QOS FAIRNESS FOR LOW PRIORITY TRAFFIC

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QoS Fairness for Low Priority Traffic

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ABSTRACT OF THE THESIS

QoS Fairness for Low Priority Traffic
by
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The IEEE 802.11e standard bounds to starve the low priority users when the network is dominated by non-real time traffic flows. To alleviate this limitation, a FAIR MAC scheme is proposed to provide acceptable throughput and delay performance. Thus, considerable research efforts have been carried out to investigate the performance of our proposed approach through NS2 simulations.
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>ABSTRACT</th>
<th>iv</th>
</tr>
</thead>
<tbody>
<tr>
<td>LIST OF TABLES</td>
<td>vii</td>
</tr>
<tr>
<td>LIST OF FIGURES</td>
<td>viii</td>
</tr>
<tr>
<td>GLOSSARY</td>
<td>x</td>
</tr>
<tr>
<td>ACKNOWLEDGEMENTS</td>
<td>xii</td>
</tr>
<tr>
<td>CHAPTER</td>
<td></td>
</tr>
<tr>
<td>1  INTRODUCTION</td>
<td>1</td>
</tr>
<tr>
<td>1.1 Thesis Objective</td>
<td>2</td>
</tr>
<tr>
<td>1.2 Thesis Structure and Organization</td>
<td>3</td>
</tr>
<tr>
<td>2  BACKGROUND AND LITERATURE REVIEW OF IEEE 802.11E</td>
<td>4</td>
</tr>
<tr>
<td>2.1 Hybrid Coordinator Function</td>
<td>4</td>
</tr>
<tr>
<td>2.1.1 Enhanced Distributed Channel Access (EDCA)</td>
<td>5</td>
</tr>
<tr>
<td>2.1.2 HCF Controlled Channel Access (HCCA)</td>
<td>8</td>
</tr>
<tr>
<td>2.2 Drawback of IEEE802.11e</td>
<td>14</td>
</tr>
<tr>
<td>3  PROPOSED MAC SCHEME</td>
<td>16</td>
</tr>
<tr>
<td>3.1 Description of the Fair MAC Scheme</td>
<td>16</td>
</tr>
<tr>
<td>3.1.1 HP &amp; LP Split in Contention Free Phase</td>
<td>17</td>
</tr>
<tr>
<td>3.1.2 HCCA – Polling Scheme Working Procedure</td>
<td>18</td>
</tr>
<tr>
<td>3.2 Analysis of the Scheme</td>
<td>20</td>
</tr>
<tr>
<td>3.2.1 System Model</td>
<td>20</td>
</tr>
<tr>
<td>3.2.1.1 Modeling Throughput</td>
<td>21</td>
</tr>
<tr>
<td>3.2.1.2 Modeling Delay</td>
<td>24</td>
</tr>
<tr>
<td>3.2.2 Validation of the Proposed MAC Scheme</td>
<td>27</td>
</tr>
<tr>
<td>4  SIMULATION RESULTS</td>
<td>29</td>
</tr>
<tr>
<td>4.1 Simulation Setup</td>
<td>29</td>
</tr>
<tr>
<td>4.2 Simulation Results</td>
<td>30</td>
</tr>
<tr>
<td>4.2.1 Scenario 1</td>
<td>30</td>
</tr>
</tbody>
</table>
4.2.1.1 LP Throughput – Fair MAC Scheme vs 802.11e MAC Scheme .......................................................................................................31
4.2.1.2 HP Throughput – Fair MAC Scheme vs 802.11e MAC Scheme .............................................................................................34
4.2.1.3 HP Delay – Fair MAC Scheme vs 802.11e MAC Scheme ..........35
4.2.1.4 LP delay – Fair MAC Scheme vs 802.11e MAC Scheme ..........35
4.2.2 Scenario 2 – Setup ..................................................................................35
  4.2.2.1 All_LP_Traffic_Throughput – Fair MAC Scheme vs
  802.11e MAC Scheme ...............................................................................36
  4.2.2.2 All_LP_Traffic_Delay – Fair MAC Scheme vs 802.11e
  MAC Scheme .............................................................................................36
  4.2.2.3 All_HP_Traffic_Throughput – Fair MAC Scheme vs
  802.11e MAC Scheme ...............................................................................37
  4.2.2.4 All_HP_Traffic_Delay – Fair MAC Scheme vs 802.11e
  MAC Scheme .............................................................................................37
5  CONCLUSION ............................................................................................................39
BIBLIOGRAPHY ....................................................................................................................40
LIST OF TABLES

Table 2.1. User Priority to Access Category Mapping ..............................................................6
Table 4.1. Simulation Parameters ............................................................................................30
# LIST OF FIGURES

| Figure 2.1. 802.11e MAC architecture. | ................................................................. | 5 |
| Figure 2.2. Timing relationship of EDCA. | ................................................................. | 6 |
| Figure 2.3. The four access categories. | ................................................................. | 8 |
| Figure 2.4. Controlled access period in CFP and CP. | ....................................................... | 10 |
| Figure 2.5. 802.11e beacon interval in HCF algorithm. | ....................................................... | 10 |
| Figure 2.6. TSPEC frame structure. | ................................................................. | 11 |
| Figure 2.7. IEEE 802.11e schedule for streams from different QSTA(s). | ........................................ | 13 |
| Figure 2.8. HCCA reference scheduler. | ................................................................. | 14 |
| Figure 3.1. 802.11e super frame showing HP traffic constrained to the CFP while LP and HP traffic compete for channel access during the CP. The HC in the CP also polls stations for HP traffic. | ....................................................... | 17 |
| Figure 3.2. The block diagram for proposed Fair MAC scheme. | ........................................ | 19 |
| Figure 3.3. Proposed MAC Superframe where low priority traffic also gets channel access during the contention free phase. | ....................................................... | 21 |
| Figure 3.4. Throughput of Fair MAC scheme (in kbps) – Simulation vs analytical model. | ....................................................... | 28 |
| Figure 3.5. Delay of Fair MAC scheme (in ms) – simulation vs analytical model. | ....................................................... | 28 |
| Figure 4.1. LP Throughput (kbps) – Comparison of Fair MAC scheme vs 802.11e MAC scheme. | ....................................................... | 32 |
| Figure 4.2. HP Throughput (kbps) – Comparison of Fair MAC scheme vs 802.11e MAC scheme. | ....................................................... | 32 |
| Figure 4.3. HP delay (ms) – Comparison of Fair MAC scheme vs 802.11e MAC scheme. | ....................................................... | 33 |
| Figure 4.4. LP delay (ms) – Comparison of Fair MAC scheme vs 802.11e MAC scheme. | ....................................................... | 33 |
| Figure 4.5. All_LP_Traffic throughput (kbps) – Comparison of Fair MAC scheme vs 802.11e MAC scheme. | ....................................................... | 36 |
| Figure 4.6. All_LP_Traffic delay (ms) – Comparison of Fair MAC scheme Vs 802.11e MAC scheme. | ....................................................... | 37 |
| Figure 4.7. All_HP_Traffic throughput (kbps) – Comparison of Fair MAC scheme Vs 802.11e MAC scheme. | ....................................................... | 38 |
Figure 4.8. All_HP_Traffic delay (secs) – Comparison of Fair MAC scheme Vs 802.11e MAC scheme.
GLOSSARY

AC  Access Category
ACK  Acknowledgement
ADDTS  Add Traffic Stream
AIFS  Arbitration Interframe Space
AIFSN  Arbitration Interframe Space Number
AP  Access point
BI  Beacon Interval
BSS  Basic Service Set
BSA  Basic Service Area
CA  Collision Avoidance
CAP  Controlled Access period
CBR  Constant Bit Rate
CFP  Contention Free Period
CF-Poll  Contention Free Poll Frame
CF-end  Contention Free End Frame
CP  Contention Period
CTS  Clear to Send
CSMA  Carrier Sense Multiple Access
CW  Contention Window
CWmax  Maximum Contention Window
CWmin  Minimum Contention Window
DCF  Distributed Coordination Function
DIFS  DCF Interframe Space
EDCA  Enhanced Distributed Channel Access
FTP  File Transfer Protocol
HCF  Hybrid Coordination Function
HCCA  Hybrid Controlled Channel Access
<table>
<thead>
<tr>
<th>Acronym</th>
<th>Definition</th>
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<tr>
<td>HOL</td>
<td>Head Of Line</td>
</tr>
<tr>
<td>IEEE</td>
<td>Institute of Electrical and Electronics Engineers</td>
</tr>
<tr>
<td>IFS</td>
<td>Inter Frame Spacing</td>
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<tr>
<td>LAN</td>
<td>Local Area Network</td>
</tr>
<tr>
<td>LP</td>
<td>Low Priority</td>
</tr>
<tr>
<td>MAC</td>
<td>Medium Access Control</td>
</tr>
<tr>
<td>MSDU</td>
<td>MAC Service Data Units</td>
</tr>
<tr>
<td>NAV</td>
<td>Network Allocation Vector</td>
</tr>
<tr>
<td>PC</td>
<td>Point Coordinator</td>
</tr>
<tr>
<td>PCF</td>
<td>Point Coordination Function</td>
</tr>
<tr>
<td>PHY</td>
<td>Physical Layer</td>
</tr>
<tr>
<td>PIFS</td>
<td>PCF Inter-Frame Space</td>
</tr>
<tr>
<td>QAP</td>
<td>QoS Access Point</td>
</tr>
<tr>
<td>QBSS</td>
<td>Quality of Service enabled Basic Service Set</td>
</tr>
<tr>
<td>QoS</td>
<td>Quality of Service</td>
</tr>
<tr>
<td>QSTA</td>
<td>Quality of Service enabled station</td>
</tr>
<tr>
<td>RTS</td>
<td>Request to Send</td>
</tr>
<tr>
<td>SIFS</td>
<td>Short Inter-Frame Space</td>
</tr>
<tr>
<td>TS</td>
<td>Traffic Stream</td>
</tr>
<tr>
<td>TSID</td>
<td>Traffic Stream Identifier</td>
</tr>
<tr>
<td>TSPEC</td>
<td>Traffic Specification</td>
</tr>
<tr>
<td>TXOP</td>
<td>Transmission Opportunity</td>
</tr>
<tr>
<td>UP</td>
<td>User Priority</td>
</tr>
<tr>
<td>VBR</td>
<td>Variable Bit Rate</td>
</tr>
<tr>
<td>VOIP</td>
<td>Voice Over IP</td>
</tr>
<tr>
<td>WLAN</td>
<td>Wireless LAN</td>
</tr>
<tr>
<td>WM</td>
<td>Wireless Medium</td>
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CHAPTER 1

INTRODUCTION

Wireless local area networks (WLANs) are increasingly popular because of their flexibility. This spreading of WLANs comes with an increasing use of multimedia applications. Such applications are bandwidth sensitive and require a quality of service (QoS) that guarantees high performance transmission of continuous data. This requirement is the focus of the new enhanced IEEE 802.11e standard protocol for WLANs. This technology provides people with a ubiquitous communication and computing environment in both real time applications (high priority traffic - such as streaming audio, video conferencing, internet gaming etc.,) and non-real time applications (low priority traffic - such as data file transfer, e-mail, web browsing etc.). To guarantee the QoS requirements for the multimedia (real time traffic) applications, IEEE 802.11e sets a set of Quality of Service (QoS) standards which provides traffic prioritization and differentiation services to the various traffic types over a WLAN to ensure the guaranteed bandwidth and stringent delay constraints. However, this standard is not considered efficient in the organizations like the health care industry, stock markets and educational institutions where the system comprises mostly of non-real time flows. IEEE 802.11e is considered to be biased towards real time traffic since they hog the channel and bound to starve the non-real time flows for channel access and severely degrades the low priority traffic’s throughput and delay.

From Ni [1], it is obvious that IEEE 802.11e standard is mainly to provide service differentiation to the delay sensitive applications (multimedia traffic) where the system requires stringent delay constraints. So these enhancement features mainly benefits the real time (high priority) traffic but starves the non-real time (low priority) traffic by hogging the channel during contention phase. With the default parameters given in the IEEE 802.11e standard, non-real time traffic’s throughput and delay is rapidly deteriorated especially when the network is heavily loaded (see Figures 4.1 and 4.2 on page 32– graphs of 802.11e MAC scheme). This behavior highly degrades the system performance where non-real time traffic is the backbone of some of the organizations.
Firstly, in order to overcome this drawback and provide QoS fairness for these non-real time traffic flows, a FAIR MAC scheme is proposed that allows sufficient channel access to provide acceptable performance for the low priority traffic. Secondly, this thesis presents the analytical expressions for throughput and delay performance metrics to validate the proposed MAC scheme. To evaluate the performance and efficiency of the proposed scheme, simulation results (Network Simulator platform) are presented to ensure the QoS fairness of the proposed scheme (FAIR MAC) scheme. Finally, our proposed scheme is compared with 802.11e original scheme to show that our scheme performs better than the 802.11e MAC scheme when the non-real time traffic flows dominates the network.

1.1 Thesis Objective

The main purpose of this thesis is to address the 802.11e limitations over the non-real time flows where 802.11e allocates a majority of its resources to the real time (multimedia) traffic. The same QoS fairness issue has been argued in some of the previous works [2], [3]. Financial organizations, business houses and healthcare facilities have recently and repeatedly suffered and complained against network resource hogging by multimedia traffic when a minority section of the users chooses to stream a video clip on youtube which sabotages the transmission of an important data file like a patient’s health record or a crucial business email exchange [3]. In most of these organizations, non-real time traffic is the backbone and definitely 802.11e limitations can present critical issues and cannot guarantee end-to-end user satisfaction if not handled properly.

In order to confront the 802.11e limitation to provide QoS fairness to the low priority users, our thesis proposes a new MAC algorithm called FAIR MAC scheme which alleviates this limitation by preventing resource hogging by the few real time traffic flows even when the predominant traffic in the network is non-real time. Thus, our thesis mainly focuses on alleviating this biased approach by issuing sufficient transmission time to the non-real time (low priority) traffic, while not disturbing the real time traffic (high priority) with the help of 802.11e polling mechanism. It is also important to notice that our proposed approach doesn’t weaken the real time traffic even when the network is completely dominated by real time (high priority) traffic. This can be clearly demonstrated through simulation results which are provided in later section.
1.2 THESIS STRUCTURE AND ORGANIZATION

This document is organized into five chapters. The first chapter begins with a brief introduction to Quality of Service in IEEE 802.11e networks and then presents the shortcomings of these networks for different traffic types, which motivates us to design a new MAC algorithm.

The second chapter discusses the background and literature review of the architecture of IEEE 802.11e network and discusses the drawback in these networks.

The third chapter presents the design of new MAC scheme to alleviate the limitation of IEEE802.11e. Also, the analytical expressions on proposed MAC are presented for throughput and delay performance analysis and it is validated through NS2 simulations.

The fourth chapter discusses the simulation results for two different scenarios to study the impact of our proposed MAC on the system performance, followed by a comparative study between the proposed MAC scheme and 802.11e MAC scheme through throughput and delay analysis.

The fifth chapter concludes with a brief summary of the work and NS2 simulation results.
CHAPTER 2
BACKGROUND AND LITERATURE REVIEW OF
IEEE 802.11E

IEEE 802.11 is the popular standard for WLANs. It works in the first two layers of the OSI reference model, the medium access control (MAC) and the physical (PHY) layer. It provides two MAC methods: Distributed Coordination Function (DCF) and Point Coordination Function (PCF). IEEE 802.11 did not achieve the required QoS performance for multimedia applications because it serves all transmitted frames with the same level of priority. So the IEEE Committee has developed a new standard called IEEE 802.11e to enhance the original 802.11 standard and support the required QoS. The IEEE 802.11e introduced a new access method called Hybrid Coordination Function (HCF) that enhanced the two original access methods and provided two enhanced mechanisms: Enhanced Distributed Channel Access (EDCA) and HCF Controlled Channel Access (HCCA). The main idea in both mechanisms depend on providing traffic classification to achieve priorities for real-time applications [4]. The HCF uses the DCF presented in the original 802.11 as the basis of its functionality, as depicted in Figure 2.1. In a QoS station (QSTA), both HCF and DCF are present. HCF, EDCA, and HCCA will be explained in detail in the next subsections.

2.1 HYBRID COORDINATOR FUNCTION

In IEEE 802.11e standard, a new MAC layer function called the hybrid coordination function (HCF) is proposed. HCF uses a contention-based channel access method, also called enhanced distributed channel access (EDCA) that operates concurrently with a polling-based HCF controlled channel access (HCCA) method. The AP and those STAs that implement the QoS facilities are called QoS - enhanced AP (QAP) and QSTAs (QoS-enhanced STAs), respectively. One main new feature of HCF is the concept of transmission opportunity (TXOP), which refers to a time duration during which a QSTA is allowed to transmit a burst of data frames. A TXOP is called an EDCA - TXOP when it is obtained by winning a successful EDCA contention or an HCCA-TXOP when it is obtained by receiving a QoS poll
frame from the QAP. In order to control the delay, the maximum value of a TXOP is bounded by a value called TXOPLimit, which is determined by the QAP. A QSTA can transmit multiple frames within its TXOP allocation [1]. Figure 2.1 depicts the IEEE 802.11e MAC architecture.

2.1.1 Enhanced Distributed Channel Access (EDCA)

EDCA is designed to provide prioritized QoS by enhancing the contention-based DCF. The Enhanced Distributed Coordination Function (EDCA) mechanism [3] of IEEE 802.11e provides differentiated, distributed access to the WM for QSTAs using eight different Ups [3] and defines four access categories (ACs) that provide support for the delivery of traffic with UPs at the QSTA(s). Before entering the MAC layer, each data packet received from the higher layer is assigned a specific user priority value. At the MAC layer, EDCA introduces four different first-in first-out (FIFO) queues, called access categories (ACs). Each data packet from the higher layer along with a specific user priority value should be mapped into a corresponding AC according to a Table 2.1. Different kinds of applications (e.g., background traffic, best effort traffic, video traffic, and voice traffic) can be directed into different ACs as shown in the Figure 2.2. Each AC behaves as a single DCF contending entity with its own contention parameters CWmin[AC], CWmax[AC], AIFS[AC] and
Table 2.1. User Priority to Access Category Mapping

<table>
<thead>
<tr>
<th>Priority</th>
<th>UP (Same as 802.1D user priority)</th>
<th>802.1D Designation</th>
<th>AC</th>
<th>Designation (Informative)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lowest</td>
<td>1</td>
<td>BK</td>
<td>AC_BK</td>
<td>Background</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>--</td>
<td>AC_BK</td>
<td>Background</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>BE</td>
<td>AC_BE</td>
<td>Best Effort</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>EE</td>
<td>AC_BE</td>
<td>Best Effort</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>CL</td>
<td>AC_VI</td>
<td>Video</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>VI</td>
<td>AC_VI</td>
<td>Video</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>VO</td>
<td>AC_VO</td>
<td>Voice</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>NC</td>
<td>AC_VO</td>
<td>Voice</td>
</tr>
</tbody>
</table>

Figure 2.2. Timing relationship of EDCA.

TXOPLimit[AC]. Basically, the smaller the values of CWmin[AC], CWmax [AC] , and AIFS[AC] , the shorter the channel access delay for the corresponding AC and the higher the priority for access to the medium. The EDCA parameter set, which includes:

- Contention Window (CW): A random number is drawn from this interval, or window, for the back off mechanism.
- Minimal CW value for a given AC (CWmin [AC]): CWmin can be different for different ACs. Assigning smaller values of CWmin to high priority classes can ensure that high priority classes obtain more TXOPs than low priority ones.
- Maximal CW value for a given AC (CWmax [AC]): Similar to CWmin, CWmax is also on a per AC basis.
- Arbitrary inter-frame space number (AIFSN): The minimum time interval between the wireless medium becoming idle and the start of transmission of a frame. Each AC starts its backoff procedure after the channel is idle for a period of AIFS [AC] instead of DIFS.
- **TXOPlimit [AC]**: The maximum duration for which a STA can transmit after obtaining a TXOP. TXOPs obtained via EDCA are referred as EDCA-TXOPs. During an EDCA-TXOP, a station may be allowed to transmit multiple data frames from the same AC with a SIFS gap between an ACK and the subsequent data frame transmission. **TXOPlimit [AC]** gives the limit for such a consecutive transmission.

- “Virtual Collision”: As depicted in Figure 2.2, if the backoff counters of two or more co-located ACs in one station elapse at the same time, a scheduler inside the station treats the event as a virtual collision. The TXOP is given to the AC with the highest priority among the “colliding” ACs, and the other colliding ACs defer and try again later as if the collision occurred in the real medium [3].

In EDCA a new type of IFS is introduced, the arbitrary IFS (AIFS), in place of DIFS in DCF. Each AIFS is an IFS interval with arbitrary length as follows:

\[
\text{AIFS[AC]} = \text{SIFS} + \text{AIFSN[AC]} \times \text{slot time}
\]

where AIFSN[AC] is called the arbitration IFS number. After sensing the medium idle for a time interval of AIFS[AC], each AC calculates its own random backoff time (\(\text{CWmin[AC]} \leq \text{backoff time} \leq \text{CWmax [AC]}\)). The purpose of using different contention parameters for different queues is to give a low priority class a longer waiting time than a high-priority class, so the high-priority class is likely to access the medium earlier than the low-priority class. The four Access Categories [3], [5] and the mapping between the ACs and UPs are illustrated in Table 2.1. Note that the backoff times of different ACs in one QSTA are randomly generated and may reach zero simultaneously. This can cause an internal collision. In such a case, a virtual scheduler inside every QSTA allows only the highest-priority AC to transmit frames. Figure 2.2 shows the timing relationship of EDCA [6].

Figure 2.3 shows the implementation model with four transmission queues, where each AC behaves like a virtual station: it contends for access to the medium and independently starts its backoff after sensing the medium idle for at least AIFS. The AC with the smallest AIFS has the highest priority. The purpose of using different contention parameters for different queues is to give a low-priority class a longer waiting time than a high-priority class, so the high-priority class is likely to access the medium earlier than the low-priority class. An internal collision occurs when more than one AC finishes the backoff at the same time. In such a case, a virtual collision handler in every QSTA allows only the highest-priority AC to transmit frames, and the others perform a backoff with increased CW values.
2.1.2 HCF Controlled Channel Access (HCCA)

Although EDCA improves the legacy DCF, it is not sufficient to provide effective traffic protection and QoS guarantees, especially under high traffic loads [3]. Here comes the need for the polling-based medium access mechanism, HCCA. The HCF controlled channel access (HCCA) mechanism is defined for parameterized QoS support. A QoS-aware centralized coordinator, called the Hybrid coordinator (HC), is used by the HCCA mechanism [3]. The HC is usually collocated with the AP and operates under rules that are different from the PC of the PCF and has higher priority to access the wireless medium to allocate TXOPs to STAs in order to provide limited-duration controlled access phase (CAP) for contention-free transmission [3].

Unlike the PC in legacy 802.11, the HC can access the medium during both CP and CFP intervals and perform HCF data frame exchange sequences in both periods, as shown in Figure 2.3. Moreover, the HC grants STAs different TXOPs with specified duration [3].
Therefore, STAs may transmit multiple data frames within their HCCA-TXOPs, subject to the limit on TXOP duration. To enhance the AP’s control capabilities, a new concept of Controlled Access Phase (CAP) has been defined. A CAP is a period of time in which the AP holds control of the channel and stations are not allowed to contend for the medium. An access point can start a CAP by sending a poll or data frame while it finds the medium idle for PIFS waiting time. PIFS is shorter than DIFS or AIFS (used by EDCA), thus giving the AP the capability to interrupt the contention operation and generate a CAP at any moment [3]. All STAs shall set their NAV according to the HCF rules because each frame transmitted under HCF contains the transmission duration of the current frame as well as the subsequent frames. The HCF protects the transmission during each CAP using the virtual carrier sensing mechanism. When the AP needs to access the channel to start a CFP or a TXOP in CP, it senses the medium to be idle for one PIFS period. If the medium is idle, the AP transmits the first frame in the frame exchange sequences, which contains the duration value, set to cover the CFP or the TXOP. The first frame in a CFP period is the beacon frame. In the CFP or the TXOP in CP during HCCA access mechanism, SIFS is required between each two frames exchange sequence. If the medium remains idle for a PIFS period, the AP reclaims the channel. However, the CAP period ends when the AP does not reclaim the channel after a PIFS period after the end of a TXOP [3]. Note that the CAP (controlled access phase) is defined as the time period when HC maintains the control of the medium. It can be seen that CAPs consist of not only CFPs but also parts of CPs as depicted in Figure 2.4.

The Beacon Interval (Superframe) in 802.11e is divided into two periods: the CFP and the CP. During the CFP, the HC has full control over the wireless channel and can poll QSTAs according to its scheduling algorithm in a centralized manner. STA(s) are not allowed to perform any data transmissions unless they are polled by the AP. On the other hand, during the CP interval, the HC can access the channel and generate CAP periods where TXOPs are allocated to polled QSTAs to guarantee multimedia applications requirements. Figure 2.5 [1] depicts a typical IEEE 802.11e beacon interval and the relationship between CFP, CP and CAPs.

In HCCA access mechanism, the QoS guarantee is based on the traffic specification (TSPEC) negotiation between the AP and the STAs. Each STA can establish up to 8
parameterized traffic streams (TS). In order to set a TS connection between a STA and the AP, a set of TSPEC parameters is required to be sent by the STA to the AP. The AP’s scheduler, in turn, computes the duration of the polled-TXOP for each STA, and allocates polled-TXOP for each STA. Then the STA distributes the polled-TXOP among TSs established in it. After grabbing the channel, the HC polls STAs in turn according to its polling list. In order to be included in the polling list of the HC, a STA must send a reservation request using the special QoS management frame, and each individual flow needs one particular reservation request.

The HC (collocated with the AP) maintains a list of STAs to be polled during controlled Access Periods. In order to be included in the polling list of the HC, a node must send a request frame called ADD Traffic Stream (ADDTS) to initiate a connection [7], [8]. This request frame comprises a set of parameters known as Traffic Specification (TSPEC)
element as shown in Figure 2.6. Note that each STA can establish up to 8 traffic streams (TSs) for different parameterized applications. TSID is the Identification number assigned by the STA for the TS. The standard scheduler uses some of TSPEC parameters in order to make reservations for traffic streams [3]. A TS is a series of MAC Service Data Units (MSDUs) that should be served according to a set of QoS values defined in a TSPEC element. Figure 2.6 [9] describes the TSPEC frame structure.

<table>
<thead>
<tr>
<th>Element ID</th>
<th>Length</th>
<th>TS Info</th>
<th>Nominal MSDU Size</th>
<th>Maximum MSDU Size</th>
<th>Minimum Service Interval</th>
<th>Maximum Service Interval</th>
<th>Inactivity Service</th>
<th>Suspension Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Octet</td>
<td>1 Octet</td>
<td>3 Octets</td>
<td>2 Octets</td>
<td>2 Octets</td>
<td>4 Octets</td>
<td>4 Octets</td>
<td>4 Octets</td>
<td>4 Octets</td>
</tr>
</tbody>
</table>

**Figure 2.6. TSPEC frame structure. Source: S. Shenglin et al., “An optimized QoS traffic-scheduling algorithm based on HCCA,” in Int. Conf. Intelligent Computation Technology and Automation, Hunan, China, 2008, pp. 229-233.**

The main recommended parameters of TSPEC include:

- Mean data rate - average bit rate for transfer of the TS packets in unit of bits per second (bps).
- Delay bound - maximum delay allowed transporting a packet across the wireless interface including queuing delay in milliseconds.
- Nominal MSDU size - nominal size of the packets in octets.
- Maximum MSDU size - maximum size of the TS packets in octets.
- Maximum Burst Size - maximum size of a data burst that can be transmitted at the peak data rate in octets.
- Minimum PHY rate - physical bit rate assumed by the scheduler for transmit time and admission control calculations in unit of bits per second (bps).
- Peak data rate - maximum bit rate allowed for transfer of the packets in units of bits per second (bps).

Using these parameters, the HC computes the time required for each traffic stream and responds with an ADDTS response frame. Negotiations between STAs and the HC may take place if the HC cannot accommodate a certain TS requirements. However, if the HC cannot guarantee the QoS requirements of TS, it will reject its connection and inform the STA in the response frame. These parameters are taken into account by the HC, which
dynamically decide the allocation of the radio resources per TS. The TSPEC detail frame structure is as Figure 2.6.

The wireless traffic scheduling algorithm is always based on HCCA polling mechanism because contention-based prioritized access to the wireless channel using EDCA is not fully adequate for providing firm QoS guarantees especially in the case of delay sensitive applications. In HCCA model, when QAP receive the QoS request package from QSTA, Admission Control Unit will work out the result based on parameters in TSPEC. The result shows that the TS can be accepted or rejected by the HC. In IEEE 802.11e standard the steps of HCCA Admission Control are as follows:

   Step 1: Calculate a common schedule SI (Service Interval) for all active QSTAs. SI must be less than or equal to maximum Service Interval of all QSTAs, and SI must be maximum factor of beacon interval. For example: Beacon interval=500ms, Maximum Service Intervals of three QSTAs are 180ms, 150ms, 200ms, and then the SI is 125ms.

   Step 2: Calculate the TXOP allocated to TS of QSTA based on TSPEC parameters. Firstly, calculate the number of packets arriving in the TS of one QSTA during a SI.

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

Where
\( \rho_i \): Mean Data Rate
\( L_i \): Nominal MSDU Size

Then calculate the TXOPi duration (TDi) of each QSTA. (At least transmit one MAX MSDU)

\[ TD_i = Max \left( \frac{N_i \times L_i}{R_i} + O \times \frac{M}{R_i} + O \right) \]

Where
\( R_i \): Physical Transmission Rate
\( M \): Maximum Allowable Size of MSDU (Such as 2304 bytes)
\( O \): Overhead in time units

QAP assigns polled TXOPs during SI for QSTA(s) based on TSPEC of three QSTA1, QSTA2 and QSTA3 as Figure 2.7.
Step 3: Assume there are $k$ admitted flows, a new flow $k + 1$ is accepted if it satisfies the following equation.

$$\frac{TD_{k+1}}{SI} + \sum_{i=1}^{k} \frac{TD_i}{SI} \leq \frac{T - T_{cp}}{T}$$

Where

- $T$: Beacon Interval
- $T_{cp}$: Time for EDCA Traffic

From mentioned above we can draw the conclusion that QoS requirement of TS is described in TSPEC and transmission time is calculated based on TSPEC, controlled by TXOP [3].

The IEEE 802.11e standard does not define a mandatory HCCA scheduling algorithm; however, a reference scheduler is specified and reported therein for informational purposes. The reference scheduler requires that flows specify the following TSPEC parameters: Mean Data Rate, Nominal SDU Size, Maximum SDU Size and Maximum Service Interval (MSI). The MSI of a given flow is the maximum time that elapses from the start of two subsequent service periods to that flow. The reference scheduler produces TDM-like schedules: each TS is periodically allocated a fixed amount of capacity. The period is called Service Interval (SI) and it is the same for all traffic streams. It is computed as the smallest admitted MSI. The TXOP duration is then set to the time required to transmit the packets of Nominal SDU Size that arrive at the negotiated Mean Data Rate during the SI; the TXOP is rounded up to contain an integer number of Nominal SDU Size [10]. In order to avoid head of line blocking, the actual TXOP value is the maximum between the value obtained with the above procedure and the time to transmit a packet with Maximum SDU Size. A sample schedule showing three admitted flows (i, j and k) is reported in Figure 2.8.
2.2 DRAWBACK OF IEEE802.11E

The 802.11e introduces new frame formats with QoS information fields, the capability to poll a station even during the contention period and new concepts such as transmission opportunity (TXOP). It also enables differentiation between different classes of traffic through the use of different contention window and IFS waiting times. With all the enhancements the 802.11e MAC scheme could have been justified if the majority of traffic in the system was real time. However, when we envision a system where majority of traffic is non-real time (educational institution, stock market, business organization). The EDCA mechanism provides significant improvements for high priority QoS traffic with the help of better EDCA parameters for channel access when compared to low priority applications, however these improvements are typically provided at the cost of worse performance for lower priority traffic. In the standard 802.11e during the CP phase, both the HP and the LP flows contend for channel access with their respective EDCA parameter set, but during the CFP or the Hybrid coordinator (HC) initiated polling phases CAPs during CP, polls are only issued to the high priority (QoS) traffic to enable them to enjoy dedicated channel access [3].

As depicted in Figures 2.4 and 2.5, it is clear that it is the HP traffic that gets access most of the time during the CP/CAPs/CFP periods thus making the system biased towards one type of traffic. This forces the non real time traffic to be conservative allowing it only a fraction of the CP to contend for channel access. Thus LP traffic gets channel access only during the CP phase or EDCA mode. HP traffic hogs the channel most of the time owing to the preferential service offered by the standard resulting in performance starvation of LP traffic [3]. HCCA based pure polling mechanism used in the CFP and both contention and polling initiated during CAPs in the CP, can severely delay the transmission of non-real time traffic. Hence, the fairness issue is related to each traffic throughput and the average delay a TS experiences before it gets serviced.
This functionality of 802.11e where it gives preferential service to HP traffic for a greater fraction of the beacon interval can be detrimental for the LP performance especially in networks where non real time traffic predominates. It can be very unfair and inefficient in such networks and would seriously degrade their performance. A wireless station can take advantage of the 802.11e scheme and arbitrarily set its traffic parameters to the highest priority (small AIFS, small backoff contention window, etc.) [5], [11], [12], which is not addressed in the standard. This selfish behavior can highly impact the system performance and exploit the QoS mechanisms provided in the wireless standards.
CHAPTER 3

PROPOSED MAC SCHEME

A new MAC scheme called FAIR MAC is proposed to provide sufficient transmission time for acceptable performance for the low priority traffic. The main objective of this research is to provide fair channel access opportunities to both high priority and low priority traffic such that adequate throughput is enjoyed by non-real time (or LP) flows while still supporting the QoS constraints of real time traffic (or HP) flows. Thus we have designed a scheme that would be suitable for networks dominated by LP traffic and one that would eventually revert back to normal 802.11e functionality in the absence of LP traffic.

3.1 DESCRIPTION OF THE FAIR MAC SCHEME

In the standard 802.11e during the CP phase, both the HP and the LP flows contend for channel access with their respective EDCA parameter set, but during the CFP or the Hybrid coordinator (HC) initiated polling phases, polls are only issued to the high priority (QoS) traffic to enable them to enjoy dedicated channel access. From Figure 3.1, it is clear that HP traffic gets access most of the time during the CP /CAPs/CFP periods thus making the system biased towards one type of traffic [3]. This kind of a setup would be very unfair and inefficient in networks where LP flows predominate and would seriously degrade their performance.

In our proposed scheme we assume that the majority of flows are non-real time (or LP). Our scheme alternates between a contention phase and a polling phase. The contention phase is exactly similar to that of 802.11e, in which the real-time (or HP) flows enjoy higher privilege of channel access via strategic selection of backoff and channel sensing parameters. There are no modifications made in the CP phase (EDCA parameter set is same as that of the standard), in other words the system in CP period functions similar to the standard. However, during the CFP period, LP traffic is included in the polling list and thus polled by the HC along with the HP traffic. The duration of the CFP is equally distributed to allocate transmission time for all traffic flows in the network. The polling scheme is implemented in a
circular queue such that all traffic flows gets polled almost equally. The HC collocated at the AP starts polling every station in the polling list starting with the highest priority till the lowest priority user is served such that the HP flows still retain their precedence in the queue over the LP flows.

Thus during the Contention Period even though the real time traffic gains channel access, we make sure that the non real time traffic is not penalized as they get polled by the HC during the CFP thus giving a fair chance for all the flows.

### 3.1.1 HP & LP Split in Contention Free Phase

In our FAIR MAC scheme, duration of CFP interval is 50ms out of 200ms of the whole beacon interval. The duration of CFP is equally distributed to allocate transmission time for all transmission flows (both HP & LP) in the network. Polling scheme is
implemented in a round robin manner such that all traffic flows get polled almost with equal
time period.

The amount of time that each traffic flow gets at each traffic case is as follows:

i. 5HP+5LP=> 50TU/10 = 5ms
    Total time period of HP during CFP = 5 * 5ms => 25ms
    Total time period of LP during CFP = 5 * 5ms => 25ms

ii. 5HP+10LP=> 50TU/15 = 3.33ms
    Total time period of HP during CFP = 5 * 3.33ms => 16.65ms
    Total time period of LP during CFP = 10 * 3.33ms => 33.3ms

iii. 5HP+15LP=> 50TU/20 = 2.5ms
    Total time period of HP during CFP = 5 * 2.5ms => 12.5ms
    Total time period of LP during CFP = 15 * 2.5ms => 37.5ms

iv. 5HP+20LP=> 50TU/25 = 2ms
    Total time period of HP during CFP = 5 * 2ms => 10ms
    Total time period of LP during CFP = 20 * 2ms => 40ms

v. 5HP+25LP=> 50TU/30 = 1.66ms
    Total time period of HP during CFP = 5 * 1.66ms => 8.3ms
    Total time period of LP during CFP = 25 * 1.66ms => 41.5ms

It can be observed that at each traffic case, LP gets more transmission time during
CFP using our proposed approach. Higher the CFP interval, higher the transmission time for
LP traffic. But there should be a trade-off between CFP and CP duration, in order to ensure
sufficient transmission time to the LP traffic while still maintaining the QoS for HP traffic.
Thus, it is to be noted that the duration of the CFP phase has a large bearing on the network
performance.

### 3.1.2 HCCA – Polling Scheme Working Procedure

As shown in the Figure 3.2 there can be up to 8 uplink/downlink traffic streams
within a non-AP QSTA. Each traffic stream has its own transmit queue, which means that
any non AP QSTAs can provide parameterized QoS services for up to 8 traffic flows.

The operation is summarized in the following steps:

- Inside each Non-AP nodes, there will be up to 8 kinds of sources, but due to the
  limitation of time and knowledge, the proposed protocol will only involve 2 types of
  traffic, which are voice for HP traffic and data for LP traffic.

- Inside each node, when the sources produce traffic, the data blocks is queued inside
  the node, and if the station is polled, the front-most traffic transmits to the AP, and
  the rest traffic inside the station node will queue and act like the round robin scheme.
Original round robin is a scheduling protocol which services each priority queue, starting with the highest priority queue that contains packets, services a single packet, and moves to the next lower priority queue that contains packets, servicing a single packet from each, until each queue with packets has been serviced once.

It then starts the cycle over with the highest priority queue containing packets. The HC gains control of the WM as needed to send QoS traffic to non-AP QSTAs and to issue CF Poll frames to non-AP QSTAs by waiting a shorter time PIFS between transmissions than the STAs using the EDCA procedures.

When the node is polled again, one block of traffic will be transmitted and the others remain in the queue. If there is no traffic inside the node, when it received the polling information, it will reply with a CF-end frame and the AP will not poll it. If the traffic is heavy, there will be overflow when the queue length is not long enough.

Thus during the Contention Period even though the real time traffic gains channel access, we make sure that the non real time traffic is not penalized as they get polled by the HC during the CFP thus giving a fair chance for all the flows.

Thus under scenarios where the system comprises of HP flows alone, our proposed scheme would have the same functionality as that of the standard 802.11e.

However, the extra opportunity to transmit data by the LP flows, during the CFP phase leads to significant increase in their throughput with minor dent in the QoS performance of the HP flows as illustrated in the subsequent chapter.
3.2 Analysis of the Scheme

Our proposed MAC scheme is analyzed by presenting the analytical expressions for throughput and delay performance metrics.

3.2.1 System Model

We analyze the 802.11e MAC protocol. We realize that an analysis of the exact scheme is cumbersome. We thus propose a Hybrid-MAC model that resembles the 802.11e MAC in most essential respects. Our MAC model provides us with an abstraction of the essential features of 802.11e MAC, while avoiding the complex details of the latter. We believe that the insights obtained by using our model are applicable to the 802.11e scenario. Other publications that analyze 802.11e have provided an overview of the quality of service (QoS) enhancement [13], [14] but have not attempted to model throughput and delay in analytical form. This paper takes a first step toward finding analytical expressions for modeling throughput and delay characteristics of a MAC protocol that mimics the IEEE 802.11e in every essential respect. It does so by first proposing a simplified model of the IEEE 802.11eMAC. This model can be thought of as a hybrid MAC model which operates in both the contention and contention free phases alternately akin to a legacy 802.11 MAC protocol with both its (a) Distributed Coordination Function (DCF), and (b) Point Coordination Function (PCF) mode enabled [3]. While DCF is based on the contention based CSMA/CA mode of channel access, PCF is based on the polling mechanism. Limited QoS support in the legacy 802.11 standard is available through the use of the PCF. The DCF phase mimics the Enhanced distributed channel access (EDCA) mechanism which is a contention-based channel access scheme while the PCF mimics the Hybrid Coordinator Function (HCF) controlled channel access (HCCA) which is based on a polling mechanism. EDCA and HCCA are used to provide prioritized and parameterized QoS service respectively in 802.11e.

The network topology being modeled consists of a Basic Service Set (BSS) of N low priority and M high priority traffic flows. We assume that each flow is generated by a node which we refer to as a STA (station), as done in the 802.11 standard. During the contention period (CP), each STA uses the basic access mechanism only. That is, no STA is assumed to be hidden from another STA and the RTS/CTS mechanism is not employed. During the
contention free period (CFP), the $M$ high priority traffic STAs are placed in a circular queue and are polled sequentially by the PCF. The PCF implements two periods of channel access in a duration of time referred to as the “superframe”: (i) a contention free period (CFP) and (ii) a contention period (CP). Figure 3.2 depicts an 802.11e superframe 802.11e showing HP traffic constrained to the CFP while LP and HP traffic compete for channel access during the CP. The HC in the CP also polls stations for HP traffic [3].

The proportion of time allocated to each period within a superframe is not defined by the standard. The point coordinator subsystem residing in an AP continues to poll STAs in its polling list until the CFP duration expires. The Figure 3.3 depicts the superframe of our proposed MAC scheme which shows the addition of LP traffic in the CFP interval.

![Image](image_url)

**Figure 3.3.** Proposed MAC Superframe where low priority traffic also gets channel access during the contention free phase.

### 3.2.1.1 Modeling Throughput

Our analytical model for overall system throughput is a dimensionless multivariable function $S$ of $N$, $M$, $p$, and $\alpha$. 


where \( p \) is the probability of a successful frame transmission and \( \alpha \) is a value between 0 and 1 that identifies the ratio of the time spent in the CFP to the total time spanned by a superframe which forms a repeating interval of contention and contention free time periods,

\[
\alpha = \frac{\text{CFP}}{\text{CFP} + \text{CP}}
\]  

(3.2)

As \( \alpha \) tends toward 0, the BSS reverts to a contention only based environment where the point coordinator is not used to poll STAs. With a non-zero \( \alpha \), dimensionless throughput \( S \) becomes a weighted sum of time spent in the CP and the CFP,

\[
S(N, M, p, \alpha) = (1 - \alpha)S_{CP} + \alpha S_{CFP}
\]  

(3.3)

We define \( SCP \) and \( SCFP \) as dimensionless throughput for each respective period,

\[
S_{CP} = \frac{\bar{U}_{CP}}{I_{CP} + B_{CP}}
\]  

(3.4)

\[
S_{CFP} = \frac{\bar{U}_{CFP}}{B_{CFP}}
\]  

(3.5)

The definition of \( S_{CP} \) is given by equation (3.4) where is the average duration of time useful data is received by a STA during the CP, is the average duration of time the channel remains idle during the CP, and is the average duration of time the channel is busy transmitting data, the overhead bits incurred by the data, and is handling collisions. Equation (3.4) is then a dimensionless quantity between 0 and 1 that represents throughput efficiency as the ratio of time the channel is used for sending useful data to total time. \( S_{CFP} \) is similar to \( S_{CP} \), but does not include the idle term in the denominator since it is assumed the channel is never idle during the CFP.

\[
\bar{U}_{CP} = \frac{(N + M)T_{p}}{(1 - p)(1 - (1 - p)^{N+M})}
\]  

(3.6)
\[
\overline{I}_{CP} = \frac{\sigma}{1-(1-p)^{N+M}}
\]  
(3.7)

\[
\overline{B}_{CP} = \frac{T_s}{(1-p)^{N+M}}
\]  
(3.8)

Where \(T_s\) is the time spent sensing the channel during a successful frame transmission and \(T\) is the time spent transmitting useful data in the CP. Substituting (3.6), (3.7), and (3.8) into (3.4), we obtain

\[
S_{CP} = \frac{(N + M)Tp(1-p)^{N+M-1}}{T_s + (\sigma + T_s)(1-p)^{N+M}}
\]  
(3.9)

The expression for \(T_s\) is given by

\[
T_s = DIFS + \frac{H+P}{R} + SIFS + \frac{ACK}{R} + 2\tau
\]  
(3.10)

Our derivation of \(S_{CFP}\) proceeds in a similar way. Let \(q\) represent the probability a STA has a non-null data frame to transmit during the CFP. \(U_{CFP}\) is the average time spent during the CFP to transmit useful data. By useful data we mean data bits and not bits belonging to beacon, pure ACK, and CF-End frames. If we denote \(P_{CFP}\) as the number of data bits transmitted during the CFP, then

\[
\overline{U}_{CFP} = \frac{P_{CFP}}{R}
\]  
(3.11)

where \(R\) is the fixed transceiver data rate.

To derive the expression (3.12) for the time the channel is busy in the CFP during a successful polling transaction, we need to account for all the individual frame CFP transmissions which represents the lengths of the beacon, Data/CF-Poll, Data/CF-ACK, and CF-NULL frames, respectively. CF-NULL frames are transmitted by a polled STA if the STA does not have any pending data to send. \(\tau\) is the propagation delay of the wireless LAN and \(H\) is the length of the header and frame check sequence (FCS) of an 802.11 frame.
Our analytical model for overall system delay is a dimensionless multivariable function \( D \) of \( N, M, p, \) and \( \alpha \),

\[
D = D(N, M, p, \alpha)
\]  

(3.13)

Observe that

\[
0 < \frac{D_{\text{ideal}}}{D_{\text{actual}}} \leq 1
\]  

(3.14)

Where \( D_{\text{ideal}} \) is the theoretical minimum delay a STA can experience in a superframe while \( D_{\text{actual}} \) is the true delay experienced. If we define \( D \) such that

\[
D = \left(1 - \frac{D_{\text{ideal}}}{D_{\text{actual}}}ight)
\]  

(3.15)

Then \( D \to 0 \) as the actual delay approaches the ideal and \( D \to 1 \) as actual delay diverges from the ideal. We first consider delay incurred by the DCF. Ideal delay in the CP can be expressed as the sum of ideal head-of-line (HOL) delay and ideal queuing delay,

\[
D_{\text{ideal}} = D_{\text{HOL}}^{\text{ideal}} + D_{\text{Queueing}}^{\text{ideal}}
\]  

(3.16)
Where represents the minimum time required in the CP to transmit an 802.11 frame successfully, upon the first attempt, and is equal to $T_s$. Ideal queuing delay is given by the Pollaczek- Khinchine formula [3] HOL ideal D

$$D_{\text{Queuing}}^{\text{ideal}} = \frac{\rho}{2\mu(1-\rho)}\left(1 + cv^2\right)$$

(3.17)

that describes the mean time a frame waits in queue to be serviced by the MAC, where the queue is modeled as a M/G/1 queue (a single server with frame arrivals having a Poisson distribution and service time having a general distribution). Total actual delay $D_{\text{actual}}$ is modeled as the sum of (3.17) and an expression for the expected value of HOL delay which takes into account backoff delay.

In equation (3.18), $\beta$ is the average physical time between two decrements of the backoff counter, $CW_{\text{min}}$ is the minimum contention window size, is the probability a STA’s frame transmission is successful, and $r_{\text{max}}$ is the maximum number of retransmissions permitted. In our simulation, $CW_{\text{min}}$ is set to 24 and $CW_{\text{max}}$ is set to 210 which are the values used by a PHY that employs a frequency-hopping spread spectrum (FHSS) method of transmitting radio signals. Considering now the PCF, each STA has an opportunity to transmit when polled while the CFP is in progress. If the maximum predetermined duration of the CFP in a given superframe expires before every STA has been polled, STAs that were not given an opportunity are more likely to be polled in the following CFP as the PC uses a circular queue to schedule station polling

$$E\left[D_{\text{actual}}^{\text{HOL}}\right] = T_s + \beta \left[\frac{CW_{\text{min}}}{2\left(1 - (1 - P_s)^{r_{\text{max}} + 1}\right)}\right]$$

$$+ \left[\frac{P_s\left(1 - (2(1 - P_s))^{r_{\text{max}} + 1}\right)}{1 - 2(1 - P_s)} - 1 - (1 - P_s)^{r_{\text{max}} + 1}\right] +$$

$$T_s \left[\frac{1 - P_s}{P_s}\right] \left[\frac{(1 - P_s)^{r_{\text{max}}} (-P_s r_{\text{max}} - 1) + 1}{1 - (1 - P_s)^{r_{\text{max}} + 1}}\right]$$

(3.18)
Also, \( r_{\text{max}} \) is defined as

\[
r_{\text{max}} = \log_2 \left( \frac{CW_{\text{max}}}{CW_{\text{min}}} \right)
\]

(3.19)
is (3.18) without any backoff delay,

\[
D_{\text{HOL}}^{\text{ideal}} = T_s
\]

(3.20)
Let \( \Psi \) represent the expected value of the size of a frame transmitted by a polled STA during the CFP and \( \psi \) represent the size of the body of data within this frame,

\[
\Psi = 34 + E[\psi]
\]

(3.21)
Assuming the length of data in frames transmitted during the CFP is uniformly distributed, the total time for one CFP is given by \( T_{\text{CFP}} \),

\[
T_{\text{CFP}} = \frac{CF_{\text{Beacon}}}{R} + \frac{(N + M)(\Psi_{\text{PC}} + \Psi_{\text{STA}})}{R} + \frac{[2(N + M) + 1]SIFS + \frac{CF_{\text{End}}}{R} + (N + M)\tau}{(N + M - 1)SIFS + \left( \frac{N + M}{2} \right)\tau}
\]

(3.22)
Let \( D_{\text{CFP}} \) represent the average time a frame must wait at the head-of-line once the CFP begins,

\[
D_{\text{CFP}} = \frac{CF_{\text{Beacon}}}{R} + \left( \frac{N + M}{2} - 1 \right) \left( \frac{\Psi_{\text{PC}} + \Psi_{\text{STA}}}{R} \right) + \left( N + M - 1 \right) SIFS + \left( \frac{N + M}{2} \right) \tau
\]

(3.23)
From (3.16), (3.17), (3.20), and (3.23) we now have

\[
D_{\text{ideal}} = T_s + \frac{\rho}{2\mu(1 - \rho)} \left( 1 + c\nu^2 \right) + \frac{CF_{\text{Beacon}}}{R} + \left( \frac{N + M}{2} - 1 \right) \left( \frac{\Psi_{\text{PC}} + \Psi_{\text{STA}}}{R} \right) + \left( N + M - 1 \right) SIFS + \left( \frac{N + M}{2} \right) \tau
\]

(3.24)
Accounting for backoff delay, is modified to give $D_{\text{actual}}$ which is shown in (3.25).

\[
D_{\text{actual}} = T_s + \beta \left[ \frac{C W_{\text{min}}}{2 \left( 1 - (1 - P_s)^{r_{\text{max}} + 1} \right)} \right]
\]

\[
+ \left[ \frac{P_s \left( 1 - \left( 2(1 - P_s) \right)^{r_{\text{max}} + 1} \right)}{1 - 2(1 - P_s)} \right] - 1 - (1 - P_s)^{r_{\text{max}} + 1} +
\]

\[
T_s \left[ \frac{1 - P_s}{P_s} \right] \left[ \frac{(1 - P_s)^{r_{\text{max}}}}{1 - (1 - P_s)^{r_{\text{max}} + 1}} \right] +
\]

\[
\frac{\rho}{2 \mu (1 - \rho)} \left( 1 + cv^2 \right) +
\]

\[
\frac{C F_{\text{Beacon}}}{R} + \left( \frac{N + M}{2} - 1 \right) \left( \frac{\Psi_{PC} + \Psi_{STA}}{R} \right) +
\]

\[
( N + M - 1 ) SIFS + \left( \frac{N + M}{2} \right) \tau
\]

(3.25)

3.2.2 Validation of the Proposed MAC Scheme

Our proposed model is validated through NS2 simulation results (Figures 3.4 and 3.5) to ensure both analytical and FAIR MAC scheme match. Corresponding throughput and delay metrics is shown in Figures 3.4 and 3.5. From the Figures 3.4 and 3.5, it is seen that our proposed model matches the analytical throughput and delay values which ensures that our FAIR MAC scheme performs the way as we expected.
Figure 3.4. Throughput of Fair MAC scheme (in kbps) – Simulation vs analytical model.

Figure 3.5. Delay of Fair MAC scheme (in ms) – simulation vs analytical model.
CHAPTER 4

SIMULATION RESULTS

All the simulations are evaluated using NS2 (Network Simulator platform). NS2 is an object-oriented, discrete event driven network simulator. It is possible to setup simulation networks of many kinds, because NS2 is a set of well documented C++ classes.

NS2 is Open Source, so that its user can change and extend existed classes very easily. Especially for the research in computer networks, NS2 is preferable because any adjustments of its internal behavior are easy to implement directly by changing proper parts of its source code. There are also some functional extensions of basic NS2 environment. They provide NS2 with improved functionality for many different types of simulation.

Our objective requires the support of 802.11e EDCA and HCCA functionalities for wireless network simulations [10], [15].

4.1 SIMULATION SETUP

The wireless topology in our simulation consists of QSTA(s) and QAP where each of the wireless station is configured with the default parameter settings (depends on the access category of the node). All QSTA(s) are located such that every station could detect a transmission from every other station and QAP is placed at the centre of these QSTA(s) so that the distance will not affect the QoS. For simplicity, we assume there are no hidden terminals or radio link errors in the network.

To study the impact of FAIR MAC scheme on the system performance, we carried out extensive simulations on two baseline scenarios. The simulation parameters are outlined in Table 4.1. These scenarios are simulated using IEEE802.11b physical layer parameters which supports a data rate of 11Mbps. First set of simulation is carried out with heterogeneous access categories (comprises of both high priority and low priority traffic flows) where most of the traffic are non-real time flows. Second set of simulation contains either all high priority traffic or all low priority traffic which is evaluated on both 802.11e original MAC scheme and our proposed FAIR MAC scheme to study the comparison.
Table 4.1. Simulation Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>PHY data rate</td>
<td>802.11b – 11Mbps</td>
</tr>
<tr>
<td>Beacon Interval</td>
<td>200ms</td>
</tr>
<tr>
<td>CFP Duration</td>
<td>50ms</td>
</tr>
<tr>
<td>Simulation duration</td>
<td>400s</td>
</tr>
<tr>
<td>Number of access categories per station</td>
<td>2 (one for low priority and other for high priority)</td>
</tr>
<tr>
<td>Time slot</td>
<td>20us</td>
</tr>
<tr>
<td>SIFS</td>
<td>1 timeslot</td>
</tr>
<tr>
<td>Access category AC_VO - AIFS [HP]</td>
<td>3 timeslots</td>
</tr>
<tr>
<td>Access category AC_BE - AIFS [LP]</td>
<td>4 timeslots</td>
</tr>
<tr>
<td>CWmin [HP]</td>
<td>7</td>
</tr>
<tr>
<td>CWmin [LP]</td>
<td>31</td>
</tr>
</tbody>
</table>

To avoid complexity in the network, we consider only two access categories per station. Once access category is for higher priority and the other is for lower priority. Both traffic types use CBR traffic, which means the rate of the output data is constant. In the wireless transmission, traffic with higher bit rate should have higher priority. Thus voice traffic flow has the higher priority and data has the lower priority.

4.2 SIMULATION RESULTS

We measure the system performance in both the cases in terms of the average system throughput and average end-to-end delay per user. The two baseline scenarios are configured as follows in the following sections.

4.2.1 Scenario 1

In Scenario 1, the network consists of five non-real time traffic flows or LP flows and five real-time or high priority traffic flows. This kind of set up is consistent with the network scenarios discussed earlier, where non real time traffic pre-dominates the real time traffic. Now in order to study the impact of increasing the volume of low priority traffic on the system performance the LP flows are increased from five to twenty five while maintaining the HP flows constant at five. i.e., 10LP, 15LP, 20 LP and 25LP flows are added
to the Baseline scenario for the second, third, fourth and fifth traffic combinations respectively. So the baseline scenario 1 has five different traffic cases namely

i. 5HP + 5LP traffic flows
ii. 5HP + 10LP traffic flows
iii. 5HP + 15LP traffic flows
iv. 5HP + 20LP traffic flows
v. 5HP + 25LP traffic flows

Scenario 1 – simulation result.

4.2.1.1 LP THROUGHPUT – FAIR MAC SCHEME VS 802.11e MAC SCHEME

Figure 4.1 and Figure 4.2 depict the LP and HP throughput characteristics respectively. Figure 4.3 and Figure 4.4 depict the LP and HP delay characteristics respectively. The X-axis in Figure 4.1, Figure 4.2, Figure 4.3 and Figure 4.4 depicts five different traffic combinations, namely (i) 5HP + 5LP traffic flows, (ii) 5HP + 10LP traffic flows, (iii) 5HP + 15LP traffic flows, (iv) 5HP + 20LP traffic flows, and (v) 5HP + 25LP traffic flows. The Y-axis in Figure 4.1 and Figure 4.2 denotes the throughput in kilobits/sec. The Y-axis in Figure 4.3 and Figure 4.4 denotes the end-to-end delay in milliseconds. This kind of set up is consistent with the network scenarios discussed earlier, where non real time traffic pre-dominates the real time traffic.

As depicted in Figure 4.1 the throughput for the LP flows in the Fair MAC scheme is about 22% higher than that of the throughput of the LP users in the basic 802.11e MAC scheme. In the proposed scheme, it can be seen that the LP throughput (the Fair MAC scheme LP throughput in the graph) increases significantly at every point compared to the standard (about 22% on an average) because of the fair channel access they get by polling during the CFP phase. The increase in the throughput can be accounted to the fact that in the proposed scheme the LP throughput is a sum of the throughput obtained during CP phase of EDCA and also polling by HC. However, in the standard 802.11e MAC scheme with the increase in the number of flows, LP traffic performs so unpredictably and poorly because most of the resources are dedicated for the higher priority traffic depriving LP traffic to the extent of starvation [5], [16].
Figure 4.1. LP Throughput (kbps) – Comparison of Fair MAC scheme vs 802.11e MAC scheme.

Figure 4.2. HP Throughput (kbps) – Comparison of Fair MAC scheme vs 802.11e MAC scheme.
Figure 4.3. HP delay (ms) – Comparison of Fair MAC scheme vs 802.11e MAC scheme.

Figure 4.4. LP delay (ms) – Comparison of Fair MAC scheme vs 802.11e MAC scheme.
The average Throughput for LP traffic/non real time traffic decreases as the number of LP flows increase in 802.11e. This trend can be attributed to the fact that LP traffic gets served only during the contention period in the standard and the LP throughput obtained is the throughput obtained during the contention phase alone depicted in Figure 3.1. So, as the number of LP flows increase, it will lead to more collisions during the CP phase, thus lowering the LP throughput. The throughput curve for LP users in the proposed scheme tend to saturate when the traffic flow in the network increases. This can be attributed to an increase in collisions during the contention phase (CP) because of the dominance of the Contention based scheme, i.e. the system still operates mostly in CP phase (CFP is only 50ms in the 200 ms of Beacon Interval) which leads to higher collisions when network load increases thereby leading to saturation in the LP throughput with increase in number of flows. Hence, the extra transmission opportunity rendered to the LP traffic in our scheme during the CFP phase leads to significantly higher throughput (average 22% increase).

4.2.1.2 HP THROUGHPUT – FAIR MAC SCHEME VS 802.11E MAC SCHEME

Firstly, the HP throughput curve for both the schemes tends to decrease gradually when the number of traffic flow increases in the network. This is because number of HP traffic remains constant at each traffic case and increased number of traffic flows during the CP phase leads to increased collision. Secondly, when compared to the original scheme Fair MAC scheme shows a slight dent in HP throughput which drops by 1.5% (on the average). This dent is attributed to the inclusion of LP traffic in CFP interval. So the HP traffic’s transmission time is considerably reduced. But this minor brunt is acceptable when non-real time traffic is the dominant traffic in the network. The increasing number of LP traffic flows also does not affect the average HP throughput much, since HP users contend for the channel more aggressively (better EDCA parameter set than LP) than the LP users and thus almost always gains access to the channel over LP users. It also gets served when the HC polls the HP nodes to grant dedicated channel access during CAPs and CFP. So, it’s unlikely to be affected by the increase in the LP traffic load.
4.2.1.3 HP DELAY – FAIR MAC SCHEME VS 802.11e MAC SCHEME

The increase in HP delay curve in both schemes attribute to the same fact as we discussed earlier (collision in CP phase as the load increases).

As depicted in Figure 4.3, HP delay for Fair MAC scheme shows 3.2% increase when compared to 802.11e MAC scheme as expected, since the CFP phase is now utilized to serve the LP traffic as well in addition to the HP traffic which increases the wait time of the HP packets [17], [18]. However the increase is not an issue of concern since the delay performance still lies within the acceptable delay bounds for HP traffic. Moreover since majority of the flows are LP, this slight increment in HP delay is compensated by the almost 22% increase in throughput of the LP traffic.

4.2.1.4 LP DELAY – FAIR MAC SCHEME VS 802.11e MAC SCHEME

Figure 4.4 demonstrates the fact that the delay of LP traffic decreases considerably in the proposed MAC scheme when compared to the basic IEEE 802.11e MAC scheme. LP delay performance in the original MAC scheme is sabotaged due to the increase in collision during CP phase whereas, in the proposed scheme LP delay performance is improved comparatively owing to the fairness of the proposed scheme, where the hybrid coordinator serves the LP traffic by polling during the CFP interval.

4.2.2 Scenario 2 – Setup

In scenario 2, the QSTA(s) in the wireless network consists only of one access category, either high priority (HP) flow or low priority (LP) flow. We investigate to see how the proposed MAC scheme impacts the system performance when the traffic is only HP/ LP flows. The numbers of the LP/ HP flows are increased in the order of 5, for instance, 5LP, 10LP, 15LP, 20LP, 25LP and 5HP, 10HP, 15HP, 20HP, 25HP respectively The same configuration is applied on the 802.11e MAC scheme as well to compare the throughput and delay characteristics. The above traffic case is evaluated to study the following:

i. All_LP_Traffic throughput – Fair MAC scheme Vs 802.11e MAC scheme.

ii. All_LP_Traffic delay – Fair MAC scheme Vs 802.11e MAC scheme.
iii. All_HP_Traffic throughput – Fair MAC scheme Vs 802.11e MAC scheme.
iv. All_HP_Traffic delay – Fair MAC scheme Vs 802.11e MAC scheme.

4.2.2.1 **ALL_LP_TRAFFIC_THROUGHPUT – FAIR MAC SCHEME VS 802.11E MAC SCHEME**

As depicted in Figure 4.5, 802.11e MAC scheme admits the LP traffic only during EDCA period and all CAP(s) are blocked in contention phase. But in the Fair MAC scheme, the addition of LP traffic in Contention free phase contributes additional transmission time in the network. Thus, the LP throughput is now the summation of CFP and CP phase which proves our proposed scheme offers better throughput when compared to the basic 802.11e scheme.

![Figure 4.5. All_LP_Traffic throughput (kbps) – Comparison of Fair MAC scheme vs 802.11e MAC scheme](image)

**Figure 4.5. All_LP_Traffic throughput (kbps) – Comparison of Fair MAC scheme vs 802.11e MAC scheme**

4.2.2.2 **ALL_LP_TRAFFIC_DELAY – FAIR MAC SCHEME VS 802.11E MAC SCHEME**

As depicted in Figure 4.6, All_LP_Traffic delay for Fair MAC scheme is lesser than the 802.11e MAC due to the additional transmission time (during CFP) in our proposed scheme.
4.2.2.3 **ALL_HP_TRAFFIC THROUGHPUT – FAIR MAC SCHEME VS 802.11E MAC SCHEME**

Generally, HP traffic is admitted during both contention free phase and contention phase. As depicted in Figure 4.7, in 802.11e MAC scheme when the traffic case is All_HP_Traffic, the real time (HP) flow occupies the whole superframe (includes CFP, EDCA and CAP(s) in CP). When the number of HP traffic is increased, we observed that the HP throughput is much higher than the 802.11e basic MAC scheme (4.1). It is interesting to notice that the Fair also performs the same way as 802.11e does The only difference in our proposed MAC scheme is that the CFP phase is now utilized to serve the LP traffic in addition to the HP traffic. When the traffic case is All_HP_Traffic, LP flows are not considered during the CFP phase since the system consists of the HP traffic alone.

4.2.2.4 **ALL_HP_TRAFFIC DELAY – FAIR MAC SCHEME VS 802.11E MAC SCHEME**

The same fact (All_HP_Traffic throughput) can be applied to justify the All_HP_Traffic delay performance (see Figure 4.8) where both schemes behave similarly. Thus by comparing the throughput and delay characteristics of scenario2, it is understood that our Fair MAC scheme performs much better than the 802.11e MAC scheme even when the network is completely HP centric (or) LP centric.
Figure 4.7. All_HP_Traffic throughput (kbps) – Comparison of Fair MAC scheme Vs 802.11e MAC scheme.

Figure 4.8. All_HP_Traffic delay (secs) – Comparison of Fair MAC scheme Vs 802.11e MAC scheme.
CHAPTER 5

CONCLUSION

An unbiased MAC layer approach has been proposed to provide QoS for both real
time and non-real time applications. We claim that the QoS fairness for the low priority users
can be achieved by giving the non-real time traffic flows with sufficient transmission time
during the contention free phase of 802.11e. To evaluate and validate our proposed FAIR
MAC scheme, we simulate two different baseline scenarios on NS2 simulator. The patch
[10], [15] provides the EDCA and HCCA functionalities on NS2.

Series of simulations have been carried out to validate our proposal. The NS2
simulation results from scenario 1, show that the proposed MAC scheme indeed boosts the
LP throughput (about 22% on the average) and delay performance with a minor brunt in the
HP throughput (about 1.5%) and delay (about 3.2%). Here our main objective is to provide
opportunity for the low priority users when the network is LP dominant, so this little dent in
HP’s performance is acceptable since it stays within the bound. And from scenario 2,
simulation results illustrate that our proposed MAC scheme doesn’t weaken the high priority
traffic even when the majority of traffic are real time flows. Thus our proposed scheme
ensures QoS fairness to the low priority traffic by preventing the starvation while meeting the
demands of high priority traffic to an extent.
BIBLIOGRAPHY

WORKS CITED


WORKS CONSULTED
