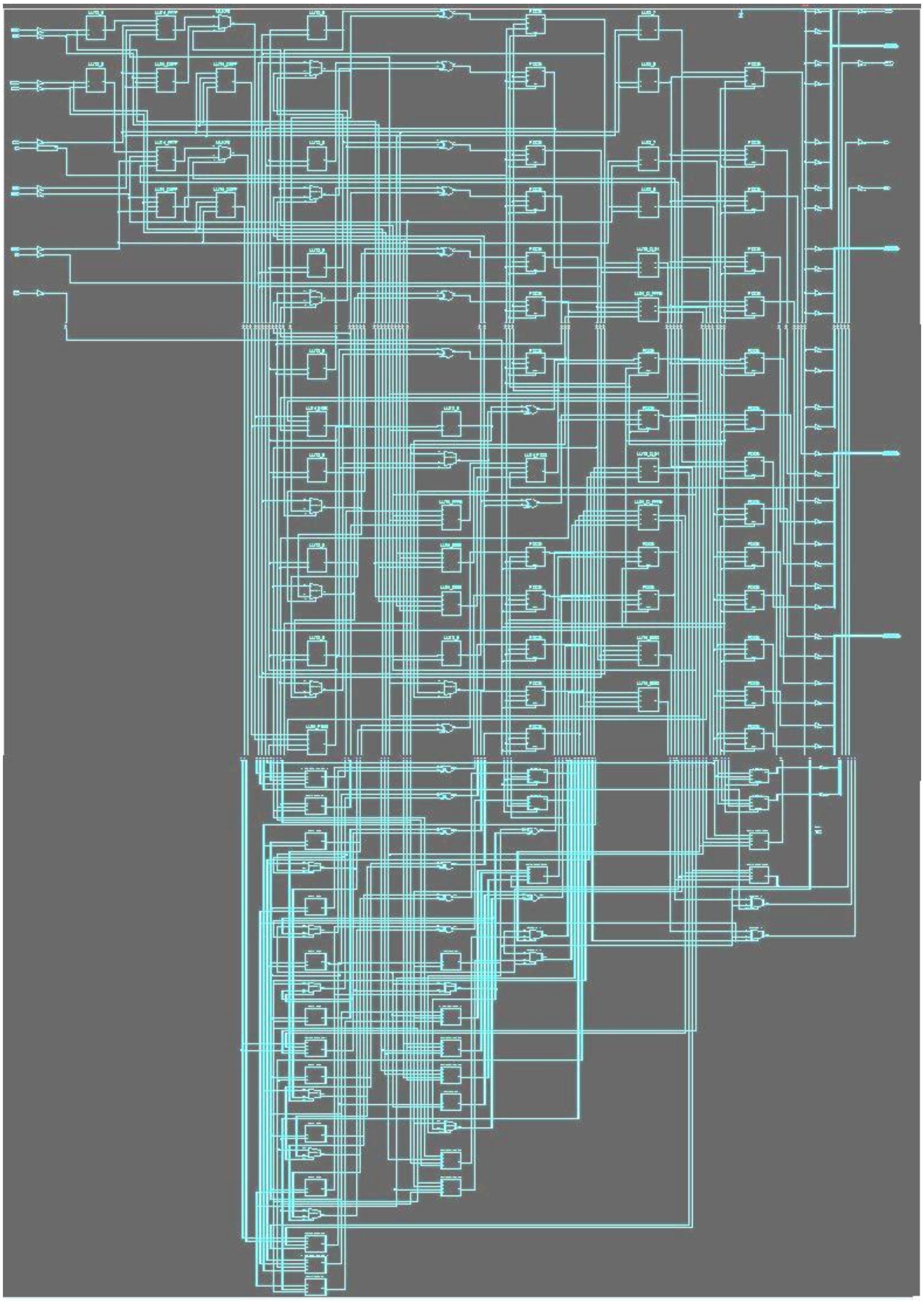


Figure 6.5: Technology Schematic

6.5 Conclusion

The description of architecture and hardware design implementation of QoSM for wireless real-time multimedia applications is developed using Xilinx 9.1i with VHDL language, which integrates wireless access block and user interfaces. The implemented hardware is intended for providing the real-time application system on wireless medium with less complexity and low cost. As it is able to differentiate the traffic flows, so it will not going to use the CPU cycle. Using this hardware module one can met the QoS for real time multimedia applications. This also supports priority issues of real-time traffic, dual memory with FIFO access. As this is an application specific dedicated hardware, it will not add any overhead to the software modules for forwarding the packets. This work can be further extended to implement it on System on Chip (SoC) or NoC.

Chapter 7

Conclusion and Future Work

The work in this thesis primarily focuses on real-time multimedia traffic in WLAN to provide QoS. Schemes to provide QoS for real-time traffic have been devised with tuning the parameters and reservation based channel access. The work reported in this thesis is summarized in this chapter. Section 7.1 lists the pros and cons of the work. Section 7.2 provides some scope of further research in different application area of WLAN.

7.1 Conclusion and Limitations

Due to lack of proper QoS support, IEEE 802.11 WLAN experiences serious challenges to meet the demands of time critical applications in real world. We have proposed a finite state model of the legacy MAC DCF, which is followed by two protocols for QoS, *(i) quality of service management (QoSM) with slow decrease of CW* and *(ii) shortened CW with slow contention window decrease.* A hardware implementation of QoSM, features and scopes are considered in this thesis.

The first contribution is the *finite state modelling* of legacy MAC DCF, which describes the details about the state transition model of the legacy DCF. It is based on the state value, with some input value it transit to another state.

The second contribution, *quality of service management (QoSM) strategy* in coordination with DCF for priority based stations. Which is implemented above the MAC sub-layer so as to differentiate the traffic flows and put it into two separate queues. A strict packet forwarding mechanism (as long as the real-time packets are available then it transfers only those packets) is followed to achieve the throughput gain for the real-time traffic. It achieves the high throughput for the real-time traffic, by decreasing the delay. But the overall throughput of the system remains same as the legacy 802.11 MAC DCF. It only differentiates between the real time multimedia traffic and keeps on providing services to these traffic without considering any tunable parameter. The *QoSM strategy with Slow Decrease of CW*, achieves a better throughput than QoSM, legacy MAC and MAC with slow decrease of CW but is limited to real time traffic flows. It also does not provide any guarantee for best-effort services, rather it just maintains a separate queue to store the best-effort packets and does not provide any service as long as there are real-time packets available in the queue. To provide service to best effort traffic in presence of real time traffic, a reservation based packet forwarding mechanism is introduced in presence of QoSM with slow decrease of CW. Which achieves a higher throughput than legacy 802.11.

The third contribution is *modified MAC*, that uses *shortened CW with slow decrease* and *reservation based channel access* to provide priority to real time traffic flows. Throughput results is also compared with IEEE 802.11e QoS standard. The throughput achieved for real time traffic is greater than that of 802.11e. Under low load condition, throughput achieved by best effort traffic in the protocol is almost equal to that of 802.11e. But under high load condition the throughput achieved for best effort traffic is less than that of 802.11e. Because throughput of the best effort traffic at the nodes which sends both types of traffic is much lower (as it employs a reservation time for real time traffic is more) than the other nodes which are carrying only best effort traffic.

The Chapter 6 describes on, *hardware implementation of QoSM* deals with the hardware implementation of QoSM to provide prioritized service to the real time traffic without using the CPU cycle. The simulation result shows the generated RTL schematic, technology schematic and test bench waveform of the QoSM model.

7.2 Future Work

To conclude this thesis, following are some points that may lead to some better and interesting results.

The finite state transition model of WLAN MAC protocol can be further enhanced considering the following assumptions, *i.e.* (i) fixed network topology in which sending station cannot also be destination station, (ii) timing synchronization, and (iii) with increasing the number of participating stations etc.

Priority station based QoSM scheme can be further modified to accommodate both type of traffic from a station by differentiating between them. Some of the future work is also cited in Section 4.6.

The modified MAC scheme is handling only two types of traffic, which can be extended to handle more than two different traffic flow, which can be further enhanced considering contention window, and inter frame space to achieve better throughput in modified MAC.

Application specific hardware implementation of QoSM for can be further enhanced to implement it on system on chip (SoC) and can validate with the real time environments. The design flow can be further enhanced after VHDL simulation towards synthesis & field-programmable gate array (FPGA) prototyping, and compatibility with back end.

A cross layer design approach can be employed to achieve better throughput. One possible avenue of future development in wireless LAN technology is in the area of "cooperative diversity". Cooperative diversity can be viewed as somewhat of a cross between multiple input, multiple output (MIMO) techniques and mesh networking. In a cooperative diversity scheme, redundancy in transmission is achieved in a manner analogous with diversity transmission in MIMO. However, the redundant transmission is realized via the cooperation of third party devices rather than solely from the originating device. In a cooperative diversity scheme, third parties which can successfully decode an on-going exchange will effectively regenerate and relay, with appropriate coding, the original transmission in order to improve the effective link quality between the intended parties.

Video is an engaging visual experience. Video subscribers expect high QoS: a clear picture with good resolution, no downtime, and fast channel changing. Consequently, IPTV/video providers must be able to assign priorities to critical services, such as video and voice, which ensure their access to the required network resources. Further investigation is required to incorporate the above QoS on IPTV/video to the propose protocol.

Of course, maintaining high quality service is impossible if system availability is at risk. Therefore, service providers must configure an IP-based network transporting video traffic with faster convergence, redundant components, and multiple connections throughout to guarantee uninterrupted service in the event of a failure.

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Dissemination of Work

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