Summary of Master Thesis:

Implementation and Evaluation of IEEE 802.11e Wireless LAN in GloMoSim

0.1 Problem Specification

0.1.1 Background

The IEEE 802.11 Wireless Local Area Network (WLAN) is one of the most widely deployed wireless network technologies in the world today. With the enhanced versions 802.11b and 802.11a, it supports data transmission rates of up to 11 and 54 Mbps, respectively.

The basic MAC (Medium Access Control) mechanism of 802.11 is called Distributed Coordination Function (DCF). DCF is based on distributed channel access and employs CSMA (Carrier Sense Multiple Access) protocol for the medium access. IEEE 802.11 also defines an optional access mechanism, called Point Coordination Function (PCF), based on centrally controlled access. Most of the 802.11 installations today use DCF, whereas the PCF is hardly implemented mainly due to its complex design and inefficient access mechanism.

Although IEEE 802.11 has become more and more popular due to its low cost and easy deployment, it does not provide quality of service (QoS) support. QoS refers to the ability of network to provide some consistent services for data transmission, and measured in terms of qualitative characteristics, such as throughput, delay, jitter and packet loss, which describes quality of data traffic over a network. Basically all types of data traffic are treated equally in both DCF and PCF, regardless of the QoS requirements of the traffic, which vary from application to application. Specifically, multimedia applications such as audio/video streaming, teleconferencing, Internet telephony and interactive games require certain level of QoS guarantees. Lost packets or delays can seriously destroy the performance of these applications. Some kind of service differentiation must be employed to let higher priority multimedia traffic get better served. This inability of 802.11 MAC mechanism in providing QoS support is a big hurdle in the adaptation of modern multimedia applications in 802.11 networks.

Thus, a lot of research works have been carried out to enhance the QoS support in IEEE 802.11 networks. IEEE 802.11 Working Group is currently focusing on an enhanced version of IEEE 802.11, known as 802.11e, in order to support Quality of Service. IEEE 802.11e is in its standardization process and the final draft has been released. IEEE 802.11e defines new distributed access mechanism called EDCA (Enhanced Distributed Channel Access), which is basically the improved version of DCF in the original standard. It supports Quality of Service by introducing service differentiation. Different types of traffic are assigned with different priorities based on their QoS requirements, and service differentiation is introduced by using a different set of medium access parameters for each priority.

0.1.2 Introduction to IEEE 802.11 and 802.11e

0.1.2.1 IEEE 802.11 DCF (Distributed Coordination Function)

DCF is the basic access mechanism of 802.11 and is based on Carrier Sense Multiple Access (CSMA). CSMA works as listen-before-talk. If the medium is found idle at least for DIFS (DCF Inter-Frame Space) time period, the station starts transmission, and other stations wait until medium becomes idle again at least for DIFS time period.

As the destination station successfully receives a frame, it acknowledges by sending back an ACK frame after SIFS (Short Inter-Frame Space) time period. Figure 1 illustrates the mechanism.

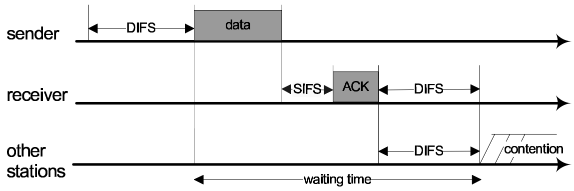

Figure 1: DCF basic access mechanism.

SIFS is the shortest of the three Inter-Frame Spaces (IFS) defined in IEEE 802.11 to control the access to the medium. IFS relationships can be seen in Figure 2. Subsequent frame transmissions are separated by these inter-frame spaces depending on the priority of the frame exchange sequence, i.e., higher the priority of the frame exchange sequence, shorter is the inter-frame space used between the frames.

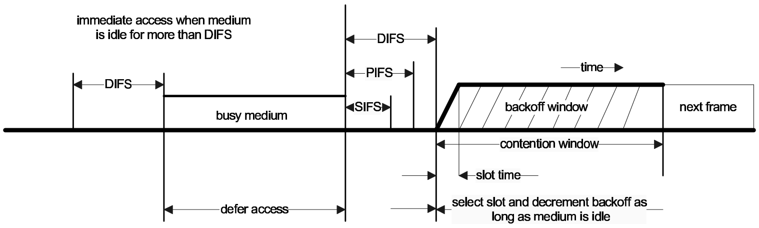

Figure 2: Medium access and IFS relationships.

In order to avoid such collisions, station has to wait an additional time period prior to transmitting if the medium is sensed busy in the DIFS period. In these situations, the station defers access until the medium becomes idle, and chooses a random backoff value, which specifies the time period, measured in time slots, the station has to wait in addition to the DIFS after the medium becomes idle. This additional random delay in form of backoff helps to avoid collisions, otherwise all stations would try to transmit as soon as medium becomes idle for the DIFS period.

After choosing the backoff value, as the medium is sensed idle at least for DIFS time period, the station starts decrementing its backoff timer by one for each time slot. If the medium becomes busy during this backoff process, the station backoffs, i.e., it pauses its backoff timer. The backoff timer is then resumed as soon as the medium is sensed idle for the DIFS period again. The station is allowed to transmit as the backoff timer reaches zero.

The random backoff value is uniformly chosen from the interval [0, CW], called the Contention Window. At the first transmission attempt, CW is set to the minimum

Contention Window size, CWmin. CW is doubled after each unsuccessful transmission until it reaches the maximum Contention Window size, CWmax. The values for CWmin and CWmax are 31 and 1023 respectively. The CW size is reset to CWmin after each successful transmission. Figure 3 illustrates an example scenario to explain the operation of DCF with backoff procedure. (Please refer to the complete master thesis report for the detailed description of example scenario.)

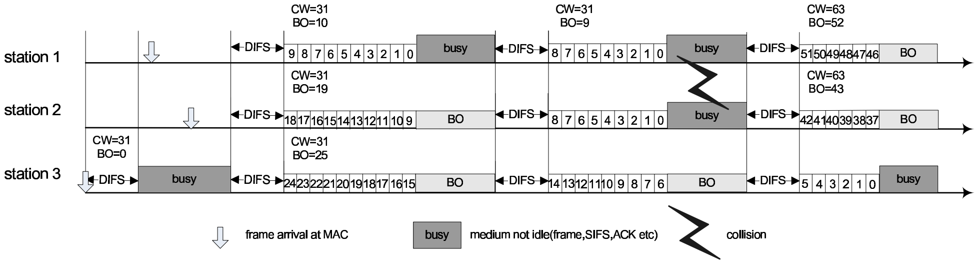

Figure 3: DCF access mechanism with backoff procedure.

0.1.2.2 IEEE 802.11e EDCA (Enhanced Distributed Channel Access)

IEEE 802.11e EDCA supports quality of service by introducing priority mechanism. All types of data traffic are not treated equally as it is done in the original standard, instead, 802.11e EDCA supports service differentiation by assigning data traffic with different priorities based on their QoS requirements. Furthermore, four different Access Categories (AC) have been defined each for data traffic of a different priority. Access to the medium is then granted based on the priorities of data traffic, such that each frame with a particular priority is mapped to an Access Category, and service differentiation is realized by using a different set of contention parameters to contend for the medium, for each AC.

Frames from different types of data traffic are mapped into different ACs depending on the QoS requirements of the traffic/application the frames belong to. The four Access Categories are named AC_BK, AC_BE, AC_VI and AC_VO, for Background, Best Effort, Video and Voice data traffic, respectively, where AC_BK has the lowest and AC_VO has the highest priority.

Each frame from the higher layer arrives at the MAC layer along with a priority value assigned according to the type of application/traffic the frame belongs to. At the MAC layer, a frame with a particular priority is further mapped to the corresponding AC.

Every station maintains four transmit queues one for each AC, and four independent EDCAFs (Enhanced Distributed Channel Access Function), one for each queue, as illustrated in Figure 4. EDCAF is an enhanced version of DCF, and contends for the medium on the same principles of CSMA/CA and backoff, but based on the parameters specific to the AC it is contending for.

An EDCAF contends for medium based on the following parameters associated to an AC, known as EDCA parameters:

- AIFS - The time period the medium is sensed idle before the transmission or backoff is started.
- CWmin, CWmax - Size of Contention Window used for backoff.

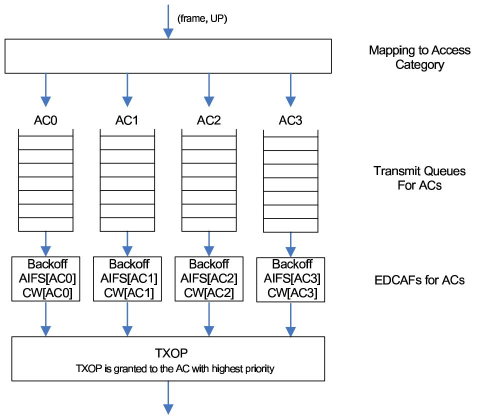

Figure 4: Four ACs, each with its own queue, AIFS, CW and backoff timer.

The values of EDCA parameters are different for different ACs. The higher priority ACs wait a small AIFS time period while the lower priority ACs have to wait a longer AIFS time before they can access the medium. The size of Contention Window varies such that the higher priority ACs choose backoff values from a smaller Contention Window compared to the lower priority ACs. Thus, basically the main difference between DCF and EDCAF is that EDCAF uses AC specific parameters AIFS[AC], CWmin[AC] and CWmax[AC] instead of using fixed values DIFS, CWmin, and CWmax.

EDCA parameters are periodically advertised by the QAP. QAP can adapt these parameters dynamically depending on the network conditions. The draft standard specifies default values of EDCAF parameters if not advertised by the QAP. The default values can be seen in Table 1.

AC	**CWmin**	**CWmax**	**AIFSN**	**TXOP Limit**	
				FHSS	**DSSS**
AC_BK	CWmin	CWmax	7	0	0
AC_BE	CWmin	CWmax	3	0	0
AC_VI	(CWmin+1)/2-1	CWmin	2	6.016ms	3.008ms
AC_VO	(CWmin+1)/4-1	(CW+1)/2-1	2	3.264ms	1.504ms

Table 1: Default EDCA parameter values.

Besides the different AIFS, CWmin and CWmax values for different ACs, the rest of medium access mechanism is same as in DCF, i.e., as the medium becomes idle at least for AIFS time period, the EDCAF chooses a random backoff value from its Contention Window and starts decreasing its backoff timer. The EDCAF can start transmission as its backoff timer reaches to zero.

The four EDCAFs at the AC transmit queues behave like virtual stations inside the real station such that each EDCAF contends for the medium independently of other EDCAFs. Figure 5 shows an example of EDCA operation. (Please refer to the complete master thesis report for the detailed description of example scenario.)

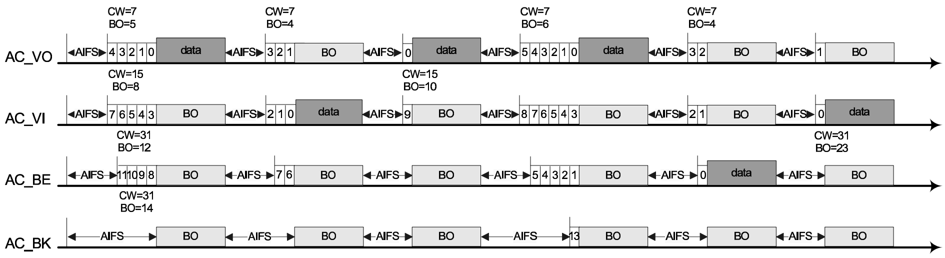

FIGURE 5: EDCA ACCESS MECHANISM.

0.2 Task

The task was divided into two parts: Implementation and Evaluation. In the first part, IEEE 802.11e EDCA simulation model was implemented in GloMoSim (Global Mobile Information System Simulator), which is a simulation software for mobile and wireless networks, developed by Parallel Computing Laboratory at UCLA. GloMoSim is built using a layered approach similar to the OSI seven layers network architecture, with standard APIs between the layers. A wide range of protocols are supported at each layer. IEEE 802.11 DCF is currently one of the several protocols available at the MAC layer. The primary goal was to design and develop IEEE 802.11e EDCA protocol on the basis of the available DCF design. The work included thorough understanding of the IEEE 802.11e standard, especially its complex MAC algorithm designed to support quality of service, and, complete understanding and command on GloMoSim, its architecture and API operating at different layers. The development was done using C programming language, comprising hundreds of lines of code.

In the second part, the performance of IEEE 802.11e EDCA was evaluated using the implemented 802.11 EDCA simulation model. It included studying the QoS/service differentiation mechanism of 802.11e EDCA with the help of extensive simulations and wide range of performance metrics.

The evaluation phase was divided into two parts. The first part evaluated the IEEE 802.11e EDCA QoS scheme with some simple scenarios in order to more clearly observe the role of individual EDCA parameters in providing service differentiation. It also served as the verification of the implemented IEEE 802.11e EDCA design. The second part focused on the evaluation of EDCA by considering some more realistic simulation scenarios. Comparisons of 802.11e EDCA and 802.11 DCF were also presented to analyze their performance with respect to different real world traffic scenarios. The performance metrics considered were throughput, average end-to-end delay, MAC delay, packet transmission ratio, packet loss, packet drop and collision rate. Figure 6 illustrates the throughtput result, showing how effectively service differentiation is achieved through different Access Categories for different types of traffic. While the throughput for low priority ACs starts to drop as the network becomes congested, the high priority ACs, AC_VI and AC_VO, keep receiving the constant shares of bandwidth. Throughput for the traffic streams of two lowest priority ACs, AC_BK and AC_BE, starts to drop as the total network load approaches to 1.6 and 1.9 Mbps, respectively.

Out of around 200 total graphs, 88 were presented in final report, showing results for several simulation scenarios. Only one graph has been presented here due to lack of space. Please refer to the complete master thesis report for all scenarios and results.

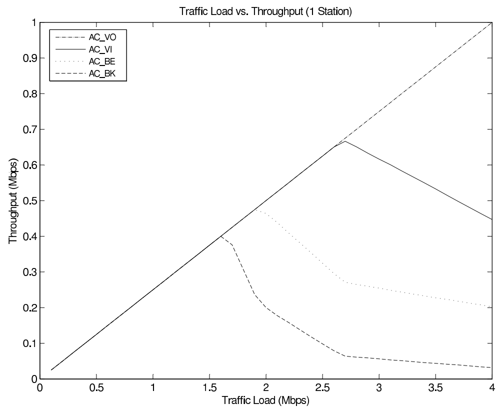

Figure 6: Throughput results.

0.3 Conclusions and Further Research

From the results, it is concluded that IEEE 802.11e introduces a very effective service differentiation mechanism to provide the QoS support. With the service differentiation mechanism, the high priority traffic receives larger and consistent share of bandwidth while delay remains under acceptable limits. In the first part of the evaluation, a set of simple simulation scenarios was considered in order to more clearly study the role of individual EDCA parameters in realizing service differentiation. The results showed that both EDCA parameters, AIFS and CWmin and CWmax, are very effective in realizing service differentiation when used individually. Following are a few key points (out of 28 presented in conclusion section of thesis report) extracted from the evaluation phase.

1. Under highly loaded network situations, high priority ACs, AC_VO and AC_VI, suffer from high number of collisions due to their small CWmin and CWmax values. High collision rate severally degrades the performance of these ACs, and proved to be the biggest weakness of service differentiation scheme.

2. The poor performance of low priority ACs (AC_BK and AC_BE) under high load of high priority ACs (AC_VI and AC_VI) shows that high load of high priority traffic starves the low priority traffic.

3. Comparing the CWmin and CWmax based differentiation with AIFS based differentiation shows that the latter provides superior and more reliable service differentiation because: (a) The performance of an AC is consistently controlled by its AIFSN value. For example, from high to low priority AC, the relative differences in throughput results clearly reflect the AIFSN values of ACs, i.e., 2, 2, 3 and 7, (b) AIFS difference of a single slot time is very effective in realizing differentiation, and, (c) AIFS provides consistent and more reliable differentiation independent of the different network conditions. It is in contrast to the CWmin and CWmax based differentiation which becomes less effective with increase in network congestion.

4. High collision rate for high priority ACs concludes that performance of a high priority AC drops with the addition of every new station transmitting the traffic of high priority AC. And too many stations transmitting high priority traffic severally degrade the overall performance of the network.

5. The above point highlights the importance of an admission control mechanism which enables the AP to allow or disallow a new station or traffic stream to use a high priority AC according to network conditions.

6. An effective solution would be to dynamically increasing the values of EDCA parameters with addition of every new station or traffic stream. It is because a specific set of parameter values is optimal only for a specific number of stations/traffic, after which it required to be updated. This points towards the importance of optimization of AC performance by adjusting the EDCA parameters according to network conditions and available resources.

Note: Only very few results and conclusions could be presented here due to lack of space. Please refer to the master thesis report for full description of the dissertation. The report can be downloaded from http://www.jahanzeb.com/masterthesis.pdf.